Cranfield
UNIVERSITY

Melinda Lyons

Evaluation of a Task Performance Resource Constraint Model to Assess the Impact of Offshore Emergency Management on Risk Reduction

SCHOOL OF INDUSTRIAL AND MANUFACTURING
SCIENCE

Ph.D. Thesis

Cranfield
UNIVERSITY

SCHOOL OF INDUSTRIAL AND
MANUFACTURING SCIENCE

Ph.D. Thesis

Academic Year of Submission 2000.

Melinda Lyons

Evaluation of a Task Performance Resource Constraint Model to Assess the Impact of Offshore Emergency Management on Risk Reduction

Supervisor: Professor J.E.Strutt

Date of Presentation: May 2000

ABSTRACT

In this age of safety awareness, technological emergencies still happen, occasionally with catastrophic results. Often human intervention is the only way of averting disaster. Ensuring that the chosen emergency managers are competent requires a combination of training and assessment. However, assessment currently relies on expert judgement of behaviour as opposed to its impact on outcome, therefore it would be difficult to incorporate such data into formal Quantitative Risk Assessments (QRA).

Although there is, as yet, no suitable alternative to expert judgement, there is a need for methods of quantifying the impact of emergency management on risk reduction in accident and incidents.

The Task Performance Resource Constraint (TPRC) model is capable of representing the critical factors. It calculates probability of task success with respect to time based on uncertainties associated with the task and resource variables. The results can then be used to assess the management performance based on the physical outcome in the emergency, thereby providing a measure of the impact of emergency management on risk with a high degree of objectivity.

Data obtained from training exercises for offshore and onshore emergency management were measured and successfully used with the TPRC model. The resulting probability of success functions also demonstrated a high level of external validity when used with improvements in emergency management or design changes or real data from the Piper Alpha disaster. It also appeared to have more external validity than other HRQ/QRA techniques as it uses physical data that are a greater influence on outcome than psychological changes - though this could be because the current HRA/QRA techniques view human unreliability as probability of error rather than probability of failure. The simulation data were also used to build up distributions of timings for simple emergency management tasks. Using additional theoretical data, this demonstrated the model's potential for assessing the probability of success for novel situations and future designs.

ACKNOWLEDGEMENTS

I dedicate this work to my Mum and Dad to thank them for their continuous encouragement, support and love; together with the promise that I will never do anything like this again.

* * *

Special thanks are due to Professor John Strutt for his help and advice throughout the project.

Thanks are also due to:
Keith Allsopp and Wei-Whua Loa, of SIMS, Cranfield University, for assistance with the computer modelling.

Rear Admiral Jeremy Larken, Captain Ted Hackett and Helen Shannon of OCTO Ltd. for their financial support, provision of data collection opportunities and advice.

EPSRC for their financial support
Dr Bob Allwood, School of Industrial and Manufacturing Science, Cranfield University
David Mitchell of Offshore Safety Services, Aberdeen.
Colleagues at the Point of Ayr Installation, BHP UK Ltd.
Colleagues at the Ravenspurn North offshore gas platform, BHP UK Ltd.
Dr Barry Kirwan of Eurocontrol EEC.
Professor Helen Muir, Professor John Rolfe and Dr Frank Taylor,
College of Aeronautics, Cranfield University.
Dr David Embrey, Human Reliability Associates Ltd. Wigan.
Jean and Mike Wilding of the British Red Cross.
Robin Heels of Kværner Oil and Gas
Professor Ragnar Værnes of NUTEC Norway
Last but not least, my friends

CONTENTS PAGE

Page Numbers

LIST OF TABLES

Page numbers

LIST OF FIGURES

Page numbers

Page numbers

LIST OF ACRONYMS

ADS - Accident Dynamic Simulator
ALARP - As low as reasonably practicable
APJ - Absolute Probability Judgment
ASEP - Accident Sequence Evaluation Process
BA - Breathing Apparatus
CO - Carbon Monoxide
CO_2 - Carbon Dioxide
COGENT - Cognitive Event Tree System
COHb - Carboxyhaemoglobin
CES - Cognitive Environment Simulation
CFD - Cumulative Frequency Distribution
CGS - Concrete gravity structure
CIMAH - Control of Industrial Major Accident Hazards Regulations (1984)
CISR - Centre for Industrial Safety and Reliability
COMAH - Control of Major Accident Hazards Regulations (1999)
COSHH - Control of Substances hazardous to health
CP - Central platform
CR - Control Room
CREATE - Cognitive Reliability Assessment Technique
CREWSIM - Crew Simulation
CRM - Crew / Cockpit Resource Management
CRO - Control Room Operator
DYLAM - Dynamic Logical Analytical Methodology
EHRM - Emergent Human Resources Model
EM - Emergency Manager
EMDS - Emergency Management Decision Support
EMIS - Emergency Management Information Systems
EMT - Emergency Management Team
EPC - Error producing conditions
ESD - Emergency shutdown
ESDA - Exploratory Sequential Data Analysis
ESV - Emergency shutdown valve
FMEA - Fault Modes and Effects Analysis
FPSO - Floating Production Supply and Offloading
FRC - Fast Rescue Craft
GCD - Gas compression deck
GEMS - Generic Error Modelling System
H_2S - Hydrogen Sulphide
HAZOP - Hazard and Operability Study
HCR - Human Cognitive Reliability
HEART - Human Error Assessment and Reduction Technique
HEP - Human error probabilities
HEMECA - Human Error Mode Effect and Criticality Analysis
HEP - Human Error Probability

HLO - Helicopter Landing Officer
HRA - Human Reliability Assessment
HRMS - Human Reliability Management System
HRQ - Human Reliability Quantification
HSC - Health and Safety Commission
HSE - Health and Safety Executive
HV - High voltage
HVAC - Heating, ventilation and air conditioning
IDLH - Immediate danger to life and health
INPO - Institute of Nuclear Power Operators
JHEDI - Justification of Human Error Data Information
LC_{50} - Lethal Concentration for 50% Percent
LC_{LO} - Lethal Concentration Low
LV - Low voltage
MAC - Manual activated alarm
MOB - Man overboard
NDM - Naturalistic decision making
NDT - Non-destructive testing
NIOSH - National Institute of Occupational Safety and Health
NPD - Norwegian Petroleum Directorate
NPP - Nuclear Power Plant
NUTEC - Norwegian Underwater Technology Centre
O_2 - Oxygen
OCTO - Operational Command and Training Organisation
OHRA - Offshore Hazard and Risk Analysis
OIM - Offshore Installation Manager
OPITO - Offshore Petroleum Industry Training Organisation
OSD - Offshore Safety Division (of the HSE)
PAPA - Prepare to abandon platform
PARLOC - Pipeline and Riser Loss of Containment
PC - Personal computer
PDF - Probability Density Function
PFEER - Prevention of Fire and Explosion and Emergency Response Regulations (1988)
PHECA - Potential Human Error Causes Analysis
POB - Personnel / People on Board
PPE - Personal protective equipment
PRA - Probabilistic Risk Assessment
PREDICT - Procedure to Review and Evaluate Dependency in Complex Technologies
PSA - Probabilistic Safety Analysis
PSF - Performance shaping factors
PTSD - Post-traumatic stress disorder
QRA - Quantitative Risk Assessment
QUA - Quantitative Uncertainty Assessment
RIDDOR - Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (1995)

RMV	-	Respiratory Minute Volume
RO	-	Radio operator
RODOS	-	Real-time Online DecisiOn Support system
RO-RO	-	Roll-on roll-off (ferry)
RPD	-	Recognition primed decision (model)
SADCAR	-	Situation Awareness Decision Communication And Response
SAINT	-	System Analysis of Integrated Networks of Tasks
SAM	-	System Action Management
SBV	-	Standby vessel
SCUBA	-	Self- contained underwater breathing apparatus
SHERPA	-	Systematic Human Error Reduction and Prediction Approach
SLIM-MAUD	-	Success Likelihood Index Methodology using Multi-Attribute Utility Decomposition
SOT	-	Scenario Organisation Team
SRK	-	Skill, Rule, Knowledge
STEL	-	Short-term exposure limit
TEMPSC	-	Totally Enclosed Motor-Propelled Survival Crafts
TESEO	-	Tecnica Empirica Stima Errori Operatori
TGU	-	Tail gas unit
THERP	-	Technique for Human Error Rate Prediction
TR	-	Temporary Refuge
TRM	-	Team Resource Management
TPRC	-	Task Performance Resource Constraint
TSR / TSH	-	Temporary Safe Refuge / Temporary Safe Haven
UKOOA	-	United Kingdom Offshore Operators Association
VDU	-	Visual display unit
WPAM	-	Work Process Analysis Model
WT	-	Well tower

NOTATION

a	Linear work rate
AP	Actual Performance
b_o	Initial level of knowledge
b	Jumps in knowledge / short-cut
C_b	Basic rate of resource consumption
dc	Deviation coefficient of C_b
$F(t)$	Cumulative frequency distribution of time
$f(t)$	Probability density function of variable t
k	Common cause factor
P_f	Probability of failure
Ps	Probability of success
r	Resource consumption rate
RP	Required Performance
r^S	Spearman's Coefficient
$R(t)$	Reliability function
S_N	Overall probability of Success of a series of sub-tasks
W	Task Requirement / Task standards
$W(t)$	Work progress as a function of time
X	Initial resource capacity
Δt	Time between work rate changes
σ	Standard deviation
μ	Mean
η	Scale parameter of Weibull distribution
β	Shape parameter of Weibull distribution
γ	Location parameter of Weibull distribution
$\Gamma(x)$	Gamma function

DEFINITION OF TERMS

EMERGENCY MANAGEMENT

For the benefit of this research, emergency management is the culmination of tasks that work to produce a successful outcome in an emergency. Therefore, this does not focus just on the decisions and communications of a management team or just on the actions in response to these decisions and communications but a combination of the two processes and their collective impact on the risk.

Chapter 1

INTRODUCTION

SECTION 1.1: MAIN INTRODUCTION

A large majority of the technological accidents that have occurred during the last century have been attributed to human error. Except for those rare and unmanageable "Acts of God", every technological accident has a human cause, simply because it was humans who invented the technology in the first place. However, it may seem inconceivable to us to merely accept that such accidents happen. Consequently, as science advances, we also try to control the advance and to safeguard the environment in which we live.

Quantitative Risk Assessment (QRA) is used to measure the risks posed both by technological change and in everyday life. It generally involves an objective process of collecting reliability information on the relevant technological hardware and software. However, given that the human contribution to accidents is so great, it is critical to quantify the probability of human as well as "non-human" errors in the system.

The field of Human Reliability Assessment (HRA) attempts to provide this information by scientifically assessing the contribution of human error to accidents. This requires great understanding of how humans respond to particular environments and systems. We, as humans, sometimes pride ourselves on being unique and unpredictable, making this process extremely difficult. Generally, such data can be estimated through scientifically controlled experiments and observation. When large amounts of data have been collected, probable error rates can be assumed - in the same way that it is calculated for the reliability of technological systems. However, collecting data on human reactions to an emergency is even more problematic. Firstly, human behaviour in an emergency is likely to be as unpredictable as the nature of the emergency itself. To wait for a real emergency to occur so that behaviour could be recorded is an impractical method of obtaining data. It is also strongly unethical to set up emergencies without informing the people involved. Consequently, informing the people of an emergency simulation or drill reassures them that the situation is not going to escalate out of all control - hence affecting their reaction. Therefore, data on emergency behaviour are mostly anecdotal or are assumed from observation of simulated exercises.

The tragic Piper Alpha disaster of 1988 brought many of the failures of the offshore industry to light. The Cullen Report (1990) emphasised the importance of using a formal QRA process to identify and quantify the critical risks. One of the main failures was identified as being the inadequacy of the Offshore Installation Manager (OIM). In this role, he was expected to take responsibility for the incident as the Emergency Manager. However, he failed to make critical decisions at the appropriate times, which contributed to the scale of the disaster. This human failure emphasised the importance of ensuring that the emergency manager is the right person for the job.

In this disaster as in any other real life incident, the emergency manager is assessed by the general public based on the outcome of the emergency. The emergency manager would be held responsible for any deaths, injuries or losses, and acclaimed for any rescues. If a minor incident escalates into a major incident, the emergency manager is deemed to have failed. If a potentially major incident ends with no casualties or losses, the emergency manager is considered successful.

However, the emergency manager's competency cannot be established by waiting for the first real emergency and then assessing the adequacy of the outcome. Therefore, it is necessary to set up simulations to test his skill. Assessment typically involves using subjective opinions made by someone who is said to be an expert in emergency management. However, the definition of an "expert" in emergency management is also subjective - which emphasises the importance of maintaining strict guidelines for the whole procedure. Also, the expert opinion is usually based on observations of the emergency manager's behaviour rather than the estimated impact of this behaviour on the incident. This is often biased by hindsight as the expert frequently has insight into the nature of the incident that the emergency manager does not have. For these reasons, it would be difficult to develop these assessment techniques into a reliable and objective approach that can be used in the QRA process. Therefore, the competency assessments are unlikely to represent the same factors that are needed to assess the impact of emergency management on risk.

To be able to produce a useful means of assessing the impact, we would require a technique that incorporates the following features:

- Objectivity - to ensure that the assessment is not swayed by biased opinions and is based on objectively-defined observable features.
- Producing quantitative results - to facilitate the use of values in the QRA process.
- The ability to reflect small changes in timing - to express the criticality of "timeliness" in emergencies and to bring the specific quantitative values of time into the methodology.
- The ability to reflect the context of any given emergency situation - to be flexible enough to represent any situation, but to potentially be specific enough to identify the critical features of emergency management tasks, limitations and goals.
- The ability to reflect the unpredictability and uncertainty associated with human behaviour - to represent any task, appropriate or inappropriate; and to represent the whole scope of human behaviour, to be able to produce results even when some of the required data is unknown or may lie within a broad distribution.

Therefore, the main aim of the research is to make explicit the relationship between emergency management and risk. Although it is generally assumed that emergency management has an impact on the outcome of an emergency, there is no methodology that physically or numerically identifies its contribution. Ideally, this methodology should not rely on the subjective opinions of experts from the observed behaviour of the emergency management team; but rather, on numerical data related to the objective outcome of an incident. This technique should be generic in nature but be able to represent context-specific information; for example, the relationship between any emergency management tasks and the escalating situation. Finally, as there is no other technique that is capable of assessing the impact of emergency management on risk in this way; it would be difficult to validate it. Therefore, as a minimum requirement, this method should have good face validity - and produce results that are consistent with our knowledge about emergencies, management intervention and risk. Once developed, this method should then be assessed in terms of its ability to assess novel situations involving novel tasks or new designs. Therefore, the objectives are as follows:

SECTION 1.2: OBJECTIVES

1. To develop a method of obtaining objective data on management performance from emergency scenarios

2. To develop a methodology to use these data to assess the probability of success in emergency management tasks.

3. To demonstrate how these methods can be used to evaluate the impact of changes in emergency management skill and design on risk values.

4. To use the above methodology and data to define performance parameters that can be applied to evaluate generic emergency situations.

SECTION 1.3: SCOPE

As already stated in the objectives above, the project involves the development of a methodology to assess offshore emergency management performance. However, it must be stated that the research was limited by a number of factors.

1. Availability and Validity of data

It is impractical to wait for a real incident to occur to assess emergency management performance or related research topics. Therefore, the data with the greatest validity must be obtained from simulations. In this case, the quantity of data was limited primarily by the number of simulations run during the course of the project. In addition, there are ethical implication for research of this kind – for the most ecologically-valid behavioural data, it would be preferable to plan and run simulations without telling those involved that they are simulations. This is unethical therefore the ecological validity of the data was reduced to maintain ethical practices.

2. Scope of data application areas

It must be mentioned that although the project specifically refers to the offshore environment, the use of data from the onshore petrochemical industry could also be included. As these data were drawn from specific platforms and plants, assumptions of specific timings (such as muster timings) and design data (such as distances) can not be directly applied to other installations. However, where the data are specified as being generic or are based on theoretical information, they can potentially be adapted to suit any situation.

3. Experimenter control

To a large degree, the dedicated simulations were outside of the control of the experiment. Therefore, they were available for recording of data but did not allow adjustment of the arrangements of the simulation or the content of the scenario. For example, the data available involved the recording of the emergency management team's reactions to the escalation incident. Therefore the scenario data represent the decisive, communicative and active control room tasks and not the external physical tasks, for example, movements of rescuers and fire-fighters. These data were usually assumed by the scenario organisers and therefore cannot be guaranteed to be accurate by the author.

4. Thesis content and focus

Due to the multi-disciplinary nature of the research area, it can be recognised that the thesis is potentially of interest to people from many different backgrounds. These include emergency planners, emergency management assessors, simulation organisers, designers and more broadly, psychologists, ergonomists, safety personnel and reliability engineers. However, it would be difficult to successfully focus this thesis for all of these audiences. Therefore, this thesis is aimed particularly at reliability engineers who require quantification of the impact of emergency management on risk reduction. This may be for research purposes or for application in QRA.

SECTION 1.4: ORGANISATION OF THE THESIS

As shown in Figure 1a, the thesis will be organised in the traditional order of subjects. Following this chapter, Chapter 2 includes the Literature Review, which provides a review of pertinent areas in the research – including emergency management, risk assessment and related areas. Chapter 3 continues this review with an examination of the research in the specific area of offshore risks and the management of offshore emergencies.

Chapter 4 introduces the method and how it came about from the objectives defined. It illustrates the arrangements under which the research was made, including the description of the platform, the layout of rooms and equipment and personnel involved in the running of simulations. Chapter 5 describes the Task Performance Resource Constraint (TPRC) model - the technique that formed the basis of the assessment technique. Following this, the chapter describes the adaptations that were made to the TPRC model to make it suitable for the task as well as the additional data that were collected. Using examples from the observed simulations, this chapter also described how the data were applied in the model. Chapter 6 illustrates some of the additional data that were collected for use in the research. Following this, Chapter 7 gives a demonstration of how simulation data can be converted into generic and specific data representing the "reasonable responses" of an emergency manager and his team – referred to as performance parameters. Finally, this chapter describes how these data can be used in the TPRC model to assess novel situations and new designs.

Chapter 8 provides the TPRC results of the examples introduced in Chapter 5 as well as an illustration of what can be applied in the model using the Piper Alpha disaster. It also compares the results from the earlier scenarios with results that would be obtained using different QRA or HRQ methodologies – namely HEART and HAZAN. Chapter 9 shows the results of the performance parameter analysis, as described in Chapter 7, including distributions of the data and further TPRC assessments to demonstrate the model's ability to incorporate the performance parameter data.

Chapter 10 includes a critical analysis of the method and models. Considering these, Chapter 11 analyses the results in more detail and in terms of the objectives of the research. Chapter 12 concludes the thesis by describing the contribution of the research in terms of theoretical knowledge and practical applications. This also identifies areas for future work.

The locations of key parts of the research, as well as topics of interest, are shown in Figures 1a and 1b.

Figure 1a: Organisation of the thesis

Chapter	Contents	Section
1. Introduction	Objectives Scope Organisation of the Thesis	1.2 1.3 1.4
2. Literature Review	Disaster and Emergencies Emergency management Risk Assessment HRA	2.2 2.3 2.4 2.4.4
3. The Offshore Industry	Description of the Offshore Environment Legislation and the Piper Alpha Disaster Offshore Emergency Management	3.2 3.3 3.5
4. Research Methodology	Overall Research Objective and Methodology Description of Platform Layout of Simulation Environment Personnel involved Scenario Descriptions	4.3 4.5 4.7 4.8 4.9
5. The TPRC Model	Overview of method TPRC Model Changes to the TPRC Model Example of TPRC use	5.2 5.3 5.3.5 5.5
6. Supporting Data	Human Movement Rescue, escape and evacuation First Aid	6.2 6.3 6.4
7. Collection of Performance Parameters	Collection of Data Example of use in the TPRC model	7.2 7.4
8. TPRC Results	Results of TPRC use from Chapter 5 Using the TPRC model on Piper Alpha Comparison of TPRC with HEART / HAZAN	8.2 8.3.4 8.4
9. Performance Parameter Results	Scenario-specific parameters Generic parameters Results of the use of Performance Parameters with the TPRC model	9.2 9.3 9.4
10. Critique of the Method	Development of the methodology Critique of the Scenario Arrangements Critique of the TPRC model Lack of Conditional Probability Lack of Cognitive Aspects of Decision-making	10.4 10.5 10.7 10.7.1.4 10.7.2.4
11. Analysis of the Results	Implications of the TPRC Results Why was the TPRC Model chosen How successful was the TPRC in assessing the impact of emergency management on risk? Implications of the use of the Performance Parameters	11.2 11.2.1 11.2.2 11.3

12. Discussion and Conclusions	Scenario arrangements – recommendations for future research Data Collection The TPRC Model - Changes Expansion of the TPRC model Validation of the TPRC model Contribution of research with respect to previous knowledge Conclusions	12.2 12.3 12.4 12.4.1 12.4.2 12.7 12.8

Figure 1b: Organisation of the thesis

Key Topics	Chapter											
	1	2	3	4	5	6	7	8	9	10	11	12
Disasters and Emergencies	*	*	*									
Piper Alpha	*		*					*			*	
Emergency management	*	*	*									*
Offshore Environment			*	*								
Legislation and standards		*	*	*								*
QRA	*	*	*									
Simulation arrangements				*						*		*
Scenario Data Collection				*	*		*			*		*
TPRC model				*	*					*	*	*
Mathematical basis					*					*		
Supporting data from literature						*				*		*
Practical examples of TPRC use					*		*	*	*		*	
HRA		*								*		*
HAZAN / HEART		*						*			*	*
Performance Parameters							*		*	*	*	*
Questionnaires										*	*	*
Desktop simulation method										*		

Chapter 2

LITERATURE REVIEW

SECTION 2.1: INTRODUCTION

This section aims to describe where the research problem came from, what is already known about the problem and what other methods have been or could be tried to solve it.

In brief, U.K. legislation now recommends, either implicitly or explicitly, the use of risk assessment to objectively evaluate all risks to health and safety. In the offshore industry particularly, this is implemented through a "goal setting" approach to continually improve safety. However, despite reduction or elimination of some of the risks, many will remain.

If an incident occurs, it can result in anything from a near miss to a major catastrophe. The aim of emergency management is to ensure that the consequences of such an incident are as minor as possible. Therefore, it should be possible to integrate the impact of emergency management into the risk equation, ideally demonstrating that emergency management reduces risk! This information could then be used to identify what are the key factors involved in emergency management; what the critical decisions are, which must be made to optimise the outcome, and when such decisions should be made. Given that such details could be calculated, this could facilitate the identification of good emergency management practice and therefore aid in the recognition of good emergency managers and the development of emergency plans. Finally, this information could feed back into the design process, ensuring that technology is designed so that any possible incidents are manageable by a competent emergency manager.

However, to be able to assess the impact of emergency management in this way is a real challenge. Firstly, emergencies are unexpected, infrequent and unique events. Therefore, real data would be difficult to obtain and could not be easily adapted to represent or predict all incidents and their possible outcomes. Secondly, assessing the impact of any kind of management involves the prediction of human behaviour. Human nature can be as unpredictable as the emergencies to which they respond. Therefore, it would seem impossible to provide numerical figures to represent "good" or "poor" emergency management.

Nevertheless, competence in emergency management must comply with standards and this is generally assessed subjectively by observing simulated emergency exercises. There have been few attempts to identify the critical aspects of emergency management, including investigations into personality characteristics and decision-making style. However, to identify a technique that can evaluate the impact of emergency management on risk requires the presence of particular features - including some appreciation of the context of the situation and its seriousness; the time pressures involved and, ideally, independence from the current subjective evaluation techniques.

Therefore, to address the research problem, it is necessary to draw on knowledge from a number of topics. These predominantly consider

- The Nature of Disasters, Emergencies and Major Accidents
- Emergency Management
- Risk Assessment techniques
- Research Methods

Each of these issues will be discussed in more detail in the rest of this review.

SECTION 2.2: THE NATURE OF DISASTERS, EMERGENCIES AND MAJOR ACCIDENTS

> *"Maimed children, contaminated communities, ravaged landscapes, technological genocide - this is the nature of the high-tech holocaust. Man-made and rapidly spiralling out of control, it is the legacy of the post-war surge of uncontrolled technological development across the entire spectrum of everyday life; aided and abetted by governments and vested interests everywhere who blindly and cynically put economic expediency ahead of human life - who plan for today and hope that tomorrow will always come." (Bellini 1986)*

2.2.1 INTRODUCTION

This section will describe the potential consequences of hazardous occurrences - disasters, emergencies and major accidents. This illustrates the qualitative impact of emergency management by describing how events can escalate when emergency management is absent or inadequate. Therefore, this section emphasizes how important it is to be able to measure the impact of emergency management on risk, working towards a "guarantee" of a certain performance level of emergency intervention.

This section will begin by attempting to define the type of occurrences in question - using the popular terms "emergency", "accident", "crisis" etc. Following this, the review will move on to illustrate the concept by describing some of the major incidents that have occurred. Then, in more generic terms, the review will describe some of the stages that are said to occur in an emergency. Finally, this section will describe the "subjective experience" of being in an emergency before moving on to the next section, which describes how emergencies should be managed.

2.2.2 DEFINITION OF TERMS

In general, there is an implicit understanding about the words used to describe certain events as accidents, crises, disasters, tragedies, incidents, catastrophes and emergencies. Many are used inter-changeably without the consideration of the severity of consequences, the impact of the event or the culture involved.

The Chambers concise dictionary (Schwarz 1991) defines Emergency as "an unexpected occurrence, requiring immediate attention" and a Crisis as "a crucial or decisive moment, a turning-point". Although these definitions are correct, they do not encompass all of the attributes that we require for our understanding of major incidents.

For our purposes, a more clear-cut definition is required. Morin (1976) suggests a crisis as "the moment where uncertainty exists at the same time as a problem". Wiener and Kahn (1962), Milburn (1972) and Mitroff et al (1988) try to suggest lists of attributes in an attempt to define crises. These include time pressure, threats to the system goals, lack of control over events, information overload, inter-personal conflicts and ambiguity (All references in this paragraph cited in Lagadec 1993). Wilson (1991) suggests that "in any emergency, there is virtually always one common factor - a shortage of time for people to reach a position of safety".

Further to these, Kirchsteiger (1997) gives the following definition of a major accident:
"It is a sudden, unexpected, unplanned event, resulting from uncontrolled developments during an industrial activity, which causes, or has the potential to cause, serious adverse effects, immediate or delayed (death, injuries, poisoning or hospitalisation), to a number of people inside the installation and/or persons outside the establishment".

In terms of description of severity and content, this definition fits our purposes adequately. The following points will discuss the different uses of the main terms that also sometimes imply this definition.

1. Accident is often used to mean quite different events including road traffic accidents, which are not industrially based and chemical leaks, which may or may not have caused injuries (Montiel et al 1996, Explosion Group, TU Delft 1997). The term "accident" is commonly used in the nuclear industry to refer to an incident of the sort identified in Kirchsteiger's definition (Catton & Lim 1994, Asmolov 1997) and is occasionally used in aircraft and chemical incidents (Muir 1996 and Montiel et al 1996 respectively). However, popularity of the term is probably due to common use in general circles - for example, accident investigation (Johnson & Telford 1996) and accident statistics (HSE 1997b).

2. The most popular term used in the literature is "emergency". It is commonly used in research circles when developing computer packages to train and assess managers in "emergency management" (Petty et al 1996, Doheny & Fraser 1996) as well as psychological research into stress and decision-making (Kaempf & Militello 1992, Kontogiannis 1996). This term has common use in the offshore (Brandie 1995, Skriver & Flin 1997, UKOOA 1997a), chemical (Ramabrahmam et al 1996) and maritime industries (Clemmensen 1995). It is also used worldwide. It has been used in Russian and American research to refer to natural and industrial incidents (Kosyachenko et al 1998 and Simard

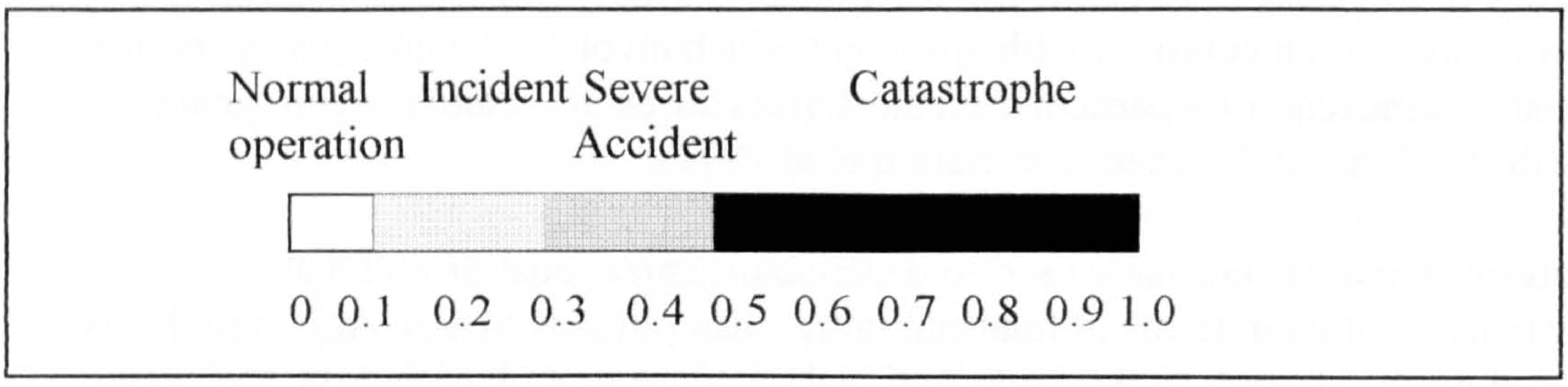
1997) and French and Japanese research to describe only technological incidents (Samurçay & Rogalski 1993 and Ujita, Kawano & Yoshimura 1995 respectively). However, this is often confused with any event which involves the emergency services as well as any event requiring particular medical procedures, for example, emergency childbirth (St. John Ambulance Association et al 1997).

3. The term "Crisis" is normally used to describe organizational or political circumstances - often in terms of financial rather than physical losses. Although this is often used when referring to the organizational response to a physical loss, the events that fit Kirchsteiger's definition have already finished. Shrivastava et al (1988 p.285) define industrial crises as "organizationally-based disasters which cause extensive damage and social disruption, involve multiple stakeholders, and unfold through complex technological, organizational and social processes". Mitroff (1988) attempts to identify all the types of crisis; his list includes hostile takeovers, bribery, sexual harassment, major computer breakdowns and major product defects. However, Smith (1994) warns that there may be confusion in defining the difference between a crisis and a period of controlled change in a short period of time. He suggests that occasionally this type of change is necessary or even welcome and so does not constitute a crisis but is "a learning process by which crises may be avoided". Some references uses crises to describe all such problems - both within our definition and outside of it (Smith 1990, Read 1995). Richardson (1994) attempts to distinguish between the "socio-technical disaster crisis" and the "business-failure crisis" in terms of the suddenness of onset, the contribution of technology and the fact that lives, as opposed to careers, finances and public perception, are under threat.

4. The term "disaster" frequently relates to natural disasters. These differ from Kirchsteiger's definition in that an industrial process does not produce them and therefore no management can attempt to control their effects, except by evacuating the area of people and resources prior to the event. Therefore disaster management frequently involves humanitarian aid - the organization of clean-up operations, relocating and re-uniting survivors (Lerner 1991). This, therefore, may not be subject to the extreme time pressure implied in Kirchsteiger's definition. However, many of the major events that have been described as crises, accidents and emergencies are called disasters by the press (Brown 1997). It also seems to be used as a term for the most severe incidents with the more tragic consequences that "differ from accidents and everyday emergencies in the sense that they disrupt the fabric of society" (Quarantelli 1993 cited in Flin 1998 p.88).

5. The term "catastrophe" is used less than the other terms. However, in response to a chemical disaster in Basel, Switzerland, Christen et al (1994) used fuzzy set theory to devise a set of indicators to describe the severity of an incident, where catastrophe is defined as the highest level. These indicators include number of fatalities, injured persons and evacuees; number of dead animals, ecosystems and areas of contaminated soil and polluted groundwater. This disaster scale used is shown in Figure 2.

Figure 2: Disaster scale



Using this scale, the Bhopal disaster was given a value of 1.0 indicating the highest severity possible on the scale. Seveso was given 0.71 and Amoco Cadiz was given 0.61. The Flixborough disaster resulted in a value of 0.50 - indicating that this was on the lowest limit to be given the definition of catastrophe. However, this scale involves some degree of subjectivity and it is questionable whether scales providing definitions are actually useful.

Generally, to quibble over the definitions and terminology relating to such tragedies does not bring us closer to understanding the causes or preventative measures. As in the literature, the most popular term used when referring to such an event is "emergency" (using the definition by Kirchsteiger 1997 above). Therefore, this review will continue to use the term "Emergency management" to refer to the attempts to mitigate such an event and limit these adverse effects. However, at this point, this review will continue by describing some of the worst events of this kind - those that escalated into "worst case scenarios" becoming tragic disasters.

2.2.3 MAJOR DISASTERS OF OUR TIME

There are a number of disasters that are frequently cited in research, mainly because they involved large loss of life or because they occurred in an unexpected manner, perhaps to a company, industry or in a country that was assumed by the public to be "safe". These include Bhopal, Challenger space shuttle, Chernobyl, Estonia, Flixborough, Herald of Free Enterprise, Hillsborough, Kegworth Air disaster, King's Cross, Piper Alpha and more recently the Ladbroke Grove and Southall rail disasters. Often when the accident investigation has been completed, it can be identified that many of the initiating events involved in these emergencies had occurred before. Many RO-RO (Roll on Roll off) ferries had left Zeebrugge with their bow doors open prior to the Herald of Free Enterprise disaster; many fires on London Underground escalators had occurred prior to the King's Cross disaster (Lucas 1992). It could easily be concluded that these accidents were "waiting to happen".

As can be seen from this very short list of major disasters, no industrial sector is immune from tragedy. These examples also refute the beliefs that "it couldn't happen *here*", "it couldn't happen *today*" and even worse - "it couldn't happen *again*!".

In addition, these accidents have all resulted from a number of contributory failing factors from the root causes through to the final failing act. Such causes include:

- Poor government decisions
- Poor attitude towards safety at management and/or operations level

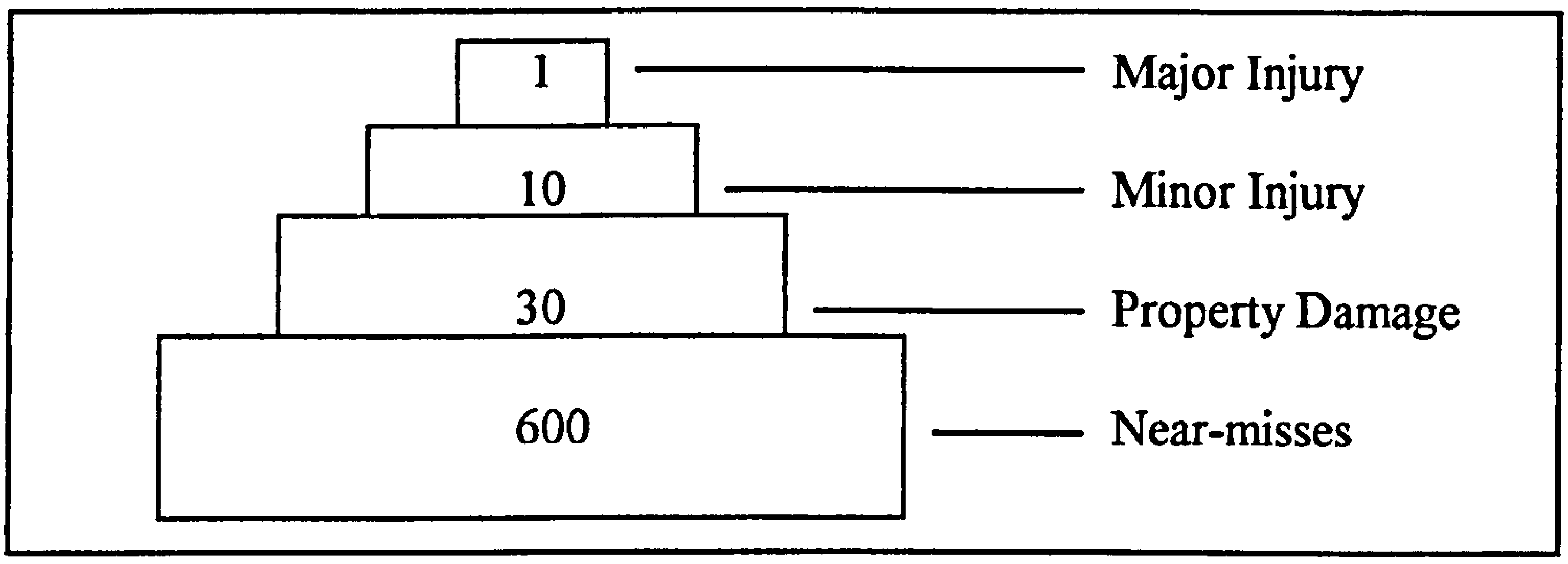
- Inadequate training
- Inadequate or incorrect procedures
- Poor communication
- Poor environmental conditions for the activity involved
- Maintenance errors
- Poor design
- Design modifications without consideration for their implications
- Operational errors
- System failure
- Malicious Acts
- Inadequate secondary safety devices or procedures

It is notable that none of these tragedies resulted from so-called "Acts of God", such as a lightning strike or some other unusual environmental condition. All could have been prevented by reasonable human foresight. For example, although the cold weather was a contributory cause of the Challenger disaster, it was the strength of the management desire to launch that resulted in the disaster. There were political and organizational implications and these overrode the consideration of a possible technical failure due to the effects of cold weather on the o-rings (Presidential Commission 1986). In the King's Cross disaster of 1987, smoking material ignited rubbish that collected in the workings of the elevator. The fire that resulted was left to escalate due to poor emergency and evacuation procedures and lack of staff training (Fennell 1988). This emphasizes the importance of secondary safety systems - that although a fire had occurred, it was the lack of action in response to the fire that resulted in the 31 deaths. In many of the accidents described, it was the lack of adequate response to the incident that resulted in its severity. Titanic is a famous example of where emergency preparedness and management would have made a difference. The fact that the ship struck the iceberg and sank is only the trigger event of the disaster. If there had been enough lifeboats, which had been loaded to the correct capacity and if the warning to abandon ship had been given earlier, more, if not all, of the 1503 victims would have been saved (Watson 1995, Smith 1995).

Disasters of this magnitude are rare but unfortunately, their incidence is rising (Richardson 1994) and it is not sufficient to rely on the low statistics of occurrence. Once a disaster has occurred, there is much effort placed on finding the contributory causes to prevent re-occurrence. This involves a formal accident investigation process. A large amount of information must be collected including the damage to people and assets, relevant procedures, management structures and background, design and design changes. However, there has been suggestion that some investigations are biased towards interested parties in terms of blame and exoneration, perhaps due to their being lead by legal as opposed to independent engineering personnel (Lees 1994). Therefore Johnson & Telford (1996) proposed an investigation technique and team structure including forensic scientists, metallurgists, meteorologists, software engineers and human factors experts, as necessary, to bring together their knowledge to provide accurate and consistent recommendations. Examples of the details examined are given in some of the public inquiries that have been carried out, for example, into the Piper Alpha (Cullen 1990) and Hillsborough (Taylor 1989) disasters.

However, there is always the possibility that a minor incident can escalate into a major disaster and so just responding to the specific disasters that have occurred is inadequate. Statistics can be used to examine the potential for disaster. These might include specific types and severity of injuries (HSE 1997b), types of error (Bradley 1995), types of tasks (HSE 1997b) or can represent the injury rate for the whole industry in question (Lancaster 1996). However, it is better to take a pro-active approach. It has been demonstrated that there is a relationship between the number of near misses, minor incidents and major accidents as shown in the "Iceberg concept" represented in Figure 3 (cited in Jones et al 1999).

Figure 3: Iceberg concept



Despite this, there is an *inverse* relationship between the number of accidents and the number of near misses *reported* (Jones et al 1999). This suggests that if you investigate the large number of near misses, it can help to prevent both the smaller and larger incidents, hence taking a reactive approach.

However, these issues are primarily the concern of conventional risk and safety management as opposed to emergency management. They focus more on the global objectives of this research project (trying to reduce overall risk by identifying weaknesses in the emergency management system) than the objectives of an emergency management team (reducing the risk in the specific emergency situation). As there is an enormous body of research in the former area, this will not be discussed in further detail. Therefore, the next sub-section will return to a more pertinent issue by describing, in generic terms, the stages through which an emergency is said to progress.

2.2.4 STAGES IN AN EMERGENCY

Within an incident of the type described in the Kirchsteiger definition, it is believed that the time phases in the event can be placed in various categories. Strutt & Lakey (1995) suggest that the physical stages in the emergency are as follows:

- Initiating Event - This is the triggering event and might involve a relatively insignificant human or system failure.

- Loss of control - This is the first stage of escalation, whereby the triggering event has an impact on the rest of the system, perhaps through a lack of controlling systems.
- Escalation and spread - This is said to be the stage at which the incident escalates from a minor to a major incident. The risks to personnel, assets and the environment are greatly increased and regaining control becomes more difficult, if not impossible.
- Failure to evacuate - This is the final stage of an emergency - where there are no control-based alternatives, evacuation is the only safe measure. In this case, evacuation could be prevented through escalation, leading to the worst possible outcome.

These stages of incident progress also imply the stages of actions that should be taken in response to them. In qualitative terms, this can be used to assess the impact of emergency management on risk. The incident's potential (negative and positive) compared with the eventual outcome are a measure of emergency management performance - and progressing to the final stage would usually imply poor emergency management.

In contrast, Tyhurst (cited in Rolfe & Taylor 1989) focuses on the psychological reactions to the event and proposes that the phases include:

- Threat
- Warning
- Impact
- Recoil
- Post-impact

These psychological phases can be linked to the physical phases as used by Strutt & Lakey (1995). The initial threat stage occurs where people realise that the potential of a disaster occurring is probable and that they may be affected. As the realisation increases that a disaster is imminent, the individual(s) involved enters the warning phase. Occasionally, there is no pre-impact stage of realisation and the disaster occurs without any threat or warning. This is the impact stage, which is the area we will focus on in our examination of emergency management. Once the initial dangers have been removed by either escape, mitigation or by ceasing naturally, this signifies the period of recoil. In this phase, it is disaster management that plays its part - where the slow process of humanitarian aid and clean-up operations are required. Finally, there is a period of post-impact trauma, where the people involved must recover from the experience psychologically and rebuild their lives (Leach 1994).

The fact that these psychological changes occur cause problems both in an emergency and when studying the assessment of emergency management and its impact on risk. Firstly, it is likely that the point when an incident really requires intervention by an emergency manager is going to be the same point at which they are unable to respond. Secondly, as it is difficult to recreate these same psychological reactions under "safe" conditions, assessment of emergency management performance is somewhat artificial.

However, the behaviour of those involved prior to and during the emergency may have a critical (negative or positive) impact on its outcome and it is this behaviour, and the emotions behind it, that will be discussed in the next section.

2.2.5 THE EMERGENCY EXPERIENCE

Despite this age of technological advances, often it is the human responses that provide the main mitigation between minor incident and major accident. This is known as Emergency Management, which will be discussed in Section 2.3. However, the current section will consider the natural untrained response to an emergency. How does an emergency experience affect feelings and behaviour, and does this experience contribute to a successful or unsuccessful outcome?

What is an emergency for one person may be perceived as a normal event for another person. Consider, for a moment, the emergency services - their working lives consist of involvement with people with severe injuries and fatalities; whereas to the public in general, only one of these incidents in a whole working lifetime may be an irrepressible and incomprehensible event. As Lagadec states "An event is defined by how it is perceived" or more specifically for the subject of crises; Bolzinger (1982 cited in Lagadec 1993) states "Without this feeling of being in crisis, there is no crisis; the mere clinical perception of the symptom is enough to make the diagnosis". This is comparable to one definition of stress - the transactional model (Cox & Mackay 1976) - where stress is the perceived inability to cope. In both cases, it is the perception of the reality, rather than the reality itself, that creates the experience.

The reaction to an emergency situation may or may not contribute to a successful outcome of the emergency. The stress can be extreme causing unusual reactions. However, the early idea that people immediately panic in response to an emergency is not strictly true. Neil Townsend suggests "I think that when people die in fires it's not because of panic - it's more likely to be the lack of panic (Faith 1999 p.161). However, panic can occur, particularly where escape routes are blocked or there is confined space. Such behaviour can be irrational and self-destructive as judgment and reasoning deteriorate even to the stage where mass panic spreads throughout a group of people (Leach 1994). However, it is not always the case.

In an incident where all 4 engines failed on a Jumbo Jet flying to Kuala Lumpar, Betty Tootell reported "After the initial flurry on the plane - not panic, that's too strong a word - people said goodbye to each other, put their arms around one another. Some sat sobbing quietly, some appeared not to have noticed what was happening. My heart was thumping like mad, but although people say panic is infectious it was calm that seemed to have spread" (The Times 19th August 1985 cited in Leach 1994). Other reactions include paralysing anxiety (being frozen to the spot), tunnel vision and perceptual distortions, denial, depression, hypoactivity, hyperactivity, guilt, anger or irrational behaviour (Leach 1994). Rolfe & Taylor (1989) suggest that "passive trust" may occur, where a victim "acknowledges the existence of the threat but takes no positive action, arguing that "they" (i.e. community leaders, the police...) are in command of the situation and all will be well". Such a response emphasizes the importance of the emergency managers in these situations.

However, David Canter adds "...The most remarkable thing about people's behaviour in a fire is that "they carry on with their ordinary, conventional, day-to-day activity with the script that guides what they do when there's no emergency. They follow through on that until the circumstances are so dramatic, so disturbing, so demanding that they feel they have to do something very different" (Faith 1999 p.151). Such a reaction was exhibited in the King's Cross and Bradford Stadium fires and the Manchester air disaster of 1985.

Whether or not these behaviours are beneficial to the individual can only be determined by the outcome. If such reactions lead the individual to save themselves and perhaps other people, they are obviously beneficial. However, if the reactions lead the individual into further danger, this could be either due to the disorganised perceptions and poor planning or could be just bad luck.

The following section discusses the factors important in emergency management. This requires an individual to be able to control these naturally occurring reactions, not only in himself, but also in others, to maximise a positive outcome from the incident.

SECTION 2.3: EMERGENCY MANAGEMENT

2.3.1 INTRODUCTION

This section describes the concept of emergency management in 5 main sections. These are as follows:

- What is emergency management? - describing its goal and objectives
- How does emergency management work? - describing the means by which it obtains these objectives.
- What types of emergency management are there? - describing various types of emergency management shown in the literature
- How can good emergency management be identified? - describing characteristics that have been linked with good emergency management.
- How can emergency management be assessed and improved? - This describes the training and assessment that is available for emergency management and the additional factors that influence a good outcome in an emergency

2.3.2 WHAT IS EMERGENCY MANAGEMENT?

As Section 2.2.2 described, an emergency is an "unexpected, unplanned event resulting from uncontrolled developments". As Lerner (1991) states, "A disaster is, by definition, a situation beyond control. Therefore the term "disaster management" may seem an oxymoron". Similarly, emergencies are unmanageable, if you consider the ordinary definition of management, and thus they require skills above and beyond those of normal duties.

In the same way that there is confusion between the terms emergency, crisis, disaster and accident, the term "management" has been used in connection with these terms to mean very different duties. Using the earlier definitions by Kirchsteiger (1997) and Wilson (1991), it can be assumed that an event has occurred which has the potential to cause great damage in a short length of time. The extent of damage that occurs depends on initial conditions (for example the presence of latent errors or availability of mitigation systems) and the actions that can be taken to limit the damage. Limiting the damage to workers, members of the public, assets and the environment is the essence of emergency management. It does not involve preventing the initial event - this would be normal safe management practice. It does not involve humanitarian aid given that the worst-case scenario manifested itself: - This is disaster management (or disaster relief). It also must be distinguished from crisis management, which is concerned more with corporate image and other economic concerns. Therefore, emergency management involves the direct attempts to prevent the initial event from becoming the worst case scenario in terms of injuries sustained, lives lost, assets damaged and environmental pollution.

Baldwin (1994 p.20) distinguishes between the "different tiers of management required as follows:

- Emergency response - This focuses on the reaction to the physical emergency to protect people, the environment and property.
- Emergency management - This concentrates on managing the immediate repercussions of the emergency, for example, the media and public reaction, minimizing its impact on normal operations and ensuring the emergency response team is handling the incident in an adequate way;
- Crisis management - This can be defined as the loss of management control; so the corporate team is tasked with developing and implementing pre-emptive strategies to secure the company's long-term future which has been threatened by the emergency".

However, to maintain consistency with Kirchsteiger's definition and that shown in the Definition of Terms, this report will use the term "emergency management" to refer to Baldwin's definitions of Emergency Response together with the initial stages of Emergency Management.

2.3.3 HOW DOES EMERGENCY MANAGEMENT WORK?

An emergency can be compared to a competitive game of chess. Once the first move has been taken, there are a large number of possibilities to how the game may end. It may involve a win or a loss. It may end with a large number of pieces on the board or just two or three. One player may lose as they run out of time or because of their lack of insight. Each player wants to maximize their own chance of winning and will take the actions they believe are correct to gain this end. In emergency management, it is the player versus the situation. An emergency manager wants to successfully win over the emergency and to minimise the losses. One of the key aspects of an emergency situation is that it involves a time base that is non-negotiable. The emergency will "wait for no man". Delays in response only result in escalation - increasing the probability that the worst-case scenario may arise. However, this is not a totally reactive process. Some emergencies are unmanageable - perhaps due to poor design, lack of resources or because the situation escalates too quickly to allow intervention. These issues will be considered in section 2.3.6.4 and 2.3.6.5.

Even with all the technological advances that we have today, it is still humans that provide the important intervention in an emergency. This is surprising when you consider that it is estimated that up to 90% of accidents are caused by human error in the first place (Hollnagel (1993 p.4) and some bodies consider this adequate justification for the complete automation of safety-critical systems. Professor van der Schaaf argues "Whatever you do, don't design humans out of your systems, they are probably all that stands between you and catastrophe" - adding that "human beings remedy between 60 to 80% of the errors that occur in processes" (van der Schaaf 1999 p.6). As a human is capable of creatively experimenting and gaining "deeper knowledge" of systems, they become more competent in error recovery.

In general, the tasks involved in emergency management are wide and varying. They involve making appropriate responses to the escalating incident and so cannot be fully explained by a single definition. Strutt & Lakey (1995) suggest "the key objectives of an emergency management system are to prevent or reduce the likelihood of consequential loss in the event of an emergency occurring" and more specifically, "The avoidance of a disaster will depend on the knowledge of the emergency management team and its ability to control events, to prevent escalation and to successfully plan evacuation, escape and rescue, under adverse and highly stressful conditions". However, this does not indicate HOW these should be achieved, therefore the next section will give a closer examination of emergency management by looking at types of emergency management approaches.

2.3.4 WHAT TYPES OF EMERGENCY MANAGEMENT ARE THERE?

The previous sections described generally what emergency management is and how it works. This section will describe some approaches that can be observed as being used when managing an emergency. In general, emergency management is reactive – and therefore, it is difficult to define specific approaches to be followed – as often emergencies rapidly escalate beyond the scope of a defined approach. Therefore, the approaches to be considered here are often more concepts relating to the attitude towards how the emergency should be managed - namely "Team Resource Management", the "Command and Control" approach and the Emergent Human Resources model.

2.3.4.1 Team Resource Management

Team (or Crew) Resource Management (TRM or CRM) has become increasingly popular in the emergency management field, particularly in the aviation industry – its importance being emphasized by the chain of failure leading to the Kegworth disaster. In this, a fire occurred in one engine and because the instrumentation was confusing, the pilot shut down the other engine. The aeroplane then appeared to regain control and so the pilot did not realise his mistake. However, the cabin services crew had information as to the location of the fire but did not pass this information on to the pilot. This was due to the culture and the communications in the environment (Smith 1995) - that either pilots gave the impression that they did not need feedback from the cabin crew - or that the cabin crew have utmost confidence in the abilities and knowledge of the pilots or did not feel that the pilots would listen to them anyway. In this case, such assumptions were disastrous and there are many other examples where the "macho pilot" attitude has caused serious incidents. Team Resource Management emphasised a shift in focus away from the militaristic authoritarian attitudes and the alleged "superiority" of the captain (McIntyre & Salas 1995) towards an information-sharing culture. Many other industries have started to implement this approach – also calling it Team Resource Management to reflect environments outside of the flight deck

For this reason, the main characteristics of Team Resource Management have also been used to train and assess emergency management. In this context, it can be used to consider all aspects of human team behaviour that promote and reduce the probability of success in emergency management. This helps people to understand why accidents occur and so enables them to identify error-producing conditions in themselves and others – both under normal and emergency conditions. These conditions may include personal factors such as stress, conflict, lowered attention or perception, fatigue or health problems. They may also include understanding of the potential for failure of the man-machine interface. Each member of the team is encouraged to participate and learn about team resource management. Some of the main issues include:

- Communication - Open and honest communication is encouraged, where information and discussion is carried out and conflicts and ambiguity about information are resolved.
- Teamwork - Leadership is developed through cordial social contact with all the team members rather than emphasizing the hierarchical leadership role. Teams are motivated to contribute to problem solving.
- Workload Management - This involves making flexible plans to suit the situation, to identify risks and to recognize and manage stress in oneself and others. A good level of situation awareness is essential and involves a continuous information-gathering and assessment approach. At each point, the information is assessed to see if the current conclusions are still valid or whether other possibilities could be correct.
- Attitudes, behaviour and inter-personal skills - These help to facilitate the communications and teamwork through positive intervention. Training may include demonstration of the benefits of Team Resource Management and identifying any weaknesses in the teams involved.

(Paris et al 2000, McIntyre & Salas 1995)

2.3.4.2 "Command and control" or Bureaucratic Approach

However, the "Command and Control" approach is still popular in emergency management. It rests primarily on military experience, including the type of attitude that team resource management is encouraging aircrew to abandon. As much of their background involves stressful, time-contingent decision making under life-threatening conditions, the military leadership approach is thought to be an appropriate method of dealing with an emergency. It is based on creating and using a centralized hierarchical structure headed by a "commander" exerting strong leadership over societal chaos.

Siegel (1985) favours this "planned, controlled, and organized response over ad hoc configurations". However, Dynes (1994 cited in Neal & Phillips 1995) criticizes the approach due to its assumptions of the emergency situation involving "Social chaos, reduced capacity of individuals and organizations to cope or respond to the incident, a level of deep mistrust of effective decision making, and a weak view of civil society".

Neal & Phillips (1995) cite a large body of research that refutes the merits of this approach saying that "Command and control approaches tend to ignore or misinterpret a massive existing literature on disaster behaviour" and thus "generally lead to an ineffective emergency response".

2.3.4.3 Emergent Human Resources Model (EHRM)

This is the opposite of the Command and Control approach. It emphasizes that the emergent norms, groups and social structure that are generated in an emergency can result in a more effective response than the rigid methods of the command and control approach. This is also more flexible than the Team Resource Management approach allowing teams, ideas and rules to emerge as required. Neal & Phillips (1995) state that "EHRM proponents assume that a non-bureaucratic, loosely-coupled, organizational approach to emergency management is most effective. Flexible and emergent structures can provide basic emergency response needs until traditional bureaucratic forms can again operate". They also provide a scientific basis to support these arguments and give examples of humanitarian aid whereby the requirements fell outside of the duties set down in the bureaucratic guidelines and the groups re-organise to effectively meet the needs of the people.

Perrow (1984) supports this argument by suggesting that "bureaucratic structures are typically not designed to respond to unpredictable turbulent environments created by a disaster". Even the military, typical advocates of the Command and Control Approach, have been observed to deviate from their established rules and procedures in an emergency (Neal & Phillips 1995). Leach (1994) gives many examples of where emergent leaders have successfully managed incidents, including evidence from the Zeebrugge ferry and Aberfan landslide disasters. However, it is not prudent to rely on this occur in an effective way within industry, but it is reasonable to accept that emergency management may not work within rigid boundaries and it should be possible for effective leaders to emerge should they be more effective than the current mechanisms in place.

2.3.4.4 Which type of emergency management approach should be used?

It is not sufficient to rely on the EHRM model as an excuse to not prepare an emergency management team - to "hope" that an adequate response will be produced whatever the situation. Therefore, according to the literature, the best approach appears to be the Team Resource Management approach - where free communication is encouraged and information flows efficiently, rather than rigid "command and control" mechanisms. However, using the approach that appears to be the most effective does not guarantee a positive outcome. Therefore, the next section will examine how good emergency management, independent of type or approach, can be identified.

2.3.5 HOW CAN GOOD EMERGENCY MANAGEMENT BE IDENTIFIED?

Whichever technique is used, success is determined by the outcome. The best possible outcome under the circumstances indicates good emergency management has been applied. However, sometimes, management intervention can play no significant part - due to the design, initial hazardous conditions (for example, lack of safety mitigation systems), the environment or extremely fast escalation. Therefore, good emergency management involves making the best out of the situation, given the resources available.

Often, success is assessed subjectively. For example, if an initiating event consisted of an explosion that immediately resulted in a small number of fatalities, this would be an unmanageable event. Subsequently, even if the emergency manager successfully controlled any escalation and arranged for all other people to be taken to a place of safety, the media and members of the public may focus on the fatalities and consider it a poorly managed incident. Therefore, it is important to maintain an objective and fair view of the possible interventions that could be made.

Larken (1995) suggested that good emergency management "involves the skills of strategy formation and decision making, both of which must take place under conditions of time pressure and limited information in a situation which may be moving ever further outside the operational envelope".

Flin & Slaven (1996b) suggest that "a successful response to an emergency requires an effective deployment and coordination of resources under dynamic and dangerous conditions". To give more specific examples, Flin and Slaven (1995 p.115) list the following skills and competencies as being typical organisational requirements of emergency commanders:

- Leadership ability
- Communication skills, especially briefing and listening
- Delegating
- Team working
- Decision making under time pressure and especially under stress
- Evaluating the situation (situation awareness)
- Planning and implementing a course of action
- Remaining calm and managing stress in self and others
- Preplanning to prepare for possible emergencies

It should be noted that these are very similar to the key skills identified as features of team resource management as mentioned in Section 2.3.4.1. Therefore identification of "good" team resource management is likely to be akin to the identification of "good" emergency management.

Given these features, the next sub-sections will discuss some of the main characteristics:

- Leadership and personality factors
- Teamwork
- Decision making
- Stress management

This will start with the first of these - leadership and personality factors.

2.3.5.1 Leadership and Personality Factors

Given the generic nature of emergencies, it would be difficult to focus on numerous procedures to cover every possible scenario. Some research in the area has attempted to identify personality characteristics of an individual who could successfully manage any of the possible events.

Until an emergency occurs, it is difficult to determine whether an individual or a team will be good at emergency management. One method involves using expensive scenario-based selection and training techniques, which will be discussed in a later section. However, there has been a great deal of effort oriented towards identifying generic personality characteristics that would identify ideal emergency managers.

Much attention has been devoted to the study of leadership - as part of emergency and normal management. In normal management, there have been studies into whether leadership is a natural personality attribute or a skill to be learnt. There have been studies as to which style of leadership is appropriate for each situation, known as the Contingency theory (Fielder 1978). This theory maintains that leader effectiveness depends on a relationship between the leader's personality and the characteristics of the situation, which is consistent with the concept of the Emergency Human Resource Model of emergency management described in the previous section.

The Normative theory of leadership (Vroom & Yetton 1973) suggests that leader effectiveness is based on adopting the style of leadership that is most appropriate for the situation as follows:

- Autocratic - The leader would take advantage of his position of responsibility and is gripped with compulsion to dominate others.
- Democratic - The leader tends to seek group decision consensus when making a decision.
- Laissez-faire - The leader is indecisive and leaves problems to "solve themselves".

In normal circumstances, the democratic style is considered the most effective. However, in a crucial situation where time is short and the leader is required to make decisions alone, the autocratic style is considered more efficient. If team support and acceptance are also necessary, the democratic style is still the best option (Baron & Byrne 1991). However, as Arnold et al (1991) conclude - "No current approach to leadership is substantially better than all the others, but several approaches offer useful insights". Therefore perhaps other personality attributes may be identified as characterizing a good emergency manager.

Mike Smith (1996) considers the personal characteristics that are needed in high-risk occupations and he mentions high vigilance and perceptual ability, mental ability, physical ability and emotional stability. However, these must be specified in more detail for each high-risk working environment. In addition, just because they are appropriate for high-risk occupations does not necessarily mean they are appropriate for responding to an emergency situation. For example, hazardous environments such as working in the Antarctic may not require quick and timely decision-making. Similarly, those who have the personality attributes to experience and survive emergency conditions are not necessarily those who would be good at coordinating the management process.

Leach (1994) suggests that the requirements of on-scene emergency management change over time. Evidence suggests that the first leader is "authoritarian, decisive and will lead by example". But as the incident progresses, another, more empathic and understanding leader emerges to deal with the social needs of the group. He adds that, surprisingly, it is the second leader that shows more perseverance in the role.

However, in emergency management, it has been suggested that the emergency commander should have the following personality characteristics:
"intelligence, commonsense, integrity, judgement, enthusiasm, loyalty, cheerfulness, sense of humour, energy, high fortitude, moral courage, the will to dominate and decisiveness" (Downes 1991 cited in Flin & Slaven 1996b).

These characteristics were based primarily on the military domain and may not be appropriate for all types of emergency management. At first, these seem to be reasonable assertions. However, there should be some discretion taken in using such terms. For example, although a sense of humour is recommended, it is more important that it is appropriately and sensitively used.

In addition, Flin & Slaven (1996a) note that the current research has not found a correlation between these characteristics and those of competent emergency managers in the offshore industry. However, they comment that this could be a criticism of the psychometric tests used or the subjective judgment of the simulation assessors. Again, it is not clear whether either of these criteria are linked to high probability of success of obtaining a good outcome in a real emergency.

However, an emergency manager cannot manage an emergency on his own. Therefore the next section will discuss the requirements and abilities of the emergency management team.

2.3.5.2 Teamwork

If the focus is on the individual leader, one must not neglect to mention the importance of the team in the emergency management process. Emergency management usually requires action beyond the capabilities of one person. Whichever type of emergency management technique is used, teamwork is essential. If a leader has all of the ideal characteristics described above but their team is not competent or is incapable of working as a team, the management process will probably fail. Orasanu & Salas (1993) emphasize that the participants must form a "shared mental model of both the situation and the roles of the other individuals in order to be successful".

Further to this, McIntyre & Salas (1995 cited in Flin & Slaven 1996a) noted that good emergency management teams typically exhibited the following behaviour:

- Monitoring - whereby team members monitor their colleagues
- Feedback - where information on good or poor performance is fed back to the team
- Closed-loop communication - where information is passed on in a methodical manner
- Backup - where team members feel responsible for helping each other
- Values - loyalty and interdependence between team members

Again, like the issues of personality and leadership, it is not definite that these characteristics are the key features that contribute to a positive outcome in a real emergency. Obviously, it seems likely but without clear measurement and perhaps weighting of characteristics, it is not certain how to assess emergency management teams based on these criteria.

2.3.5.3 Decision-making

However, in an emergency, it is necessary to have a team of decision makers as "the rate of evolution of the situation was faster than the rate of processing by any given individual", particularly with the large amount of information that must be gathered and understood (Samurçay et al 1993 p.56). Therefore, focusing on the leader may explain how the strategic decisions are made but may not explain how decisions are made throughout the whole hierarchical structure (Danielsson & Ohlsson (1997). This requires the study of distributed decision-making. It has been demonstrated that although each individual may be highly competent in the respective task, this does not guarantee efficient working once they have been brought together as a team (Samurçay et al 1993). There are roles for information management (ensuring each member of the team is provided with the relevant information), logistics (ensuring external resources are coordinated) and many others. As the decision-making is now distributed between a number of individuals, it is essential to maintain a good communication structure to ensure that both the leader and the team are making their decisions based on high quality information.

Orasanu (1995) suggests that the quality of decision-making can be determined by the crew's understanding of the problems that they faced. She cites Endsley's (1994) levels of situation awareness to explain how flight crews cope with abnormal situations, namely:

1. Perception of cues
2. Comprehension of cues
3. Projecting future developments

Therefore to rectify problems in decision-making, Orasanu (1995) made a number of recommendations to improve team situation awareness including verbalisation of flight condition status, questioning their own decisions and working as a team to monitor each other's performance.

As with the other characteristics, decision-making and situation awareness appear to be important issues in emergency management. However, with clear indication of how to measure situation awareness or how to categorise decision-making strategies and link these to success in terms of outcome of an emergency, it is impossible to indicate their influence.

2.3.5.4 Stress Management

Weick (1988 p.315) noted that "Stress in an accompaniment of all crises, and ... many crises escalate because of the secondary effects of crisis-induced stress...". Lagadec (1993) noted that the stress caused by a crisis can be very disruptive to performance, particular in learning and decision-making. The decision maker may use avoidance strategies to deal with it and so the escalation of an event may continue unhindered. Stress also may result in a "certain regression" whereby individuals resort to basic behaviour rather than more complex cognitive tasks, including rigid reasoning and narrow-minded option generation. Similarly, negative personality traits may emerge resulting in problems in team coordination or non-productive emotional reactions. Task-oriented leaders may become more task-focused and so will neglect the human-relations aspects and vice versa.

Orasanu (1997) suggests that any weak links in decision making strategies are likely to be exposed under stressful conditions and adds that training should help to counteract such effects. Breznitz & Ben-Zur (1997) support this by suggesting that "time pressure leads to the usage of simpler decision rules" and that "use of information management techniques should improve the quality of decision making".

However, according to the arousal theory of stress (Cox 1993), we can observe that a certain degree of stress can bring out the best in people. And if we combine this idea with the Transactional model by Cox and Mackay (1976), stress is based on perceptions so reactions to stress will be very different for each individual. For example, in a mine disaster, cited by Idzikowski & Baddeley (1983), "the person who emerged as the group leader was one of the men who had originally shown the greatest fear and had apparently "cracked" under the strain". Therefore, there are people who can perform well under stress even in the worst type of situation.

Research into parachuting by Epstein & Fenz (cited in Idzikowski & Baddeley 1983) found there was a significant difference in the reactions of expert and novice or incompetent parachutists. For novices, the greatest self-ratings of avoidance occurred just before the jump itself. However, for the experts, the greatest level of avoidance was the night before the jump. In terms of physiological arousal, the novices had a much stronger reaction than the experts, which rose gradually as the time of the jump approached. The experts, however, showed their greatest increase in arousal just before entering the aircraft. This was attributed more to excitement than fear.

2.3.5.5 Conclusion

The implications of this for emergency management is the benefits of experience and training:- that learning to control one's anxiety in these situations is extremely important. However, it must be re-iterated that it is the outcome of an emergency that is the important aspect - having strong leadership, decision-making, stress management and teamwork do not guarantee a good outcome but they provide a strong influence. Therefore, psychological attributes cannot be relied upon as a measurement of the impact of emergency management on risk. They certainly influence the actions that physically impact on the emergency but may not always be successful - based on the type of incident, design parameters and, to a certain extent, luck. The next section will move on to discuss issues in training and methods of improving emergency management.

2.3.6 HOW CAN EMERGENCY MANAGEMENT BE ASSESSED AND IMPROVED?

This section addresses some of the main issues in improving emergency management - not just addressing the actions of the team but issues that can be dealt with long before an incident arises. Some of these sections go hand-in-hand. For example, assessment and training. Assessment can be used to identify the skills required by a task, by developing techniques to assess "expert emergency managers" and then these skills can be incorporated into training. On the other hand, assessment can identify whether skills have been improved by training.

Therefore the following sections include:

- Training
- Assessment
- Planning
- Design
- Resources

2.3.6.1 Training Techniques

As emergency management involves minimizing loss through the control and prevention of escalation, it is reasonable to suggest that it can be assessed in terms of its outcome. There are as many stories of heroic rescues as there are of disasters. Airline pilots who have completed safe landings in a damaged aircraft "against all odds" are key examples of successful emergency management (Stewart, S. 1992).

However, this review includes descriptions of real emergencies assessed in terms of their physical outcome. It has also mentioned the personality and team factors believed to be linked to good emergency management. As yet there has been no evidence to suggest that the recommended types of emergency management team are successful in managing the real emergency. To try and rectify this issue, individuals can be selected or trained using realistic simulations and then assessed in terms of outcome that resulted. Although simulations have been criticized as being artificial and less stressful than a real emergency, Larken (1995) suggests that "it is not necessary to subject people to extremes of pressure and fear in order to produce an adequate vehicle for training "outside the operational envelope'"". Therefore, often this is the most realistic method of predicting emergency management ability.

Strutt & Lakey (1995) suggest that an emergency management training programme should include the following relevant subjects:

- Industrial Hazards and Technical Information about the workplace involved
- Risk Analysis
- Protection measures, Emergency equipment and systems
- Emergency plans and procedures, Alarms and notification schemes
- Emergency management
- Escape, evacuation and rescue
- Accident investigations
- Communications and dealing with outside agencies
- Human Factors, Performance Shaping Factors and the causes of Stress

In most cases, emergency management training involves simulations of varying degrees of realism. Larken (1995) suggests that "dry" management should be avoided - where command, decision-making and other aspects are taught in isolation from each other and that it is an "intellectual not a physical exercise". In addition, training can be somewhat reactive and focuses on previous emergencies that have occurred by using similar scenarios (Rosenthal & Pijnenburg 1990). Although this facilitates improvements in emergency preparedness, care should be taken to ensure that the focus is not too narrow and that many different scenarios are considered.

Carrol & Kidd (1991) mention a number of issues that should be considered when planning a scenario.

1. Its aims must be identified - whether they are solely for training purposes or to identify weaknesses in the system. It must also consider the number of people who should be included in the emergency management process - the whole organisation or a small team.
2. A realistic scenario should be developed and the appropriate equipment for management should be identified and placed at the emergency management team's disposal.
3. The scenario organisers should be chosen - those who have considerable knowledge of the organisation and its emergency management potential and people who can fulfil the role of "actors" - to play emergency service personnel, casualties or outside organisations. These people also must exercise enough control to ensure that the scenario does not become a real emergency. Briefings must be given before and after the exercise to provide feedback on performance from the scenario organisers and comments about realism to the emergency managers.
4. Plans must be in place to ensure that the organisation returns to normal operation once the exercise is complete.

Kaempf & Militello (1992) recommend that emergency decision makers undergo the standard stress management training but also learn to make decisions under time pressure. Pattern-matching exercises and increasing the situational awareness are benefited by training but most of these can be learnt through regular emergency management exercises. The military advocate the use of stressful exercises and even recommend extra "stressors" to enhance the effects, including forced use of training/operations when the team are fatigued; additional, disruptive tasks; time pressure, the presence of other military units and additional navigational constraints (Forster 1996).

Roth et al (1992) emphasised the importance of "completeness" in emergency management training exercises. That is, ensuring that teams are tested with the full range of cognitive problems with which they may be faced.

For example: Kontogiannis gives the following list of information uncertainties which "should be incorporated into an emergency exercise:-

- Eliminated or missing cues - simulations that remove or obscure critical evidence
- Masked cues - simulations involving a latent failure which is masked partially by the symptoms of a more recent operational problem
- Unreliable cues - simulations involving unreliable information
- Delayed cues - simulations where auxiliary operators delay to collect or communicate information
- Attention-diverting cues - simulations which produce salient information in one area to the extent that indications in another area are neglected
- Familiar or stereotyped cues - simulations in which part of the available evidence suggests very familiar explanations which turn out to be incorrect
- Unfamiliar cues (novel events) - simulations involving unfamiliar failures which have not been foreseen in the design process
- Unfamiliar cues (multiple failures) - simulations of interactions of multiple failures
- Poorly integrated cues - simulations which require integrating knowledge from various team members in order to gain a complete understanding of the problem".

(Kontogiannis 1996 p.96)

Such training is believed to have the positive effects partly through the development of coping strategies. Muir (1997) suggests the following coping strategies can be adopted:

- Action coping - By taking positive action to reduce the level of demand, by removing the problem or altering the situation so it becomes less demanding. The measures may be extreme - for example, getting a divorce or moving jobs. In some cases, it may just involve breaking a task into small sections so that it appears less daunting.
- Cognitive coping - This involves reducing the emotional and physiological impact of stress on the individual by changing the perceptions of the demand if not the demand itself. These include defence mechanisms, including repression, denial and rationalisation.

Therefore, the following sub-sections will describe the main types of training used in emergency management:- drills, computer simulation, talk-through and table-top exercises, dedicated simulations and "real" exercises.

2.3.6.1.1 Drills

These are not normally concerned with the actual management of an incident but usually focus on the actions that are required within it. They may include mustering, using fire-fighting equipment or breathing apparatus (Strutt & Lakey 1995). Physical tasks are normally included rather than the cognitive decision-making required by emergency management. However, without knowledge of these physical tasks, the emergency management process would be futile.

2.3.6.1.2 Computer simulation

Computer simulations are becoming increasingly more popular in the area of emergency management - mainly evolving from the earlier models testing building fire escalation or hurricane evacuation (Sullivan 1989). These were primarily used to investigate design or environmental factors as opposed to management intervention. At the other end of the scale, they have also been developed to simulate the critical financial and economic indicators to assist in crisis management training (Booth 1990).

With the increased use of computers, packages can be installed simply on a PC and many users can learn and test themselves in emergency management. This is a very cheap approach and has a critical advantage over other means of training - that the success of the training can be objectively and quantitatively measured. However, some systems are very complex and involve an interactive network to include a whole emergency management team. An important factor in developing computer-based simulation is its fidelity to the real situation - namely, are the key issues present in the real situation (cognitive, physical etc) represented in an appropriate way in the simulation to ensure that it provides an effective training technique? Jentsch & Bowers's (1998) work in the aviation industry concluded that PC simulations are a "valid alternative to high-fidelity full mission simulation...including testing team coordination exercises" therefore supporting a positive cost-benefit from their use.

Beroggi et al (1995) has suggested the advantages of using virtual reality in emergency management training to really "feel the heat, hear the noise and see their actions being implemented". However, most of the software has involved 2D representation such as Plowshares (Petty et al 1996), which involved the adaptation of the U.S. Army's Janus combat simulation model to cater for civilian emergency management actions. This program was then used in combination with a hurricane incident causing tornadoes and fires. Using a network of computers controlled by an exercise and message controllers, the emergency managers played their role from their individual terminals. Other software of this kind includes Tutor (Adamson 1999) and C^3 Fire (Granlund 1999). In addition, Lin & Su (1998) used a chemical spills expert system and demonstrated its improvement of rule-based performance in emergency management.

However, the computer systems may have a serious limitation in that they do not represent the social aspects of the emergency - for example, in reality, people may give misleading information or that conflicts can arise within the team. They also can be restrictive - only allowing the types of emergency in the software to be considered. Users may also discover solutions that the scope of a computer program may not consider or allow roles to emerge in teams where individual problems-solvers fail.

2.3.6.1.3 Talk-through and Table top exercises

A talk-through involves those who would be the key decision-makers in a real emergency lead by an "exercise leader" or moderator who has determined and/or designed the scenario to be managed. Within the group, there are experts in their respective areas, including those from the emergency services and those who are familiar with the environment involved. They are given a scenario to manage and simply discuss their expected actions step-by-step. Experts make contributions on the expected outcomes from each decision. The exercise leader will introduce the escalation points of the scenario and any additional information that emerges. The group will discuss this until all are satisfied that the emergency has been completely managed. This allows all the individuals involved to learn from the scenario and to identify weaknesses in their current organisational plans (from Rutherford 1990).

A tabletop exercise involves representing the entire emergency on a map or diagram on a table. This gives the managers the chance to "see" the emergency and appreciate the distances involved, the relationship between specific areas and any problems with routes. In the case where this may involve a gas leak, it allows the managers to work out which areas are at risk. The discussions involved are similar to the talk-through where the decisions made and actions to be taken are discussed. In some cases, the moderator asks specific questions to motivate the team to consider particular factors (from Dowell 1995).

Strutt & Lakey (1995) consider 4 types of tabletop exercise.

- Linear exercises - where the participants follow a route for which correct solutions are known
- Open exercises - where the scenario is free-running and the outcome is not known
- Communication exercises - where the communication factors is the only aspect under test.
- Committee exercises - where a committee encourages an exchange of views on the subject

These are not usually run in "real-time" so, although they allow the full scope of the emergency to be discussed, they do not work under the time pressure that will be evident in a real emergency (Baldwin 1994). This is also a reasonably cheap technique (Rutherford 1990). Dowell et al (1995) suggest, "the table-top exercise has been accepted as an invaluable contribution to improving emergency management coordination".

2.3.6.1.4 Dedicated simulations

These are commonly used in highly technological industries - for example the nuclear, air traffic control and petrochemical industries. Typically, they involve the use of control panels and VDUs that are similar to those used in the real control rooms.

Therefore this technique is expensive but can be used to train a large number of people working in the respective industries (Ellison et al 1992). Booth (1990) also recommends their use for crisis management training and so classrooms for discussions are also useful. The team are also provided with any equipment that they would normally expect when managing an emergency. These include phones, hand-held radios, personnel address systems and alarms. However, such equipment as fire fighting or breathing apparatus is not normally included as this sort of training is expected to be covered by the use of drills.

These simulations are usually internal to organisations and therefore do not involve the emergency services. However, they are more realistic than the talk-through and tabletop exercises as they are run in real-time. They are also preferred to wholly computer simulations as they involve communication between personnel, the social aspects of emergency management and are more similar to the actions required in a real emergency. For example, if an emergency manager is excellent in choosing decisions on a computer but is incapable of sounding the alarm or using a hand-held radio, the weaknesses become evident in a dedicated simulation.

In these scenarios, the personnel involved in managing the scenario are isolated from the "real world" and so are only given information from a scenario organisation team, who play roles in the emergency services, advisory organisations and as other internal and external personnel. Often the teams are monitored by television cameras for the scenario organisation team to get feedback on their current thoughts and actions (Baldwin 1994).

Baldwin (1994) also recommends this technique should be taught on 4 day courses including at least 5 real-time simulations that get progressively more difficult. He also suggests that it includes discussions of stress, communications and information management.

2.3.6.1.5 "Real" exercises

These are a rare and expensive means of testing emergency management and require a great deal of coordination to organise. However, in some industries, they are necessary. For example, an airport may need to simulate a crash on the runway and the military frequently use real-life exercises (Rutherford 1990, Baldwin 1994). In these cases, the emergency services would be mobilised and would act in their expected role. Actors would be required to play large numbers of casualties and their families. In most cases, all those involved in the incident are aware that it is about to occur. However, in any emergency management training exercise, it is recommended to "expect the unexpected". For example, personnel may be told the incident will be arranged for Tuesday morning - then they are called at 2 a.m. to attend. As they reach the incident site, they may be questioned by members of the press, who insist on answers before letting the personnel fulfil their management roles.

Because of the degree of realism used in this technique of training, it is excellent at identifying weaknesses in the emergency plans (Rutherford 1990). For example, Richardson (1995 p.11) describes the following problems that occurred in the Hillsborough disaster:

"While water, electricity, transport, communication etc. support was made available rapidly to provide positive help quickly, ambulances initially created their own traffic jam and the telephone receptionist for the fire service was unable to respond to the first request for help until the request had been formulated in a way that was acceptable to the computerized recording/administrating system she managed. She later explained "My training is not to assume what an address is; it is up to me to ascertain that from the person calling ... The fire service computer would not recognize the Hillsborough ground as a place". Such communication problems would have been identified by a real-life exercise and could easily have been rectified, preventing critical delays in response".

However, training does not work for everyone and the personality characteristics mentioned in Section 2.3.5.1 do have a part to play. Baldwin (1994 p.19) comments that "very clearly it is impossible to train anybody (to the highest level) to guarantee their performance in the event of an emergency". But how can trainers ensure that the training is really working? There must be some form of assessment to indicate improvement in performance. Therefore, the next section will consider some aspects of assessment in emergency management

2.3.6.2 Assessment

Assessment of complex skills is always problematic. Emergency management requires teamwork and a combination of technical and non-technical skills - as well as adapting these to fit the situation. Some methods of assessment may focus on evaluating individual skills and attempting to weight their importance. Other methods of assessment may use a global approach, trying to establish overall performance for a scenario or set of scenarios. There is also the use of self-assessment, including questionnaires on perception of workload, attitudes towards the use of skills and other factors (Salas & Prince 1999).

For a scientific approach, ideally assessment would involve the use of objective techniques. These could include the use of computer-based simulations that are capable of giving quantitative outcomes in response to the user-interventions or recording and analysis of team behaviour to establish delay times or numbers of errors. However, in most cases, emergency management simulations are assessed subjectively.

Many of the problems in assessing emergency management are the same as those experienced in trying to identify good team resource management, as described in Section 2.3.4.1.

Walters (1998) notes that "If we were to observe a crew that has truly integrated CRM skill into their daily operations, their behaviour would be transparent to the untrained eye". Hence indicating the importance of a trained assessor! However, this creates another problem. They should be experts - either in the environment under test or in emergency management. However, according to Lagadec (1993), "There is virtually no such thing as an expert in crisis management" and comments on the importance of an inter-disciplinary team with wide-ranging experience. This is often not practical when training is run on a restrictive budget. Therefore, the assessor is often the same person that designed the scenario. The scenario designer usually has a pre-ordained plan of how he/she expects the emergency to be managed. This, as in all subjective methods, could result in biases. Hindsight may lead the assessors to expect quicker, better solutions than those provided by the emergency management team. Ujita et al (1997) confirm this tendency towards negative judgments and suggest that assessment should focus not on the errors made but on positive objective factors such as response times and error recovery probabilities in emergency situations. In general, an objective structure should be drawn up before using a scenario so that criteria for good and bad emergency management can be pre-defined to reduce biases. However, this may be problematic. Ideally, emergency management should be assessed in terms of its outcome and, in artificial situations, the outcome may not reflect a real emergency accurately. Therefore, it is necessary to base scenarios on realistic data to ensure an accurate and objective assessment can be made.

Given that the individuals have been selected, trained and assessed as competent emergency managers, the next section will discuss the plans, equipment and resources that must be made available to assist them.

2.3.6.3 Emergency planning

The successful outcome of an emergency cannot be guaranteed by just having a competent and well-trained emergency management team. There are a number of factors that must be also present to facilitate a good response (Quarantelli 1988). As stated earlier, one of the key aspects of an emergency is the time pressure involved. If the workplace or technology is designed so that an initiating event may escalate to become a major incident in seconds, it is unlikely that any human intervention can play a part. Similarly, if there are no resources for an emergency management team to manage - it is unlikely that they can make any impact on the escalating incident. Given that time is such a key issue, it should be maximised by all possible means. One key method to maximize time in an emergency is to make well-defined emergency plans. These provide guidance to the emergency management team to remind them of factors to be considered, decisions that should be made and to notify them of resources available or system limitations.

As an emergency plan can be developed before an incident occurs, there is plenty of time to consider alternatives and to test the feasibility of various aspects of the plan (Brandie 1995). This should also involve the use of the training methods like the "real-life" or simulated exercises described earlier. Plans can be made to cater for various types of emergency so that they can be generic and flexible rather than focused on specific occurrences (Kosyachenko et al 1998).

However, the provision of a plan does not guarantee that it is adequate or that it will work. Quarantelli (1988) argues that plans, that are too "agent-specific" as opposed to generic or demand artificial rather than realistic activities, result in poor management activities and so are destined to fail.

The *CIMAH* (1984) and more recently the *COMAH* (1999) Regulations require that all appropriate steps are taken to prevent the occurrence of major accidents and to mitigate the consequences of any which may occur. Plans must consider on-site and off-site impacts as well as communications with operators, local authorities and the emergency services. They must also set out arrangements for initiating the plan, sounding the alarm, organising the personnel involved and notifying the public as required (Cassidy 1988). Kosyachenko et al (1998) adds that it should consider "bottlenecks" in material and technical supply services.

Jones (1995 p.18) notes that Health and Safety Inspectors identify problems with emergency planning by assessing:

- Does the plan contain sufficient detail for the most probable events whilst retaining the flexibility to cope with the largest incident that can have reasonably been foreseen?
- Are there sufficient resources in terms of personnel and equipment to implement the plan?
- Are individual and group responsibilities clearly specified?
- Has adequate training been given to those involved in implementing the plan?
- Are there adequate emergency services both before and during incidents?
- Are there adequate arrangements for rehearsing and reviewing the plan?

Strutt & Lakey (1995) suggest that an emergency plan should contain the following elements

- The type of accident which might occur
- The organisations involved in the emergency management and key personnel
- Communications links telephones, radios etc.
- Fire-fighting equipment, damage control and repair
- Technical information, e.g. chemical and physical characteristics and dangers relating to the substances involved.
- Physical information relating to the layout of the plant, pipelines and safety critical components such as emergency shutdown and venting equipment etc.
- The emergency procedures and evacuations arrangements to be used
- Contacts for obtaining advice on for example, meteorological conditions, emergency transport systems, first aid, hospital services
- Arrangements for dealing with the press

Kowalski (1995) suggests that stress should be incorporated into emergency management plans. She suggests that emergency managers should be provided with information on stress so that they can recognise it in themselves and others. There should also be guidelines to work hours, frequency of rest periods and short unstructured debriefings to defuse the event. After the emergency is completed, there should be access to organisations that can provide support and counselling. Kowalski (1995) suggests that the most serious of stress reactions - Post-Traumatic Stress Disorder (PTSD) can be averted through sensible mediation of this kind.

Frequently, these plans are written out in forms of procedures to be followed and so assist the emergency management team in making decisions. However, for these decisions to result in a successful outcome, particular resources must be available - people, equipment and enough time!

2.3.6.4 Design Parameters

It is often thought that when examining emergency management, it is too late to consider design parameters. Emergency management is supposed to be flexible enough to deal with incidents and to "work around" the problems caused by the design. However, it is now recognised that "inherently safer design" cannot only reduce the probability of an incident but also can control escalation speed - hence maximising the time for emergency management intervention (Strutt 1999).

Weick (1988) suggests that the human contribution should be "exaggerated" in complex and hazardous systems, again consistent with the ideas of Van der Schaaf (1999) from Section 2.3.3. Perrow (1984 cited in Weick 1988) adds that "interactive complexity, in the presence of tight coupling, leads to rapid escalation of crisis events". Therefore by designing human intervention <u>into</u> a system, rather than out of it, would slow down escalation and facilitate the impact of emergency management.

Snow et al (1970 cited in Muir 1996 p.178) suggest that the critical factors influencing survival in aircraft accidents can be grouped into four categories. These include the procedural actions of the crew, the behavioural actions of the passengers, the configuration of the cabin and environmental features (for example smoke ingress and external conditions). As earlier stated, the behavioural actions of a survivor can be guided by effective emergency management. However, emergency management can do nothing about the pre-determined cabin design. In addition, the environmental conditions can be influenced by design parameters. Using highly flammable seat materials would increase the escalation of a fire therefore reducing the time available to make a successful evacuation. Once a fire has started, it is too late to consider the use of alternative materials so this should also be considered at the design stage.

Many aspects of design contribute to a successful outcome in an emergency. It is not sufficient just to provide a safety system but it must be guaranteed to work in the correct way and be reliable and robust enough to work under the circumstances for which it was designed (Strutt 1999). However, considering emergencies at the design stage is an enormous task. It must include alarm bells and lighting, evacuation routes, the integrity of safe havens, rescue facilities, the potential for structural collapse or infringement and interactions between these factors and many others. The complexity involved in such modelling and analysis is the key reason that these ideas have been slow to implement in industry. This leads on to the more flexible aspect of design - the technical and human resources.

2.3.6.5 Resources

Kowalski (1995) suggests the necessary resources to manage an emergency include "an emergency management plan, trained manpower, appropriate equipment, available communication plus knowledgeable and decisive leaders". Many of these have been considered in other sections, so this section will focus mainly on the subjects of equipment and manpower.

Weightman (1996 p.6) illustrates the importance of resources in his description of the rail disaster in Harrow and Wealdstone Station in 1952 compared with the Kegworth air crash of 1989, as follows:

"At Harrow, the services had no emergency plans in place to speak of, except loud-hailers, calling for doctors to come and help, and many turned up with little idea of what they were supposed to do. Ambulancemen then had no higher qualifications than a first-aid certificate, and Middlesex, as in many other counties, the ambulance driver was a member of the fire brigade, though regarded as a lesser being than the noble firefighter... By contrast, at Kegworth in 1989 there were hospital flying squads, highly trained ambulancemen and women, whom we would now call paramedics, firefighters trained to cut people free from wreckage, their skills honed by the frequent extrication of motorists in road accidents; and police who by then had a concept of how order might be created from the confusion of a disaster scene".

People are an essential part of emergency management process - including the emergency services, supporting crews as well as the witnesses, survivors or bystanders who suddenly find themselves in the midst of an incident. As far as the emergency manager is concerned, bystanders, the media or members of the public may be help or a hindrance (Richardson 1995). The emergency plan should therefore cater for such eventualities and prepare for their coordination.

There are certain pieces of equipment that are considered essential in an emergency and therefore the plan should include locations and numbers of such items. They may include hand-held radios, fire-fighting equipment, breathing apparatus, personal protective equipment, first-aid kits and stretchers to more extreme equipment such as cutting gear, spinal boards, cranes and helicopters. As far as the management team are concerned, they must not only consider the coordination of the equipment required in the escalating incident, but they require certain resources for coordination purposes. These may include white boards and pens to communicate within the team, internal and external telephones, public address systems and all available data to help manage the incident. Given that it is never certain how long an emergency may last, it may also be necessary to have back-up - management team members to replace tired or hungry members. In these circumstances, it is also necessary to have some supporting staff to provide food and drinks for the team (Ramabrahmam et al 1996).

One other resource that has not been studied is that of "technological decision support". In the same way that computers have the potential to train emergency management, they also can provide assistance once an emergency has arisen by providing quick analyses of large quantities of complex data. Such examples include RODOS for nuclear accidents (Kelly et al 1996), Emergency Management Decision Support (EMDS) for mainly natural disasters (Subramaniam 1996) and other Emergency Management Information Systems (EMISs) for chemical disasters (Reed et al 1991). These are examples of systems that are widely available to any organization involved in emergency or disaster management. It is likely that similar systems exist internally in more hazardous organizations.

2.3.7 CONCLUSION OF EMERGENCY MANAGEMENT SECTION

This section has discussed the key issues involved the study of emergency management and therefore has identified some of the problems for this research. Most particularly, these include the objective assessment of emergency management skill and its relationship with risk. As yet, there appears to be no objective way of assessing emergency management as a global team process. Therefore, this review will now move on to examine the techniques that could potentially be used to evaluate the impact of emergency management on risk reduction.

SECTION 2.4: RISK ASSESSMENT TECHNIQUES

This section provides the academic background to the proposed solution to the research problem. The previous sections have discussed the nature of the issue - the emergency and how it is managed. This section will continue by addressing the scientific aspect - how this attempt at management influences the risk value. Therefore, this section will initially discuss the nature of risk and how it can be quantified.

Risk is defined as "a measure of the probability that the potential for harm or loss posed by a hazard will materialize" (Andrews 1999). Employers are now required by legislation to be aware of the risks evident in their workplace and, where present, demonstrate that risks are reduced to "as low as reasonably practicable" (ALARP) through control and risk reduction measures. Usually this requires a quantitative result - therefore applying the use of Quantitative Risk Assessment.

It is necessary to be cautious when quantifying risks as they are sensitive to many influencing factors. As stated by Flin, Mearns, Gordon & Fleming (1996), "People do not necessarily rely on objective quantified measures of risk but instead make their own judgments on the risks present". These subjective judgments may involve over-estimating the risks, resulting in worry and stress; or underestimating the risks, potentially producing "risk-taking behaviour", both of which would affect the evaluation of the impact of emergency management. Therefore, Quantitative Risk Assessment should rely on objective criteria - such as scientific theories of physical and mechanical phenomena or statistical values based on prior experience. For example, the Health and Safety Executive publishes annual statistics on injuries and fatalities of people at work (HSE 1998d, 1999). This could be used to provide information on risk of injury for people in various work-roles. However, it does not demonstrate the effects of change, or produce estimates of risk for specific situations. Therefore, it is necessary to use techniques that can evaluate this from first principles.

Quantitative Risk Assessment involves evaluating the risks through identification of the hazards, evaluation of the possible frequency of the undesired events as well as estimating the possible consequences of such an event. In this research, we would require it to take this one step further - given that undesired events HAVE occurred, what is the probability of the worst consequences occurring?

Whereas Qualitative Risk Assessment may be quick and inexpensive, the results may be inaccurate (Quin & Widera 1996)- this is particularly likely when the perception of risk in an emergency situation is likely to be biased. Therefore, Quantitative Risk Assessment takes this process further by assigning a numerical value to the risk. Even so, producing realistic values can be somewhat problematic. Sometimes the event can have a variable risk, depending on certain factors. Sometimes the event is caused by human error or relies on human actions to control it - which is inherently difficult to evaluate. Sometimes the models used do not produce values that have face validity, or they achieve ungrounded confidence in their results when they do (Tweedale 1992). Therefore provision of a quantitative risk value may rely on other techniques such as probabilistic safety analysis and human reliability assessment. Therefore, it is necessary to examine a number of techniques and evaluate their potential for quantifying the impact of emergency management on risk reduction.

2.4.1 QUANTITATIVE RISK ASSESSMENT

Quantitative risk assessment is now a well-known and well-used technique for assessing risk in the field of health and safety. It typically involves the following steps:

1. Consider all tasks and situations
2. Identify the hazards that are, or may be involved
3. Identify those who may be exposed to the hazards
4. Analyse the risks of injury or loss from the hazards
5. Evaluate if the risk is adequately controlled against acceptance criteria
6. Consider measures that may eliminate or reduce risk further in line with the basic principles of hazard control.
7. Implement the risk control measures
8. Monitor the measures
9. Review and feedback any corrective action.

(Andrews 1999)

The definition of an "acceptable" risk is a problem. Lowering risks involves a consideration of cost whereas assigning a cost to a human life is a controversial issue (Reinertsen 1995). Also, there is some question to the validity of the techniques. One of the main issues is the use of deterministic approaches rather than probabilistic methods. Many of the inputs into risk assessment have uncertainties associated with them and using a point value for each means that important information may be lost. Similarly risk itself is a probability so should reflect changes in time, conditions or exposure/dose rather than using a point value to express a wide range of situations (Burmaster 1996). This leads to the use of probabilistic risk assessment (PRA) / probabilistic safety analysis (PSA).

2.4.2 PROBABILISTIC RISK ASSESSMENT / PROBABILISTIC SAFETY ANALYSIS

Probabilistic Risk Assessment (PRA) and Probabilistic Safety Analysis (PSA) are terms that are often used interchangeably. They are more complicated than the QRA as can be seen from the description of the technique by Kahn & Abbasi (1998) as follows:
1. Hazard Identification - sources of potential releases and initiating events
2. Accident sequence modelling - analysis of the initiating events and the response of the installation
3. Data acquisition and parameter estimation - frequencies of initiating events, component unavailability and probabilities of human actions
4. Accident sequence quantification - calculates the frequency of occurrence of the accidents using the parameters from step 3.
5. Hazardous substance release categories assessment - this streamlines the calculation of accident consequences and the associated frequencies.
6. Consequence assessment - undesirable consequences and associated probabilities are calculated for each release category. If the hazardous substance is toxic, immediate health effects can be estimated by calculation of the atmospheric dispersion of the released substance, the assessment of the dose an individual would receive at each point around the site, and by establishing a dose/response model.
7. Integration of results - establishes a range of possible consequences and the associated uncertainties.

This method is said to take "50% more time than QRA for the same level of accuracy", probably due to the amount of factual and operational data required (Khan & Abbasi 1998). It often relies on the event tree method but this can cause problems due to the reliance on expert judgement in identifying failure paths and assigning probabilities - potentially leading to biases. Therefore, there was call for more objective methods to identify potential failures, outcomes as well as the calculation of probability values.

Therefore, as the research requires the development of a method to assess the impact of emergency management on risk reduction, the next section will describe some of the key techniques that have the potential to be used within this project.

2.4.3 RISK ASSESSMENT TECHNIQUES

For many of these steps, there are specific techniques that are available. These include:
- Hazard Operability Study (HAZOP) / Hazard Analysis (HAZAN)
- Fault Modes and Effects Analysis (FMEA)
- Influence Diagrams
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Quantitative Uncertainty Analysis (QUA)

Each of these will be described in the following sub-sections together with a preliminary evaluation of their suitability for the assessment of the impact of emergency management on risk or how they could be applied as part of the research.

2.4.3.1 Hazard Operability Study (HAZOP) / Hazard Analysis (HAZAN)

The HAZOP method involves the use of a team of people, of whom the leader must be experienced with the HAZOP method and the team must be familiar with the process under investigation (Kletz 1999). It uses a set of guide-words (NONE, MORE OF, TOO LATE) in relation to the process to look for weaknesses in design. From these, it can look at the consequences and actions required to avert these consequences. Normally, this involves examining physical processes such as chemical flows and temperature changes. However, it can also be applied to management tasks as shown in the example in Table 1.

Table 1: Example of contents of a HAZOP (from Redmill, Chudleigh & Catmur1999)

Guide word	Deviation	Consequences
Flow of Data	NO	No information flow
	PART OF	Information passed is incomplete
Speech (flow of data between humans)	NO	They do not or cannot communicate
	AS WELL AS	Recipient hears originator but someone else talking causes confusion
	PART OF	Recipient only hears part of message
	OTHER THAN	The originator gives the wrong information or it is totally misunderstood
	MORE	The originator says more than is necessary

Although HAZOP has the potential to identify necessary actions and responses, there is no means of quantifying the risk - hence the development of HAZAN.

HAZAN is quite a simple method of quantification, primarily relying on past experience such as "events/year" data. It caters for novel processes by likening them to processes with known failure rate that may not always be appropriate. Further to this, its treatment of human error is very simplistic, giving the following suggestions for human failure rate:
"When complex and rapid action is needed to avoid a serious incident - (...the probability of failure is..) 1 in 1 - The operator will not be as unreliable as this but he will be very unreliable and we should assume this figure and install fully automatic systems" (Kletz 1999).

As "complex and rapid action etc." would be a typical description of any emergency, this would imply that this probability would be assumed for most, if not all, emergency management tasks - leading to an overly pessimistic view of their chances. In addition, if the statements of Van der Schaaf (1999) from section 2.3.3 were to be considered, the recommendation of fully automatic systems would not be ideal. This suggests that HAZAN (or its derivatives) would not be the ideal method for examining the impact of emergency management on risk. However, if such a method was to be developed, it could be used within HAZAN to make design recommendations.

2.4.3.2 Fault Modes and Effects Analysis (FMEA)

FMEA is comparable with HAZOP but is more structured and can be carried out by an individual (Kirwan & Ainsworth 1992). It involves the following steps (as described by Khan & Abbasi 1998):

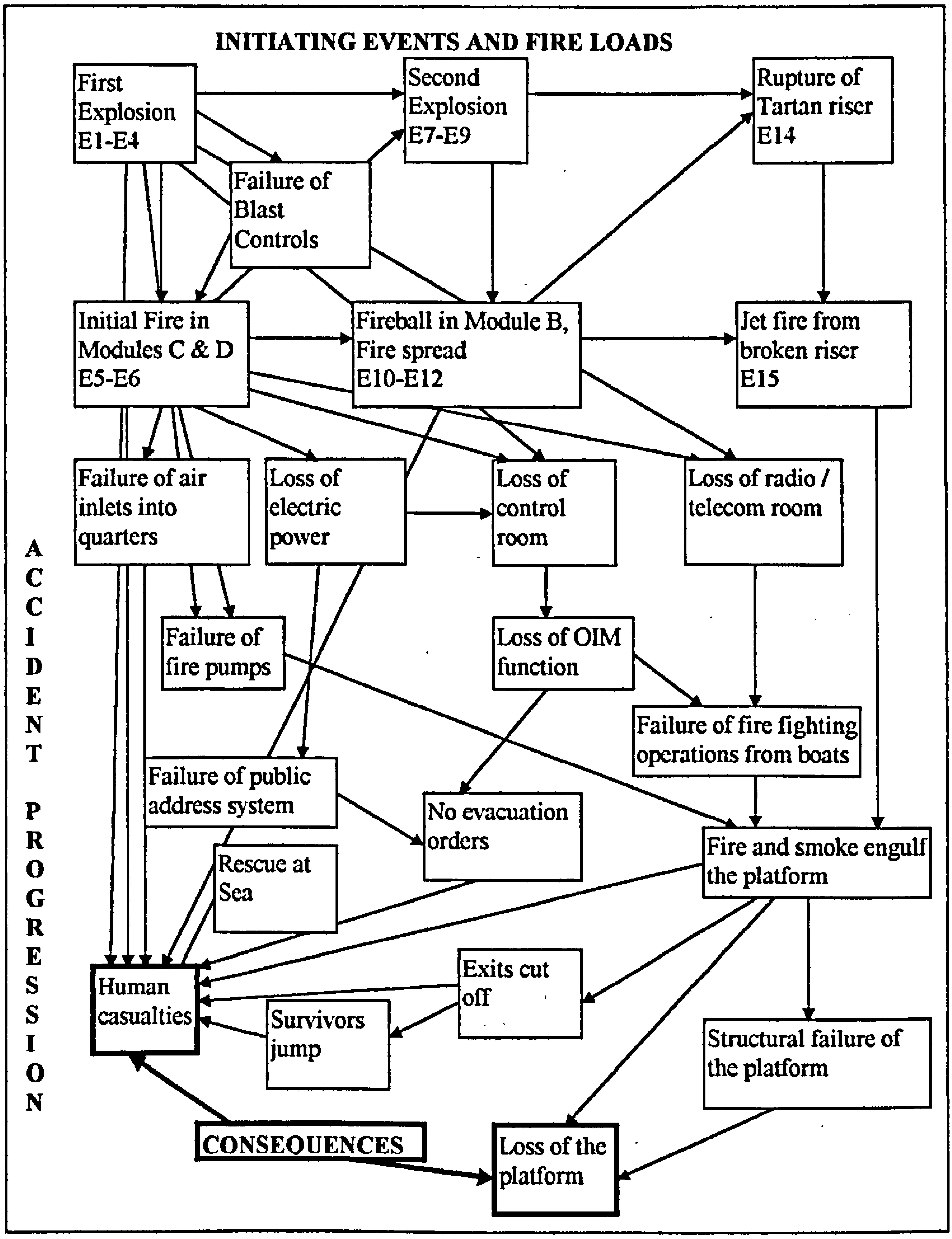
1. Identification of each failure mode, of the sequence of events associated with it, its causes and effects.
2. Classification of each failure mode by relevant characteristics, including deductibility, diagnosability, testability, item replaceability, and compensating and operating provisions.

Its main general criticisms include its time-consuming nature plus the fact that it considers the component level of tasks whereas some errors arise at the sub-component level. The main problem for its use in this research is its lack of a quantification module. Therefore, it is the Failure Modes, Effects, Criticality Analysis (FMECA) method that must be considered here. This adds in the probability of component failure (mostly obtained by expert opinion) to produce an overall probability of failure. However, as for HAZAN, there is no definitive method of examining human tasks - Kirwan & Ainsworth (1992) suggest it should be used in conjunction with a checklist of human errors. Quin & Widera (1996) add that this technique cannot be used for complicated situations such as multiple failures or when the uncertainties surrounding data values have non-uniform distributions. Therefore, in its current form, it cannot easily contribute to the examination of the impact of emergency management on risk reduction.

2.4.3.3 Influence Diagrams

This approach involves graphically representing the factors that influence the occurrence of a particular event (Kirwan & Ainsworth 1992). This approach can be used for quantification of failure probabilities by assessing the influence of various factors on the event and the likelihood of them being present in the given scenario. Like the HAZOPs, this requires a team of experts who are familiar with the scenario under examination as well as the expected influences of the factors. Figure 4 shows an example of an "a posteriori" influence diagram to explain the event dependencies in the Piper Alpha disaster (by Paté-cornell 1995). This shows how influence diagrams could be potentially used to quantify the impact of emergency management on risk reduction. However, the weightings and probabilities used in this technique are obtained from expert judgment and therefore there is still a risk of bias in the technique (Kirwan & Ainsworth 1992).

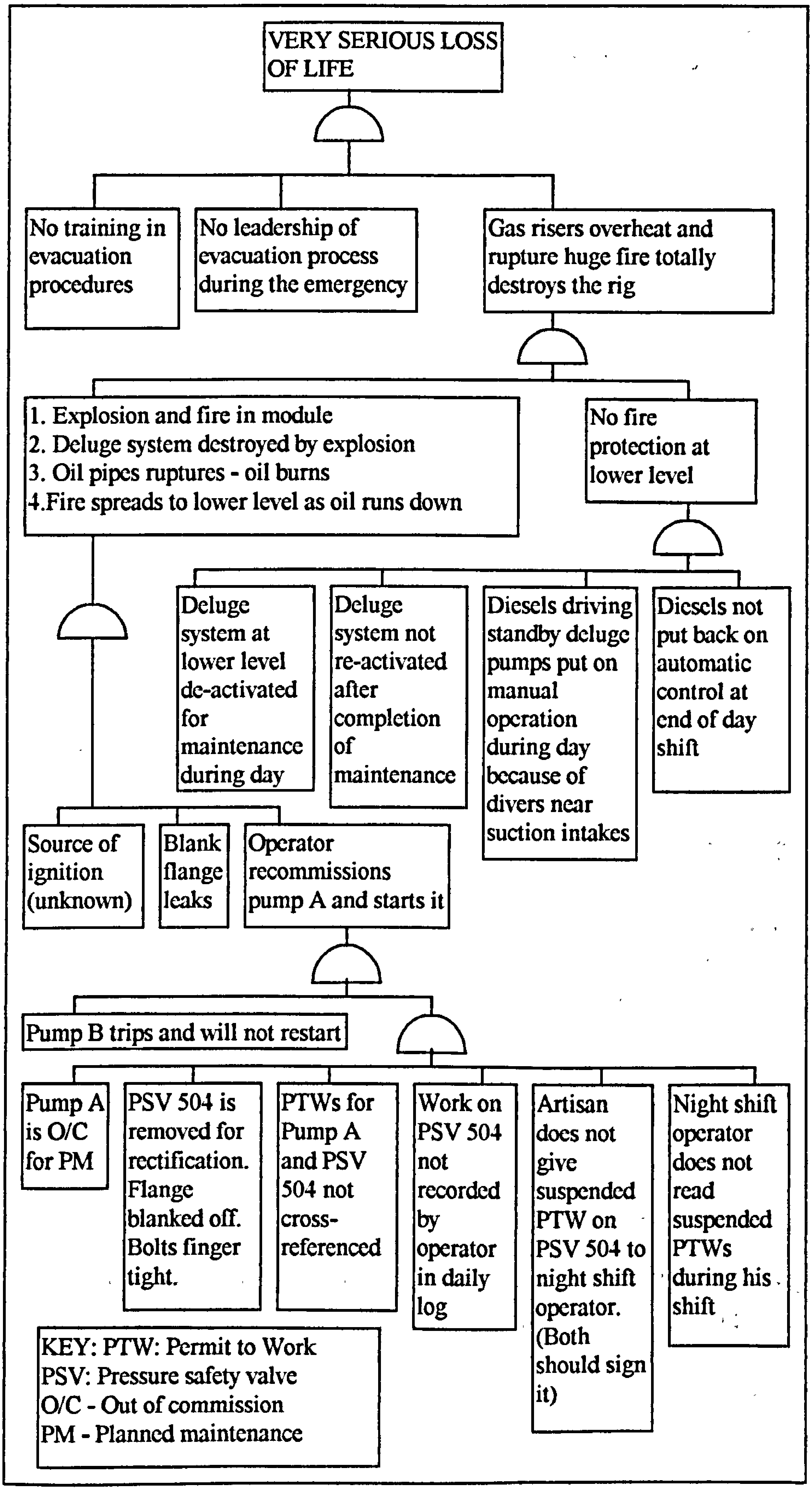
Figure 4: Event dependencies in the Piper Alpha accident; influence diagram representation



2.4.3.4 Fault Tree Analysis (FTA)

Fault tree analysis provides the user with all the possible minimum combinations of basic human, instrument or equipment failures (called minimal cut-sets) that could lead to the occurrence of the critical or "top" event. It uses deductive logic including AND and OR gates and therefore can be used to yield probabilities of events through calculation of the probability of the cut-sets. An example of a simple fault tree (based on the Piper Alpha disaster and taken from Bradley 1995) is shown in Figure 5.

Figure 5: Example of a Fault Tree (Bradley 1995)

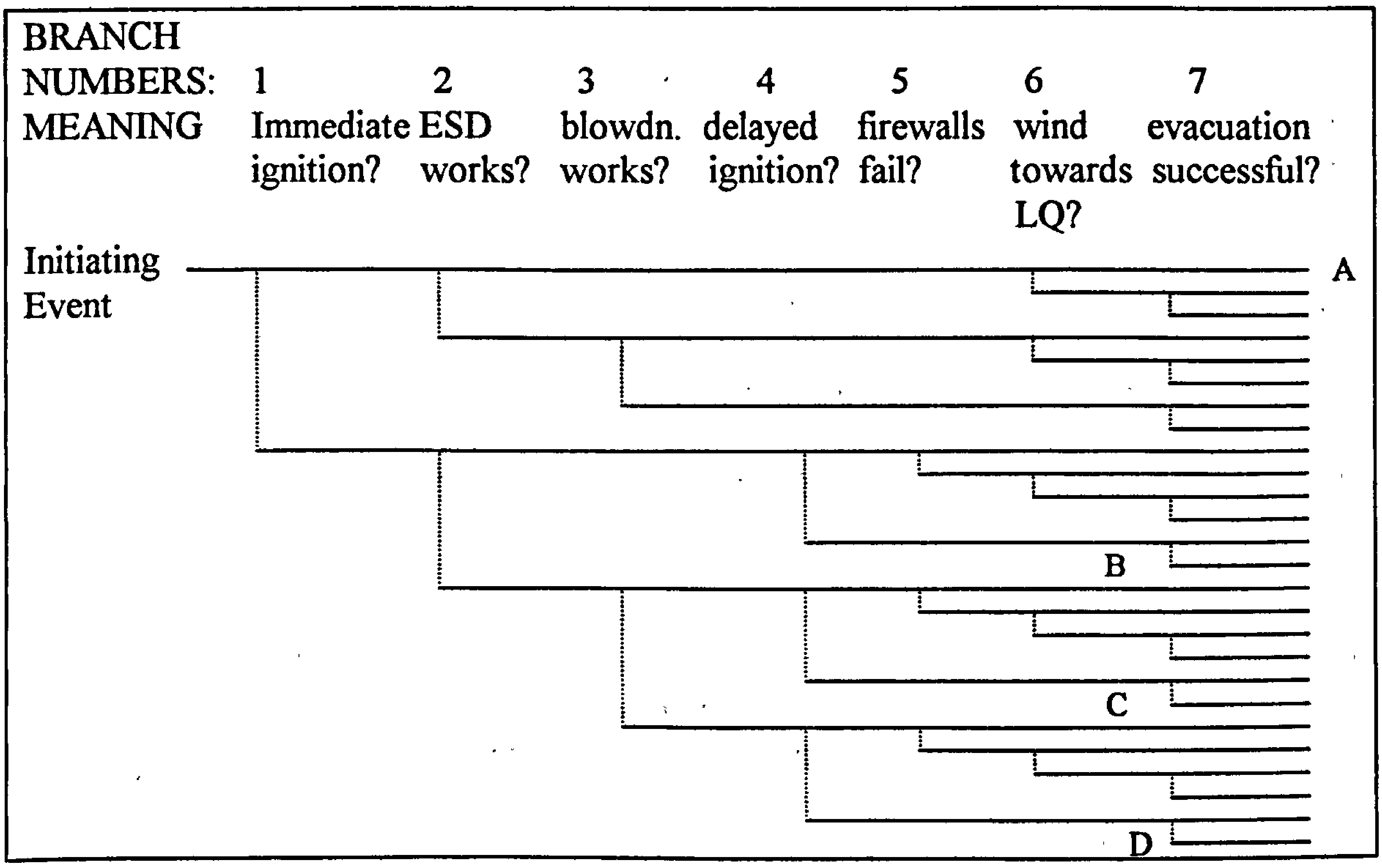


This can be compared with the Influence diagram shown in Figure 4 - but shows different aspects of the same incident. However, the probabilities must still be obtained from some alternative source and the reliability of these data will affect the reliability of the whole tree. In terms of the problem in this research project, this technique could be used to identify the critical features of emergency management that mitigate a given incident. However, the probabilities of success of emergency management tasks would still be obtained from some sort of expert judgment technique. Therefore, a technique that is capable of quantifying the probability of success in emergency management tasks would be a useful contribution when developing a fault tree.

2.4.3.5 Event Tree Analysis (ETA)

Whereas Fault Tree analysis works out the possible circumstances that can lead to a "top event", an event tree works out all of the possible consequences from an initial event. Therefore, it can also represent time-dependency or the sequential pattern of events - where one event may lead to a choice of two or more other events. An example of an event tree (also based on the Piper Alpha incident and taken from Cox & Miles 1991) is shown in Figure 6.

Figure 6: An example of a simple event tree (Cox & Miles 1991)



From Figure 6, it can be seen that the final consequences are dependent on mitigating and escalating events that occur following the initiating event. If each branch (representing Yes or No answers to each question) is assigned a probability of occurrence, the likelihood of the final events can be established. It is normal that the Yes or No labels are shown on the tree or are used consistently (yes above no for each branch). In this example, however, this is not the case. Also, it is questionable that, in the event that there is immediate ignition, the emergency shutdown does not work and the wind direction is not towards the LQ, that no evacuation is attempted (branch A). However, where there is no immediate ignition or delayed ignition (and therefore no fire), the evacuation is attempted (branches B, C & D). However, as an example, this represents the concept of an event tree.

Therefore, if each branch represented a particular emergency management task, the impact of emergency management on risk reduction could be calculated. However, as for the fault tree analysis technique, many of the quantification values (in this case, probabilities of occurrence) are obtained from expert judgment techniques. Therefore this technique would only be successful if a reliable method of obtaining the probabilities is used.

2.4.3.6 Quantitative Uncertainty Assessment (QUA)

Up this point, most of the techniques have required the acquisition of error and failure probabilities from alternative sources. Quantitative uncertainty assessment is a technique that can be used to assist this process by incorporating uncertainty into the risk equation. This technique has been described using the following steps:

1. Identify the desired numerical expression and characteristic of risk for each endpoint in the analysis, e.g. 100% growth rate impairment, 25% reduction in disease.
2. Specify the equation that will estimate risk
3. Generate an uncertainty distribution for each input variable (a probability density function) in the risk equation.
4. Generate the output distribution by combining the input probability density functions (PDFs) as specified in the risk equation.

This step typically involved Monte Carlo simulation, which carries out numerous reiterations of the risk assessment equation to produce a PDF of expected risk representing the "best" estimate of variability in risk as a result of variability in input parameters (Bartlett et al 1996). Another approach is the Dynamic Logical Analytical Methodology (DYLAM) that is said to be more sensitive than the Monte-Carlo approach (Devooght & Smidts 1996) and is preferred for treating rare events (Marseguerra & Zio 1996). This considers time-dependent states of components in a system. As described by Cojazzi (1996 p.280) "It follows all the paths resulting from the initial states of the components of the system and from transitions in-time of the components states and to drive the corresponding simulations" and thus is complementary to the fault tree - event tree method. However, this method may be somewhat inflexible as certain events, such as simultaneous multiple failures of components, cannot be included.

5. Fine-tune the analysis. One may use the results of a sensitivity analysis to determine those input PDFs that had an important influence on the estimate of risk. The input PDFs must be re-examined to ensure that the data used and distributions selected are scientifically acceptable. Often the tails of input PDFs must be truncated to eliminate physically or logically impossible values (for example, below zero).
6. Summarise the results in terms of a risk distribution graph.

Finkel 1990 (cited in Moore & Elliott 1996)

However, this method requires many more data than a quantitative risk assessment, some of which can only be acquired during operation - due to the ranges of values required in the modelling process. The users of such models must acquire new skills to gain the "expert judgment" capable of acquiring the best input parameters, assessing their realism and then to choose a "best fit" distribution (Moore & Elliot 1996, Carrington 1996). Therefore the resultant distribution is only as good as the models used and the practitioners using them (Bartlett et al 1996). For reliable results, it is essential that risks are accurate, unbiased and that they cannot be manipulated to serve parties with vested interests (Heyes 1995).

2.4.3.7 The Need for Improved Assessment Techniques

Therefore, considering the inadequacies with the current methods, as shown in the previous sub-sections, there was call for methods that represent human, organisational and design failures as well as additional dynamic uncertainties produced by component ageing (Bley et al 1992). Hsueh & Mosleh (1996) emphasise the importance of time in PRA - from short time constraints, such as operator response time, to long time constraints, such as seasonal changes, plant configurational change and component ageing. They suggest a computerised approach to dynamic PRA known as Accident Dynamic Simulator (ADS) to ensure such variables are incorporated into the risk distribution.

With regard to the issue to human failures, there has been much more research into the incorporation of human errors into the probabilistic risk equation. Such work includes the Work Process Analysis Model (WPAM) by Davoudian et al (1994b) and the System Action Management (SAM) approach by Paté-cornell & Murphy (1996) or the aforementioned DYLAM methodology.

However, none of these complete methodologies provide the flexibility to be applied to the research problem. Therefore, to introduce the issue of human reliability into the risk equation, it is necessary to examine the original assessment methods and their potential for understanding the impact of emergency management.

2.4.4 HUMAN RELIABILITY ASSESSMENT

2.4.4.1 Introduction

This section will attempt to summarize the area of human reliability assessment, by defining the term, giving an example of the structure of the method, briefly discuss some of the techniques available, mentioning the new developments in the field as well as the advantages and disadvantages of HRA for assessing the impact of emergency management on risk reduction.

Reliability has been defined as "The probability that an item will operate adequately for a specified period of time in its intended application" (Park 1987 cited in Hollnagel 1993 p.51). This mainly addresses the reliability of a hardware system rather than a person. Human Reliability is not as easy to define as humans are much more complex and are continuously working on tasks in parallel - for example, the physical processes required to stay alive as well as mental processes. They do not have one particular purpose to perform.

Swain and Guttman (1983) define Human Reliability as " the probability that a person (1) correctly performs some system-required activity in a required time period (if time is a limiting factor) and (2) performs no extraneous activity that can degrade the system.

Human Reliability Assessment (HRA) is an essential part of risk analysis and management. It was designed to assess the probability of human errors particularly in complex and unsafe environments. This involves a number of stages as follows:

- Problem definition - this stage attempts to define the scope of the HRA process - the environment, tasks and roles to be assessed.
- Task Analysis - this stage involves formally describing the human-system interaction by collecting the information on the tasks and breaking the task down into small parts to be able to analyse what is involved.
- Human Error Identification - this involves examining the tasks to see whether they would produce dire consequences if particular errors occurred.
- Representation - this stage involves building a model to represent the information obtained from the previous stages in a form whereby the errors can be quantified.
- Human Error Quantification - this involves trying to quantify the probability of the occurrence of the errors.
- Impact Assessment - This stage involves considering whether the risks are low enough to be acceptable and discovered which sorts of events contribute to the risk.
- Human Error Reduction - Once the errors and their importance have been established, ideas to reduce the critical errors must be analysed. This involves reducing the likelihood of root causes, negative mitigating factors or the final dire consequences. Some of these reduction techniques will cost too much to implement, whereas some will not produce enough impact to be worthwhile.
- Quality Assurance - This stage is an ongoing check that the analysis has been carried out correctly. This ensures that system changes are incorporated into the analysis and that the documentation is kept up to date.
- Documentation - Once the whole process has been completed, it is important to document the results so that they may be kept for reference and so the process does not need to be repeated unnecessarily.

(from Kirwan 1994)

Within each of these stages, there may be a number of techniques available for use depending on the importance of the results, the resources available and the skills of the personnel involved. Some of the more structured techniques involve a number of these stages and may use computational models to produce quantitative probabilities of error. There have been a number of comprehensive reviews of the techniques available including Swain & Guttman (1983), Reason (1990), Kirwan (1992a), Hollnagel (1993), Kirwan (1994), Loa & Strutt (1995), Kirwan 1998a & b, 1999). As there are at least 38 human error identification methods (Kirwan 1998a) and at least 8 human reliability quantification techniques (Kirwan 1990), it would be difficult to describe each technique, its advantages and disadvantages. Therefore, as the purpose of this research is to examine the impact of emergency management on risk reduction, the main factors that are important for the technique to represent are as follows.

1. Taking into account real measures of time as opposed to a subjectively assessed variable for "time pressure".
In an emergency, there is always time pressure due to the nature (and definition) of emergencies. Therefore, to assess the risk, this factor must discriminate between degrees of time pressure that result in a successful outcome (as we know some can!) and those that fail. Therefore, as time makes such a critical contribution to the outcome of an emergency, it should feature predominantly as a variable in an assessment of the impact of emergency management on risk.

2. Quantitative measures
As it is intended that this research should produce a technique that measures the impact of emergency management on risk reduction - it is necessary to have more than the "good/bad" criteria produced by some techniques. Therefore, quantitative measures are required to indicate by how much a certain delay worsens the situation or by how much a particular decision improves the situation. These should ideally be based on objective criteria. Certain quantitative techniques, such as Paired Comparisons and Absolute Probability Judgment, rely on expert judgment. Both are subject to bias for the assessment of "non-emergency" tasks. Due to the increased amount of uncertainty inherent in an emergency situation, it is likely that these biases would be increased when analysing the impact of emergency management on risk reduction. Therefore, they are not considered as possible techniques for use in this research.

Further to this, some of the HRA techniques are based on the risk assessment techniques described in Section 2.4.3 including PREDICT (Procedure to Review and Evaluate Dependency in Complex Technologies) by Williams & Munley (1992) based on HAZOP; HEMECA (Human Error Mode Effect and Criticality Analysis) by Whittingham & Reed (1989) based on FMEA and COGENT (Cognitive Event Tree System) by Gertman (1993) - based on the event tree approach. (all cited in Kirwan 1998a). These HRA techniques are subject to the same criticisms as their parent reliability techniques - namely, the problems in producing a reliable means of error quantification. Therefore, they will not be discussed further in this section.

Therefore the next sub-section will look at the following techniques:

- THERP
- HEART
- SLIM-MAUD
- HRMS
- Time-line Analysis
- MicroSAINT
- TESEO
- Other methods that consider time

2.4.4.2 Human Reliability Assessment Techniques

2.4.4.2.1 THERP (Technique for Human Error Rate Prediction) (Swain & Guttman 1983)

This is a complete HRA technique incorporating a database of human errors, event tree modelling and assessment of recovery paths (Kirwan 1992b). Initially, this involves defining all the possible system failures. It then uses task analysis to describe the operator's tasks. Following this, it examines the failure points for each sub-task, which is often done using an event tree structure. For each failure, the impact of human errors must be established.

The errors are simply classified as follows:

- Error of omission - acts omitted (not carried out)
- Error of commission - acts carried out inadequately; in the wrong sequence, too early or too late; to either too small or too great an extent (or degree), or in the wrong direction (errors of quality)
- Extraneous error - wrong (unrequired) act performed

The error rates are then estimated from the database, considering Performance Shaping Factors (PSFs) as well as any dependency between the human errors. At this point, any potential error recovery paths can also be established (from Taylor 1994 and Kirwan 1994).

THERP was considered a step forward in HRA due to the introduction of PSFs including situational characteristics, task and equipment characteristics as well as environmental, physiological and psychological stressors. Park & Jung (1996) use the PSFs and modify them to reflect distributions of values rather than a single point estimate, therefore introducing the concept of variability into the process. Kirwan (1998a) suggest that the method can be low on resources usage but the reliability of the results is dependent on the assessor and his understanding and experience of the technique and the context being analysed. It is difficult to use for novel situations and demonstrates variation between assessors, possibly due to the high level of decomposition involved. Loa & Strutt (1995) suggest it is suitable for assessing individual human reliability performance but not particularly good for evaluating human errors concerned with diagnosis, crew operation and/or high level decisions.

For the purpose of examining emergency management, THERP may be subject to a number of criticisms. The level of decomposition of tasks and error definitions make it impossible to represent the physical features of the situation that would have a large impact on the risk. In addition, it is likely to result in a pessimistic view of emergency management tasks due to its representation of the impact of performance shaping factors, such as time pressure. For example, as shown in Kirwan (1994), the Human Error Probability (HEP) of diagnosing a single abnormal event 1 minute after its occurrence is 1.0. Further to this, the HEP of diagnosing a second event is still 1.0 after 10 minutes. Obviously, these are situation-specific and the data are based on nuclear events. However, using these specific probabilities and times, this would indicate that very few abnormal events in the offshore industry could be diagnosed before further escalation occurs, which in practice is not the case. By the nature of an offshore emergency, it is usual that an operator has more information than is provided by the control panels. For example, emergencies include helicopter crashes. ship collisions, explosions and fires. All of these would result in additional stimuli - whether it is structural movement, impact noise or communications from platform personnel - therefore speeding up the diagnostic process. Normally, a nuclear emergency can only be diagnosed from the control panels - resulting in more complex cognitive tasks. These are therefore likely to take longer than diagnosis in an offshore incident and so the timings are probably inappropriate. Kirwan (1997) suggests that it is not known whether THERP can be extrapolated to the offshore industry - this specific example suggests that, in this form, this is not the case.

2.4.4.2.2 HEART (Human Error Assessment and Reduction Technique) (Williams 1986).

Following the advancements in the field by THERP, the HEART technique attempts to quantify the effects of error-producing conditions (EPCs) on human error probability – comparable to the PSFs of THERP but with more definition of the predicted influence of these factors. HEART includes 38 different error-producing conditions each with a value indicating the potential strength of its effect on reliability. Such factors include "Unfamiliarity" (x17), "Time shortage" (x11), "No obvious means of reversing an unintended action" (x8), "Ambiguity in the performance standards" (x5) and many others. After giving a weighting to each value, the result is then multiplied with nominal human reliability values (error probability) assigned to generic tasks, such as "totally unfamiliar, performed at speed, with no real idea of consequences" and "fairly simple task performed rapidly or given scant attention". In this case, a distribution of values for each error probability is given with 5th - 95th percentile boundaries.

Loa & Strutt (1995) suggest it is quick, flexible and cost-effective and provides the user with reasonable human error reduction techniques. However, there has been some criticism to the method in that it does not consider interactions or overlapping between the EPCs. In addition, the nominal human error probabilities have not yet been validated (Kirwan 1992b).

However, using HEART to quantify the impact of emergency management tasks on risk is difficult as the categories are too generic to give an indication of the context of the task. For example, most emergency management tasks have features such as "unfamiliarity" or "time pressure" yet there is no discrimination between the physical features of the situation on the resulting risk values. The combination of all the error-producing conditions that are present in an emergency are likely to result in a large number of multipliers leading to pessimistic values for probability of success in emergency management tasks. In reality, many emergency management tasks ARE successful, which questions the reliability of the technique for this purpose. Although, the attitude of obtaining the "worst case scenario" is adequate for normal risk assessment as it leads to the necessary improvement of the risks, it also leads to the implication that all emergency management tasks will fail and therefore, providing any effort in improving the probability of success for such tasks is fruitless.

2.4.4.2.3 SLIM-MAUD Success Likelihood Index Methodology using Multi-Attribute Utility Decomposition (Embrey 1986)

This technique requires the presence of a panel of experts - including operators experienced in the task, a human factors analyst and a reliability analyst. They are required to examine the specific task and to identify the relevant Performance Shaping Factors (PSFs) as used by THERP. Following this, they are required to rate the PSFs in the situation in terms of their quality (optimal vs sub-optimal) then their importance. This gives the "Success Likelihood Index" which can then be converted into Human Error Probabilities.

Loa & Strutt (1995) argue that it is based on a strong theoretical understanding of decision-making and is highly auditable. Also, it does not require the extensive decomposition of a task used in THERP so it results in more holistic representations of the Human Error Probabilities.

However, as these PSFs are identified and rated by people, some subjective biases may occur. There is also a computerised technique that produces slightly different results to the panel of experts. Therefore, the group technique is only as good as the experts taking part and, for this, there is no definition or verification of what skills or knowledge are required of the experts involved (Kirwan 1992b, 1994). These are weaknesses that would become particularly evident in examining emergency management. Firstly, 10 years is the recommended level of experience required of the operators to examine the error probabilities in normal everyday situations (suggested in Kirwan 1992b). It is unlikely that any operator has 10 years experience of emergency situations to give a realistic estimation of the relevant weighting of the performance shaping factors.

2.4.4.2.4 HRMS

HRMS (or the Human Reliability Management System) encapsulates some of the features of the other techniques into a new technique - primarily based on sets of questions for the assessor. It initially involves the use of Hierarchical Task Analysis. Using this, it then establishes whether there is a risk of cognitive errors then continues to identify the possible errors associated with the task. This requires a high level of expert judgment and used the following concepts:

- External Error Modes - the overt form of the error (e.g. turn valve in wrong direction)
- Psychological Error Mechanisms - the internal mechanism of failure (e.g. stereotype take-over - the valve design violates the local plant population stereotype for closing a valve)

(Kirwan 1997).

Following this, the errors were screened (removed if they were deemed "incredible" or if there were no consequences) and the result was represented in a fault tree or event tree as described in Sections 2.4.3.4 and 2.4.3.5. Quantification was carried out using the PHOENIX module - where human error data were obtained from various sources, including THERP, HEART and APJ, then modified using 6 of the main PSFs from the THERP/SLIM methodology.

In general, this method relies strongly on expert judgment, but this is mainly for the human error identification module. In terms of quantification, it is data-driven but has the same problem that all methods using Human Error Probabilities have:-

- They risk having a description that is too generic to distinguish between two different situations in terms of numerical error probabilities.

or

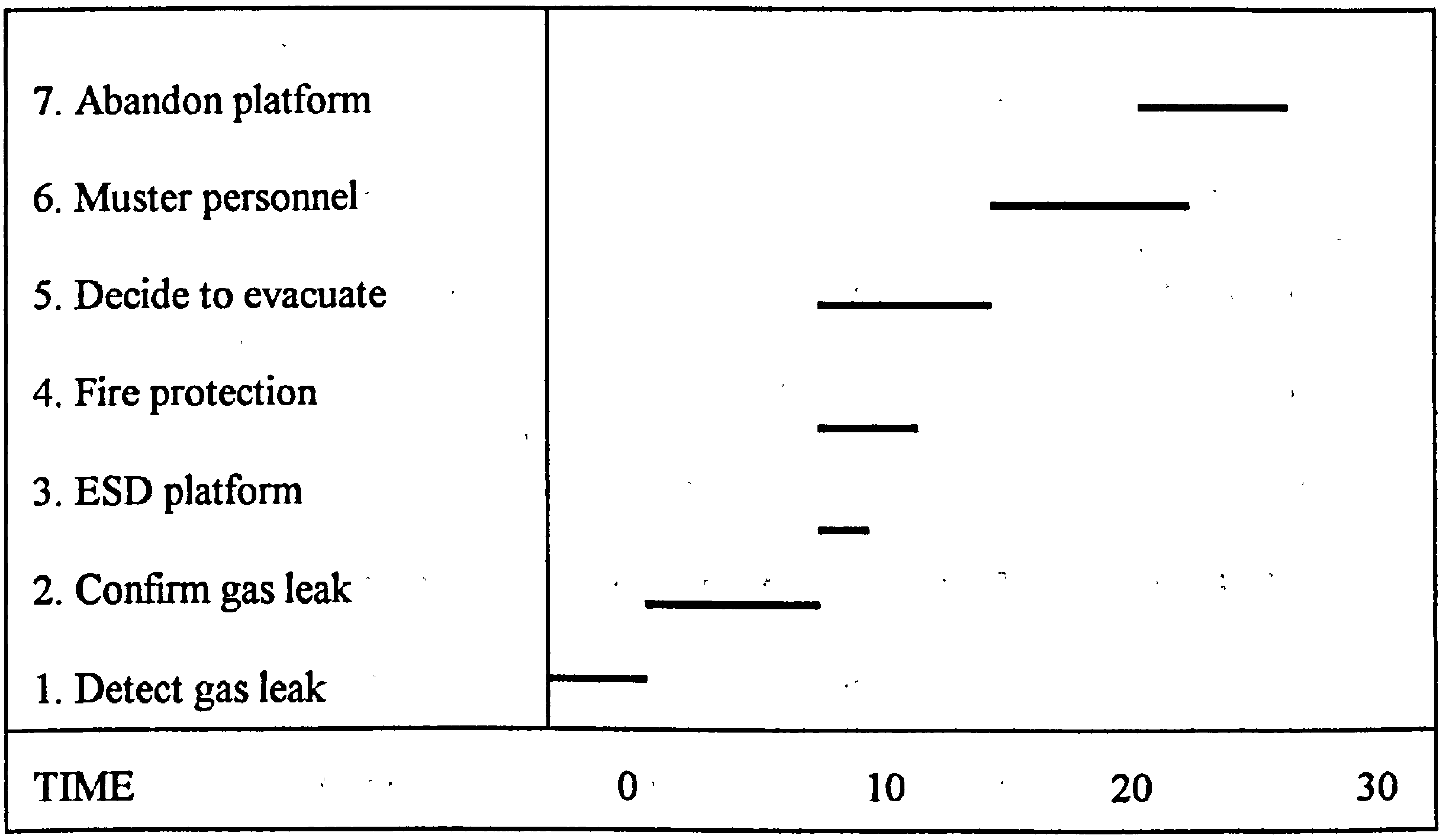
- They are obtained from data that is too specific to be generalized to another situation.

These are both problems for the assessment of emergency management as there are very little data available for specific situations and it is nearly impossible to generalize data from one emergency to another.

2.4.4.2.5 Time-line Analysis

This is not a Human Reliability Assessment tool in itself but could potentially be applied to the development of a new technique for examining emergency management. It can be used to determine which sub-tasks are required to achieve a goal and how long the overall task is likely to take. Quite simply, it uses bars on a chart to represent how long each sub-task will take. Horizontal time-line analysis is the most relevant for analysing emergency management tasks as shown in Figure 7 (from Kirwan 1996a).

Figure 7: Horizontal timeline analysis for evacuation scenario (from Kirwan 1996a)



The inputted data are based on observation, timed trials and expert judgment - therefore it can use a variety of sources to get the most accurate estimation of time taken. It can even represent variability by showing the deviations on the chart and can represent time constraints as vertical lines by which point the various sub-tasks should have been completed (From Kirwan 1994). Its main criticisms (as shown in Kirwan & Ainsworth 1992) are that it does not indicate how problems can be resolved, that the timing of events may be based on expert judgment and that it does not represent interdependencies between tasks.

For the purpose of evaluating the impact of emergency management on risk, timeline analysis has great potential. As shown in Figure 7, it can represent the specific features of a task in a sequence including numerical values of time. If these are not known, it can represent them using a distribution of times. Therefore, the only issue to consider now is how this information can be converted into a useful form for input into the risk equation; namely - how the values of human error probability can be obtained from the analysis.

2.4.4.2.6 MicroSAINT

MicroSAINT evolved from the SAINT (system analysis of integrated networks of tasks) approach (Laughery 1984 cited in Kirwan & Ainsworth 1992). SAINT takes the concept of timeline analysis further by including a Monte Carlo simulation of the performance (Kirwan 1994) – and therefore, like the timeline analysis technique described in Section 2.4.4.2.5, is not a Human Reliability Assessment Technique in itself. However, it can be used to produce the average, maximum and minimum times taken to perform a task. MicroSAINT is the computerised version - providing a language for the representation of physical events in a simulation. To obtain the time information, it uses the GOMS (goals, operators, methods, selection modelling) method - where the time taken for each activity comprises a perceptual processing, cognitive and motor components. The results obtained from this analysis are usually relating to workload or the time taken by various tasks. The main criticisms of this technique are the effort required to produce accurate results, the number of parameters necessary to be specified, the number of assumptions to be made and the problems in representing cognitive tasks (Kirwan & Ainsworth 1992). For investigating emergency management, the problem is the same as for timeline analysis. There is no analysis of the time limits for completing the task - or this limit is fixed and does not represent the uncertainty in timing that is likely to be present. Therefore, there is no obvious method of obtaining human error probabilities from this technique alone, though like timeline analysis, it has the potential to be applied with other concepts to be useful in this analysis.

2.4.4.2.7 TESEO (Tecnica Empirica Stima Errori Operatori) (Bello & Colombari 1980)

This technique uses the multiplication of values from 5 parameters:-
type of activity, time available, human operator's characteristics, their emotional state and the environment. However, each value was categorised in terms of levels not relating to continuous variables. For example, time available is a choice of 3, 30, 45 or 60 seconds. Therefore even though actual times are incorporated into the model, their use is limited by the choice involved. For example, in an emergency, it may be more than 60 seconds before the incident escalates and by this point, particular tasks must have been

completed. It is therefore too orientated towards a control room operator role and is unlikely to be capable of being extrapolated to physical tasks in an emergency. Loa & Strutt (1995) add that there is a lack of supporting data for the model.

2.4.4.2.8 Other methods that consider time

As emphasized in section 2.4.4.1, Time has an enormous impact on the success or failure of an emergency management task. Even if a correct decision is made and the correct action is initiated, even small time delays may mean a failure results. In qualitative terms, it is known that a fire escalates very quickly – and consequently, it takes more effort to control the longer it has been left. The delay in initiation may mean a) the team still can put out the fire but at considerable effort and risk to themselves, b) the fire impinges on another system making it unapproachable, or c) the fire causes an explosion injuring people and destroying the bridge to an emergency exit. The qualitative construct "too late" may be applicable to all of these situations therefore would not distinguish between the context of the qualitative outcomes. Therefore, it is more appropriate to use quantitative measures – and as time is a key feature, it is best to include this as a value in the measures.

There are a number of other techniques can consider "time availability" or "time required" as key features. This is obviously desirable for a technique to analyse the impact of emergency management on risk as time plays a major part in determining the success or failure of tasks.

HCR (Human Cognitive Reliability) was the first model of this kind to be successful (Hannaman & Worledge 1988). It includes the concept that, during an accident sequence, a crew has a limited time to perform key actions to deal with the situation. This involves the use of a task analysis method, then categorisation of the cognitive processing required into skill-based, rule-based and knowledge-based actions. The median time to complete the tasks must be calculated based on experience. This is then adjusted by Performance Shaping Factors (PSFs). The "system time window" - the time in which the actions must be taken, is also calculated. A normalised time value is calculated from the median response time and the system time window. Using this, and a set of time-reliability curves, the probability of non-response can be calculated. Despite this use of real time values and the representation of variance, this model has the problem that it is unlikely to be capable of representing the relevant physical characteristics that dictate the probability of success in an emergency situation.

There are other models that use the concept of time-reliability curves (TRCs). In general, these use the formulae:
Time-dependent Reliability = Probability (Performance time < Available Time)

(Reer (1994), Dougherty (1997) and Moieni et al (1994a)

In these cases, the distributions of the times are calculated from simulations, expert judgment and/or lognormal distributions as used in the HCR methodology.

Dougherty (1993) criticises the use of TRCs in that just because there is "too much" available time, this does not guarantee success. Likewise, "too little" time should not guarantee failure. Care should be taken particularly at the median response time, where probability is 50:50 for success:failure. Dougherty (1993) suggests that some of these problems can be resolved by using a normal instead of a lognormal distribution. However, as a concept, this has the potential to be developed to provide numerical values to assess the impact of emergency management on risk reduction and will be considered in more detail in the method chapters.

Kolarik et al (1998) suggests that a time-varying model of human reliability should be developed. They suggest that this technique should have:
1. Ability to tailor models to specific situations.
2. Ability of models to self-generate and evolve with respect to situational change.
3. Ability of models to offer timely information relevant to operational decisions.

However, at this point, they make no specification of how should a model should be developed, but the approach used in this research has the potential to be used in this way. It is apparent that the mathematical approach to the influence of time is the way forward in this domain – particular as the probability of success in emergency management is so contingent on time-based parameters.

2.4.4.3 New Developments in the field

In general, the research in the area is now working towards correcting some of the disadvantages of the current methods. Kirwan (1998a) notes that there has been an increased move towards examining errors of commission and violation analysis and the use of cognitive simulations and cognitive psychology based techniques. He adds that there has been interest in developing a database of human error probabilities including CORE-DATA (Taylor-Adams 1994) and others (reviewed in Dhillon 1990). These would be particularly useful for quantifying the impact of emergency management on risk reduction if they included the relevant emergency tasks.

There also appears to be greater focus on cognition behind human errors (Meister 1995, Yoon et al 1996, Shen et al 1997), context of tasks (Dougherty 1993, Gertman et al 1996), errors in a continuous time frame (Reer 1994, Kim & Bishu 1996, Hollnagel 1996) and in team decision making (Furuta & Kondo 1992, Gertman et al 1996). There has also been some interest in the nature of human reliability for developing such models - whether the models should be "fuzzy", stochastic or precise (Lee et al 1988, Liang & Wang 1993, Kim & Bishu 1996, Dougherty 1997). On this point, the literature agreed that that point values should not be used to represent variable performance in a variable context, where understanding is not great enough to produce precise representations; but opinion is that it should not resort to the use of random variables either (Dougherty 1997).

Kirwan (1998b) recommends the criteria for the development of a new HRA system as follows:
1. Accuracy - including consistency between different assessors and erring on the conservative (pessimistic) side in areas of uncertainty

2. Theoretical validity - ensuring it is consistent with current frameworks
3. Usefulness - easy to use, considering context-specific information and incorporating practical and flexible error reduction in terms of training, procedures and design
4. Comprehensiveness - considering all forms of human error as well as rule violations and communication errors in all stages of the plant (system) life cycle.
5. Auditability - the system, its inputs and outputs should all be informative, explanative, auditable and transparent.
6. Resource-effectiveness and efficiency - the system should channel most resources to the high-priority human error concerns and should not use excessive resources. It should not require a great degree of expertise to use or equipment resources or facilities.

Kirwan (1998b) also suggests the use of a toolkit approach so that a range of techniques can be selected to solve the particular situation.

Despite these moves towards cognitive approaches in the general field of HRA, this may be too far ahead for the examination of human reliability in an emergency management. In HRA analysis of non-emergency situations, usually the physical behaviour is easier to categorise as "right" or "wrong" – or even "timely" and "too late" – therefore, it is easier to start working towards the underlying cognitive processes in these situations. The emergency situation itself is so dynamic that it can determine whether the decision is good or bad – depending on the timing, the context and situation-specific features. Therefore, looking at the cognitive aspects as "right" or "wrong" is inappropriate until the outcome of such decisions (in terms of the actions and their impact on the emergency) has been established. Therefore, to examine the impact of human behaviour on the probability of success in emergency management tasks, it is necessary to start by looking at the active physical behaviour – that which impacts upon the physical emergency – in a positive or negative way. These are observable actions and therefore are recordable and objective. Following this, it may then be possible to look at the cognitive behaviour behind this physical behaviour – with regard to quality and timeliness of the communications leading to the action then finally the decisions behind the communications. Therefore, it is important to first examiner the result measured in terms of PHYSICAL outcome (the probability of failure in a physical task carried out by a person or group of people) before moving on to look at the probability of human error (probability of making the decision error leading to this failure).

However, currently, there is not even a technique that can currently provide a time-contingent distribution of values quantifying probabilities of success in emergency management tasks at the physical level of human behaviour. Therefore, this is what this research must address. The impact of time is crucial and giving point values to represent "too early" and "too late" would be meaningless in such a dynamic context. In addition, expert judgment techniques cannot be used, as they would lead to unreliable values for the error probabilities as an "expert" in emergency situations would be difficult to identify and verify. Therefore, it would require a model or combination of models, with all of the improvements listed above and more, to adequately model the impact of emergency management on risk reduction.

SECTION 2.5: RESEARCH METHODS

Some of the methods used in this research area have already been mentioned in the earlier sections. For example:
Simulations of emergencies to test emergency management competency
Modelling of physical incidents and human reactions for the QRA
Expert judgment to provide input to human error quantification or to assess human performance
Collection of anecdotal information from real emergencies

However, if these are to contribute to scientific knowledge, the methods must follow the strict guidelines laid down by established methods. Most of the scope of this research involves the understanding of human behaviour, which has always been a problem when the aim is to produce reliable scientific data. Fortunately, the area of psychology has specified methods to optimise the collection of meaningful scientific data.

There are two main areas that must be considered when designing psychological research tools.
1. Validity - the extent that a test measures what it is supposed to measure
2. Reliability - the consistency of a test within itself
These will therefore be considered in turn.

2.5.1 VALIDITY

It seems pointless to develop tests that do not measure what they are supposed to measure. However, finding corroborative data is often difficult and therefore many tests and methods are used without full validation.

In general, it can be said at this stage that the emphasis in this research is leaning towards the use of mathematical models based on comparison of time values as described in Section 2.4.4.2.8. Therefore, unlike most techniques used in psychological research, as long as the equations are correct, the validity of the method rest primarily on the appropriateness of the data that are used.

In our case, validity is most critical in data collection. For example, use of simulations to assess emergency management behaviour has questionable validity. Does the simulation reflect behaviour in a real emergency? If so, is the assessment technique measuring the correct aspects of behaviour when making a judgment of competency? Are the models that result from the research consistent with knowledge about emergency management and its impact on risk? Considering the "subject and experimenter effects", an emergency management candidate may use behaviour that they know the assessor favours. This will produce an assessment of competency for themselves as well as a mark of endorsement for the examiner's methods. Whether or not this behaviour really reflects good emergency management or if the candidate really would use this behaviour in an emergency has not been determined by the assessment. Therefore these factors should be considered strongly when developing the methodology.

2.5.2 RELIABILITY

Obviously, a test of reliability should itself be reliable. However, what are the features that should be considered? In general, this is concerned with the reproducibility of the technique. Therefore, these include the following issues:

- Inter-rater reliability - one person's measure should agree with anyone else's measure of the same variable measured in the same way.
- Test-retest reliability - if a test is repeated, it should produce the same results
- Internal consistency - if all parts of a test are measuring the same thing, they should all correlate with each other.

Again, as the emphasis is towards mathematical models of the probability of success in emergency management tasks, it should be reliable – being influenced only by any statistical applications and the data applied.

Validity and Reliability are both important parts of psychological research. However, it should be noted that these are not "all or nothing" concepts and that all tests and models have degrees of validity and reliability (Graziano & Raulin 1989).

SECTION 2.6: CONCLUSION

This Chapter has discussed the background to the research problem as well as some of the methods used to understand it and their respective findings. Overall, it is clear that there is much to be learnt about the impact of emergency management on risk reduction and how to measure this in scientific terms.

To summarise the issues in this chapter, some of the key factors that have emerged are as follows:

- Although human errors are the main cause of technological accidents, designing human intervention out of the system is not to be recommended. Humans are better than machines in recovering systems from emergency situations. However, in an emergency situation, good design can facilitate the human interventions by slowing the escalation time.
- An emergency manager is required to make "good and timely" decisions to control the escalation and to prevent the worst-case scenario from occurring. Such decision making skill, can be enhanced through realistic training exercises, which should be as representative of an emergency situation as possible.
- Assessment of performance in emergency management exercises is usually assessed by the subjective technique of expert judgment. This is based on the assumptions that certain types of behaviour are conducive to a positive result rather than focusing on the physical outcome. This means that the technique is subject to biases as well as having questionable face validity.
- The techniques used to provide quantitative values of risk or human reliability have not yet provided any definitive means of representing time availability, uncertainties associated with each parameter, team work and the modelling of situation-specific

tasks. All of these are critical aspects of emergency management. Therefore, it is necessary to produce an innovative technique to solve the research problem.

By the descriptions of some of the emergencies that have occurred, it is clear that this is a most important field to research. The consequences of failure can be devastating – and any work that promotes even small successes in emergency management is clearly valid. This chapter has examined the links between the physical emergency and how it escalates over time – as well as the psychological reaction. As the physical aspect of the emergency can only be influenced by physical reactions – it is important that the psychological reactions to this promote "good and timely" physical reactions, hence facilitating a positive physical outcome. This is the most important concept of emergency management. Therefore, to test and measure the effectiveness of emergency management, it is necessary to predict the likely outcome in physical terms

However, there is no technique that adequately addresses the issue of how to quantify the impact of human behaviour on the probability of success in an emergency management task. The Risk Assessment techniques used to examine emergency management usually address the impact of human behaviour with expert judgment techniques or global coverage of human failures in an emergency with one quantitative value and little consideration of the contextual factors considered. Therefore, for this, it would be necessary to apply HRA techniques – and none of these approaches can cater for quantification, the impact of real time on outcome, contextual factors, and particularly, the result measured in terms of PHYSICAL outcome (the probability of failure in a physical task carried out by a person or group of people rather than the probability of human error). This is what this research must attempt to address – thereby creating a foundation on which other techniques can be built to incorporate the cognitive aspects of human reliability in emergency management.

Given that the relevant theoretical subjects have been discussed, the next chapter will describe the background to our study by introducing the nature of the offshore oil and gas industry and the relevant research carried out therein.

Chapter 3

THE OFFSHORE INDUSTRY

SECTION 3.1: INTRODUCTION

The previous chapter discussed the general research carried out that is relevant to this project. This chapter aims to introduce the context of the research - by introducing work carried out specifically in the offshore industry. Therefore the following sections include a description of the offshore industry - including the roles of the personnel emphasising the importance of on-site emergency management in reducing risk. Following this, there will be a brief introduction of health and safety and the development of legislation in the offshore industry. This ensures that the research takes account of the structure in which risk reduction and emergency management are implemented. Therefore, any conclusions drawn from this research must be consistent with current ideas or future strategies for safety legislation in the offshore industry.
Next the review will move on to the relevant areas of research, starting with a discussion of emergencies - in particular, the Piper Alpha disaster - then discussing offshore emergency management. Finally, this chapter will discuss some of the specific risk analysis techniques that have been applied in the offshore industry. This will therefore cover all the relevant research in the areas of interest.

SECTION 3.2: DESCRIPTION OF THE OFFSHORE ENVIRONMENT

3.2.1 GENERAL INTRODUCTION

In the United Kingdom sector of the North Sea, natural gas was discovered in 1965 and oil in 1970. However, the petrochemical industries were slow to exploit the oil and gas reserves in the North Sea, probably due to lack of knowledge and an underestimation of the quantities available (UKOOA 1998b). However, offshore oil and gas now provides 85% of all the United Kingdom's total energy output and is expected to dominate for many years to come (Odell 1995).

The workplaces of the offshore industry typically fall into one of the following types:

- Mobile drilling rigs for oil exploration.
- The larger production platforms for drilling and processing the hydrocarbons before transporting them to an onshore facility.
- Floating Production Supply & Offloading (FPSO) (floating installations using flexible risers from the subsea system) These normally separate the petrochemicals then transfer them to a shuttle tanker to be carried ashore.
- Service vessels including floating hotels "flotels", standby vessels & supply vessels

(Flin, Slaven & Whyte 1996, Strutt 2000)

Mobile drilling rigs can be of four main types: the older shallow-use submersibles, semi-submersibles, jack-up platforms and drill ships. As far as production platforms are concerned, there are four main types: steel jackets, artificial islands, concrete structures and tension leg platforms. A comprehensive description of these types of platform can be found in Lancaster (1996).

3.2.2 THE OFFSHORE ENVIRONMENT AND PERSONNEL

Even under normal conditions, the offshore environment is an unusual workplace. Accommodation is only metres away from the workplace, both surrounded by hazardous and noisy drilling and processing technology, then situated in the middle of the sea. Work colleagues are the only social companions. Shift work is a normal requirement, potentially leading to fatigue (Parkes 1992). Some days, when weather is particularly poor, personnel may not be able to leave the internal accommodation and offices. The only normal way on and off the platform is by helicopter, wearing a survival suit, with journeys lasting between 20 minutes to over 2 hours. Therefore, there is no opportunity to freely "come and go as you please" (Flin, Slaven & Whyte 1996). Even when leave is scheduled, this may not be possible due to bad weather. Then, if the worst-case scenario does occur, forcing workers to abandon the platform, the only escape is via helicopter, lifeboat or, in the most desperate situations, jumping from a large height into the freezing North Sea. Hence the people who choose to work offshore are often visualised as a "rough, tough bunch, battling against harsh weather elements to "bring home the oil"" - but it is a far cry from the glamorous view of luxurious floating hotels and above-average salaries held by some members of the public and the media (Whyte 1989).

Obviously, this means that only a certain type of person is suitable to work in the offshore environment. Usually this is self-selecting. Few people who were afraid of water, flying or heights would choose to work in the offshore industry. Also, a large number of the workers are contractors, making it difficult to ensure consistency on an installation (Flin, Slaven & Whyte 1996) and therefore creating a problem in maintaining a competent emergency management team.

As such platforms are almost self-sufficient, there are a number of different roles that must be fulfilled on a platform. These have been categorised by Flin, Mearns, Gordon & Fleming (1996) as technicians and mechanics, production, maintenance, caterers, administration and management, drillers, deck crew, auxiliary staff, medics and logistics. However, specialist roles such as divers and crane drivers must have been incorporated into one of the above categories or have been erroneously left out of the research. Over and above these normal roles, an emergency situation requires these personnel to adapt to become muster captains, fire-fighters, rescue teams and lifeboat coxswains.

The work involved can potentially involve physical exertion, adverse weather, hot and cold exposure, helicopter and boat travel, exposure to heights and, possibly, exposure to smoke (Flin, Slaven & Whyte 1996). Therefore, medically, there are a number of conditions that would make a person unsuitable for offshore work. Logically, these include insulin-dependent diabetes, gross obesity, infectious diseases, psychoses, pregnancy or congenital heart disease. Detailed guidelines as to the acceptable and unacceptable conditions are given in UKOOA (1986) and Flin & Slaven (1996a).

There have also been a number of psychological attributes suggested to be indicative of someone who will be ideal for the offshore environment. These include "coping with long hours, isolation, teamwork ability" and, for Offshore Installation Managers (OIMs), "an ability to stay calm, leadership, decisive under pressure, ability to assess the overall situation, ability to communicate and self-confidence" (Flin & Slaven 1996a). These are consistent with the ideas of Crew or Team Resource Management, described in Section 2.3.4.1. and will be considered further in Section 3.5. However, psychological attributes are difficult to measure and to define standards therefore these are usually only implied in the relevant legislation. Therefore, this section will discuss the development of offshore legislation with particular regard to emergency management and risk assessment.

SECTION 3.3: HEALTH AND SAFETY LEGISLATION IN THE OFFSHORE INDUSTRY

3.3.1 PRE-PIPER ALPHA

Historically, legislation in the offshore oil and gas industry has responded to a number of major accidents. The *Minerals Working (Offshore Installations) Act* (1971) was introduced in response to the collapse of the Sea Gem rig in the North Sea. Despite already using a risk management based approach, the Norwegian Petroleum Directorate (NPD) issued their "Regulations concerning safety related to petroleum and installations" in 1976. Eventually, this technique grew into full Quantitative Risk Assessments (QRAs) including safety systems and the design process (cited in Smith,E.J. 1995). Further to this, the NPD Guidelines for simultaneous operations and concept safety evaluation were introduced in response to the Ekofisk blowout and oil spill of 1977 and Alexander Kielland capsize in 1980.

Up until Piper Alpha, the law in the U.K. regarding offshore safety was primarily rule-based based on "prescriptive legislation and associated Guidance notes" without any application of QRAs (Lloyd & Hunter 1991). Further to this, Lloyd & Hunter (1991) state that the design process was "relatively straightforward and quick with assessment based on a checklist approach to compliance". However, the Piper Alpha disaster drew attention to many of the weaknesses in these strategies.

3.3.2 THE PIPER ALPHA DISASTER

Piper Alpha was a large production platform situated in the UK sector of the North Sea, 110 miles northeast of Aberdeen. It was of the steel jacket design with 8 legs piled into the sea-bed in 144m of water. It began production in 1976; operated by Occidental Petroleum (Caledonia) Ltd., initially exporting oil then, at a later date, gas too. In terms of oil pipelines, Piper and Claymore were connected to the Flotta oil terminal on the Orkney Islands. Gas was received from the Tartan platform for onward transmission to the MCP-01 where it joined the trunk-line between the Frigg gas field and the onshore St.Fergus gas terminal in Aberdeen. Further to this, Piper provided gas to assist the Claymore platform with production (Cullen 1990, Hales 1995, Lancaster 1996).

At approximately 22:00 hours on Wednesday 6th July 1988, there was an explosion on the production deck of the platform, which was caused by ignition of a cloud of gas condensate leaking from a temporary flange. Large oil fires then caused a rupture of a pipeline carrying gas from Piper to the Tartan platform resulting in a massive explosion. The fires and explosions lead to structural collapse of the platform resulting in the deaths of 167 people, including two rescue workers. 65 people, including 3 rescue workers, survived but were injured. Most of these did so by jumping heights of up to 175 feet into the sea (Cullen 1990, Hales 1995, Flin & Slaven 1996a).

The cause of this incident all stemmed from a combination of actions that occurred earlier in the day. Maintenance was scheduled for condensate injection pump A and so this pump was electrically isolated but no other actions had been taken. Another contracting firm were scheduled to carrying out rectification work on a safety release valve so this was removed and replaced with a blind seal (now known to be inadequate). In addition, divers were working near the seawater intakes and so the standby pumps were set to manual and the deluge system was deactivated due to welding work. Later in the evening, condensate injection pump B tripped and would not restart. Because of poor procedures in the permit to work system, the operator was unaware of the status of pump A and put this into service. The high-pressure condensate began to escape through the inadequate blind seal. About 30 seconds later, an explosion destroyed the firewalls on both sides, damaging the crude oil pipes and the deluge system. The burning oil spilled down and heated the risers of the gas pipelines resulting in the subsequent and deadly explosions. Within all of this chaos, the OIM (Offshore Installation Manager) panicked and made no attempt to communicate with surrounding vessels, installations, helicopters or the shore. He provided no guidance or leadership for the other personnel on Piper, contributing to the large loss of life. (Cullen 1990, Bradley 1995). With the current legislation in place, there was no reason to suggest that this could not occur again and it was necessary to make changes to prevent this or another tragic accident.

3.3.3 THE CULLEN REPORT

After the incident and before the public inquiry was released, the initial response by industry was to conduct assessments of their installations and management systems, considering:

- Improvements to "Permit to work" management systems
- Relocation of some pipeline emergency shutdown valves
- Installation of subsea pipeline isolation systems
- Mitigation of smoke hazards
- Improvements to evacuation and escape systems, and
- Initiation of Formal Safety Assessments

(UKOOA 1998c)

The Public Inquiry was chaired by Lord Cullen and consisted of an investigation to establish the causes of the disaster then recommendations towards safety changes, some of which will be discussed in Section 3.3.4. Cullen's Recommendations lead to the introduction of the *Offshore Installation (Safety Case) Regulations 1992*. These have been compared to the previously introduced *Control of Industrial Major Accident Hazards* CIMAH (1984) Regulations but were "considerably extended" (Mansfield 1992, Flin, Mearns, Gordon & Fleming 1996).

These regulations required installation operators to provide safety cases for designing, operating and abandoning an installation. The safety case must include:

- a full description of the platform,
- the meteorological and oceanographic conditions involved,
- numbers of people,
- details of the hazards involved in the processes,
- information regarding temporary refuge, routes to the safe haven and means of safe evacuation (HSE 1993), and
- evidence of an adequate safety management system (Smith, E.J. 1995).

Operators were required to identify all possible hazards, to quantify the risks arising from such hazards, and then demonstrate that these risks have been controlled to a level "as low as reasonably practicable". Further to this, operators were required to provide statements of performance standards for their emergency arrangements to deal with major hazards (Finucane 1994). By 1989, the Offshore Installations (Safety Representatives and Safety Committees) Regulations were in place, to ensure that the communications of safety concerns were being brought to the attention of managers (UKOOA 1998c).

Also, a new HSE division - the Offshore Safety Division (OSD) - was created to oversee the implementation of all of the inquiry's recommendations. By the end of 1996, this was successfully completed. This division is responsible for research to assess the risks involved in offshore work, conduct accident investigations and provide technical guidance to support legislation (HSE 1998e). Further to this, The Offshore Safety Act (1992) was created so that the HSE and HSC held the formal responsibility for offshore safety and could create new legislation as required. Since then, the Offshore Safety Division has "inherited the Department of Energy's program of research into offshore safety" (Lane et al 1994).

Apart from these changes, a large research project investigating blast and fire engineering for topside structures was initiated to look at the behaviour of fires on offshore installations. (See Selby & Burgan 1998 for results).

The Cullen report (1990) intended to both identify the causes of the disaster as well as make recommendations for future safety improvements. This report made 106 recommendations including the following:

- Introduction of a single regulatory body responsible for safety in the offshore oil and gas industry

- Use of Formal Safety Assessments including HAZOPs, QRAs and Safety Audits.
- Improved permit-to-work systems
- Evacuation, escape and rescue procedures and training
- Attention to the vulnerability of emergency systems analysis
- Prevention of smoke and gas ingress into the accommodation
- Fire Risk Analysis
- Adequate temporary safe refuge
- Involvement of the work force in the Safety Case preparation and in improving safety performance
- Chain of command for safety
- Leadership from the top
- Goal-setting approach as opposed to a prescriptive approach

(Cullen 1990, emphasised in Mansfield 1992, Barrell 1992, Bellamy & Geyer 1991, Miller 1996, Lloyd & Hunter 1991).

Many of these improvements are outside the scope of the research. Therefore, this report will continue by focusing on the provision of resources, training and personnel selection for emergency management. In general, Cullen's recommendations and the corresponding legislation have not supplied a large amount of detail regarding the skills required of an offshore emergency management team, or the training and assessment process. Therefore, the following section will discuss the literature that speculates on how this problem should be approached.

3.3.4 RELEVANT CHANGES IN OFFSHORE HEALTH AND SAFETY LAW AFTER THE CULLEN REPORT

The Offshore Installations (Prevention of Fire and Explosion and Emergency Response) Regulations were introduced in 1995. These placed obligations on the installation operator covering emergency response and specify goals for preventative and protective measures for controlling the hazards of fire and explosion. This requires that they establish the appropriate performance standards for items of equipment or systems that they have installed to deal with the risks. This would include the provision of an adequate temporary refuge as well as a safe means of evacuation.

The Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995 require that "a competent manager is appointed as manager of the installation and provision made for appropriate resources to be available for managers to be able to carry out their functions effectively. Managers are responsible to the duty holder for day-to-day management of operations and are in charge of the health and safety of persons on board, including the command and control function in an emergency."

The Offshore Installations and Wells (Design and Construction etc.) Regulations 1996 provide regulations to ensure that the integrity of the installations is ensured at all times as is reasonably practicable. The duty holder must therefore address the forces that act on the installations, its layout and configuration, including the changes brought about by decommissioning.

UKOOA (1998b) stated that by November 1993, every installation in UK waters had submitted a safety case to the HSE. However, all was not as it seemed. A questionnaire-based study by Whyte et al (1995) suggested that "the current system of safety representatives and safety committees was unable to deal adequately with workforce input to safety", particularly due to fear of reprisal. Even with the introduction of the safety case regulations, many of the respondents in the study were not asked to contribute to the safety case - and those that were usually found their suggestions rejected by management as "either inappropriate or deliberately obstructive". In general, the study found that although the workforce were willing to cooperate with the new focus on safety, the management and oil companies were still aiming for cost-cutting by reducing the number of support vessels, encouraging workers to supply their own safety equipment and reducing training times (Whyte et al 1995). This is further backed up in a statement by Dr Charles Woolfson, who said "Despite Lord Cullen's recommendations that "it is essential for the whole workforce to be committed to and involved in safe operations", neither effective means for workforce participation, nor the legal backup required by safety representatives or worker whistle-blowers has yet been put in place...Unlike in the Norwegian sector, the workforce have been consigned to the role of passive onlookers" (Yahoo! News 1998).

3.3.5 A STEP CHANGE IN SAFETY ?

However, some aspects appeared to have shown improvement. The industry agreed to report offshore hydrocarbon releases to the HSE on a voluntary basis. From 1992 to 1994/95. the numbers of reported releases were as follows:

36 major releases
170 significant releases and
111 minor releases

From 1994/95 to 1997/98, these values decreased to

22 major releases
102 significant releases
50 minor releases (data from UKOOA 1998c).

These figures showed a significant improvement which may have lead UKOOA to introduce "a step change in safety" in 1997, which stated their objectives as follows:

- Deliver a 50% improvement in the whole industry's safety performance over the next 3 years
- Establish our own safety performance contracts which will demonstrate visibly our personal concern for safety as an equal to business performance
- Work together to improve sharing of safety information and good practice across the whole industry, through active involvement of employees, service companies, operators, trades unions, regulators and representative bodies.

(quoted from UKOOA 1997c)

UKOOA (1997c 1998c) emphasised the use of cooperation between individual companies and across all industry sectors to improve safety performance.

However, it is now clear that the first of their goals will not be achieved. In a report by Gibb (1999b), it was noted that this had been a "stretch target" and that injury rate figures from early in 1999 had showed a 20% improvement compared with when Step Change was initiated.

However, Gibb (1999a) described an incident in which a 10½ tonne tank of liquid nitrogen was being lifted from a supply vessel to the Britannia oil and gas platform. In this case, the crane pennant snapped and the tank crashed to the deck. It was fortunate in this case that it had snapped early in the lift as if this had occurred high above the platform during processing, it could have caused an incident as serious as the Piper Alpha disaster. In this report, Gibb quoted Jake Molloy who said, "All the elements that existed in the run-up to Piper Alpha are back again - a cost-cutting environment, rationalisation and massive down-manning". However, in Gibb (1999b), these allegations were denied by UKOOA's director of operational and technical affairs, Dr John Wils, who stated that "Safety will always remain this industry's highest priority. It is a pre-requisite of good business". This debate is likely to continue for some time without a solution. Therefore, this review will briefly mention some of the other major emergencies that have occurred in the offshore industry before discussing emergency management.

SECTION 3.4: MAJOR EMERGENCIES IN THE OFFSHORE INDUSTRY

Apart from the Piper Alpha disaster, safety and reliability in the offshore industry has been drawn to the public's attention by other memorable accidents. The ten worst offshore accidents worldwide from between 1955 and 1988 are shown in Table 2.

Table 2: The 10 Worst Accidents in the Offshore Industry between 1995 and 1988

Date	Name	Installation	Location	Activity	Fatalities
6/6/88	Piper Alpha	Fixed Steel Jacket	UK sector North Sea	Production	167
27/3/80	Alexander Kielland	Semi-submersible	Norwegian sector	Accommodation	123
11/3/89	Sea Crest	Drillship	Thailand	Stand-by (storm)	91
15/2/82	Ocean Ranger	Semi-submersible	Newfoundland	Stand-by (storm)	84
26/10/83	Glomar Java Sea	Drillship	China	Stand-by (storm)	81
25/11/79	Pohai 2	Jack up	China	Under tow	72
16/8/84	Enchova PCE-1	Fixed steel jacket	Brazil	Development drilling	37
30/6/64	C.P.Baker	Drillship	Louisiana	Exploratory Drilling	22
30/12/56	Qatar 1	Jack up	Qatar	Dry tow	20
2/10/80	Ron Tappmeyer	Jack up	Saudi Arabia	Exploratory Drilling	19

(Strutt 1994)

The Worldwide Offshore Accident Databank (WOAD) run by the Bureau Veritas in Oslo publishes biennial reports of the industry's accident record. However, in terms of fatalities, the Piper Alpha disaster is the worst to date and has had the greatest impact on the organisation of safety and emergency management in the industry through the aforementioned Cullen report. Therefore, this review will move on to discuss the implementation of the recommendations with respect to emergency management.

SECTION 3.5: OFFSHORE EMERGENCY MANAGEMENT

One of the critical aspects of an emergency on an offshore installation is that, due to their location, personnel are required to exhibit a certain degree of self-sufficiency. External assistance is unlikely to arrive within the first half hour of an emergency and responding to any incident with an immediate evacuation carries other risks. Therefore, the role of an emergency manager is likely to have a significant impact on the outcome of an incident - through the early on-site application of control, prevention of escalation and rescue (Stewart, K. 1994).

Many of the issues regarding generic emergency management have been discussed in Section 2.3. Therefore, this section will continue by looking at the specific research in the area of offshore emergency management, including the roles of the OIM and his team, training, assessment, emergency planning, design and resources. This will start by examining the development of the role of the Offshore Installation Manager (OIM).

3.5.1 THE OFFSHORE INSTALLATION MANAGER (OIM)

The role and responsibilities of the Offshore Installation Manager first became defined in response to the Sea Gem accident. On Dec 27th of 1965, the Sea Gem collapsed while drilling, capsized and sank with the loss of 13 of the 32 men on board. This led to the introduction of the *Minerals Workings (Offshore Installations) Act of 1971* - facilitating regulations for the health, safety and welfare on offshore installations. The public inquiry into the disaster recommended that the person in charge or "master" should be clearly defined, together with a chain of command (Flin & Slaven 1996a).

However, the Piper Alpha disaster further illustrated the importance of the Offshore Installation Manager. If the OIM had not panicked, he may have provided some positive interventions in terms of evacuation or co-ordination of fire-fighting and many lives could have been saved. However, it is futile to assign blame to this single individual. Errors occurred in promoting him to the OIM status without proper emergency training, and, not providing any available chain of command if he was found to be unable to fulfil his duties. (Paté-cornell 1993).

The Offshore Installations (Safety Case) Regulations (1992) and the Offshore Installations (Prevention of Fire and Explosion and Emergency Response) Regulations (1995) attempted to rectify this by clarifying the importance of "command by competent persons" and a specified "chain of command" should the OIM or his deputy become unable to cope.
UKOOA (1995a p.20) suggests that the factors contributing to a successful assessment of an incident and activation of an appropriate response include:

- Clearly identified responsibilities for decision making
- Clearly identified lines of command and control
- Competence in those with responsibility for decisions, based upon selection, experience, knowledge, training and practice.

These Regulations and Guidance obviously promote the techniques of "command and control" emergency management above the other types mentioned in Section 2.3 (Crew Resource Management and Emergent Human Resources).
So, given that it was a commander that was required to fulfil the role of OIM, it was deemed necessary to identify selection and training techniques to ensure that the person in the role had "the right stuff". Therefore, it was also necessary to identify what that "right stuff" was (Flin & Slaven 1995).

Larken (1995) suggests that the emergency manager must have a broad base of skills, including

- Capability to manage under pressure
- Capability to operate outside the operational envelope. The broader the range of operational experience, the less likely the emergency commander is to find himself having to operate outside of his personal objective envelope
- Ability in emergency team command; leadership
- Skills in the basics of emergency management - logistics; personnel accounting and movement, evacuation plans; communication and information processing.

- Skills in major hazard management - process plant; drilling; technical diagnosis
- Knowledge of major hazards; fire and explosions; chemical; radiation
- Knowledge of the facility itself

In practical terms, Larken (1995) also emphasises the importance of developing "the big picture", making early appraisals, planning ahead and monitoring incoming information. However, although these are reasonable assumptions of the requirements of an OIM, there is no evidence that these are actually tested in the selection process. Paté-cornell & Murphy (1996) also suggest that the OIM must fulfil the role of the on-scene commander in the event of an emergency, however other literature does not support this view. Mills & Coleshaw (1998) comment that the OIMs often have little understanding of the on-scene processes (such as loading casualties into a lifeboat) and that this impairs their management performance. This suggests that OIMs should have personal experience of the physical tasks in an emergency - including fire-fighting and medical support, before being appointed to the management role. In terms of our research, this could be interpreted as "greater understanding of how the physical actions make an impact on risk leads to better fulfilment of the management role".

Flin, Slaven & Whyte (1996) investigate the use of scientific selection techniques and found that there was "a general lack of objective assessment measures and psychometric testing" for the role of offshore installation manager and that selection was mostly based on recruitment within the company, a good track record or personal recommendations (p.90-91). The companies who did use psychometric tests described the ideal personal qualities for an OIM were as follows:

- Leadership ability
- Stable personality
- Communication skills
- Delegating
- Team working
- Decision making under time pressure and stress
- Evaluating the situation
- Planning a course of action
- Remaining calm and managing stress in self and others
- Pre-planning to prepare for possible emergencies

(Flin, Slaven & Whyte 1996)

This appears to be more consistent with the concept of crew resource management than the command and control approach implied by the Regulations. However, Flin, Slaven & Whyte (1996) concluded that none of the companies had any means of validating their selection procedure. Flin & Slaven (1996b) attempted to define a set of personality criteria for those judged as competent in dealing with a simulated offshore emergency. They discovered few significant correlations between performance measures and personality factors. Their results indicated that "the OIMs with the highest rated performance were those who:

- like to take charge and supervise others
- consider themselves to be fun-loving, sociable and humorous

- are less interested in analysing human behaviour
- are more interested in practical than abstract problem solving, and
- prefer to make decisions quickly rather than take time to weigh up all the evidence".

However, the performance measures are still based on subjective views of observing behaviour in a simulation rather than based on the impact of the emergency management on the outcome of the emergency. Further to this, this section has focused on the OIM alone - and must now examine the broader scope of emergency management and its impact on risk by considering the skills of his team.

3.5.2 THE OFFSHORE EMERGENCY MANAGEMENT TEAM

Despite the focus on the importance of the OIM and his "command presence", the supporting team are critical for successful management. Flin & Slaven (1995 p.118) state "an important principle is that leaders should be as familiar as possible with the strengths and weaknesses of the teams they would have to rely on in an emergency, as decision quality can depend on appropriate use of other members of the command team". Larken (1995 p.108) suggests the "key points in constructing an emergency management team are:

- There must be a balance between totally overloading a single individual with information-handling duties and creating, at the other extreme, too complex a matrix of interfaces
- Information-handling and presentation systems must reflect the specific needs of the team and the demands placed (on them) by the nature of the installation
- Team members should be trained to observe and support each other, including support of the emergency commander at difficult moments".

The skills required of the team include situation assessment and maintaining "the big picture", maintaining effective communication with installation personnel, onshore personnel, other installations and external resources, keeping an accurate log and accounting for personnel, directing and deploying on-scene fire-teams, rescue teams and other resources, controlling process operations and shutdown. They therefore have a large amount of information to gather and assimilate so that they can plan and anticipate responses (Flin & Slaven 1996b).

Keith Stewart (1994) suggests that the OIM and perhaps one or two others hold the shared problem model and the rest of the team are responsible for gathering and processing the information to ensure that the key people maintain "the big picture". Therefore, this is consistent with the concept of naturalistic decision-making. Skriver et al (cited in Flin & Slaven 1996a) also found that 90% of the decisions made by OIMs in a simulated table-top exercise were of the types described in Klein's Recognition Primed Decision model (1989) - one of the main models used in the naturalistic approach. Initially, there were some doubts that OIMs have the experiential basis on which to make naturalistic decisions, as they do not experience emergency management on a day-to-day basis as fire-fighters do. However, Flin, Slaven & Stewart (1996) identified that OIMs have such an excellent mental model of the workings of their installation including risks, layout and technical understanding, this can substitute for their lack of practical emergency management experience.

However, few of these concepts have objectively-measured scales of performance which can be developed as a training or assessment tool. Therefore, although it appears likely that naturalistic decision-making is used by effective emergency management teams, the research in the area does not yet show signs of solving this research problem. Instead, it is more likely that a technique that can quantify the impact of emergency management on risk reduction can be used to validate these concepts - by demonstrating that emergency management teams having particular decision-making skills do indeed have a greater impact on risk reduction.

3.5.3 TRAINING

Given that particular skills are necessary for both OIM and his team, it is unlikely that they would be able to form an effective emergency management team without any practice. Flin & Slaven (1995 p. 118) add that "Deficiencies in team performance frequently relate to communication problems and these can be minimised by training teams together in emergency response procedures". Despite this, Flin & Slaven (1994 cited in Flin & Slaven 1996a) found that "28% of the OIMs received no specific emergency command training, though some had received such training through earlier careers in the armed forces".

The Offshore Petroleum Industry Training Organisation (OPITO) is the body responsible for ensuring the quality and content of key safety and emergency training for the workforce and to develop measurable standards of competence for the industry to meet the requirements of UKOOA guidelines". (Institute of Petroleum 1998). It specified that duty holders (usually operators) are required to provide emergency response training to OPITO standards, if not from an OPITO approved training provider (UKOOA 1997c). The Safety Case regulations required more formal specification of selection and training than previous legislation, mostly based on simulated exercises and the use of "command and control" management. However, David (1996) argues that the military-type of command and leadership training that OIMs frequently attend may provide some benefits in emergency response but is "organizationally, operationally and culturally specific" so may not be time or cost-effective. He suggests that training should be properly designed for the industry in which it is applied and suggests that perhaps the Crew Resource Management approach taken by the aviation industry would be more applicable. As stated before, it has not yet been determined which approach is more effective - and this is another reason why a technique of assessing the impact of emergency management on risk reduction would be useful.

Therefore, the next set of sub-sections will consider all the various types of emergency management training that are used in the offshore industry.

3.5.3.1 Drills

All offshore personnel must undergo basic training for musters, interpretation of alarms as well as emergency evacuation, fire-fighting and survival which is normally carried out in the form of team drills (Strutt & Lakey 1995). UKOOA (1997a) requires that all workers must complete a basic offshore safety induction and emergency training, which must be refreshed every 4 years. OPITO specifies the requirements for the survival course (incorporating a simulated evacuation from a submerged helicopter) and maintains an up to date register of those currently certified (Flin & Slaven 1996a). The training must be platform-specific and includes the location of muster stations, lifeboats, rescue equipment and survival suits for all personnel including visitors (Flin & Slaven 1996a). However, there are other important skills that may be learnt which are essential for effective emergency management. As stated earlier, maintaining communication is a critical skill and it cannot be identified using a questionnaire. Communication skills are often taught in combination with radio skills and learning to make messages clear, accurate, informative and concise is essential. This is particular crucial for those who speak a different language to the rest of the group so that it can be ensured that all personnel are able to communicate together.

3.5.3.2 Computer Simulation

There has been some training conducted in the industry using computer simulation. Flin & Slaven (1996a) give an account of its success in training personnel to use permit to work systems. It was found to significantly enhance performance in the short-term and 4 weeks after training. However, there seems to be no other software available that fulfils aspects of emergency management training in the offshore industry.

3.5.3.3 Major (real-life) exercises

These can involve both onshore and offshore emergency management as well as co-ordination with external bodies, for example, the coastguard and police. UKOOA (1997a) suggests that these should be held annually, though this an expensive technique in terms of personnel, resources and organisation time. For these reasons, although this is the technique producing results with the greatest validity, it would not be practical to use it as a research tool or for testing all-round breadth of emergency management knowledge for each individual.

3.5.3.4 Dedicated simulations or "Integrated Onshore Exercises"

These are the main type of emergency management training. UKOOA (1997a) emphasise the importance of competent training providers running "integrated and realistic" scenarios to maintain competence. They recommend the use of an integrated onshore exercise as it frees the team from their normal offshore roles to be able to concentrate on their role in an emergency. UKOOA (1997a) recommends that if these are carried out successfully at least once every 3 years, this will fulfil their competence requirements. Similarly the onshore role in an offshore emergency should be assessed at least once a year.

Flin & Slaven (1996a and Skriver & Flin 1997) suggest that training should focus on improving situation awareness and building up experience by managing realistic and complex scenario-based exercises. Further to this, OPITO Guidelines require that emergency managers must prove that they are capable of managing at least 3 of the following emergency scenarios:

- Well control incident
- Explosion and fire
- Accommodation fire
- Helicopter incident
- Collision or wave damage causing structural collapse
- Loss of stability (Flin & Slaven 1996a)

Further to these requirements, UKOOA (1997a) recommend that training should also consider the following issues:

Mustering and Evacuation
Fire-fighting
Breathing apparatus
All emergency equipment
Casualty handling
Process emergencies
Loss of station keeping
First aid
Man overboard
Standby and emergency service vessels
Well control
Security - terrorist threat
Loss of stability
Loss of structural integrity

These simulations are run as described in Section 2.3.6 and they are obviously quite popular. OIMs have listed the following points to describe how they feel the simulations benefited them:

1. Discovering how one responds and makes decisions under pressure
2. Practice in thinking of possible courses of action to deal with emergencies
3. An increase in self-confidence from having performed well
4. The opportunity to test the team structure and identify strengths and weaknesses
5. An appreciation of the importance of communication during an incident. (Flin, Slaven & Stewart 1996 p.265)

3.5.4 ASSESSMENT

The problems of assessment of emergency management performance in the offshore industry are the same as for most other industrial sectors as described in Section 2.3.6.2, for example, obtaining objective measures of behaviour, use of artificial situations and assessing a team rather than individuals. Competency assessment of an OIM is based primarily on judgement of his performance in an emergency exercise - usually of the "dedicated simulation" type described in Section 3.5.3.4. UKOOA (1997a) suggests that assessment should be carried out by "at least 2" assessors, where at least one of these should be a "discipline expert" - that is "someone who has served in a position of authority within an operational group" (UKOOA 1997a p.13). UKOOA

(1997a) also recommends the inclusion of someone who has served as an OIM on the installation in question or a similar installation. Flin & Slaven (1995 p.120) add "it is obviously vitally important that the competence assessments are carried out by experienced and highly trained individuals, to ensure the quality of the evaluation and also to maintain the credibility of the process for those being assessed". Therefore, competence in emergency management is primarily judged through observation of these exercises and the use of specific criteria. However, some flexibility is given where there is proven ability in real emergencies or evidence of competence from other sources (UKOOA 1997a p.14).

OPITO (Institute of Petroleum 1998) have attempted to clarify the performance criteria which is accepted as "competent" by drawing up checklists and assessment material to be used on a platform manager appraisal form.
The levels of competence are defined as

- No evidence of competence
- Competence not demonstrated fully
- Competence demonstrated fully
- Excellent competence demonstrated

The skills that must be demonstrated are specified in a checklist prepared by OPITO (see Appendix 1 for details). However, as indicated earlier in Sections 2.3.5, 3.5.1 and 3.5.2, it is the outcome of an emergency that is the critical factor. Stewart, K. (1994) has analysed the possibility of identifying the behavioural characteristics of high performance emergency management teams. He therefore used observation of live and recorded training exercises and analysed the conversations that took place. Although his paper described a model of crew decision making offshore, this illustrated the point that it is not necessary to rely entirely on subjective judgements or checklists of positive attributes to assess emergency management performance. Such a concept could be useful for this research - as objective measures provide a reliable base from which quantitative methods can be developed.

3.5.5 EMERGENCY PLANNING

Emergency planning can have a critical impact on the outcome of an emergency. For example, in the Alexander Kielland disaster, the onshore emergency plan had not catered for prolonged incidents and so did not consider that the emergency personnel may need rest or replacement over the time period involved (Bellamy & Brabazon 1993).

The Offshore Installations (Prevention of Fire and Explosion and Emergency Response) Regulations (1995) require each installation to have an Emergency Response Plan, containing sufficient information for the guidance of personnel:-

- on the organisation and arrangements to take effect in an emergency, and
- on the procedures by way of emergency response to be followed in different circumstances. (Flin & Slaven 1996a)

UKOOA (1995a p.17) specified that the arrangements must include:

- Incident detection
- Raising alarm
- Assessment of incident and activation of response
- Access to muster areas
- Muster
- Egress from muster areas
- Evacuation
- Escape
- Recovery and Rescue
- Place of Safety
- Preparation for emergencies, emergency planning and communications

Planning should include all of the emergencies included in the Safety Case as specified in Section 3.3.3 as well as planning for longer term incidents such as a serious illness on board the platform. The next section will therefore consider the other factors that affect the escalation of an emergency and therefore dictate the potential success of emergency management.

3.5.6 DESIGN

Design has played a critical part in the serious accidents that have occurred offshore. In Piper Alpha, the location of the production modules near the control room, radio room and accommodation resulted in the lack of a save haven to congregate once the incident had occurred. In addition, the exits and evacuation routes were poorly planned leading to blockages and inaccessibility of the TEMPSC's (Totally Enclosed motor-propelled survival crafts). Even on a large scale, it was known that the steel structure could not tolerate an intense and prolonged fire (Paté-cornell 1995).

Similarly, the capsize of the Alexander L. Kielland occurred due to "fatigue cracking" of a brace on one of the columns. Both the design and the use of materials were blamed for the incident (Lancaster 1996) though other design considerations promoted the escalation of the incident. Such problems included the lifeboat release and hatch design (Bellamy and Brabazon 1993).

Because of these incidents, design has become a popular focus of research in offshore emergency management - including the impact of deluge on fire and explosions (van Wingerden et al 1998), structural response to explosions (Fraser & Wilkie 1998), extended life temporary refuges (Rogers 1998) as well as evacuation routes (Bellamy & Brabazon (1993) and lifeboat design (Wilson 1991).

Given that these issues have been recognised, there is an ongoing project to develop "design performance parameters" - design standards that facilitate emergency prevention and control and can be identified at the conceptual stage. These can be identified through the collation of current ideas on "good design practice" as well as information on designs that have failed (Strutt et al 1998).

The "impact of design on risk in emergencies " obviously has closely- related objectives to this research. If particular design-features have a recognisable and measurable impact on risk, it is likely that the methods used to identify this could be applied to emergency management as required by this research.

3.5.7 RESOURCES

On a smaller scale, the equipment available on a platform must be sufficient to allow emergency management to have an impact. Resources include both human and technological resources. The earlier sections have already emphasised the importance of communications, In the Piper Alpha disaster, electrical power failed resulting in the loss of the public address system and emergency lighting (Paté-cornell 1993). Although this was in fact a design error, the lack of the public address system meant that no coordination was possible. Consequently, UKOOA (1995a p.29) recommends that communications systems should include "PA and alarm system, telephone, hand held radio, marine based radio, aeronautical band radio".

In the emergency management room, there are a number of pieces of equipment that facilitate the management process. These include white boards - some with permanently marked checklists or grids to be filled with relevant information; a board for muster information; a time log and diagrams of the installation. Temporary markers for these boards must be provided so that the information on the boards can be updated as necessary. The Emergency management procedures should be readily available. Other useful information includes manuals on hazardous materials, detailed plant description and contacts for information. A clock is considered essential so that all of the management team have access to time information and can co-ordinate their activities to the correct time. As suggested in Section 3.5.2, there are many roles to be fulfilled in the team. Apart from the emergency manager himself, there must be people assigned to the boards, the log keeping and communications. This is likely to involve some process expertise so a production supervisor is likely to be present.

UKOOA (1997a) specify particular roles and their duties in an emergency. Apart from the aforementioned emergency management team, there are also the on-scene commander and his team, offshore lifeboat coxswain, radio operator, muster checker, muster co-ordinator, helicopter landing officer, emergency helideck team control room operators, standby/rescue vessel crew, marine crew - support vessels and production/drilling crew. Even for personnel who have no specialist duties, there are training specifications as well as performance standards required.

As far as the resources outside the control centre are concerned, the main focus is on adequate fire-fighting, medical and rescue resources. The Alexander Kielland disaster illustrates problems with these resources as "7 out of 8 people could not fasten the zips on their survival suits and those that jumped into the water wearing a lifejacket were subjected to hitting their head and face due to it riding up on impact" (Bellamy & Brabazon 1993 p. 2). Flin & Slaven (1996a) add that the sick bay should fully equipped to be able to set up an infusion or treat a casualty with oxygen. Information such as this illustrates the scope of resources and their potential impact on the outcome of an emergency.

In all cases, there should be a tested plan to ensure that the resources are more than adequate for any incident. If a method can be developed that assesses the impact of emergency management on risk, there is a possibility that it can also be used to test these plans. Therefore, given that all the relevant aspects of offshore emergency management have been considered, this review will move on to looking at techniques that have been used to examine and quantify risk in the offshore industry.

SECTION 3.6: HRA, PSA AND QRA IN THE OFFSHORE INDUSTRY

3.6.1 INTRODUCTION

Most of the techniques used to assess risk in the offshore industry are those that have already been described in Section 2.4. Therefore, this section will examine risks that are evident in the offshore industry, through the collection and analysis of accident statistics, some techniques that have examined the subjective attitude to risk and finally, application of the risk assessment techniques used in the offshore industry.

3.6.2 SAFETY STATISTICS

One of the first aspects of assessing risk involves the examination of the accident statistics. These give some indication of the breadth and frequency of unsafe practices. A report from the Offshore Safety Division of the HSE gives the provisional summary of numbers of accidents and incidents from 1991-1997 in Table 3.

Table 3: Summary of Accident and Incidents in the Offshore Industry

	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97
Estimated workforce*	33,200	29,500	34,200	27,200	29,003	26,853
Total Fatalities	13#	5	1	1	5	2
Total major injuries	73	79	52	41	42	25
Combined total of major injuries and fatalities	86	84	53	42	47	27
Total over 3 day injuries	571	511	412	270	375	328
Dangerous occurrences	373	525	633	594	528	585

* - From Inland Revenue statistics for the period shown.
\# - figures include Cormorant Alpha helicopter accident.
(HSE 1997b)

Clearly, although this shows there were still a large number of injuries and dangerous occurrences in 1996/97, some slow improvement is being made. However, compared to the work hour/accident statistics in the United States, these are still disappointing (Falker & Nickerson 1996). In terms of incident type, the statistics for the year Apr 1996 - March 1997 are shown in Table 4.

Table 4: Types of Offshore Incidents between April 1996 to March 1997

Broad Incident Type	Fatal Accidents	Major Injuries	Over 3 day Injuries	Total Injuries	Dangerous occurrences	Totals
Loss of containment			1	1	238	239
Fire / Explosion			1	1	47	48
Air Transport					1	1
Sea Transport			1	1	15	16
Slips/Trips/Falls		15	110	125	2	127
Falling objects	1	1	21	23	69	92
Handling goods/materials		4	76	80	3	83
Lifting / crane operations		3	18	21	64	85
Use of hand tool			19	19	3	22
Use of machinery		1	21	22	6	28
Exposure to/contact with harmful substances			6	6	3	9
Diving related			8	8	11	19
Electrical					10	10
Structural / Foundation					4	4
Mooring					14	14
Radiation					0	0
Other	1	1	46	48	95	143
TOTAL	2	25	328	355	585	940

(HSE 1997b)

Obviously, as shown in the iceberg concept in Figure 2, it is likely that there are many more near misses that should be analysed to create a safer work environment. However, statistics such as these help to identify the tasks where safety is critical and therefore where the efforts should be focused.

Statistics can also help to identify where safe practice is providing a strong contribution. For example, statistics have been used to estimate that standby ships in the UK sector have been responsible for saving 190 lives in the last decade (Daniel & Westwood 1997) which obviously is a prominent argument why these vessels should not be replaced (Gibb 2000). Techniques that examine the impact of change on risk would be useful for strategic safety decision-making - therefore a method that can quantify the impact of intervention in an offshore emergency could indicate its positive influence - perhaps leading to more of an emphasis on the training and selection of emergency managers.

3.6.3 RISK PERCEPTION

Risk perception is the study of the subjective estimations of risk. Mearns & Flin (1995) identified many factors that directly affect risk perception in the offshore industry - including experience and job satisfaction. Further to this, Rundmo (1996) examined the changes in risk perception on Norwegian platforms in the period 1990 to 1994. This obviously reflected the feelings after the Piper Alpha disaster as well as the impact of the changes that this disaster provoked. In general, it was found that a greater percentage felt "safe" in 1994 compared to 1990. Flin, Mearns, Gordon & Fleming (1996) used a similar questionnaire in the UK sector examining risk perceptions associated with the probability of a hazardous event occurring and its respective outcome and generally found positive results. The majority of the personnel felt safe with regards to the hazards to themselves, the installation and in their working tasks. The items which provoked safe feelings in half or less than half of the population included "handling radioactive materials, completing a task started by others, being on the platform when drilling is taking place and helicopter flight". Rundmo & Sjöberg (1998) added to this with a study of the effects of bad weather on risk perception, concluding that "the specifically potentially hazardous consequences of platform movement" were the main worries.

However, most importantly, often such research has been criticised for not identifying causal relationships between risk perception and risk factors. Consequently, Fleming et al (1998) did a comparative study between QRAs and risk perception and concluded that in general, workers do have "a reasonably accurate perception of the relative risks". This indicates there is a possibility of obtaining reasonably reliable quantitative risk values from subjective techniques in this research.

3.6.4 EXAMPLES OF HRA, QRA AND PSA IN THE OFFSHORE INDUSTRY

As stated at the beginning of this section, many of the techniques described in Section 2.4 are applied in the offshore industry. For that reason, many of the examples shown within that section described how the techniques could be applied to the Piper Alpha disaster or other offshore incidents.

Carrying out a QRA is a specified requirement in the Offshore Installations (Safety Case) Regulations (1992). QRA was particularly emphasised in assessing the design of the Temporary Safe Refuge (TSR), evacuation routes and lifeboats as well as when considering fire and gas hazards, flammable gas or smoke ingress and loss of integrity. To be able to produce reasonably accurate values of risk, the technique relies on information such as hardware failure rates, human error and human response, consequence and escalation modelling as well as use of a valid QRA technique (Pape 1992, O'Donnell & Smallman 1993).

Therefore, research in modelling and quantifying the risks from explosions and escalation mechanisms proceeded: from the use of event trees (Cox & Miles 1991) to building up databases of relevant factors such as the Pipeline and Riser Loss of Containment Study PARLOC (Robertson et al 1996) and creating complex computerised models of particular aspects such as PLATO (Morris et al 1994), the Offshore Hazard and Risk Analysis (OHRA) toolkit (Ramsay et al 1994) and others (Crawley & Grant 1997). There was also research that focused on calculating the risks at the design stage (Shaw 1992, Malone 1996, Vivalda & Carpignano 1997, Trbojevic et al 1997) as well as risks that could occur during construction and installation (Trbojevic et al 1994). In general, these techniques have the same problems that are evident in all risk assessment techniques - that the results are either based on expert judgment, assumptions from singular events or that they cannot represent the full "dynamic range" of risks present in an emergency situation.

If the uncertainty in risk values is not considered, it will limit the usefulness of QRA (Pitblado 1994, Bolsover et al 1998). K Miller (1994 p.334) suggests that these inaccuracies could be critical when considering an emergency - for example in the Piper Alpha disaster "the escalations produced smoke which entered the accommodation much earlier than might have been expected. Small changes in time-scales could have reduced the number of fatalities by nearly two orders of magnitude". Therefore again, the importance of representing uncertainty and the impact of time on risk values when examining emergency situations is evident.

Using the Piper Alpha disaster as a case study, Paté-Cornell (1995) suggests the use of a dynamic risk analysis model incorporating time-contingent fire propagation and the mitigation provided by firewater pumps on an offshore platform. This model can therefore identify the most effective practical risk reduction intervention. Paté-Cornell & Murphy (1996) developed this into the System Action Management (SAM) Approach. This calculates the probability of system failure through the addition of initiating events, including those produced by human actions and decisions, which are said to be indirectly reflecting management and organisational structure. Mathematically, this uses the idea of conditional probability to represent the links between events - as used in the quantification of an event tree. As a concept, the SAM approach has a lot of potential for this research - however, it currently uses expert judgement to acquire quantitative values. Therefore a technique that provided objective quantitative values of risk for specific events could contribute to the development of this technique.

There has been very little research in the area of HRA specifically focusing on the offshore industry. Gudmestad (1996) has considered the relevant human factors in the construction, fabrication and installation stages of a platform life cycle, though this relied on the methodologies analysed in the earlier section on HRA. Kirwan (1997) made some development in the field by the initiation of a database of human error probabilities including those observed in the offshore industry. He also discussed the use of current HRA techniques in the offshore industry. He suggests that because THERP was conceived for the nuclear industry, its applicability to the less-proceduralised offshore industry may be inappropriate and that this could be rectified by using the more pessimistic values for risk. Kirwan (1997) also comments that HEART is to be adapted to the offshore industry. However, the main issues concerning the use of these techniques in this research have already been discussed in depth in Sections 2.4.4.2.1 and 2.4.4.2.2.

Bellamy & Geyer (1991 p.58) suggest that the critical human factors to be considered in a QRA on escape, evacuation and rescue are as follows:

- Available time (e.g. 30 minutes to platform collapse)
- Available courses of action (e.g. Escape alternatives)
- Response goals (e.g. Get to TSR).

They add that the fatalities would be dependent on:

- The time available
- The personnel location and manning levels
- The likelihood of installation/emergency control/rescue personnel carrying out appropriate actions in time, including recognition, communication and decision making
- Performance shaping factors (design characteristic, procedures, weather conditions etc.)

Therefore they suggest that modelling should reflect time-contingence rather than being restricted by the rigidity of "risk at a fixed time point" approach. Therefore, this should consider:

- Whether appropriate actions occur in time to avoid the threat (e.g. whether the platform is evacuated before structural collapse)
- Whether these actions are successful, given the inherently hazardous nature of certain of them (e.g. lifeboat evacuation, jumping into the sea) - The hazards associated with certain actions will also vary, dependent upon factors such as weather and the capacities of personnel to meet action demands (e.g. problems in gripping ladders when wearing survival suits).

(All from Bellamy & Geyer 1991).

These concepts have great potential when examining the objectives of this research. Focusing on the outcome provides the technique with an objective measure of performance - which may be quantified when considering the degree of success or time margin involved. However, this is only at the conceptual stage and the practical issues in developing such a model will be discussed in later chapters.

3.7: CONCLUSION

Therefore, this chapter further illustrates the issues as described at the end of the previous chapter with particular regard to the offshore industry. This chapter has discussed the legislation in place in the offshore industry and the emergencies that have impacted upon it; then the issue of emergency management and how it is identified, trained and assessed. Finally, this chapter has discussed the risk and reliability techniques used in the offshore industry. Despite the obvious need to assess the competency of emergency managers in an offshore incident, it is apparent that there is not yet an established technique of predicting the impact of emergency management on risk in an offshore situation. As emphasised in the previous chapter, it is the impact on the physical emergency that is important and therefore, it is this that should be used as a basis. Furthermore, as it is the "dedicated simulation" type of assessment that is recommended to establish emergency management competency in the industry, these should be available for research use. Therefore, this should give some indication of the emergency management behaviour performed in an emergency – and thus provide indications of the timing spent in making emergency management decisions and actions. Together with timings recorded in real simulations, these can be used to predict the probability of success (using the time available / time required concept described Section 2.4.4.2.8) – therefore producing the probability of success in emergency management tasks and therefore assessing the impact of emergency management on (physical) risk. Therefore this thesis will now move on to the method – initially by describing the arrangements of the scenarios that were available for research use.

Chapter 4

RESEARCH METHODOLOGY

SECTION 4.1: INTRODUCTION

This chapter outlines the rationale for the research, the initial assumptions made and the research methodology that was adopted to progress the research and then illustrates the scenario arrangements that were available for the research.

The first half of this chapter will focus on how and why the research was carried out in this way, including the decisions that were taken – the second half will focus on the fixed aspects of the research – the scenario arrangements that were provided for data collection by the companies involved.

The next section starts with the research rationale and assumptions associated with it. Following this, Section 4.3 will define the overall research objective – then the 4 objectives that were derived from this and the methodology chosen to approach these objectives. Section 4.4 will introduce the scenario arrangements.
Section 4.5 describes the specific offshore platform that was used in the scenarios. Sections 4.6 and 4.7 describe the layout of the rooms involved in the scenarios and the equipment available in the simulation. Section 4.8 describes the personnel roles involved. Section 4.9 describes the content of the scenarios used for data capture in this research.
Finally, Section 4.10 concludes the chapter.

SECTION 4.2: RESEARCH RATIONALE AND ASSUMPTIONS

It had been decided from the beginning to focus the research on Emergency Management and its relationship with risk. The reason for this was twofold.

Firstly, it was considered to be an important field of research through which the Cranfield Reliability Engineering Risk Management Group could achieve one of its core mission objectives, namely to provide research in support of the offshore oil and gas industry. The need for more effective emergency management had clearly been called for in the Cullen Report (1990) and the "Safety Case" Regulations (1993). Since then, all Offshore Installation Managers (OIMs) have been required to undergo emergency management competency assessments. The need for research to progress the development of tools to assess the impact of Emergency Management on risk reduction was of particular significance to the "Safety Case" Regulations. In these Regulations, it is essential that the Duty Holder can demonstrate that the installation design and its safety management system (which includes Emergency Management) is such that risk of a major accident has been reduced to a level which is as low as reasonably practicable (ALARP). This research and the use of the Task Performance Resource Constraint

(TPRC) model or similar type of technique had the potential to facilitate decision makers in this task.

Secondly, the research was considered relevant and necessary. Prior research in this area had largely been qualitative in nature and although there had been academic research and joint industry work on understanding the effectiveness of emergency management decision making and competence (OPITO 1992, Flin et al 1996), the tools for quantifying the impact of emergency management performance on risk reduction were very limited. Research was considered necessary to address this deficiency.

The TPRC model had been developed in a previous research study (Loa et al 1996). It had, as its basis, the idea that task success is time dependent – a concept that is even more evident in an emergency management context. The TPRC model provided a means of linking the probability of task success to uncertainty in both the time required to perform one or more tasks and the time available to perform the tasks. The core code for TPRC had already been developed and written to some extent. This core code was taken as "given" and available as a starting point for the research.

Whilst it was recognised that further development of TPRC would probably be needed at some stage, especially once data collection was in progress, it was never intended that the research would focus on mathematical model development, although it was clearly recognised that any data developed in the research programme could provide a very important input to future model development. The research therefore was focused on developing data to support future model development and how the model might be used in practice in an emergency management context and led to the following definition of research objectives.

SECTION 4.3: OVERALL RESEARCH OBJECTIVE AND METHODOLOGY

It was decided that the overall goal for the research would be to evaluate the TPRC model as a tool for assessing the impact of emergency management performance on risk reduction.

Given that this was the overall aim, in developing the research methodology, it was very important to first identify where the data would come from. It was not ethical to study this topic in set-up emergencies and not practicable to study this topic based solely on reports of real emergencies. Whilst the information for Piper Alpha was sufficiently detailed and available for use, it was considered important that the methodology should be able to cater for all the main emergency types that may occur – therefore, limiting the data to this one source during model and method development may have resulted in complications if it was necessary to broaden the scope at a later point.

Therefore, there were two possible alternatives considered, namely; desktop studies and simulated emergency scenarios. Although some effort was initially expended on developing a desktop model, it was obvious that the best that could be done was to use simulated emergencies – particularly in terms of the extrapolation of the data to real situations. Therefore, the bulk of the research effort has focused on the observations of full-scale simulations during emergency management training exercises and this is largely what is reported in the thesis.

Therefore, assuming that the main source of data would be from simulations, the first two objectives defined in working towards the overall goal were focused on extracting data from the scenarios and, using these data, obtain some objective and quantitative indication of success for the emergency management tasks. There were stated as follows:

1. To develop a method of obtaining objective data on management performance from emergency scenarios

2. To develop a methodology to use these data to assess the probability of success in emergency management tasks.

As described in the sections to follow, it was only once these had been achieved that it was realised that, to identify the significance of the results, it would be necessary to examine the impact of change in the parameters on the overall probability of success - thereby showing the IMPACT of emergency management on risk reduction. The completion of Objective 2 gave quantitative values – but without comparison with, for example, the probability of success in the absence of emergency management, these values can not be fully interpreted. Therefore, following the work on Objectives 1 and 2, Objective 3 was defined as follows:

3. To demonstrate how these methods can be used to evaluate the impact of changes in emergency management skill and design on risk values.

The work on Objective 3 also provided some face validity in support of the method used and the application of the TPRC model to this problem. However, at this point, whilst changes in the parameters obtained from theoretical data (platform sizes, distances of platform from shore, survival time of casualty in water) could be applied according to externally defined equations, at this point there were no "rules" available to speculate on the changes in emergency management performance. The main contribution of management performance in the TPRC model was to the "initial delay" parameter. Therefore, being that the emergency simulation data were available for any sort of analysis, it was speculated that they could be "decomposed" into "unit management tasks", then built to model the performance of an emergency management team (and its impact on the delay parameter) for generic emergency situations. This concept gave rise to objective 4, defined as follows:

4. To use the above methodology and data to define performance parameters that can be applied to evaluate generic emergency situations.

Together these four objectives were intended to provide a "complete" method for the evaluation of the impact of risk reduction – allowing a user to collect information from scenarios and supporting theoretical data to produce an analysis of the impact of the emergency management on risk in specific circumstances. Where necessary, this model could also be used in the absence of scenario data to test the extent to which emergency management could reduce risk with particular design criteria.

This section has described, in brief, how the objectives arose in response to the needs identified within the research and thus, why the decisions to work on these were made. How each of these objectives were addressed in the research process will be discussed in more detail in the sections to follow.

4.3.1: RESEARCH GOAL 1: DEVELOP A METHOD OF OBTAINING OBJECTIVE DATA ON MANAGEMENT PERFORMANCE FROM EMERGENCY SCENARIOS

The first step in this was to identify sites where Emergency Management simulations could be observed and data could be extracted. This was actually achieved by developing a link with and then working collaboratively with an Emergency Management training provider, OCTO. Immediately prior to and during the project, OCTO had been working with a number of companies, providing training and performing competency assessments.

These scenarios were essentially the practical examination following a taught course on emergency management skills. An overall pass in the scenarios results in the candidate and his team being judged as "Competent" or "Highly competent" to manage emergencies. A marginal fail (known as "Notable Shortfalls") would result in further training and another examination in the future. If passed as competent, it was likely that the candidate would be given more responsibility in their day-to-day work as well as adopting the position of emergency manager should an incident arise. The assurance that individuals are capable of fulfilling this role was seen as critical. Therefore to obtain a valid assessment, it was essential that the scenarios were carefully planned to ensure testing of the relevant skills and that each test was as realistic as possible.

Through an agreement with OCTO and the companies working with them, an arrangement was made whereby the author could observe scenarios, the Emergency Management task sequences and "behind the scenes" scenario developments and assessments. (For commercial reasons, the names of the company and the installations on which the training was performed and the names of the trainees cannot be reported.) Once the opportunity to observe training exercises had been established, the next step was to develop a method for data collection, recording and analysis. It is important to point out here, that the author was only an observer and had no control over the actual scenarios or the progress of the scenarios. Therefore, the method had to be pre-designed to be flexible enough to cater for any scenario situation – in terms of the content, environment and personnel involved. However, a method of data gathering, recording and analysis was developed and this is described below – within the context of OCTO's scenario procedure. This procedure was used for all of the scenarios used in this research.

4.3.1.1 Pre-Scenario Procedure

Prior to the scenarios, the scenario organiser spent time – usually at the installation itself – collecting information to make sure that the scenarios were both testing and accurate. At this stage, whilst the author was invited to attend this development work, it was not clear how the research would unfold and therefore the information that should be collected could not be defined formally as a procedure – but it seemed the best plan to gain awareness of what information was relevant in the development of scenarios and therefore to take <u>any</u> opportunity to capture information relevant to hazards, risk (particularly QRA information), emergency procedures, evacuation routes, training and installation statistics. The relevant documents were copied for future reference, where permitted by the company involved.

However, as the overall method had to be flexible enough to cater for an observer inexperienced with the simulation and/or assessment process to collect information from the scenarios, it was important that this pre-scenario data capture process would not affect the quality of the eventual results. Therefore, it was required that the method should be designed so that all the data required outside of the scenario could be identified and obtained post-hoc. Therefore, to allow this, it must be assumed that the scenario organiser was experienced and competent in his role. Once the author gained more experience in this role, it was realised that whilst the information (outside of the video-recorded scenarios) required for the TPRC analysis could be obtained post-hoc, it was easier to obtain much of this during this development stage – as the installation personnel were focussed on providing such information for the scenario organiser. This could also assist the scenario organiser in their work by contributing valuable numerical (for example, timing) data to be integrated into their scenario. Overall, the type of data that was usually seen as useful for the post-hoc analysis included :

For the offshore scenarios:-

- Distances on the platform (from a platform map including all floors) – particularly walking distances from muster points to evacuation points and "furthest point" to muster points, medical bay to evacuation site/ helicopter pad.
- Expected muster times
- Expected shutdown / blowdown times for individual and whole system(s)
- Expected rescue helicopter travel duration
- Source of rescue helicopters (distances from platform)
- Expected crew-change helicopter travel times
- Source of crew-change helicopter (distance from platform)
- Likely hazards – location of hazards and travel distance from them to medical bay / muster point and evacuation points
- Duration of availability of personal rescue equipment (fire extinguishers / breathing apparatus)

For the onshore scenarios:-

- Distances on the platform (from a platform map including all floors) – particularly walking distances from muster points to evacuation points and "furthest point" to muster points, medical bay to exit/entrance.

- Expected muster times
- Expected shutdown / blowdown times for individual and whole system(s)
- Expected emergency service travel times (distances and allowable speeds)
- Likely hazards – location of hazards and travel distance from them to medical bay / muster point and evacuation points
- Duration of availability of personal rescue equipment (fire extinguishers / breathing apparatus)

On the day of the scenario, the scenario organiser gave the brief (example in Appendix 3) to those concerned, i.e., the scenario organisation team, the observer and, if he required it - the assessor. Care was taken to ensure that this information was kept from the emergency management team. Once all the relevant personnel were present and in their specified place, the scenario organiser briefed the emergency management team on the status of the platform, as specified in the plan. This brief included weather conditions; hot work, cold work, lifting or diving operations that were ongoing; time of day and any other relevant information. This information may have given the emergency management team some clue to the problems that were involved. However, it was sometimes irrelevant and used to draw the team away from the main issues. Following this brief, the teams settled into their normal roles. Members of the emergency management team who were not usually present in the control room were asked to leave the emergency management room for the start of the scenario.

It should be noted that as these scenarios took place in rooms within an office environment (i.e. onshore), occasionally there were interruptions of a non-scenario nature. For example, fire engines and ambulances passed outside and prevented the team from hearing radio messages. Other interruptions from within the organisation were rare but occasionally included people wandering in accidentally or phone calls from people who were unaware that the scenario was taking place. If this had provided a major disruption, it was agreed that the exercise would be stopped, either temporarily to re-organise or permanently. Fortunately, no major disruptions occurred within this set of simulations.

Initially within the research, OCTO were hoping that the scenario data required for the research would rely mainly on the subjective recording and assessment technique used by the assessors. However, the author persuaded them that the data required for a quantitative and probabilistic technique should be based on data that are as objective as possible – and to a level of detail that could not reasonably be recorded by someone observing and recording the scenario as it happened. Therefore, once this was realised, OCTO persuaded their client companies to agree to video-recording of their scenarios – with the agreement that this information would be anonymous and used only within the context of this research. Therefore, once this was agreed, prior to each scenario, the author set up the video camera in the test environment to record all the actions of the emergency management team from when the scenario began. Together with the collection of the scenario organiser's brief, this was the initial task that addressed the objective of obtaining data from the scenarios.

4.3.1.2 Scenario Procedure

Once the teams had been briefed and the emergency management team had settled into their normal (i.e. non-emergency) roles, the scenario would start. This either started with the occurrence of an immediate incident (e.g. a helicopter crash) or a small problem that escalated (maintenance required on a pipe which leaks and injures the technician who tries to fix it). Once a state of emergency existed, it was usual for the control room operator or the production supervisor to call a muster, which would bring the rest of the emergency management team into the room. The team then attempted to manage the emergency by imagining the normal resources that they had available and communicating their orders to the scenario organisation team. To the emergency management team, this was treated like a real emergency. They had to consider the resources available and all the possible risks to personnel. They also had to give clear communications to the on-scene commanders (played by the field supervisor and the scenario organisation team) and respond quickly to incoming information about the emergency.

The scenario organisation team received the communications of the emergency management team and then discussed the practicality and the validity of the decisions made. To them, this was more of a real-time tabletop exercise, analysing how the emergency would progress if they really did carry out the orders of the emergency management team. Poor decisions by the emergency management team were either rejected by the scenario organisation team or were carried out resulting in failure. However, this had to be communicated to the emergency management team in a realistic way; for example, workers refusing to go into a certain area because of the smoke. The scenario organisation team were essentially able to "play God" in that they could allow all, some or none of the emergency management team's suggestions to succeed.

The scenario organisation team attempted to follow the plan specified in the brief. Obviously, the interventions of the emergency management team may have an impact on the plan so post-hoc changes were sometimes made. Therefore, the planned event timings were not always accurate. Scenarios generally lasted about 30 minutes and could end even if the situation had not been brought back to normality. The ending was normally preceded by a short discussion between the scenario organiser and the assessor. If the assessor was satisfied that he had seen enough to make an assessment, the scenario organiser could then end the scenario. At this point, all communications were stopped and the emergency management team could relax.

During this, the author would use the video camera to record all the activities of the emergency management team – focussing on the conversations taking place, the control panels used and the contributions written on the white-boards. This would attempt to record the essence of the scenario for post-hoc analysis.

4.3.1.3 Post-Scenario Procedure

The normal post-scenario procedure would involve the assessors discussing the performance of the emergency management candidate and his team. At the same time, the candidate and his team were given the opportunity to discuss what they think happened and how they had dealt with it. After this, the candidate had a debriefing from the examiners in which he was informed of the real "big picture" and given an indication of his performance. Often, he was asked to justify why he made particular decisions. Any actions, which the assessors believed should have been carried out but were not, were discussed and, if necessary, justified by the emergency management candidate. Following this, the candidate updated his team on the results of the debriefing. This would include any feedback on how their emergency management performance could be improved.

For the first set of scenarios attended by the author, it was not possible to influence any change to this stage of the process and as there was often no structure to the decision and sometimes not even a unanimous opinion on the result, it was difficult to incorporate this into the scientific process. For example, often the conclusions recorded only represented the subjective opinion of the assessors and were sometimes in contradiction to what the emergency management candidate believed was possible on his installation.

As this subjectivity could not necessarily be linked to the "objective" risk that the research was looking for, the decision was made not to record the outcome as a precise indication of competency until the method could be adjusted to allow the recording of both assessors and candidate's views. Therefore, at this point, the author's role in this process was to gain information to clarify the links between the hazards revealed to the emergency management team and their responses to them – their actions and the risks they were intending to prevent or mitigate. This was done using the structure of the TPRC model as a guide, as will be described in the next section.

However, these subjective opinions may have had some link with the impact of emergency management on risk reduction, and it was decided that where possible, this information should be recorded also. Therefore, later in the research, in some of the onshore scenarios, it was possible to formalise this data-collection process by allowing the distribution of questionnaires by the author (As shown in Appendix 9). These questionnaires were designed to capture the opinions of the main assessor and the emergency management candidate - in terms of their opinions on decision quality, timeliness and whether the team responded in the desired way. Also, they were asked to given an indication of the overall level of competency displayed. This would immediate follow the simulation; therefore the discussions between the assessors and emergency management team would follow the completion of the questionnaires.

Further details on how the scenarios were laid out – in terms of environment, equipment and personnel is described in Sections 4.4 to 4.8.

4.3.1.4 Presentation of Scenario Data

To successfully achieve the goal as defined in objective 1, it was necessary to process the data in a form in which they could easily be used to evaluate management performance. Whilst the video-recording (plus the later addition of questionnaires) formed the bulk of the data collection process for management performance, it was considered best to produce this as a transcript of the whole scenario to facilitate further analysis. This would allow quick reference from point to point in the scenarios, comparison across scenarios and easy identification of the times taken to carry out tasks, conversation or delays. Therefore the video of each scenario was observed together with a timing device (in this case, incorporated into the video). The scenario transcript was started at the point the video recording started and was given a start point of 0 min 00 seconds – often also the point at which the initiating event of the emergency took place. Sometimes, there was a short period of "non-emergency" activity that was also recorded in the transcript. From the 0.00 point onwards, every activity was recorded on the transcript with respect to person involved and time.

In the case of events that were instant or of equal to or less than 1 second's duration (for example, a loud crash or a controller pressing a button) – these were recorded as point timings. For events of 2 seconds or longer – the start and finish of the event were recorded separately according to the times at which they occurred. If this was a spoken instruction or response – the content was recorded in the space next to where the start of the event was recorded. Therefore if there were a number of conversations taking place at the same time, the start and finish of each person's contribution would be recorded individually as well as the delays between, for example, a question and a response.

For each event recorded, if there was a person associated with it, their name or role (initials) was entered on the transcript. Where the events occurred outside of the control room (and therefore their timing could not be established by the author – or the emergency management team), these timing were noted post-hoc at an appropriate time based on their nature. For example, if the content of the scenario indicates that an event has just happened, it could be inserted just before the relevant information was received. If an event could have happened at any point between two "known" times, then it was inserted directly in the middle of these two timings. Such events are easily identifiable as they are shown in capital letters in the transcript starting with the word "ASSUME". When the TPRC model was used including these events, the uncertainty in the timing of the event was broadened to reflect this degree of uncertainty. Further details are described in Section 5.4 and a full example of such a transcript is shown in Appendix 6.

Whilst only the development of the method was necessary to fulfil Objective 1, it should be noted that within this research, the data collection method was tested on 14 scenarios – 5 offshore and 9 onshore. The content of these are described in Section 4.9. One such transcript is shown in Appendix 6.

At this stage, the data collected were not yet sufficient to provide all of the data required to apply the TPRC model. As management performance data were not the only information required, the methodology used for the collection of additional data is covered within the next section.

4.3.2: RESEARCH GOAL 2: DEVELOP A METHODOLOGY TO USE THESE DATA TO ASSESS THE PROBABILITY OF SUCCESS IN EMERGENCY MANAGEMENT TASKS.

At this stage in the process, there was, at least, the following information available for further analysis:-

- The video of the scenarios
- The transcripts from the scenarios – produced from the videos
- Some information that was used to design the scenario – including the brief from the scenario organiser.

There could also be additional information on the hazards, emergency management actions and the relevant physical data - plant layout, available mitigation resources collected during the scenario design process – though this was not compulsory prior to this stage.

To fulfil Objective 2, it was now necessary to use this information to assess the probability of success in emergency tasks. The intent behind this objective was to extract data from the scenarios that were linked with success or failure in an emergency management task and could be applied within a model to give quantitative values for the probability of this success or failure. After attempts at purpose-building simplified models from scratch (as used in the pilot study shown in Appendix 2), it was decided that it would be more time-efficient to adapt the more advanced Task Performance Resource Constraint model to cater for emergency management data as it incorporated attributes that deemed it an ideal structure – particularly the incorporation of variance and the use of "real" time as well as giving the output of "probability of success/failure" with respect to time. Therefore, the TPRC model was adapted where necessary, as described in Chapter 5, and this structure was used to identify the data required.

Based on the structure of this model, in any situation, there are tasks and resources. In the terms of emergency management, these would be "attempts at management of the situation" and corresponding "events at which the attempts would be deemed futile or would be considered a failure".

Therefore, the process to successfully meet this objective involved going through the scenario and identifying all the relevant tasks and resource constraints, linking them and identifying the relevant numerical values, then finally applying them in the model - as described in the sections to follow. To achieve a full picture of the performance of an emergency manager, it would be necessary to look at all the task/resource constraint results carried out within a scenario. One observed phenomenon in "poor performances" by emergency managers was a focus on only one aspect of the emergency – therefore if this happened to be the task/resource constraint result analysed, it should show excellent results in terms of the probability of success in this task – but would not be a good indication of the performance.

4.3.2.1 Identifying the Tasks

These tasks included any actions taken by the emergency management team (whether these actions are carried out inside the control room or outside in the "real" emergency) that changed (or aimed to change) the physical characteristics of the situation. These may have been sending teams to different places, attempting rescue, activating fire control, isolating gas pipes, activating alarms – anything that could change the behaviour of people involved or physical systems. Within the scenario, they may have been considered (post-hoc) to be correct or wrong decisions; they may have succeeded or failed, they may even have been carried out by the "scenario organisation team" without the control of the emergency management team. These are all relevant and all tasks must be noted. It is helpful to list these and identify the place (or places) in the transcript where the tasks were discussed, ordered, initiated or completed. A concept that was recognised within this part of the research was the pattern of how these emergency management teams responded to events – namely Situational Awareness (of an event), Decision, Communication, Action and (system) Response. This was duly named SADCAR. Within the context of this research, the time taken for the "SADC" parts defined the delay from an event to the initiation of the physical action in response to the event. To test this part of the research, this was carried out to identify all the tasks in all 14 scenarios.

4.3.2.2 Identifying the Resource Constraints

Following the identification of the tasks, it was then necessary to identify the resource constraints. These were points in the emergency that limited the activities of the workforce – defining the situation as an emergency. These were usually also escalation points. For example, ignition of fire, explosions, helicopter crashes, injuries to personnel, blocking of routes, impingement of fire on more systems, death of personnel.
Often these could be linked to tasks – as the event(s) that could have changed the goals of the emergency management team.

Again it was helpful to list the resource constraints and where possible, identify the place (or places) in the transcript where they occurred – or if not realised, expected to occur had certain tasks not been successful, or, at points in time after the scenario was completed. To test this part of the research, this was carried out to identify the resource constraints in all 14 scenarios.

4.3.2.3 Linking the Task and Resource Constraint

Given that the lists of both tasks and resource constraints had been completed for the whole scenario, it would now be necessary to link them in content in accordance with the structure of the Task Performance Resource Constraint model. This had probably already been done in an informal way – but at this stage, it would be necessary to identify, for each task :-

- Which escalation event motivated the initiation of the task? (A)
- What goals was this task aiming to fulfil? (B)

- Which escalation point(s) – observed or possible – would signify a partial or total failure in this specific task? (C)

This could be described as:
Given that (A) has occurred, what is the probability of success in completing (B), when the occurrence of (C) would result in certain failure.

Notably, there may be more than one resource constraint for each task – where it would be desirable to succeed in the task before one resource constraint but another resource constraint would define ultimate failure in the task. In some cases, these may not materialise within the scenario – hence indicating success in the task – however, they may often be imagined as the event that the tasks were aiming to prevent.

For example,
Task: Attempting rescue of trapped workers
Resource Constraints: Injury to workers from smoke inhalation / Injury to workers from fire / Death of workers.
These resource constraints may be separated over time in the scenario and when applied in the TPRC model usually produced an increase in probability of success in the rescue task as each subsequent resource constraint was applied. Whilst it is most desirable to rescue the workers before they are injured in any way (As this complicates the rescue task as well as requiring additional "medical treatment tasks" afterwards), one would not expect to abandon the rescue task if this resource constraint limit was reached. If this was the case, then there would be no further progress in the rescue task and probability of success of rescue before the death of workers would tend towards 0.

Some resource constraint points may apply to a number of tasks. For example, a large escalation – such as an explosion of a system causing multiple fires, blocking of routes and injuries to people will change the goals (and actions taken) of the emergency management team. It makes certain tasks redundant - including the focus of cooling on a particular system and mustering people along this route. It is likely to lead to the initiation of new tasks that are intended to be completed before certain other escalations occur. Naturally, an ultimate resource constraint point would be the " collapse of platform" – if expected by the emergency management team, the goal would be to get the platform personnel evacuated before this happened. To test this part of the methodology, this process was carried out in combination with the process described in the section to follow.

4.3.2.4 Applying the Information in the Model

Given that the important events had been identified, it was now necessary to put them together in the TPRC model. Therefore, for each grouping, some of the following information should have been calculable from the scenario:-

- When in the scenario did the initiating escalation point (A) occur?
- How long did it take before the emergency management team became aware of this event?
- How long did it take to decide on this task in response to the event and communicate this decision to the relevant people / system?

- How long did it take to initiate the physical response?
- How fast is the task carried out and how much "work" must be done to succeed in the task? OR How long should it take to complete the task?
- When should the limiting "resource constraint" point (C) occur?
- When did the process leading to this point initiate? (eg. if an impingement, when did the original ignition occur; if an ignition, when did the fuel leak occur?) This initiation point is often the same as point A.

Some of these time points could be clearly defined – others could only be identified as being between two other points within the scenario – and it was in these cases that the application of the variance must be applied accordingly.
Using the basic graphs for the TPRC model, each of the parameters described in 5.4 (of which examples are shown in Section 5.5) should be available. These include:-

- Delays in initiation of the task (D)
- Speed of the task (a)
- Frequency of changes in task progress speed (Δt)
- Task performance required (W)
- Resources (Time) available to complete the task (X)
- Resource consumption rate (r)

For each of these, there should be a mean and x, the coefficient of variation (σ/μ).

Notably, it was at this stage that it was realised that whilst the scenario was adequate for a subjective assessment of the competency of emergency management (thereby providing an informal and subjective technique of assessing the impact of the emergency management on risk), not all the data required for a TPRC analysis was available therein. Therefore, theoretical information needed to be collected to support the analysis. Some of this information was fortunately collected during the scenario development phase – and any additional information could be collected from the platform personnel as well as from research literature, as appropriate. For example, it may be assumed that the shutdown of a system would take 20 minutes, or a person would be severely injured or dead after being exposed to the cold water for 3 minutes, but if it had not been recorded in the scenario, it would need to be identified from other sources for the model to be used. Whilst this was not defined as an objective in its own right, this research also aimed to collect and record a large amount of such data for future use of the model – particularly where data were commonly applicable to many scenarios. The collection of non-scenario data would reduce the reliance on the TPRC user to collect this either before or after each set of scenarios and could eventually result in the self-sufficiency of the TPRC method. This information included injury data, fire escalation data and the abilities of the rescue personnel. These data are recorded in Chapter 6.

Once all the information was described in terms of the structure of the model – including mean and variance for each value, these numerical values were applied in the model program and the output of probability of success with respect to time was obtained. The development of this methodology fulfilled the requirements for Objective 2.

As this was more intensive than the previous tasks within the methodology, this was carried out on task/resource constraint combinations chosen at random from the 14 scenarios. In total, this process was carried out for more than 60 task/resource constraint measurements. 8 examples are shown within this thesis in Chapter 8. 3 examples from Offshore scenario 2 are shown in Strutt et al (1997) and 23 examples from Offshore scenario 1 are shown in Lyons et al (1998) – both shown in Appendix 12. Chapter 8 also shows how the methodology to address Objective 2 could be carried out on real data – with 3 examples of original data from the Piper Alpha disaster. For comparison, the main crane driver scenario was assessed using two other techniques of QRA and HRA – namely HAZAN and HEART to exhibit the differences between the TPRC model and the other methods. This included a demonstration of the factors considered, the results obtained and how the results from the methods could be combined or the applicability of the data for further analysis.

4.3.3: RESEARCH GOAL 3: DEMONSTRATE HOW THESE METHODS CAN BE USED TO EVALUATE THE IMPACT OF CHANGES IN EMERGENCY MANAGEMENT SKILL AND DESIGN ON RISK VALUES.

The technique developed to address Objective 2 produced a probability of success function linked to time as required. However, this function represents only the situation that was observed in the scenario. Therefore, as this indicated the probability that this situation arose, it really represented the fortune / misfortunate of the emergency management team – not necessarily the impact of their actions on the situation. Therefore, whilst this successfully addressed Objective 2, the output did not fulfil the overall research objective as it did not indicate whether this probability of success was good or bad based on the situation presented. Therefore, it was considered necessary to compare the probability of success obtained in the scenario with those of other possible emergency management performances to identify the impact this team had on probability of success and risk. To define the impact, these should ideally include data based on the total absence of any emergency management and the actions of the "perfect" emergency management team

Already at this stage, it was observed that one of the limitations to emergency management success was often design. In reality, as well as in simulations, some emergencies ARE essentially unmanageable based on the restrictions placed on the emergency management team by the design – if the emergency management team could only make a small impact on risk reduction compared to the impact of design changes – then this indicates where the emphasis (and perhaps, industrial investment) should be placed. As design was always a fixed parameter within the scenarios and no emergency management mitigation could change this, it was also reasonable to test the impact of change in design on probability of success.

These two issues gave rise to Objective 3, which was stated as follows:-

To demonstrate how these methods can be used to evaluate the impact of changes in emergency management skill and design on risk values.

Therefore, to fulfil this objective, it was first considered necessary to examine which parameters within the TPRC model that were affected by emergency management and design.

Following this, it was necessary to examine each individual partnership of task and resource (as carried out for the observed task in Sections 4.3.2.3 and 4.3.2.4) and speculate on the values for these parameters representing the best and worst possible emergency management performances and/or best and worst design descriptions in terms of this specific situation.

Completion of these two tasks would give two benchmarks (best and worst) on which the observed performance within the scenario could be assessed, thereby giving an indication of how effective this emergency management team working with this design could be in reducing the risk associated with emergencies. Comparison between the observed values and the two benchmarks indicates how the impact of change on design and/or emergency management performance would affect probability of success – hence risk. If successful, this process would fulfil Objective 3.

In observing the scenarios and doing the post-hoc TPRC analysis, the main impact of the emergency management team in terms of parameter variables was observed as firstly, whether they made a good decision and, secondly, the extent of the delay in starting the physical management task. With great foresight, the delay could reasonably be shortened to start before the risk had manifested itself – therefore tending towards zero. Therefore, as a first attempt, it was decided that the benchmark of optimal emergency management could be defined as good decisions made with "zero delay" – and this could be applied as such in the model. In the reverse situation, poor emergency management could be seen as a poor decision, an absence of any decision or a good decision but made with maximal delay – almost certainly leading to failure in the time-dependent task. When applied in the model, where the results obtained from the observed scenario would fall between these two functions would give an indication of the impact of the observed emergency management on risk reduction. Therefore, in the model, ideal was defined as "0 delay" and poor was defined as "delay in excess of resource constraint limit". For comparison, the probability of success functions were displayed on the same graph as the original scenario data.

Similarly, the impact of design was most often observed as influencing the "task to be carried out" (for example, a distance for a rescue team to cover) and the "resource constraint" (for example, the time before fire was allowed to impinge on another system). Depending on the situation, this could also influence the task speed (for example, a change in the pressure of water used in a deluge system). Again, for each situation, speculations on the extent to which design could be changed could be applied in the model parameters to test the impact of design on risk reduction. Unlike the definition of optimal emergency management shown in the previous paragraph, there was no corresponding definition of optimal design. In theory, the design could be optimised for emergency risk reduction to an unlimited degree for each task / resource pairing – where deluge water is maximised – rescue distance is minimised or the distance between hazardous systems is maximised. Notably, the latter two parameters could be linked in opposition – where a rescue must take place before fire impinges from one system to another. The ideal for rescue distance would be short but the ideal distance for impingement would be long – depending on the speed of rescue compared with the "speed of impingement". In this case, possible distances between the features in the scenario could be "tested" using the TPRC model to identify which design results in the maximum probability of success for this specific scenario. Where realistic design data were available from published sources or on the advisement of designers, these were applied in the model. Like the emergency management data, the results from the speculative or theoretical designs could be compared with those from the observed scenario to identify what impact a change in design would have on risk.

The development of this method was deemed to have successfully fulfilled Objective 3. This was tested for more than 17 original task/resource combinations (used to fulfil objective 2), in particular, examining changes in the delay, speed of task, task to be completed and resource constraint parameters – in terms of both mean and/or variance. This produced more than 90 Probability of success results. 4 changes in the data for Offshore Scenario 2 are shown in Chapter 8. Also one change in the resource constraints parameter is shown for the Piper Alpha example. In combination with the performance parameter data, 14 examples of how the TPRC model can show the impact of change are also shown in Chapter 9. 10 examples of change in the parameters are shown in Strutt et al (1997), 21 examples of change are shown in Lyons et al (1998) both shown in Appendix 12.

4.3.4: RESEARCH GOAL 4: USE THE ABOVE METHODOLOGY AND DATA TO DEFINE PERFORMANCE PARAMETERS THAT CAN BE APPLIED TO EVALUATE GENERIC EMERGENCY SITUATIONS.

Whilst carrying out the work in fulfilling Objective 3, it was most notable that the parameters defining "best" and "worst" emergency management were primarily theoretical and only speculative – not based on observation of real emergency management teams. Therefore, whilst the observed emergency management teams were being compared with theoretical "best" and "worst" performance in each situation, it was not known how realistic these benchmarks were. As identified whilst working on Objective 3, the main impact of the emergency management team was on the quality and timeliness of the decisions – which, in terms of the model was measured as the presence or absence of a good decision and the delay in starting the physical mitigating action. From some of the onshore scenarios, the subjectively-judged quality of the team's performance was also recorded.

Putting all this information together, it was considered that it should be possible to establish more realistic definitions for best and worst performance in each situation – and identify whether this corresponded to the subjective assessments. This could be done by working out the "best" and "worst" delay that was likely to occur in this situation. This led to the decision to reconsider the scenarios as an additional source of data. It had been observed that many emergency management actions occurred in response to most emergencies – for example, to start a muster. Also, from the theoretical data, there were a number of mathematical models considering how long a muster would take – based on, for example, predictions of how people move and how fast. However, despite the data available in scenarios, there were no models to predict how long it would take to order a muster. Therefore, it seemed reasonable to obtain rules or structures for the behaviour of the emergency management team. This led to the development of Objective 4, stated as follows:-

4. To use the above methodology and data to define performance parameters that can be applied to evaluate generic emergency situations.

Given that the TPRC model could already show the impact of emergency management on risk – including the impact of theoretical changes in emergency management and design performance, fulfilling Objective 4 could allow the TPRC model to be almost self-sufficient in terms of data collection. If a set of "theoretical emergency management data" was available in the way that other theoretical data were applied in this research, then designs could be tested without relying on the input from scenarios.

To fulfil this objective, it was considered that the best technique would involve bringing together the methodologies defined to fulfil Objectives 1, 2 and 3. In this case, the data collected to fulfil Objective 1 could be re-analysed and collected together to identify and define performance parameters. The scope of these performance parameters could be from "very specific" to "very generic" – to allow a "perfect match" to be made where the desired analysis was identical to one observed in a previous scenario, or, to allow a level of behavioural decomposition based on individual parts of the SADCAR concept, where a novel situation could be built from "unit management tasks" to give a good representation of how long this novel task would take.

Once identified and defined, every incidence of each performance parameter could be recorded in terms of its duration. From the 14 scenarios recorded in this study, some (particularly the most generic) parameters would be observed occurring many times – therefore allowing a distribution of values to be obtained. It was hoped that these, in particular, might show differences between the small amount of non-emergency situation data and the emergency situation data – between the offshore and onshore team – and between those scenarios judged as being managed "highly competently", "competently" or "with notable shortfalls". Given that these data were now available, it seemed feasible that someone could consider either an entirely novel situation or a situation based on the observed scenarios and could refer to the performance parameters to choose timings from the distributions to represent these. Consistent with the concept that the smaller the delay, the better the performance of the team – the smallest values from the distribution could be chosen to represent the optimal team – now based on <u>observed</u> performance as opposed to the <u>speculative</u> optimal performance used to fulfil Objective 3. These could be then re-applied within the TPRC model to evaluate the impact of this "possible" performance on risk.

This work was carried out by going through each scenario transcript and looking at each task and communication made – both on its own and within the context of the scenario – as described in Chapter 7. First, it was necessary to ensure that the definition of each performance parameter was unambiguous. The definitions of the final set of generic performance parameters are shown in Appendix 7. For example, every radio call was defined in terms of whether it was made by the emergency management team or the scenario organisation team – and whether this provided significant information or not. Following the definition of terms, each scenario was analysed in terms of how many of each performance parameter were observed and the duration of each occurrence. For each scenario, this allowed the average length of time taken by this performance parameter to be calculated for the scenario. Following this, the data from the scenarios were collected together – categorised in terms of:-

- the emergency manager in charge
- offshore/onshore
- pre-emergency / post-emergency

and then for the onshore scenarios only:-

- the competency rating awarded by the chief assessor.

The Scenario-Specific Performance Parameter data are all shown in Appendix 8. The groupings of Generic Performance Parameter data that were considered to be the most useful to future users are shown in Appendix 10.

As stated earlier, it was hoped that these data could be compared, perhaps identifying notable differences in delays therefore reflecting emergency management performance – perhaps also linked with the subjectively assessed competency rating. But, even if no comparison was possible, it was considered important to have these distributions available for use – as this would allow the "closest" match of data to be used when designing a novel situation.

Given that this information was now available, it was necessary to test this. This was tested using the problem identified whilst working on Objective 3. Rather than having a theoretical "best", now the same pattern of performance parameters as observed in the scenario (for example, information call, delay, non-informational call) could be re-assigned optimal durations for each observed parameter, thereby producing a realistically possible "best" – improving the benchmark by which the observed performance is measured. This is shown in Chapter 9 (Figure 63).

The development of this methodology was deemed to have fulfilled Objective 4 and was duly tested. Using all 14 scenarios, Performance Parameters were categorised. leading to the definition of 46 Generic performance parameters. The Generic performance parameters were recorded in 30 different categories – based on collated combinations of onshore/offshore, pre-scenario/during-scenario, in terms of competency rating and in terms of the emergency manager in charge. There were up to 2742 data points recorded for an individual performance parameter and 17924 data points recorded in total – some of which were recorded in up to 9 of the 30 different categories.

Thus, this completes the research methodology laid down to address the four objectives. The following section will therefore continue by describing the scenario arrangement available – and thus both facilitating and limiting the progress of the research.

SECTION 4.4: SCENARIO ARRANGEMENTS

The following sections describe the scenario arrangements under which the research was conducted. These represents the actual arrangements used for the 5 offshore scenarios and is typical of arrangements used in other environments (onshore and nuclear). These arrangements were also based on how the control room would be organised in a real incident - in terms of personnel, technology and information. However, an exact reproduction would be expensive to organise. Therefore items such as particularly expensive control panels and VDUs were represented by using simplified versions of the panels (as described in section 4.4.2) including only the characteristics that would be relevant in an emergency. Where the panel was unable to provide the specific information required by the scenario, the scenario organiser would announce the relevant changes. For example "low level on valve AS2". However, any items that were not critical to the management aspect of the exercise were excluded (For example, coffee machines, breathing apparatus, fire extinguishers, overalls and hard hats). It should be noted at this stage that the onshore simulations described in the research included the use of a purpose designed dedicated simulator (of the type described in Section 2.3.6.1.4). As no details on this could be revealed, it should be assumed that the simulation environment was the same as the offshore environment. Its presence had no impact on the research methodology as described in the previous sections.

SECTION 4.5: DETAILS OF THE SPECIFIC PLATFORM USED IN THE RESEARCH

The work in this research project focused primarily on the personnel on a small (situated in approximately 42m of water) concrete gravity structure gas-production platform situated in the Southern North Sea so this will be the key emphasis throughout this review. (For clarification, a concrete gravity structure consists of metal platform mounted on top of concrete columns. This is all constructed on a reinforced concrete base that rests by gravity on the seabed - Lancaster 1996).

The platform in question consists of a central production platform, supported on two concrete columns, joined to a gas compression deck, which is supported by another column. These are connected by a bridge to a steel supported wellhead tower. This platform also processes gas from a field 7 kilometres away and from two more steel satellite towers (BHP 1994).

The Central Processing platform consists of 4 main decks - the helideck, a weather deck, mezzanine deck and cellar deck. The helideck is an octagonal deck above the accommodation section of the weather deck. It is capable of withstanding extreme wind-loads as well as the force provided by a Sikorsky helicopter. The deck is surrounded by safety nets, provided with foam release systems and can be lit up at night. The weather deck below includes one level of accommodation, the laboratory and stores, methanol laydown area, helifuel store or "skid" as well as some of the processing areas, for example, the export gas cooler. The flare stack and the crane pedestal also stand on this deck.

The mezzanine deck is situated below the weather deck and this deck accommodates the high voltage and low voltage switchgear rooms, the methanol store and more processing, for example, the glycol contactors and glycol regeneration unit. It also consists of another level of the accommodation, so that the entire accommodation block is together and is protected by fire-protective bulkheads from the rest of the platform. The main control room is situated in the lower part of the accommodation and is also protected by blast walls. Within the accommodation are a recreation area, a galley, dining room, toilets, bedrooms, a sick bay and a gymnasium. This can accommodate up to 56 people. On the technical side, there are offices for the Offshore Installation Manager (OIM) and the Maintenance Supervisor. There is also a telecommunications equipment room and a radio operations room providing communication to the shore, shipping and helicopters. Within the control room, there are panels and VDUs to oversee all parts of the production process as well as emergency shutdown and blowdown control, which starts deluge, foam monitors and fires the halon. In an emergency, this room becomes a muster point for essential personnel. Non-essential personnel, including the medic and first aid teams, enter the Temporary Safe Haven (Muster point 2), adjacent to the lifeboats on the cellar deck below.

The cellar deck includes the diesel storage tank, the slug catcher, pig launcher and receiver, HVAC (heating, ventilation and air-conditioning) room, firewater and halon stores as well as the seawater processing for use on the platform.

The gas compression deck (GCD) has 3 compression trains that are involved in exporting the gas from the platform. This is connected to the Central Production Platform by bridges on the cellar and mezzanine decks. The well-tower is connected to the main production platform via a bridge from the mezzanine and cellar deck and it has another crane on it. This deck consists of a number of well slots.

To communicate with the rest of the platform, there is the use of a tannoy (public address system), hand-held radios and telephones. In an emergency, the fire and gas panel in the control room can automatically start the muster with an intermittent alarm at 600 Hz. In non-fire and gas emergencies, this can also be started from the control room, OIM's office, radio operations or telecommunication rooms. In the event that it is decided that abandonment is the only option, a PAPA (Prepare to Abandon Platform Alarm) is started, which is a continuous tone of 800Hz. Evacuation will then take place, via lifeboats or helicopter or, in the worst case scenario, via ladders into the sea.

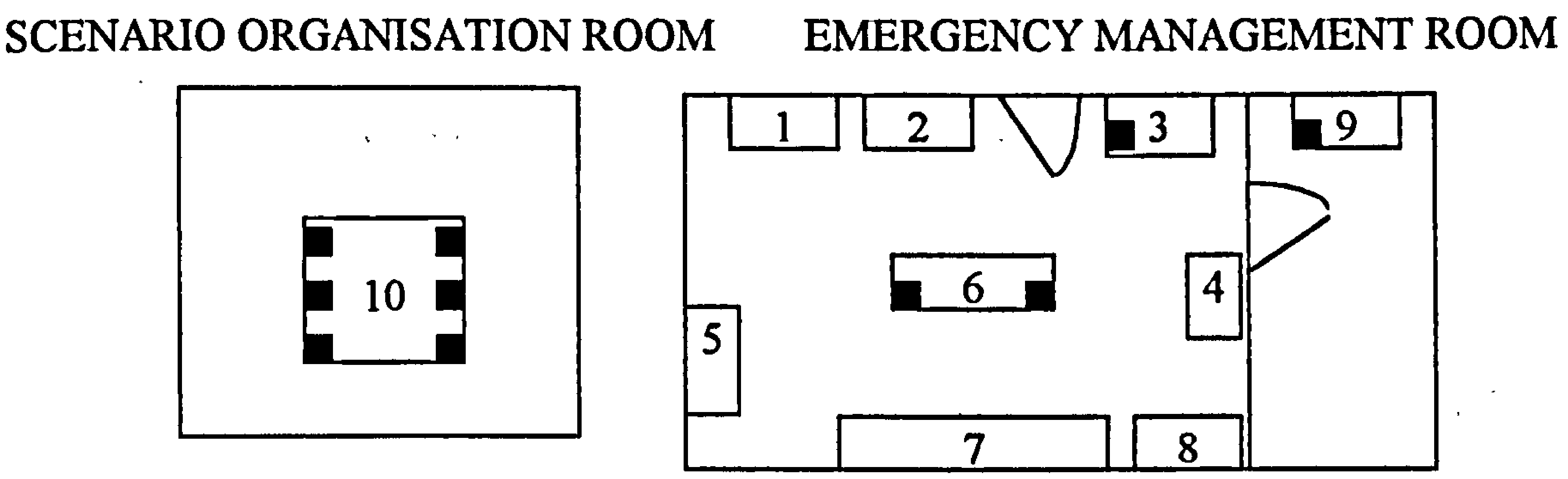
(All information provided by BHP 1994)

In terms of the installation used for the offshore scenarios, the company involved requested that no detailed description could be given to identify it.

4.6: LAYOUT OF THE SIMULATION ENVIRONMENT

The simulations used two rooms configured as shown in Figure 8. Each of the features shown in Figure 8 will be discussed in the following sections.

Figure 8: Layout of Rooms in the Emergency Management Exercise



Key

■	Phones
1	Emergency action checklist
2	Focus board
3	Event board
4	Muster board
5	Map of platform
6	Desk including controls for tannoy and muster and PAPA alarms
7	Panels - fire and gas, deluge and shutdown.
8	Scale model of platform
9	Radio operations controls (including contact with shore & standby vessel using hand held radio or phone)
10	Scenario organisation room, including map of platform, procedures and any other relevant information.

SECTION 4.7: EQUIPMENT AVAILABLE IN THE SIMULATION ENVIRONMENT

This included notice-boards, panels, manuals and communication systems so that the room used by the emergency management team should be as similar as possible to the control room that would be used to manage a real incident.

4.7.1 NOTICE-BOARDS

The notice-boards used were identical to those present in the offshore environment. Some of these were typically used on a day-to-day basis. For example, the map of the platform is used to identify where technicians are working. The other boards were only usually brought out in the event of an incident and would be stored until such a time when they are required. The boards are described in the following sections

4.7.1.1. The Emergency Action Checklist

This contained two lists - one intended for the control room staff and one intended for the OIM. Both had a list of procedures that could be useful reminders in an emergency. As the boards were specific to the platform, it is not possible to completely recreate these list due to confidentiality reasons, but it is possible to give some indication of what information was on the boards. The OIM list contained procedures similar to those shown in Figure 9.

Figure 9: OIM's Emergency Action Checklist

All Radios to Channel 15
Appoint communications / OIM assistant
Appoint team leader
Alarm initiated (silence for communications)
Shutdown plant
Blow down plant (if vent integrity sound)
Shutdown incoming / export lines
Make P.A. announcements (be informative)
Start fire pump (release deluge if required, confirm release)
Emergency systems (review isolations on emergency shut down / fire and gas panel)
Muster status
Notify 3rd parties
Availability of helicopter / vessels in vicinity
Review emergency procedures
Review permits in force
Review weather conditions

The control room list contained procedures similar to those shown in Figure 10.

Figure 10: Control Room Emergency Action List

Inform OIM
Cause identified
PA Announcement
Radios to Channel 15
Fire pumps starts
Deluge released
Isolations removed on ESD Panel
Isolations removed on Fire and Gas Panel
Have plant depressurised
Have ESD valves closed
Hot work stopped
All persons accounted for

4.7.1.2 The Focus Board

This was the sole responsibility of the Emergency Manager. He used this to note down actions which are to be taken and then would announce these to the rest of the team during a time-out. The types of entries that were made on this board included "Complete Muster", "Location missing people" or "Put out fire". Once the actions had been completed or when the Emergency Manager had brought the team up to date, he would cross out the current actions and write new ones. This was primarily designed to ensure that the team were focused on the main objectives and could maintain the "big picture" as a group.

4.7.1.3 The Event Board

This was used by one of the members of the emergency management team (not the emergency manager) to log the events that had occurred. In a real emergency, this would be included in the formal incident report. An example is shown in Figure 11.

Figure 11: Example of the Event Board

Time started	Action	Who by	Estimated Time of Completion
16:13	Explosion in regeneration plant	-	-
16.15	Muster	MC	16:30
16:17	Fight fire in regen	FTL	16:50

From this, the team could establish the chronological order of events, the person or team dealing with them and the time at which the actions can be expected to be completed. If the team reached the estimated time of completion and the action had not been completed, they would then discuss whether they needed to devote more resources to completing the action, for example, by supplying another fire team to put out the fire.

4.7.1.4 The Muster Board

This was used by one of the members of the emergency management team (not the emergency manager) to note down the status of the personnel on the platform. An example of the muster board is shown in Figure 12.

Figure 12: Example of the Muster Board

	Expected	Missing	Helicopter	Standby boat	Support Teams
Muster Point 1	14	1 - Fred			
Muster Point 2	26	0			

The expected number of personnel at each muster point was placed in the first column and once the muster captains had contacted the control centre with the numbers of people present, the numbers of missing people could be calculated. The numbers on the helicopter (for example, the arriving crew-change helicopter) and standby boat were also counted in the event of a helicopter crash or man overboard/evacuation incident. The support teams column referred to those sent out to rescue people or fight fires so that the location of people was clearly recorded for all the team to see.

4.7.1.5 Map of platform

This showed a plan view of each floor of the platform. It was recorded in permanent ink on a white board so that it can be updated using wiper-board pens to include special activities that are continuing in specific locations - for example, permits to work for hot work, cold work or work going on below the platform. During the simulation, this could be updated to give indications of the location of any problems and the wind direction. It was also used to plot possible routes across the platform.

4.7.2 PANELS

4.7.2.1 Fire and Gas Panel

This panel showed a column of locations on the platform and next to each of these was a row of lights (corresponding to fire, 20% gas, 60% gas or manually activated alarms) and a reset button. This panel was mainly controlled by the scenario organiser. When a fire, gas or manually-activated alarm occurred in a particular location, the scenario organiser would sound an audible alarm and light the bulb on the panel corresponding to the type of alarm and its location. The control room operator would then accept the audible alarm by pressing the reset button (thus stopping the audible alarm but leaving the light on the panel).

4.7.2.2 Shutdown Panel.

This panel showed a column of locations on the platform and next to each of these was a set of 2 lights (one representing shutdown, one representing blowdown) and a reset button. These could be controlled by the scenario organiser or the control room operators. Certain systems resulted in an automatic shutdown or automatic shutdown and blowdown, which were therefore activated by the scenario organiser. This lit the respective bulb and sounded an audible alarm, which could then be accepted by the control room operator. Sometimes, the emergency management team decided to shut down the system themselves, which was carried out by pressing the reset buttons.

4.7.2.3 Fire pumps and Deluge Panel

This panel was split into an upper and lower section - the upper for fire pumps and the lower for deluge. The fire pump section had rows for “A”, “B” and “C” fire pumps and next to each one was a bulb and button corresponding to their status - either “on” or “off”. The deluge section had rows corresponding to each deck of the platform.

Next to each name was a bulb, which was lit for "on". Next to the bulb was a button that allowed switching between "on" or "off". These were normally initiated by the control room operator, but could be activated by the scenario organiser, representing an automatic system response.

4.7.3 COMMUNICATIONS

4.7.3.1 Panel Alarms

These were described in section 4.7.2 and were normally activated by the Scenario Organiser.

4.7.3.2 Muster and PAPA alarms

Unlike the genuine article, these were not activated automatically by systems but were represented by a tape recording of the real alarms to be played back by the Control Room Operator at appropriate times. The Muster alarm was an intermittent tone whereas PAPA (Prepare to Abandon Platform Alarm) was a continuous tone - as described in Section 4.5.

4.7.3.3 Phones, hand-held radios and the tannoy / P.A. system

The phones were shown in the diagram of the room plan in Figure 8. There were also a number of hand held (walkie-talkie type) radios available - usually surplus to the requirements of the emergency management team. A typical arrangement involved the radio operator, control room operator and production supervisor each having a hand-held radio. The scenario organisation team also had a number of hand held radios to reply to the emergency management team. The tannoy / P.A. system was represented by a desk mounted microphone which was connected to small speakers in the emergency management and scenario organisation rooms. In a real-life incident, this could be accessed by dialling a particular number on the phone. Therefore, as this facility was not available in the scenario, the receiving team were notified that the tannoy was being used in this way.

4.7.4 SCALE MODEL OF THE PLATFORM

This was available to add another dimension to the map of the platform as described in Section 4.7.1.5. It stood approximately 1.5 metres high and 1 x 1 metres width. This would not be available to the emergency management team in a real situation. However, a real incident would take place on the actual platform in the middle of the North Sea rather than in an onshore office building. Therefore, this information would be more accessible in the actual environment. However, this model was occasionally used to aid the memory in the layout of the installation or to help communicate a specific location or route to another member of the team. As it was found to be useful in some instances, it might be a recommendation to have a smaller model available for emergency managers in the real control room. This would allow locations and routes to be clearly explained to individuals before they left the safe area.

SECTION 4.8: THE PEOPLE INVOLVED IN THE DEDICATED SIMULATIONS

This section includes descriptions of the many different roles that were involved in running the simulations. This includes the team who designed and assessed the exercises as well as those who were required to manage the simulated emergency.

4.8.1 SCENARIO ORGANISER

This person was responsible for the organisation of all the scenarios. Given that he already has some knowledge of generally emergency management, he initially discussed the potential hazards with experts from the installation and therefore defined the possible emergency scenarios. This person also discussed with the emergency management examiners as to their requirements for the scenarios. From this information, this person designed a set of scenarios. Each scenario must test different aspects of emergency management, with differing levels of severity over different times - as specified in Section 3.5.3.4. The scenario organiser then prepared a brief plan of the forthcoming scenario and gave this to the scenario organisation team and the examiners (an example plan is shown in Appendix 3). The scenario organisation team prepared any further details and when both teams were ready, the scenario started. The role of the scenario organiser often required him to go into the emergency management room to assess how the scenario was progressing, to discuss the progress with the examiner, to set off the alarms or to announce certain occurrences, e.g. smell of smoke or chemicals, vibration or sound of explosions. He was also required to act in some of the roles with the scenario organisation team.

4.8.2 SCENARIO ORGANISATION TEAM

The scenario organiser controlled this team. In their normal role, they were usually members of the internal organisation and were familiar with the emergency processes that were involved in the scenarios. For example, they were often the night-shift team corresponding to the day-shift team who were under test. In the role of the scenario organisation team, they were required to play all the roles of people external to the emergency management team. These may include people on the platform who were working on different decks or who become injured or trapped; people on the standby vessel and people onshore. Apart from playing the roles, they also provided some contribution to the progression of the scenario. For example, if they became aware that the emergency management team had ignored a critical point or had forgotten an action, they could increase the importance of this error and worsen the consequences. They also could choose to increase the difficulty of the scenario by neglecting to mention critical information until it was requested or by distracting the team from the main issue. Similarly, they could help the emergency management team by giving helpful emergency management hints.

4.8.3 ASSESSORS

In some cases, one of the group who was responsible for training the team was also responsible for assessment. Sometimes there would be a team of assessors, where the judgement of competency was based on a majority decision. In this set of simulations, this person was the main assessor and his judgement on the competency of the candidate would be the most influential. The assessor was experienced in emergency management from a military background but had no personal experience of incident management in the petrochemical or offshore industry. Typically, this assessor stayed in the room with the emergency management team to see all of their responses to the escalating scenario. In some cases, the assessor was given the plan by the scenario organiser and so was aware of the actual situation. He would then try to predict the emergency manager's response and look out for their timeliness. In other cases, the assessor preferred to watch the scenario "blind" - without using the plan, and therefore based his assessments on how he believed the emergency manager should respond to the incoming information compared with the real responses observed.

The assessors made notes on the performance of the emergency manager and his team but usually made no contribution during the scenario. In the first few assessment scenarios, they would occasionally stop the scenario to explain points. These points were usually stylistic, for example, explaining how the boards should be laid out or the order of events in a time-out. They ensured that they did not provide additional information on the scenario that the emergency management team may have missed. Once this information had been given, the scenario would continue from the point where it was stopped.

Following the scenario, this assessor, together with the scenario organiser and usually one of the scenario organisation team (typically someone senior and internal to the organisation), discussed the candidate and team's performance. They then had a debriefing with the emergency management candidate, in which they pointed out the negative and positive aspects of the performance.

4.8.4 EMERGENCY MANAGEMENT CANDIDATE (TEAM LEADER)

As stated in Section 4.4, this set of dedicated simulations were designed predominantly to assess the competency of the emergency manager - to identify if he could be approved to manage an installation as an OIM. Therefore, in this case, those chosen to manage the simulations were "candidates" in a competency examination. Although, emergency management is generally considered to involve a team effort, the responsibility for the outcome was firmly placed on the shoulders of this candidate.

The candidate usually played the role of the OIM. However, in some scenarios, it had been predetermined that the OIM would be injured in the incident, and so the candidate occasionally found himself in the role of the Field Supervisor. Following, a course in which the candidate and his team were taught the general aspects of emergency management practice, the candidates were examined, usually in pairs. This meant that when one candidate played the OIM, the other could be the Field Supervisor. This way, they could learn from each other's mistakes.

During the scenario, the candidate was expected to be responsible for the overall management of the emergency. Ideally, he provided a supervisory role to the team, merely re-focusing them on important points and giving a pro-active response to the situation. Essentially, the candidate should not get drawn into the rote actions of the group but to rise above this, by obtaining an overview of the "big picture". Sometimes the team were particularly effective and would "flatter" the emergency manager - making him look more effective than he was. In this case, it was the role of the assessor to identify this and to mark the candidate accordingly.

4.8.5 EMERGENCY MANAGEMENT TEAM

These provided the responses to the emergency management candidate's decisions. A good emergency management team should be aware of the progressing situation, communicate important issues to the other members of the team, ensure important actions are initiated quickly and react appropriately to the incoming information. Although they were not the key people under test in these scenarios, if their management of the situation is poor, it is likely that the candidate's assessment will also be affected. For example, if the emergency manager has to become involved in sorting out the detailed organisation of the scenario, he may become unable to make overall strategic decisions. Therefore, if the team are good at management, they will free the candidate to make strategic decisions therefore resulting in a better overall performance. The team typically split into a number of roles, either based on their normal roles (e.g. radio operator, control room operator), or based on carrying out required emergency management tasks (e.g. muster captain, person responsible for the event board or emergency action checklist).

4.8.5.1 Control Room Operator (CRO)

This person was one of the few people who were in the control room at the start of the exercise and therefore, one of the first people to be aware of an incident. Their role involves responsibility for the control panels that, in an emergency, involves the panel alarms, muster and PAPA alarms, the tannoy and any initial communications that are transmitted to the control room. Therefore, they were responsible for putting out the calls to start a muster or for the OIM to attend the control room.

4.8.5.2 Production Supervisor (PS)

This person was usually present in the control room at the start of an exercise, as is consistent with their role on a real installation. However, this person is senior to the control room operator and so occasionally made early tactical decisions before the OIM had arrived.

4.8.5.3 Radio Operator (RO)

As can be seen in Figure 8, the radio operations room is separated from the main control room by a door. However, as for the control room operator and production supervisor, the radio operator would be present at the start of a scenario - as is consistent with their usual role. The radio operator is responsible for communications with external bodies. This includes talking to the parent company and emergency services onshore as well as the standby vessel and helicopters.

4.8.5.4 Field Supervisor / On-Scene Commander (FS)

Whereas most of the people who muster at the control room fulfil a role there, the field supervisor is usually sent to investigate the incident. This would mean returning to the scenario organisation team and temporarily becoming one of their team. This is usually the only person who travels from one team to the other. If they are then asked to return to the emergency management team for any reason (for example, the OIM believes the situation is too dangerous and that they should return to the control room), they must not reveal the details of the emergency which they had learnt while acting as part of the scenario organisation team, which they would not have learnt in their role as the on-scene commander.

4.8.5.5 Other Emergency Management Team Members

Typically the other team members have other roles outside the emergency management role, for example, crane drivers, deck foremen, electrical technicians etc. In their emergency management role, they now become responsible for the boards. Occasionally, they are required to act in their normal role - or carry out skills at which they are particularly adept. In this case, the team must arrange that their emergency management role is adequately covered in their absence.

4.8.6 OBSERVER

The author of this research was the only "observer". Initially, this involved taking notes of how the scenario progressed, the decisions made and the outcome of the emergency. However, once permission had been granted by the companies involved in the exercises, this involved the data recording as described in the next few sections.

4.8.7 ROLES USED BY SCENARIO

In terms of each scenario, the roles fulfilled included those within the emergency management team, the scenario organisation team and some roles that involved joining both. From the transcript, all of those who were heard to speak or activate controls within the scenario are as shown in Table 5. It should be noted that this was the data obtained from the Scenarios – and so it was mainly based on that which could be seen and heard. As the other side of phone-calls could not be heard, all those roles (helicopters, fire service, police, ambulances, senior managers of the company and family members) could be played by one person, so this information on the Scenario

Organisation team was based mainly on the roles heard over radio. Where "?" is shown, this indicates that the person could not be identified from the call – so may be a new role not already accounted for.

Table 5: Personnel Roles identified in the Scenario Transcripts

Scenario	Present at beginning of scenario	Arrives later	Leaves during scenario to join Scenario Organisation team	Minimum number of Permanent Roles in Scenario Organisation team
Offshore 1: Helicopter crash	RO, CRO, PS	P, G, OIM, D, FS	FS	HP, HLO, Med, HP2, MP2, ???
Offshore 2: Methanol leak	CRO, PS, RO	OIM, FS, P, G, D	FS	CD, SB, ?,
Offshore 3: GCD cooler	PS, CRO, RO	OIM, P, G, D,FS	FS	?, Med, R28.
Offshore 4: HV switchgear room	CRO, D, RO (T / DM)	PS, G, OIM, FS, P	FS	PW, AH, Med, FT2, BA3,
Offshore 5: Dropped object	PS, CRO, RO	G, OIM, D, P, FS	FS, G	CD, CM, SB, LB2, LB3
Onshore 1: Hot oil leak	PQ, AR, W, D, G, N			PD, WR, JF, AE, MC, MI
Onshore 2: Broken leg on regen unit	AR, OIM, G, N, W, D			AE, PD, MF, JF, HS
Onshore 3: Tanker driver bangs his head	AR, PQ, W, D, G, N,			PD, MF, AE
Onshore 4: Explosion at tail gas unit	OIM, AR, W, G, D, N			AE, PD, MF
Onshore 5: Brown liquid emission	AR, OIM, G, D, W, N			PD, AE, Sec, MF, B, JF, ??, ?
Onshore 6: Leak on GSU B	AR, OIM, G, W, N, D			PD, JF, WF, AG, T
Onshore 7: Collapsed scaffolding	G, AR, OIM, N, W, D,	PO (Police officer from Scenario organisation		AE, ?, HS, PD, ?1, SF, MF, AG, ?,

		team)		
Onshore 8: Spinal injury on column, icy weather	AR, OIM, D, W, N, G	FO (fire officer from the Scenario Organisation team)		JF, AE, PD, MI, MF, HS, Sec, ?,
Onshore 9: Leak at Dewpoint A	AR, OIM, W, G, D, N	IJ (Inspector from the Scenario Organisation team)		JF, AE, MI, PD, HS, MF, MC, A, AG, ?

With regard to the abbreviations used in the table above, those that refer to the initials for the role are as follows:-
RO – Radio Operator
CRO – Control Room Operator
PS – Production Supervisor
OIM – Offshore Installation Manager
FS – Field Supervisor
HP / HP2 / R28 – Helicopter pilots
HLO – Helicopter Landing Officer
MED – Medic
MP2 – Muster Point 2
CD – Crane Driver
SB – Standby boat
FT2 – Fire Team 2
BA3 – Breathing Apparatus team 3
PO (Police officer - from Scenario organisation team)
FO (Fire officer from local fire brigade - from the Scenario Organisation team)
IJ (Police Inspector - from the Scenario Organisation team)
Sec – Security Officer

In the Offshore scenarios, P, G, D, PW, AH, and in the Onshore scenarios, PQ, AR, W, G, D, N (within the emergency management team) and PD, WR, JF, AE, MC, MI, MF, HS, B, WF, AG, T, SF, A (in the scenario organisation team) represent the initials of the people within the scenario. As described in Section 4.8.5.5, it can be assumed that these are "operational" people in their normal roles and fulfil "untitled" roles as required in an emergency. For the emergency management team, this mostly involves being assigned to update a specific board. The greater use of names in the onshore scenarios (as opposed to titles in the offshore scenario) reflects their normal procedure, so AE, PD, MF in the onshore scenarios could represent the equivalent of FT2, BA3 or FS in the offshore scenarios. Any roles defined as ?, ?? or ?1 are simply described as such because the identification could not be heard clearly in the recording. In offshore scenario number 4, T, the assessor and DM, the scenario organiser, both make a contribution from within the emergency management room so this is recorded in the scenario transcript as such.

4.9: SCENARIOS OBSERVED IN THE RESEARCH

The story-lines of the scenarios used in the research are described in the Sections to follow.

4.9.1 Offshore Scenario 1 : Helicopter Crash

The crew-change helicopter crashes on the helideck starting an explosion and fire. The EMT start a muster and shutdown. The power fails - preventing the use of additional systems including the tannoy. The EMT start the deluge system. A Fire team and Medical team are sent to investigate. The main route from the hospital is blocked. The helicopter is hanging over the edge and there are several fires. Some of the people have been thrown clear of the helicopter, some are still inside. The whole area is flooded with fuel. They order an additional rescue helicopter. The wind is in the wrong direction for the foam to be effective; therefore the fire team approach this from a different direction. The fire enters the upper level of accommodation. They dump the methanol to make it safe. Other than the 2 casualties that were thrown clear, no further survivors are to be expected. The fire team suggest that Muster Point 2 and Lifeboat 2 are no longer useful. The fire team attempt to clear the bridge to the Gas Compression Deck. The fire dies down and the field supervisor suggests that they push the wreckage into the sea. The OIM negates this order and says that the casualties can be winched off the Well Tower instead of the helideck.

4.9.2 Offshore Scenario 2 - Methanol Leak

While lifting methanol tote tanks, the wind takes the load and the tanks are knocked. This results in a methanol leak that ignites. The EMT organise a shutdown and muster and they activate the deluge. The crane driver is forced back into his cab by the fire and calls for help. The fire team attempt to get to him but he is forced to jump out of the crane and into the water before they get there. When the standby vessel reports that there is a man overboard, initially the EMT are not sure who this is. The fire team activate the foam cannon on the fire. The standby vessel rescues the man overboard. The fire team recommend the use of extra foam so another team is sent to put portable foam monitors on the gas compression deck. A diesel fire starts in the crane cabin. The foam monitors start to run out of foam so the fire team attempt to use a different foam monitor. Another team are despatched to supply them with extra foam.

4.9.3 Offshore Scenario 3 - GCD Cooler

Initially, 60% gas is detected on the Gas Compression Deck. The team initiate a shutdown, deluge and muster. Fire is detected in the same area. A number of technicians had been working on the compressor in that area. The muster is completed and 4 are missing. The fire team go to the area. The incident is believed to be located on the Mezz deck of GCD and the technicians were believed to be working in the control room. It was then established that the B cooler has gone. The bridge is inaccessible from the Mezz deck so the field supervisor suggests that he uses the Weather deck. The GCD Control Room phone the control room to say that all four missing people are there - one is injured with flash burns from opening the door. The EMT organise a medical team. The field supervisor attempts to get to the GCD control room via the main door. The field supervisor reports that his BAs are getting low so the EMT send some technicians with additional BA bottles. The field supervisor finds that one exit is too smoky so he tries another door. He is unable to open it, saying that the door handles have come off. The EMT call the GCD control room to get them to open the door. The EMT send an additional team to assess whether the GCD Weather Deck is at risk. The field supervisor finally gets into the GCD Control Room. The casualty is suffering from flash burns, concussion and is bleeding from the ear. The others are very frightened. A stretcher team is despatched with the medical team. The field supervisor suggests that the EMT stop the deluge. This is negated, as there are still fires.

4.9.4 Offshore Scenario 4 - HV Switchgear Room

A smoke alarm is activated in the HV Switchgear Room. The Halon is activated there. The operator gets to the HV Switchgear Room and finds that it is full of toxic smoke. He reports that he cannot stay there. A shutdown and muster are started. The electricians prepare to investigate. HV Power failure occurs. The field supervisor enters the accommodation to search for two missing people and the operator. The field supervisor gets to the LV Switchgear room and says there is smoke there. An alarm is activated in the Lab and Stores. The field supervisor requests backup. It turns out that someone has wedged open the door of accommodation so that it is filling with toxic smoke. The field supervisor complains about the visibility and leaves the accommodation. Their BA starts to run out so they return to the control room. There is some confusion over which teams were assigned which roles. Despite the team's complaints about the visibility, the EMT insists that the teams are wearing BA so should be able to cope with it. One casualty is found in the HV Switchgear room. He is resuscitated. The field supervisor searches level 1 of accommodation and no one is found. They continue to search level 2 and find the steward. The field supervisor requires extra BA and reports that the fire in the HV Switchgear room is escalating. The EMT start relocating to muster point 3 and they inform all external teams of this fact. The field supervisor gets the doors of the HV Switchgear Room closed to activate the reserve banks of Halon. The field supervisor starts to lose contact with the EMT and does not hear the order to pull back. They contact him on the tannoy and he then reports that he may have trouble in pulling back. They agree to send extra teams to help him escape.

4.9.5 Offshore Scenario 5 - Dropped Object

There is a 60% gas detection on Weather deck of the J facility. The muster is started. A fire is then reported on the Mezz deck. They start to activate the deluge. The crane driver radios in to say that the whole crane boom has gone down. The crane is sitting on the top of the bridge. Shutdown is activated. The wind has apparently taken the crane boom over the Weather Deck bridge and there are just a few wires attached to the load. The fire on the bridge starts to impinge on the central platform. 8 people are missing in total. Someone reports in from the GCD saying that there are 3 of them there and they are returning to the control room, as they cannot get across. The lower bridge has gone completely and the upper bridge cannot be used due to the fire and smoke. One person is found in the GCD control room and is injured but is safe there for now. A jet fire occurs on the slug catcher. The fire team are sent to investigate. Someone reports that they saw someone crossing the bridge when the incident happened and they believe they may have gone into the water. The EMT contact the standby vessel. The field supervisor starts to set up hoses to play on the ESV valves. The load is still hanging on the wires, half in and half out of the water. If it falls, it is likely to damage the platform or the subsea pipeline. The standby vessel can find no one in the water. The group on GCD launch the lifeboat. The fire starts to diminish. The OIM suggests that the load can be lowered but the field supervisor negates this plan. They agree to shut the subsea barrier.

4.9.6 Onshore Scenario 1 - Hot Oil Leak

When fixing a hot oil leak valve, a fire starts. 2 technicians are badly burnt. The EMT start a muster, which is completed minus the 2 technicians. The fire truck is called to the area. The foam monitors are activated but the on-scene team request that they are turned off to make the rescue easier. That requires a manual isolation by the on-scene team. One casualty is rescued. The fire starts to threaten the diesel and hot oil tanks. The fire brigade set up cooling on the tanks. There are problems communicating with the fire brigade to identify where they are working. The team then realise that one of the casualties is still missing and attempt to rescue him. The on-scene team are exhausted but are asked to carry out an isolation on the leak.

4.9.7 Onshore Scenario 2 - Broken Leg On Regen Unit

The levels are fluctuating on the regen unit and a technician is sent up the ladders to investigate. The pressure starts to drop. There is a massive H_2S leak. The technician sent up the ladder falls while trying to get out and his mask falls off. Another technician attempts to assist him. The EMT start a muster and shutdown and call the emergency services. The toxic alarms go off. It becomes apparent that the technician has broken his leg. He is given breathing apparatus but this is rapidly running out of air. The EMT try to bring the crane into action. The toxic gas starts spreading over the site. One other person is missing from the muster - a contractor. The emergency services are diverted round the safe routes on site. The on-scene team attempt to provide the casualty with a permanent supply of air. The contractor is found. The levels of gas start to fall around the site and the fire brigade use sprays to control the gas cloud. The on-scene team ready the crane and the stretcher to rescue the casualty.

4.9.8 Onshore Scenario 3 - Tanker driver bangs his head

The propane tanker driver falls and hits his head. There is a serious propane leak from the loading hoses and the technician tries to shut it off. The EMT activate shutdown and the fixed monitors then call the emergency services. Multiple fires start in the refrigeration building and the deluge is activated. The driver is pulled clear but is unconscious. The muster point is moved to a safer area. The emergency services must be diverted to the back gate to avoid worsening the situation. The gas cloud drifts so the team set up foam monitors on the hot oil system. They also activate cooling on the propane tanker. The muster is completed minus one person - a training consultant. A fireball occurs which send propane down the drains. Foam is put down the drains. The missing person is found. The ESV does not close properly and the on-scene team are asked to deal with this. The fire starts to die down. The casualty is put in the ambulance and the ESV is successfully closed. The main fires are put out and the refrigeration unit is depressurised so the on-scene team can concentrate on isolating the leak.

4.9.9 Onshore Scenario 4 - Explosion at tail gas unit

There is an explosion at the tail gas unit. The emergency services are contacted and the shutdown is initiated. A muster starts and a technician sent to investigate. He finds 3 casualties in the area, all of whom are badly burnt. The EMT depressurise the tail gas unit and organise the fire truck. The fire dies down and the team manage to activate water curtains on it. One person is missing from the muster and one of the casualties starts to go into shock. A search and rescue is put under way and the on-scene team turn the foam monitor off to help them with the search. Meanwhile, the missing person turns up at the muster.

4.9.10 Onshore Scenario 5 - Brown liquid emission

There are gas alarms on the tail gas unit and security report a strong smell in that area. A number of people are injured at the top of the unit and are covered in brown liquid. The EMT start the muster and shutdown. The gas cloud moves over the area and the EMT organise for fixed monitors to be activated. Security move from their block out of danger. The muster is completed with 3 people missing. However, because security were not in their unit, the emergency services were not contacted. The EMT arrange for this to be carried out. The emergency services arrive but the keys to the site are in the security block so they must use bolt cutters. The EMT suggest that they go round through the colliery gate. This involves passing underneath a low bridge but the installation manager believes this is possible. One technician is stuck in a lab and can smell gas but cannot get his breathing apparatus to work. They realise that it is solvent regen that is losing pressure. Two technicians are suited up in chemical suits and breathing apparatus to enter the unit. The HVAC trips. The on-scene team need to break into the lab to rescue the casualty. The gas affects a man and his dog walking outside the site. The technicians identify the leak and work on it. The police arrive to reassure the villagers. Resources are diverted to the man and his dog. The leak is isolated and the gas levels drop.

4.9.11 Onshore Scenario 6 - Leak On GSU B

The amine flash drum starts to lose pressure. A technician goes to investigate. A leak starts on Gas Sweetening Unit B. The EMT start a muster and shutdown. The technicians muster. Manual Alarms are activated by the Dew Point B and by the Hot oil heaters. There are strong winds on site taking the gas across the railway track. The emergency services are called. The gas affects people working on the railway track. The

EMT activate the foam monitors. 2 people are missing from the muster. One of the missing persons is found and he is suffering from gas inhalation. The EMT stop the railway traffic. The final missing person is found and he has had a fright. The plant is depressurised. One of the railway workers is found to have had a heart attack. The casualties are taken off in the ambulances.

4.9.12 Onshore Scenario 7 - Collapsed scaffolding

The scaffolding collapses around the regen unit. The technicians go to identify the problem. B train regen appears to have fallen down and there are 2 people lying on the side of the road. The technician can see at least 2 more people trapped in the wreckage. There is a flammable gas and toxic gas detection. The technician finds the scaffolding on the export pipeline. The EMT start a shutdown, muster and call the emergency services (including ordering cutting gear). They activate the monitors in the area. The muster point is moved to a safe area. Essential services are stopped and the water curtains are activated. The EMT suggest that the emergency services come round the colliery road. The ESV is shut but a hot oil spill occurs on the scaffolding. They arrange for tarpaulins to be placed over the casualties to protect them from the hot oil - however there are no tarpaulins available. The EMT suggests that they use water sprays instead. The on-scene team find that the tapping on the outlet valve has broken so it is impossible to isolate. They realise that they will need lifting gear so get the crane driver from the muster. They start cutting the men out and moving the scaffolding. This causes the platform to collapse. A policeman arrives in the control room to discuss the problems. There is a hissing noise in the region of the scaffolding. The crane driver is reluctant to go back on site until he is offered double time for the job. The on-scene team identify that the leak is an air leak. The hot oil leak is dying down and the plant is depressurising. The team find all the missing people and start to cut them out. They get a Nitrogen purge on the sales gas manifold. The casualties are badly burnt and in shock.

4.9.13 Onshore Scenario 8 - Spinal injury on column, icy weather

There are technicians working on top of regen B in icy weather. One of the technicians slips and falls off the stairs and knocks himself unconscious. Another technician climbs the column to join them and finds that the technician will need an ambulance. Spinal injuries are suspected. The EMT call an ambulance and a snorkel and start a muster. The team on top of the regeneration unit ask for a stretcher and some blankets, as they are worried about hypothermia. The casualty starts to go into shock and the nurse is convinced that he has broken his neck. They start to activate the crane. The fire engine comes over the bridge and skids into the front gate, crushing one of the security guards. The crane skids and goes into the pipeline - some technicians struggle to get the driver out. There is a smell of H_2S so they activate the monitors but the diesel firewater pumps fail. The casualty's condition deteriorates and he starts to have breathing difficulties. As the security guard is crushed against the gate, the next fire engine and snorkel cannot get through the gate. They send the resources to the colliery gate and send personnel there with bolt croppers. The casualty on the regeneration unit goes into cardiac arrest. The on-scene team work on putting Nitrogen on the flare line.

4.9.14 Onshore Scenario 9 - Leak at dewpoint A

Technicians working on Dew point A cause a leak. This gets worse then sprays fluid everywhere. There is a flammable gas detection in Dew point A. The EMT activate shutdown and the monitors. A radiographer is working with a radioactive source and they ask him to ensure it is replaced before attending the muster. The monitors are facing away from the incident. The emergency services are called. The on-scene team put the breathing apparatus on and go to turn the monitors around. The gas cloud drifts towards Dew point B. The radiographer cannot be found and they do not know whether the source is safe. 3 people are missing from Dew point A. When found, the radiographer does not want to go back on site but confirms that the source is exposed. A body is found by one of the technicians. The 2 other missing people are found. One is vomiting badly; the other is in shock with cold burns. The emergency services arrive but are reluctant to let their staff on site as they overheard messages about a "bombing source". The on-scene team agree to bring the casualties to the emergency services at the gate.

4.10: CONCLUSIONS

Given that this chapter has described both the research rationale and methodology and the scenario arrangements set down for the research, the next chapter will move on to discuss in more detail how data were collected and analysed.

Chapter 5

SCENARIO DATA ANALYSIS - THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

SECTION 5.1: INTRODUCTION

Given the arrangements for the scenario were as described in the previous chapter, it was necessary to find some way of collecting data to analyse the simulations in an objective and scientific way. At the beginning of the research, it was thought that to fulfil the objectives, the methodology would be required to:

- examine decision-making in an emergency situation
- differentiate between good and bad emergency management strategies and decisions
- produce a quantitative result based on objective measures that could be useful for HRA or QRA.
- be scientifically valid and reliable
- be consistent with real-life knowledge of emergencies and emergency management therefore could represent all the relevant features for a post-hoc analysis of a real incident (and potentially be validated in this way)
- have the potential to be developed to incorporate additional factors, different contexts or situations.
- did not rely on the provision of external resources (for example, access to emergency management teams), but could still be useful if such resources became available
- was simple enough to be used with novice emergency managers but also beneficial for those with more expertise (and therefore could be used to quantify the impact of training)
- was fully repeatable

However, these requirements were focused on developing both a medium for data collection and a method of analysis - hence the initial development of the desktop simulation (as discussed in Appendix 2). Therefore, given that the external resources and dedicated simulations were now available, the requirements had to change to compensate for this. At this point, it was deemed possible that this would require a completely new methodology. Although the dedicated simulation data could be considered as having greater external validity than the desktop simulation, it also would create problems for the analysis - namely recording the data, incorporating the complexity into the assessment methodology and coping with the lack of experimental control over the scenario organisation.

Ideally an observation methodology should have yielded data from the dedicated simulations by developing a framework to categorise the actions, events and decisions over time. However, it quickly became obvious that each scenario was so data-intensive that recording all the activities with written notes would be impossible. Also, due to lack of technical knowledge of what was generally considered to be "good" emergency management, it quickly became clear that the author would not acquire the assessment skills within the length of time assigned to this research project. Fortunately, the companies involved permitted the author to use a video camera to record the emergency management room activities during the simulations - as long as confidentiality was ensured. Together with this, the crucial boards could be photographed once the scenario was completed, allowing most of the important information to be recorded. However, the dedicated simulations were not based on a strict framework like the desktop simulation. Therefore there was no clearly identified point in time when external tasks are completed or when incidents have escalated or been controlled to a particular degree. For scientifically ideal conditions, it would be necessary to control the environment in which the investigation takes place to a degree where it is fully repeatable. This would probably involve changing the scenario arrangements (particularly the planning stage) described in the previous chapter - which was not an available option for this piece of research. However, even a highly flexible plan may be changed during the running of a simulation due to the reactions of the emergency management team. Therefore, although the scenarios themselves were not expected to be repeatable, given that the critical information was recorded, it was expected that the assessment technique should yield consistent results. Therefore, this methodology should produce reliable quantitative values of the impact of emergency management on risk for the observed decisions, independent of the assessor's judgement.

Therefore, considering these differences between the desktop and dedicated simulations, it was necessary to identify a method of scientifically evaluating the recorded data. At first, it was reasonable to return to the concepts used in the assessment of the desktop simulation. The relationship between % safe area, % people evacuated and time seemed to correspond to a valid indication of successful outcome in an emergency. Although this was a simple technique, this objective outcome-based assessment mechanism dealt with some of the criticisms of current HRA and QRA techniques suggesting their unsuitability to assess the impact of emergency management on risk reduction.
These positive features include the following:

- Situation-specific features of the tasks, such as the impact of real-time or team actions, can be incorporated into the quantification process - without task decomposition or generalisation
- Quantification is less reliant on expert judgment, in that the expertise required were mainly in the planning stage and predominantly involved physical information (such as movement speed and fire escalation), which is obtainable from objective sources.
- Consistency with real-life knowledge of emergency management - Some interventions do yield results (despite the often pessimistic views used in other HRA techniques). Also, faster pro-active intervention is observed as producing a more successful outcome than slower reactive actions.

This technique also managed to incorporate some of the positive features of the current techniques - such as the task context and real-time representation used in the time-line analysis and the relationship between time available / time required and reliability used in HCR and other HRA methods (See Sections 2.4.4.2.5 and 2.4.4.2.8 for more details).

Therefore, using a system of assessment that was objective, observable and based on the physical outcome of emergency tasks was a good starting point. This would fulfil the requirements of assessment in that it could distinguish between good and poor emergency management. Also, it was not based on "luck" - in that it could compare the observed outcome against the best possible and worst possible outcomes given the situation. However, at this stage, it was required that the technique could produce post-hoc results for real-incidents as well as the assessment of simulations. At this point, it was not clear how this level of complexity could be incorporated to give an overall quantitative value for reliability. Another main issue in HRQ was the incorporation of uncertainty in the process. It is rare that information is so accurate that point values can be obtained to apply in quantification. Therefore the superior methods of HRQ would use distributions of values to encompass the whole range of possible values in their assessment.

Therefore, at this point, it became logical to return to the TPRC model and identify whether it could use its particular features of merit within the research. These included:

- Production of a Probability of Success / Time function
- Flexibility of structure to represent any task that has a time required / time available relationship with reliability
- Ability to incorporate situation-specific factors affecting the outcome
- Incorporation of "real-time" - consistent with the importance of time impact in an emergency
- Ability to represent the concept of the desktop simulation (i.e. the objective outcome-based assessment technique)
- Results were based predominantly on physical, observable quantitative values including degrees of uncertainty
- Changes in parameters values can be tested using the model to assess the impact of change on risk reduction
- Basis in sound mathematical principles of reliability
- Minimal reliance on expert judgment for the selection of values

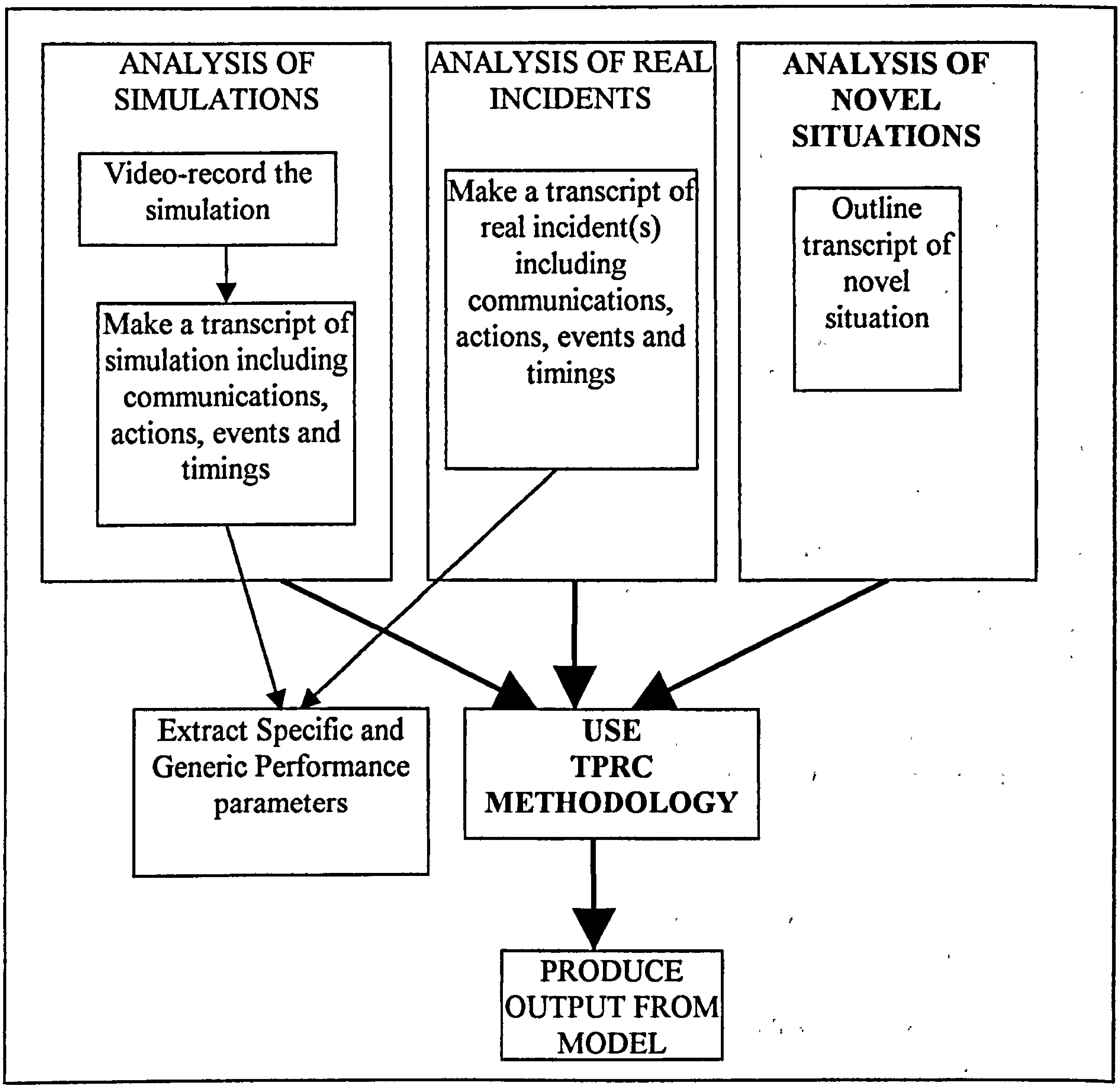
Therefore, this could be used with the same concept as the desktop simulation (i.e. objective outcome-based assessment) in the context of the dedicated simulations (multiple tasks and objectives in an offshore/onshore situation) hence fulfilling the first three objectives of the research. Therefore, this model and its use in this research will be discussed in the sections to follow – starting with a brief overview of how the model works.

SECTION 5.2: BRIEF OVERVIEW OF THE FINAL METHOD

This section describes pictorially the overview of the whole method as it appears at the end of the research. Figure 13 shows the top level of the TPRC process which demonstrates how it can be adapted for real incidents (that is, incidents that have actually happened), novel situations (possible situations that can be "imagined") and simulations (which may be developed through a combination of knowledge on real incidents and imagining novel situations and are then simulated and observed through the use of an emergency management team). Central to the analyses of these three sorts of data is the TPRC methodology that uses the TPRC model. This methodology is described in further detail in Figure 14 and the model, which is essentially mathematical, will be described later in this Chapter. From Figure 13, it can be seen that, in general, the analyses of the three different type of incident (real, novel or simulated) follow a similar pattern. In each case, a transcript of the incident including estimated timings is required. In a real incident, the transcript follows the recorded physical events as they are known or remembered therefore the time relationship between some of these events will be accurately recorded. However, often the management actions, decisions and communications are not recorded. The black boxes used in aircraft would provide this information but currently these are not used in the offshore industry so are not available for post-incident analysis.

However, in a simulated scenario, the physical events may be based on models and real events or they may be imagined, but the management actions and communications can be observed and recorded using a video camera and included with some degree of accuracy in the transcript. Therefore, for each of these two types of situation, there are uncertainties associated with at least one of the aspects - the real physical events or the management events. Therefore, information can be collected in the form of performance parameters from one to supplement the knowledge and enrich the transcript for the other. Sometimes, there will be uncertainties associated with both management and physical events - for example, in the case of a novel situation. In this case, these performance parameters must be used to provide realistic timings for both physical and managerial aspects of the scenario as required.

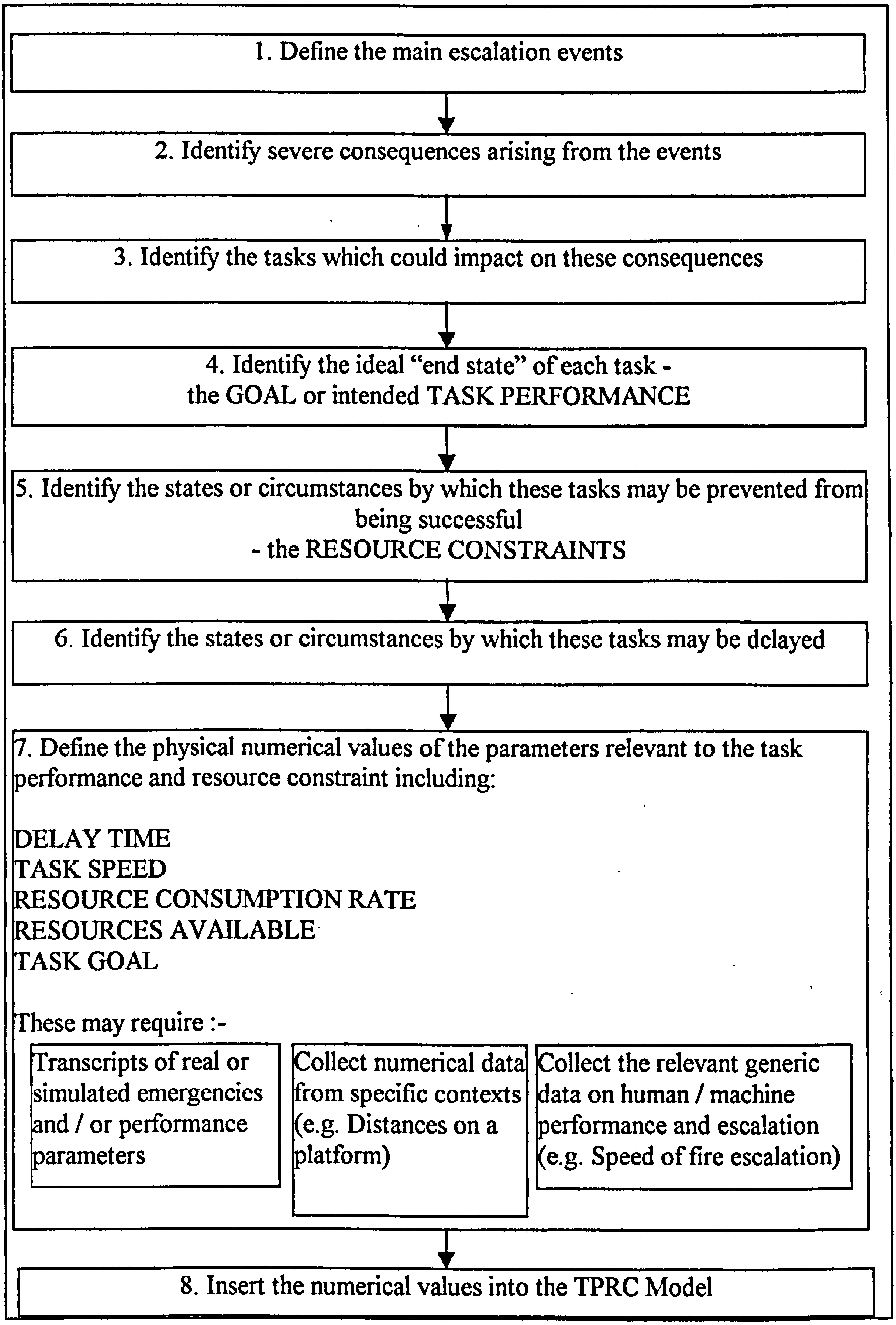
Figure 13: Description of the Top Level of the TPRC Process



Within the centre of Figure 13, is stated "Use TPRC Methodology" which is expanded in Figure 14.

Using the transcripts defined for the scenario, it is necessary to first define the main escalation events (1). These may be points at which circumstances change - for example, the fire impinges on another system or a man falls overboard. Then taking each of these escalation events in turn, it is necessary to determine the severe consequences that could occur (2). Therefore, for these events, the fire could cause another explosion, could impinge on a critical system, such as communications, or could block a possible escape route. Each of these must be considered as they could be grades of possible "severe consequences" and all may have different impacts on other aspects of the emergency. In the case of the man overboard, the worst-case scenario is that he is killed - either by injuries caused by the fall or by hitting the structure of the platform or by hypothermia.

Figure 14: Description of the TPRC Methodology



1. Define the main escalation events

2. Identify severe consequences arising from the events

3. Identify the tasks which could impact on these consequences

4. Identify the ideal "end state" of each task - the GOAL or intended TASK PERFORMANCE

5. Identify the states or circumstances by which these tasks may be prevented from being successful - the RESOURCE CONSTRAINTS

6. Identify the states or circumstances by which these tasks may be delayed

7. Define the physical numerical values of the parameters relevant to the task performance and resource constraint including:

DELAY TIME
TASK SPEED
RESOURCE CONSUMPTION RATE
RESOURCES AVAILABLE
TASK GOAL

These may require :-

- Transcripts of real or simulated emergencies and / or performance parameters
- Collect numerical data from specific contexts (e.g. Distances on a platform)
- Collect the relevant generic data on human / machine performance and escalation (e.g. Speed of fire escalation)

8. Insert the numerical values into the TPRC Model

Given that all the severe consequences have been defined, it is then necessary to try and work out what sort of tasks would impact on these consequences (3). These could be positive interventions (such as applying cooling to the fire or getting the fast rescue craft to rescue the man overboard) or negative interventions (forgetting to shut-down the platform, applying cooling to a different area, sending the fast rescue craft to rescue someone else - if the analysis is based on one specific person, this would not be considered as improving his chances!). These may even be tasks that are consider unlikely to succeed - for example, attempting to rescue the man using the rope-ladders on the platform. Some consequences (for example, assuming the man dies immediately from injuries caused by hitting the platform during his fall) are impossible to avert using emergency management tasks. Therefore, these must be analysed looking at emergency procedures and design issues to ensure that these circumstances do not arise - or that the risk is as low as reasonably practicable. In the case of the real / simulated incidents - these tasks may be those that were actually used or attempted or those that seem like "a good idea" after the event. For each task, it is necessary to identify the ideal "end-state" of the task (4) and the point (defined in terms of resource constraints) by which the task must be performed to be successful (5). In the case of the fire, one ideal end-state would be to put out the fire - another one may be to get it to a point where it is unlikely to impinge on another system. Therefore these must be done before it escalates beyond managerial control or is allowed to reach this point of impingement. For the man overboard, the end-state is "ensure he is out of danger" - either by removing him from the water by boat or by other means. Obviously, these must be done before he dies, otherwise the task will be deemed to have been unsuccessful. In each case, these may involve managerial "sub-tasks", such as situation awareness, decisions, and communications, which, in terms of the physical processes, are delays. Therefore it is necessary to work out the possible factors causing delays for each emergency management task (6). Given that all these issues have been taken into account, it should then be possible to define numerical values (including values to represent the uncertainty associated with each value) for the main parameters in each task - resource constraint relationship (7). Data can be collected from a variety of sources to produce the most accurate numerical representation of this relationship as shown in Figure 13. These values are then inputted into the TPRC model program (8). The output of the "probability of success" function for each respective task under the defined circumstances is produced as shown in Figure 13.

This section describes, in brief, how the TPRC methodology and the TPRC model work together to produce probability of success functions for emergency management tasks. Figures 13 and 14 also demonstrate how real and simulated incidents can be used to provide performance parameter data both to enrich the assessment process for each other as well as increase the accuracy in assessing novel situations. Therefore now this chapter will continue by describing the detailed functioning of the TPRC model.

SECTION 5.3: THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

This section describes the original philosophy behind the model, including the mathematical equations that define it. This also describes how the original model was constructed and then the modifications that were made to allow the emergency management exercise data to be analysed.

5.3.1 THE ORIGINS OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

The Task Performance Resource Constraint model, developed by Strutt, Loa & Allsopp (1996), has its origins in mechanical and structural reliability. The original model involved probabilistic methods to give time-contingent probabilities of success - mainly focused on component strength, the loads applied on it and the progressive effects of fatigue. This model also incorporated the idea of uncertainty - where measures of both strength and load were assigned a distribution of possible values.

These attributes indicated that the model had great potential for measuring human reliability over time. This original model then underwent considerable development to be capable of assessing human reliability in non-destructive inspection (Loa, Strutt & Lock 1995), system operations (Loa, Strutt and Allsopp 1996) and diving (Strutt, Loa and Allsopp 1996). As discussed in Section 2.4.4 and further in Section 5.1, the current methods of HRA do not represent the aspects which have an impact on risk in an emergency. Therefore the TPRC model had the potential to rectify this problem. First, it was necessary to convert the important concepts from emergency management into a form that could be used in the model. This conversion will be described in the next section.

5.3.2 THE APPLICATION OF EMERGENCY MANAGEMENT DATA IN THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

As discussed in Section 2.3.6.1, the success of emergency management is often subjectively judged by the outcome. If an optimal conclusion is obtained from a dangerous initiating event, emergency management has been successful. If a tragic outcome is produced from a minor incident, then emergency management has failed. This may be an informal and subjective assessment method but it is based on objective physical values, such as the number of survivors or amount of the building saved. This idea was already demonstrated in the desktop simulation shown in Appendix 2.

Given that emergency management is often assessed by its outcome, it must be established which factors or tasks to be completed are critical in influencing the outcome in a real incident. For example, the factors that influence the number of survivors in a fire may involve the rescue of some casualties, which may involve:

- putting out the fire
- removing the casualties away from the problem
- leaving the casualties where they are but protecting them from the problem

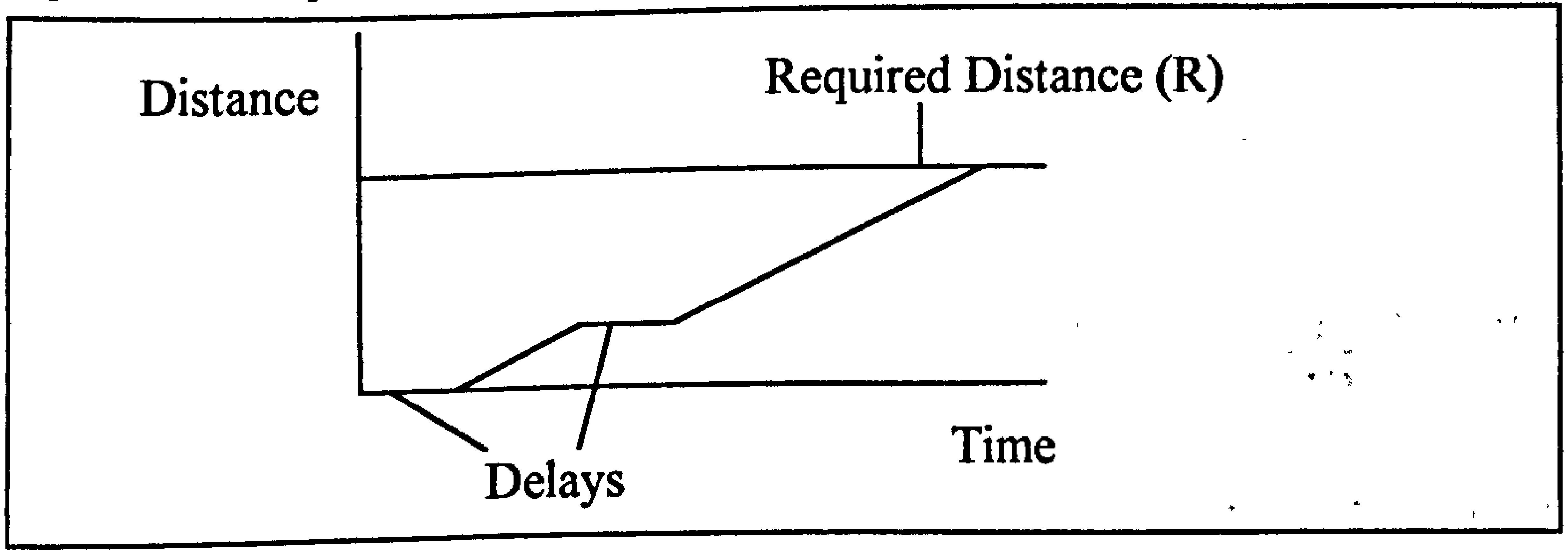
It is notable that these are all tasks that can be objectively measured and therefore, their progress can be quantitatively assessed.
The problems that occur in carrying out these tasks may include:

- increased escalation of the fire
- increased escalation of the casualties' injuries

Both of these problems would restrict the progress of the tasks - eventually preventing the tasks from being successfully completed. For example, it would be impossible to remove the casualties away from the problem if the fire escalated to make the area impenetrable. Also, the task would not be deemed successful if a team of rescuers risked their lives to reach the casualties then found that they had already died from their injuries. However, the objective view of the situation must be considered. If, given the situation, the observed outcome is compared against the best possible and worst possible outcomes - then the success of the task can be established.

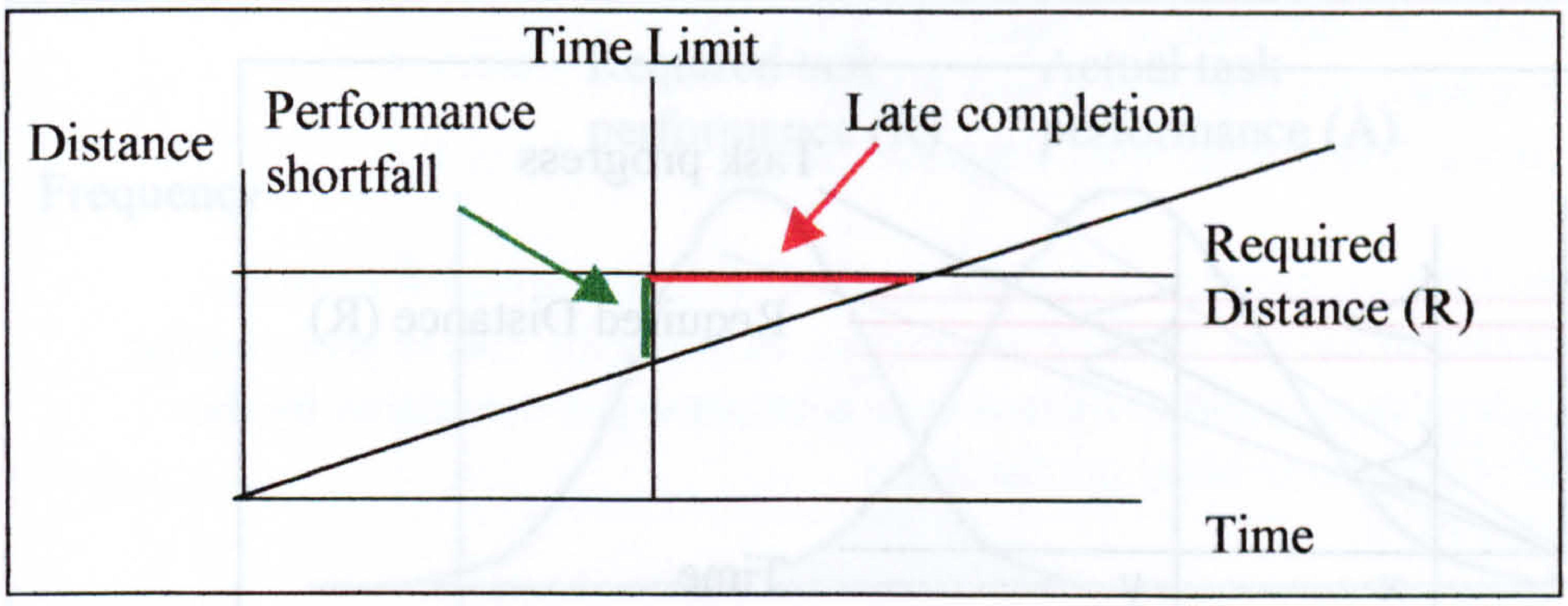
Therefore, it is necessary to consider how emergency management tasks such as these can be represented in a form where they can be used in the TPRC model. Therefore initially, a simple movement task, namely "getting to the casualties" can be used to describe how the TPRC model is used. Any task where the performance is measurable using objective physical limits can be represented in the same way. This task can be shown as the distance/time graph shown in Figure 15.

Figure 15: Simple distance/time graph



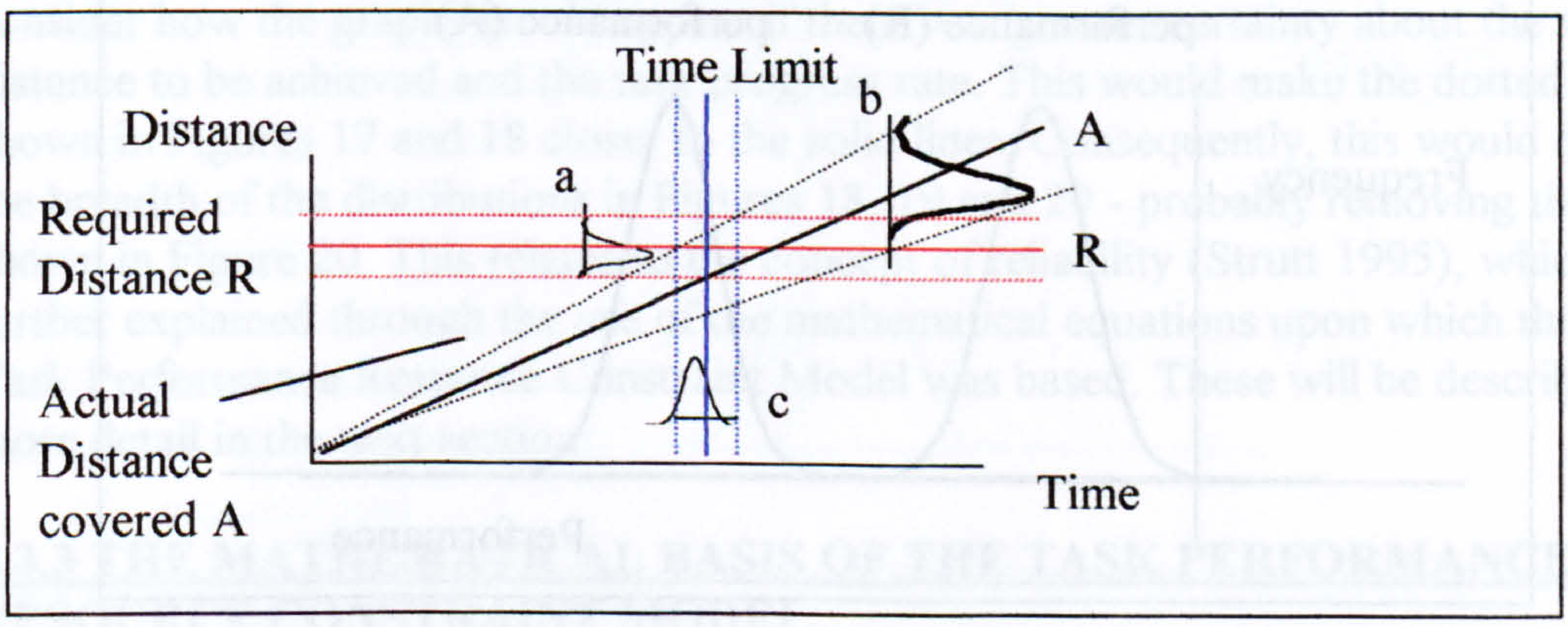
However, in an emergency, it is unlikely that there is unlimited time available to complete the distance. If the task cannot be completed within the available time, it is failed in either of two ways. A performance shortfall occurs when the task is carried out up to the limit of time available but is not completed. Late completion occurs when the task is continued until it is completed but overran the time limit. In our example of "getting to the casualties", a performance shortfall is where the rescuers do not complete the distance. This may be due to the fact that they are driven back by fire. Late completion is where the rescuers reach the casualties but it is too late to provide any assistance to them. These failures can be shown in Figure 16.

Figure 16: Task Performance graph showing failures due to time limit



This provides the fundamental concept behind the use of the TPRC model to assess the impact of emergency management on risk reduction. However, the complexity is provided by the underlying probabilities as used in the model. Each of the parameters has a degree of uncertainty associated with its numerical value. For example, it is not known how long the casualties will live, the exact speed of the rescuers or the actual distance of the casualties. If each parameter is assigned a distribution of values, we may get a graph similar to that shown in Figure 17.

Figure 17: Emergency Management task performance graph showing variances and their respective probability distributions



In this case, the solid lines represent the original values from Figure 16. However, each of the lines (representing speed, distance to be achieved and time limits) is now enclosed by two dotted lines. These represent the uncertainty around the values given to the three parameters. Therefore speed is not a specific constant value, for example, 1 metre per second. It is a range of possible values, for example, from 0.5 metres per second to 1.5 metres per second. Therefore, if each of the parameter involved has uncertainty associated with its values, it may be represented by a probability distribution, as symbolised by a, b and c on Figure 17. If the task action is initially considered on its own - without considering the available time, this gives us the graph shown in Figure 18.

Figure 18: Emergency Management task performance graph showing probability distributions of speed and distance to be achieved

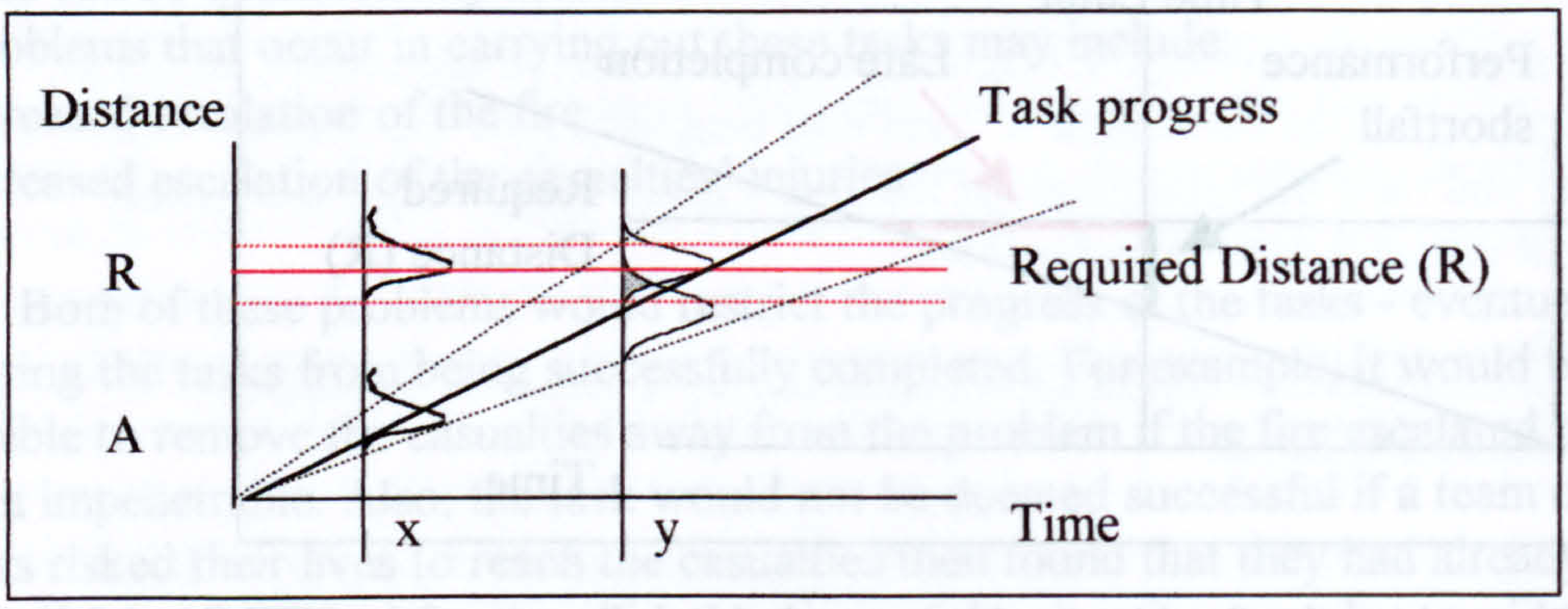
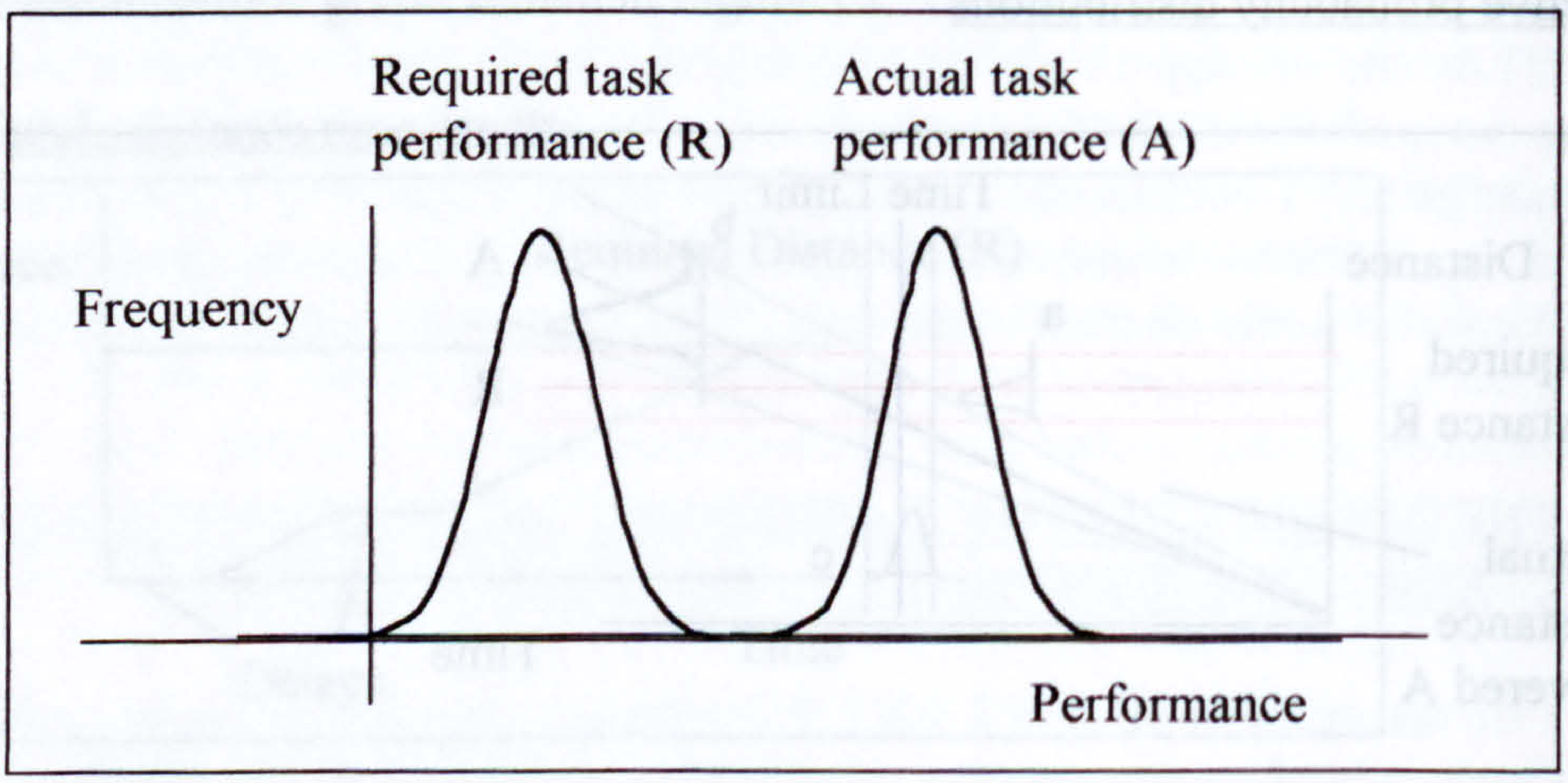


Figure 18 shows that over time the "task progress" distribution eventually reaches and overlaps the "distance to be achieved" distribution. The pattern of distributions at time x and time y will be shown individually in Figures 19 and 20 (having been rotated 90° to the left).

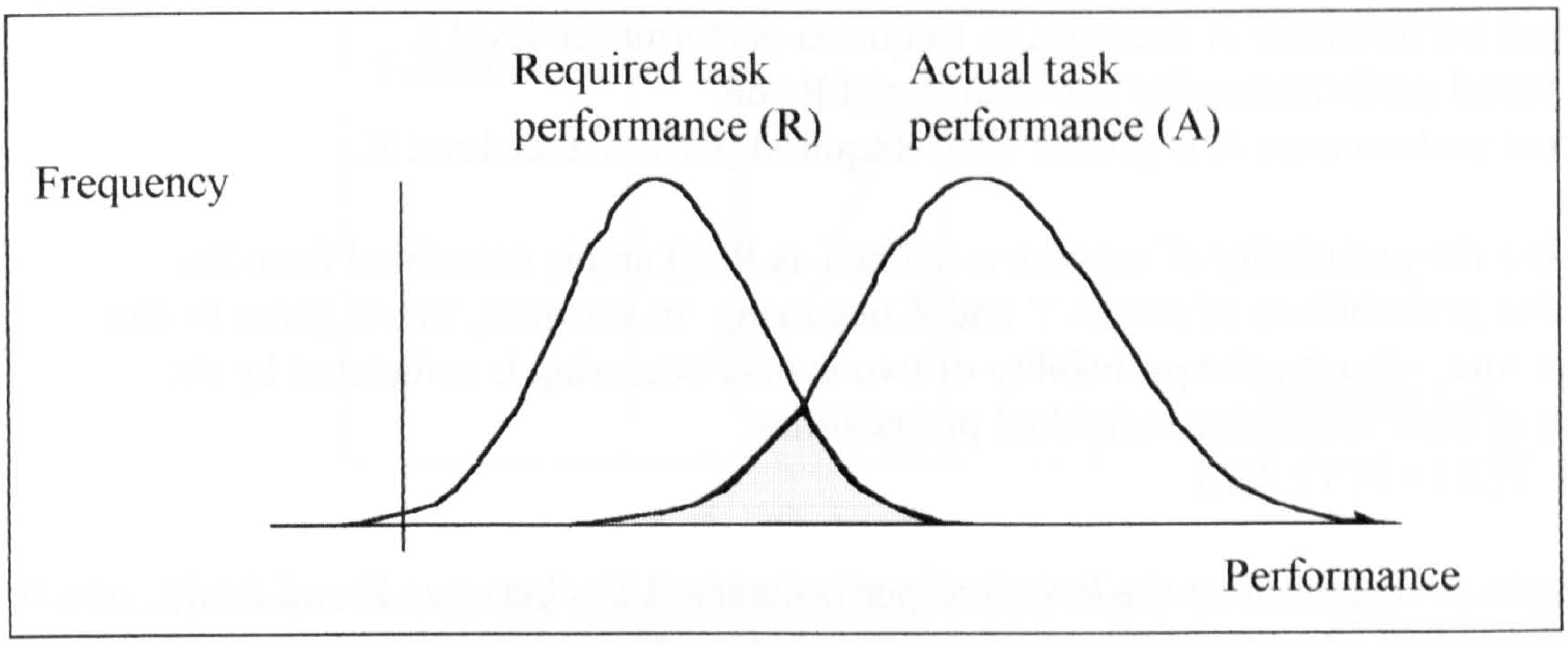
Figure 19 represents the characteristics of the distributions obtained at time x.

Figure 19: Distributions of actual performance and required performance at time x



At this point in time, there is very little overlap between the two graphs. Therefore there is a minute probability that the actual task performance (task progress) will equal the required task performance (distance to be achieved) at time x. This use of probability distributions that change over time is based on the limit state concept by Strutt (1995). Figure 20 represents the characteristics of the distributions obtained at time y.

Figure 20: Distributions of actual performance and required performance at time y



Now there is some overlap of the distributions. This indicates that although it is not definite, it is probable that the actual task performance (task progress) is equal to the required task performance (distance to be achieved). The uncertainty surrounding each value has given rise to a probability that the task will be achieved rather than discrete values of "task not achieved" or "task achieved". For example, if the actual task performance (task progress) tends towards the upper limits of its distribution and the required task performance (distance to be achieved) is at the lower limits of its distribution, it will fall within the shaded area. This means that the required task performance will be achieved (equalled by the actual task performance). However, consider how the graphs would appear if there was greater certainty about the size of the distance to be achieved and the task progress rate. This would make the dotted lines shown in Figures 17 and 18 closer to the solid lines. Consequently, this would decrease the breadth of the distributions in Figures 18, 19 and 20 - probably removing the overlap shown in Figure 20. This relates to the concept of reliability (Strutt 1995), which will be further explained through the use of the mathematical equations upon which the original Task Performance Resource Constraint Model was based. These will be described in more detail in the next section.

5.3.3 THE MATHEMATICAL BASIS OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

In terms of mathematical formulae, it is first necessary to simplify the concept of "probability of success" by calculating the probability of success of the actual performance (A) when the required performance (R) is a known, measured value. Firstly the Required Performance R is represented as a distribution from R to R+dR (where dR tends to zero). The use of a distribution at this stage facilitates calculation of the probability of success when Required performance (R) is represented as a probability density function - as will be described later. The Probability of Success is represented by the Actual performance (A) being greater than the Required Performance (R).

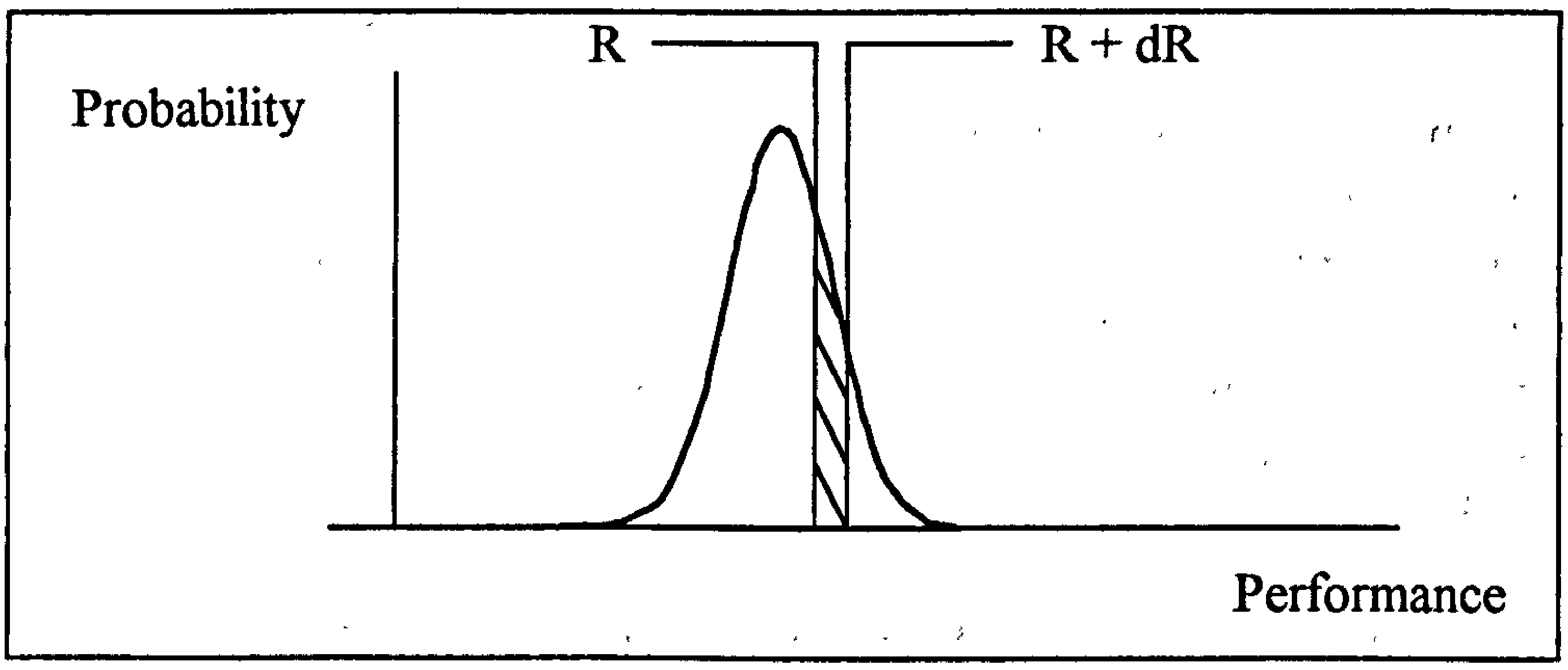
For this, the logical concept, IF Y AND Z, THEN X can be used.
Where X, Y and Z are defined as:
X: Actual performance A succeeds at Required performance level R.
Y: Required performance lies between R and R+dR
Z: Actual performance A is greater than Required performance level R.

Therefore the probability of success is defined as P(X) and is calculated from the respective probabilities of events Y and Z occurring. In statistics, this is given by the product rule, whereby the probability of two events occurring is calculated by the product of their respective individual probabilities.
That is, P(X) = P(Y).P(Z)

P(Y) is the probability that the Required performance R lies between R and R+dR, which is written as P(R, R+dR). In the graphs shown below, this is represented as a probability density function to represent the range of possible values.
P(Y) = P(R, R+dR) = f(r).dr

f(r)dr is the term that is used to calculate the area beneath the curve corresponding to the Required performance (R). This is the probability that R is a particular value obtained from a distribution of possible Required performances - as shown in Figure 21.

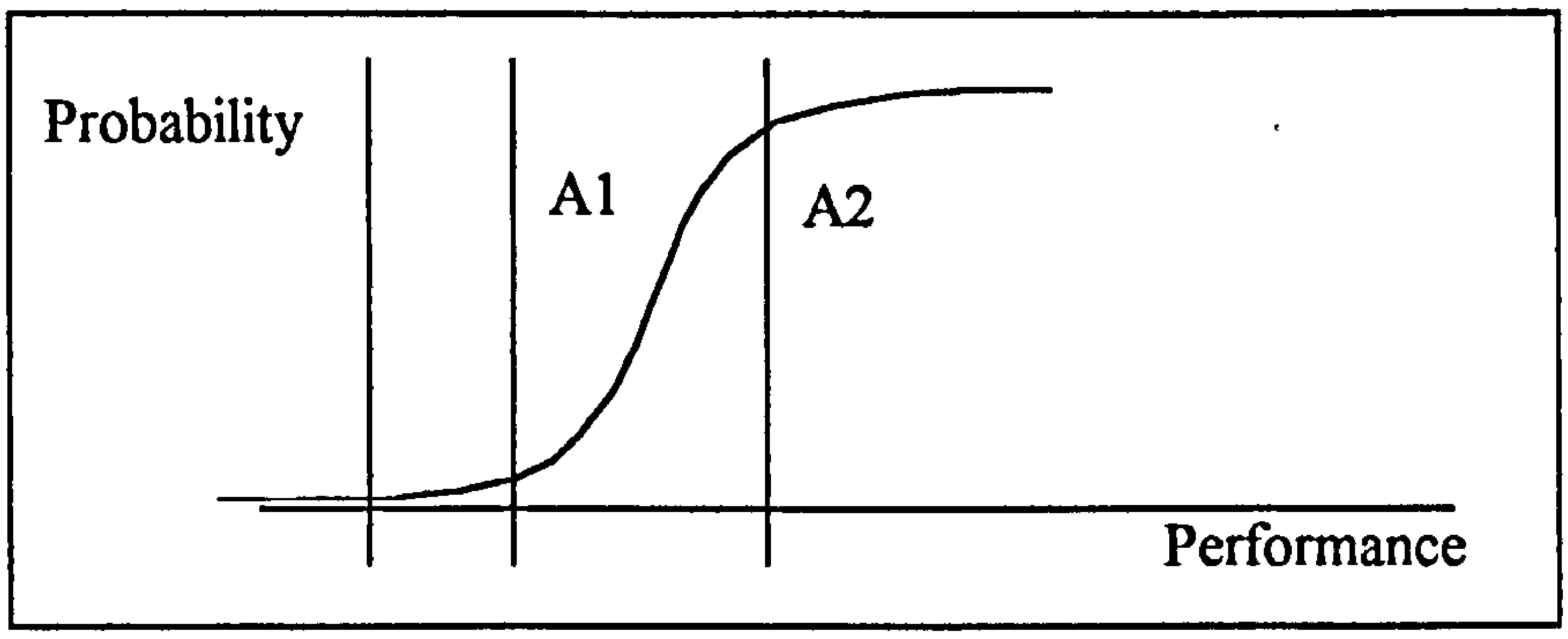
Figure 21: Representation of Probability (Y)



P(Z) is the probability that the actual performance (A) is greater than the required performance R (A>R). As this function represents the probability that one value is greater than another value, it can be represented as a Cumulative Frequency Distribution.

As shown in Figure 22, A1 is relatively low in comparison to the distribution. This indicates that it is very unlikely that the actual performance will exceed the required performance therefore indicating failure in the task. However, at A2, it is probable that the actual performance will exceed the required task performance therefore resulting in success in the task.

Figure 22: Representation of Probability (Z)



The mathematical formula for the probability is obtained from the calculation of the area bound by the curve, which is found by integrating the formula of the curve between the origin and L as follows:

$$P(Z) = P(A>R) = {}_{0}\int^{L} g(A)da$$

Given that P(X) = P(Y).P(Z),

$$P(X) = P(A>R).P(R, R+dr) \ = f(R)\ {}_{0}\int^{L} g(A)da$$

This formula considers the case for a specific known value of Required performance R. Therefore; this has only derived the formula for the probability of component failure for this Required performance level. If it is necessary to establish the formula for probability of success for ANY value of required performance in the distribution, the whole range of possible values of R must be included in the formula. This involves using the integral of the formula for R, R + dr.

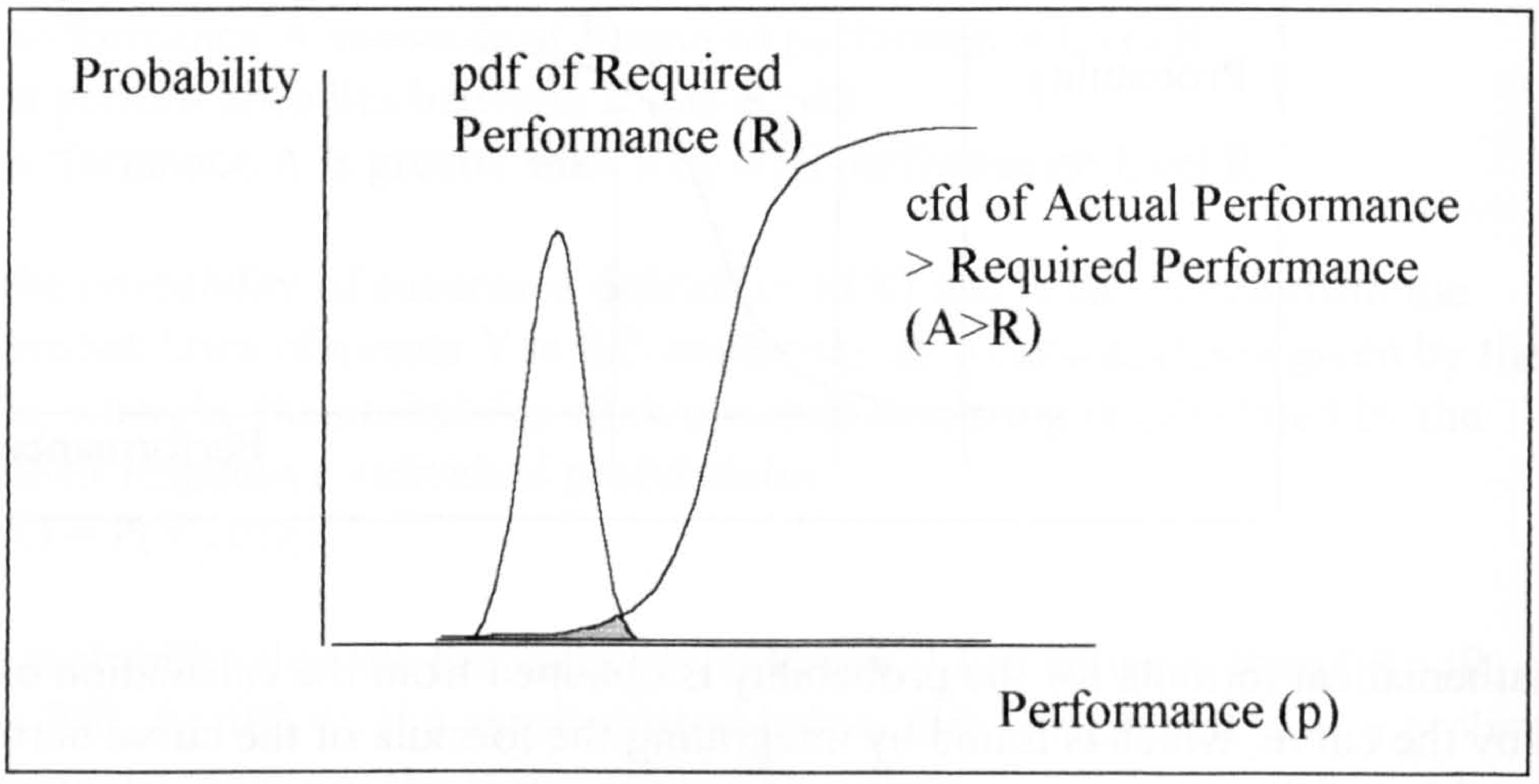
$$P(F) = {}_{-\infty}\int^{\infty} f(R)\ [\ {}_{-\infty}\int^{1} g(A)da\ ]\ dr$$

This is abbreviated as:

$$P(F) = {}_{-\infty}\int^{\infty} f(R).G(P)\ dp$$

Combining these probabilities results in the graph shown in Figure 23. This is also comparable to the graphs shown in Figures 19 and 20.

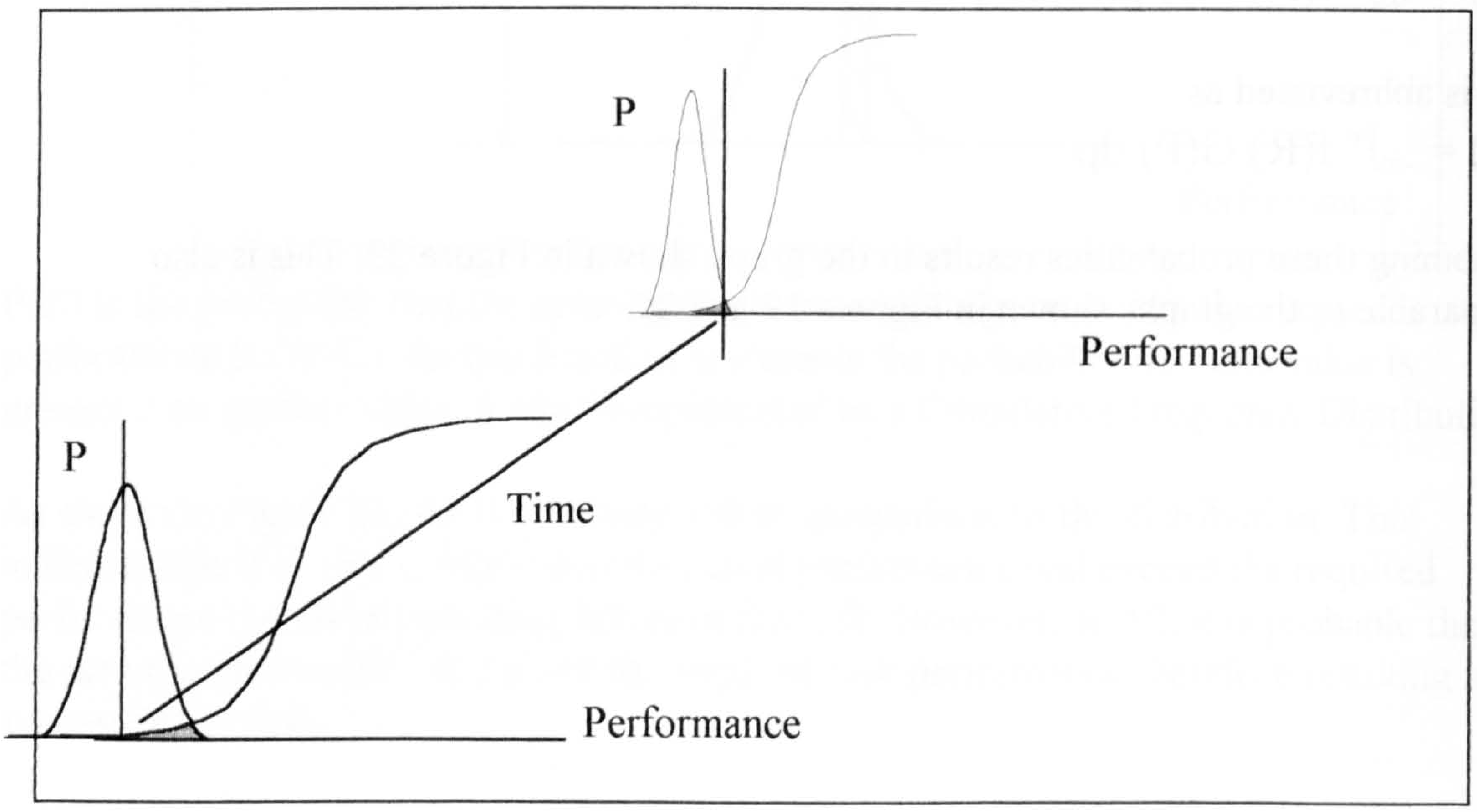
Figure 23: Combined probability of success based on distributions of actual performance and required performance



The overlap between the two curves shown in the graph above represents the probability of success. Note that if the distribution of required performance was increased, the overlap would be greater and hence the probability of success would increase. If the distribution of required performance was decreased, then the overlap (and consequently the probability of success) would be smaller.

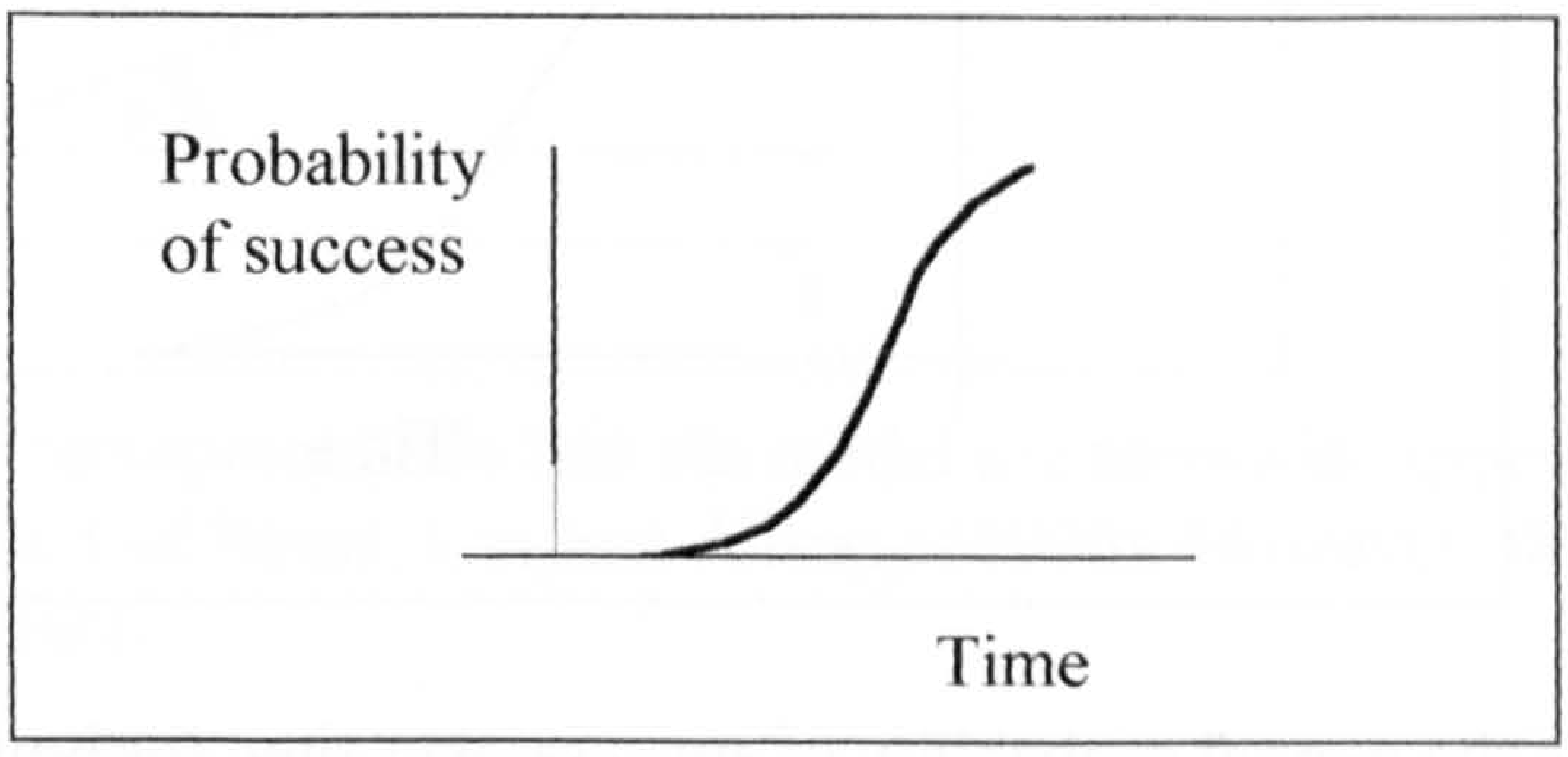
However, there is another factor be considered. As shown earlier, actual performance changes over time - usually increasing towards the required performance. Therefore in mathematical terms, this requires the use of another axis to represent change over time. As shown in Figure 19, there is initially no overlap. However, as time progresses and actual performance improves, this overlap occurs. This can be shown in Figure 24.

Figure 24: Performance change over Time



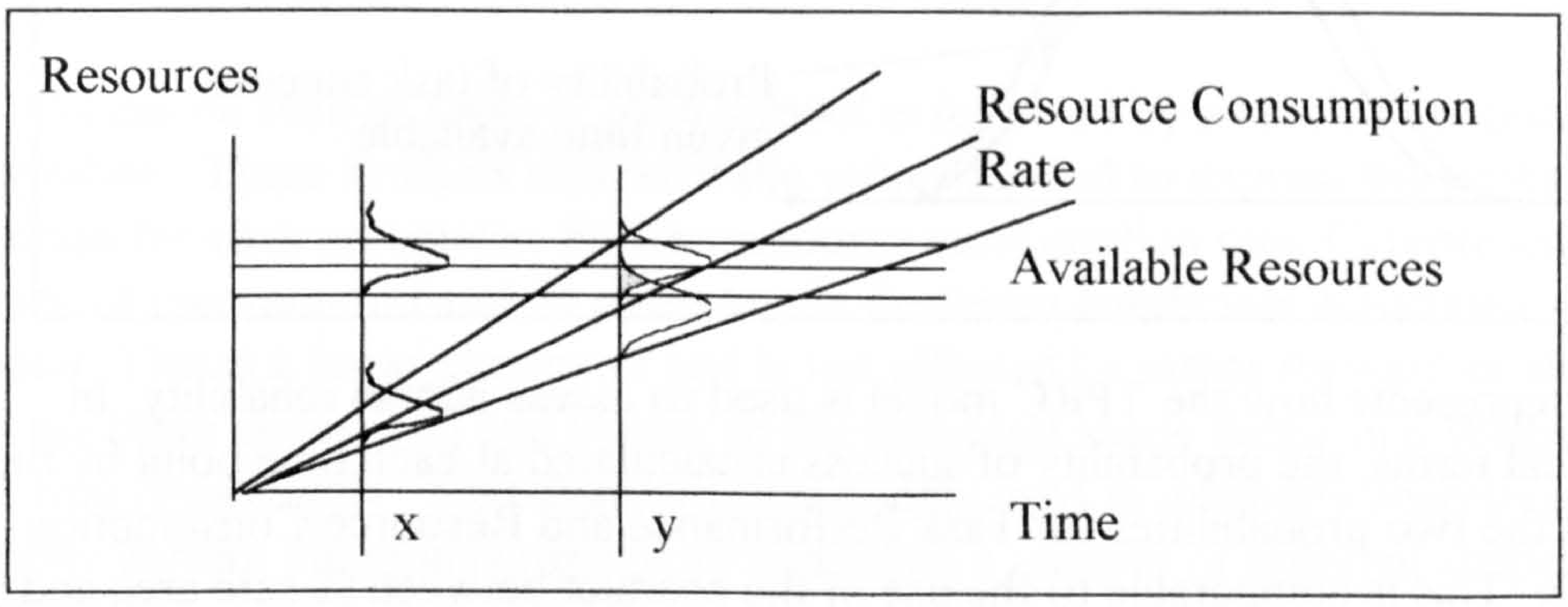
The areas bounded by the curves R and A>R (as shown in Figure 23) give the probability of success. Over time, the increasing actual performance results in an increase in the probability of success. If the probability of success is plotted with respect to time, a graph similar to that shown in Figure 25 can be obtained.

Figure 25: Probability of Success Curve from comparison of Actual Performance with Required Performance



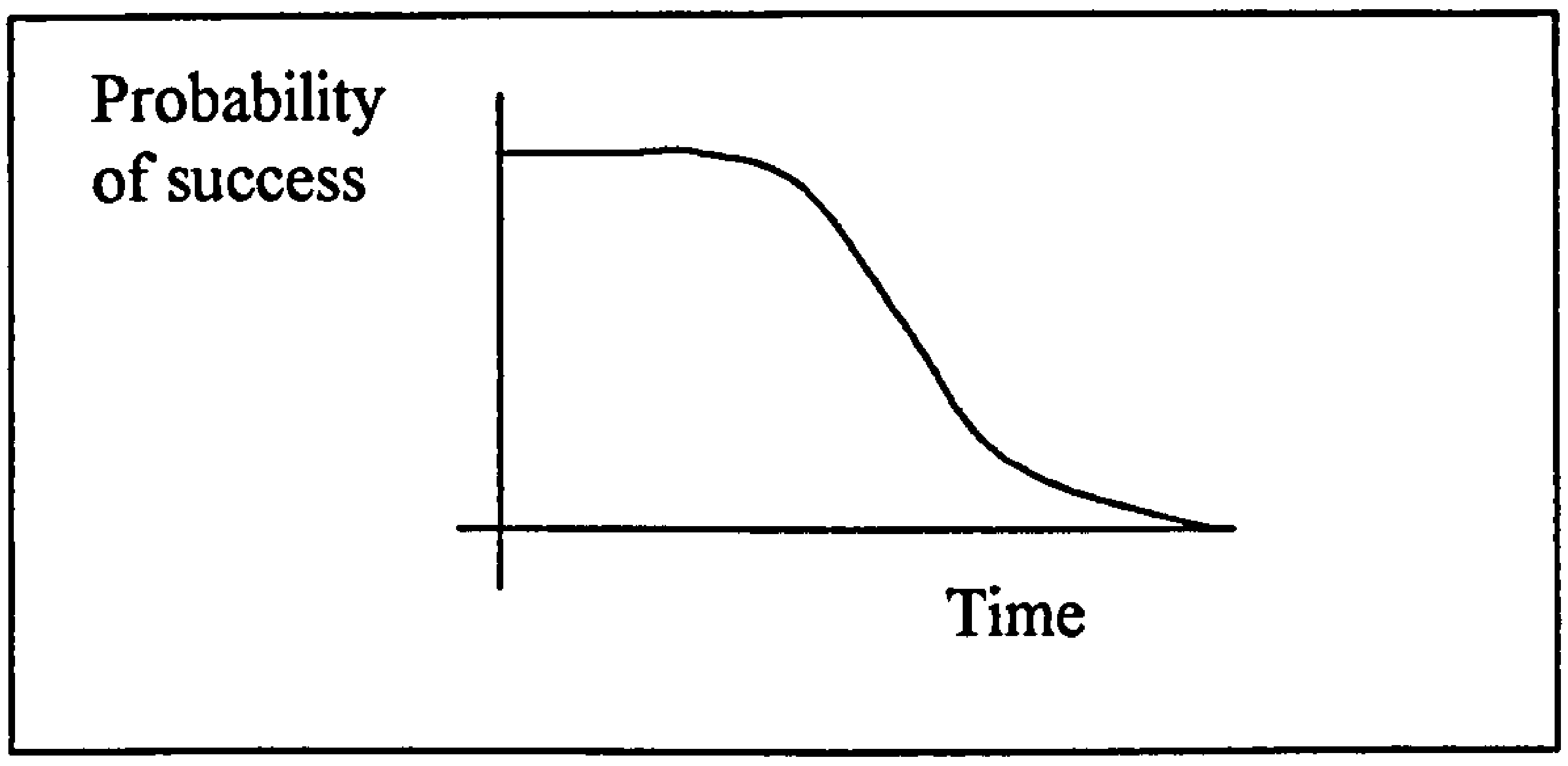
However, emergency management performance has another feature, which has not been mentioned for some time - the concept of available time (or available resources). Modelling the time or resources can be carried out using the same process as was used to model the task performance. There are resources available (the upper limit of the resource consumption) and a resource consumption rate - where resources are consumed over time. Both parameters may have uncertainties associated with them. This can be shown in Figure 26, which is comparable with Figure 18.

Figure 26: Emergency Management task performance graph showing probability distributions of resource consumption rate and available resources



However, this concept differs from the Actual Performance - Required Performance graph in that an overlap between the two distributions represents the event of running out of available resources. This therefore would result in failure. Therefore as time increases, the overlap between the two distributions increases in probability. If we take the probability of success to indicate "having available resources", this results in the graph shown in Figure 27.

Figure 27: Probability of Success Curve from comparison of Resources used with Available Resources



Therefore the overall probability of success over time (as both resource consumption rate and task progression rate can be compared to the time axis) can be represented by the area underneath the two curves as shown in Figure 28. This is similar to the HRA methods described in Section 2.4.4.2.8.

Figure 28: Probability of Success in Human Performance Tasks

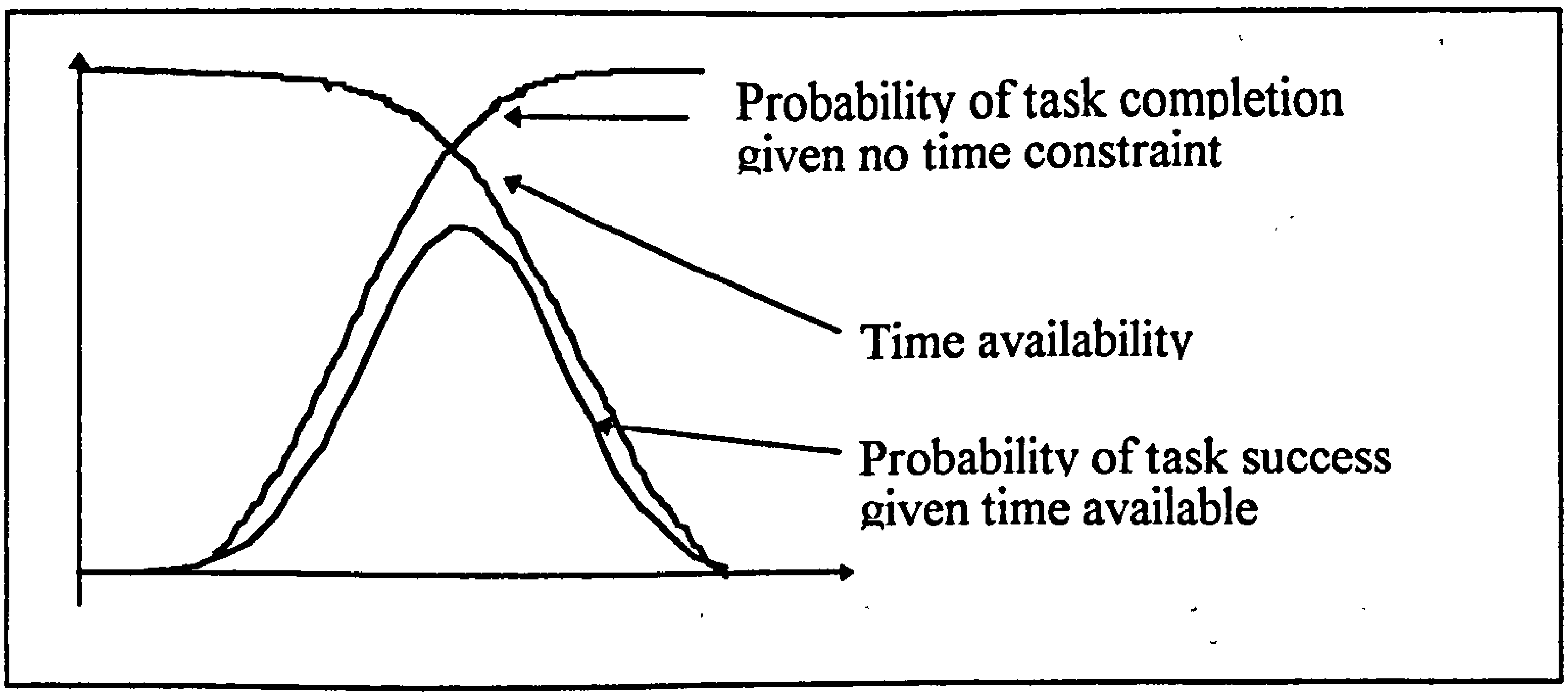
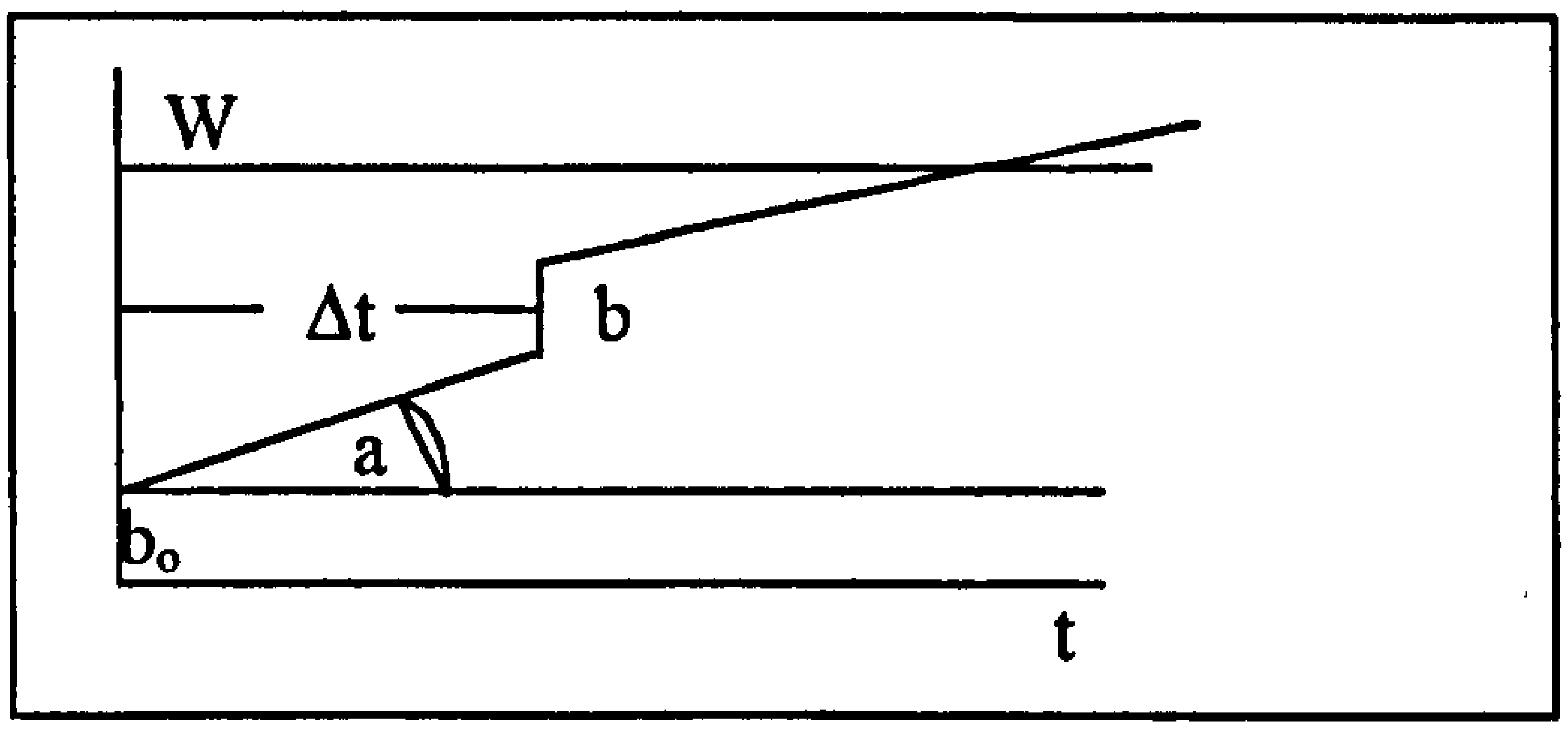


Figure 28 represents how the TPRC model is used to assess human reliability. In mathematical terms, the probability of success is calculated at each time point by the product of the two probabilities for Task Performance and Resource Consumption respectively. This is comparable to the use of the product between % safe area and % people evacuated as used in the desktop simulation. In the TPRC model, this is calculated by a computer program. Some of the terms that were used in the original TPRC computer program are shown in Figure 29 and are comparable to the graphs shown in Figures 15 and 16.

Figure 29: Task Performance Model showing terms



The formulae used to incorporate this into the model are shown in Appendix 4 and are quoted from Appendix 1 of Strutt, Loa and Allsopp (1996). However, the parameters are shown here in Table 6.

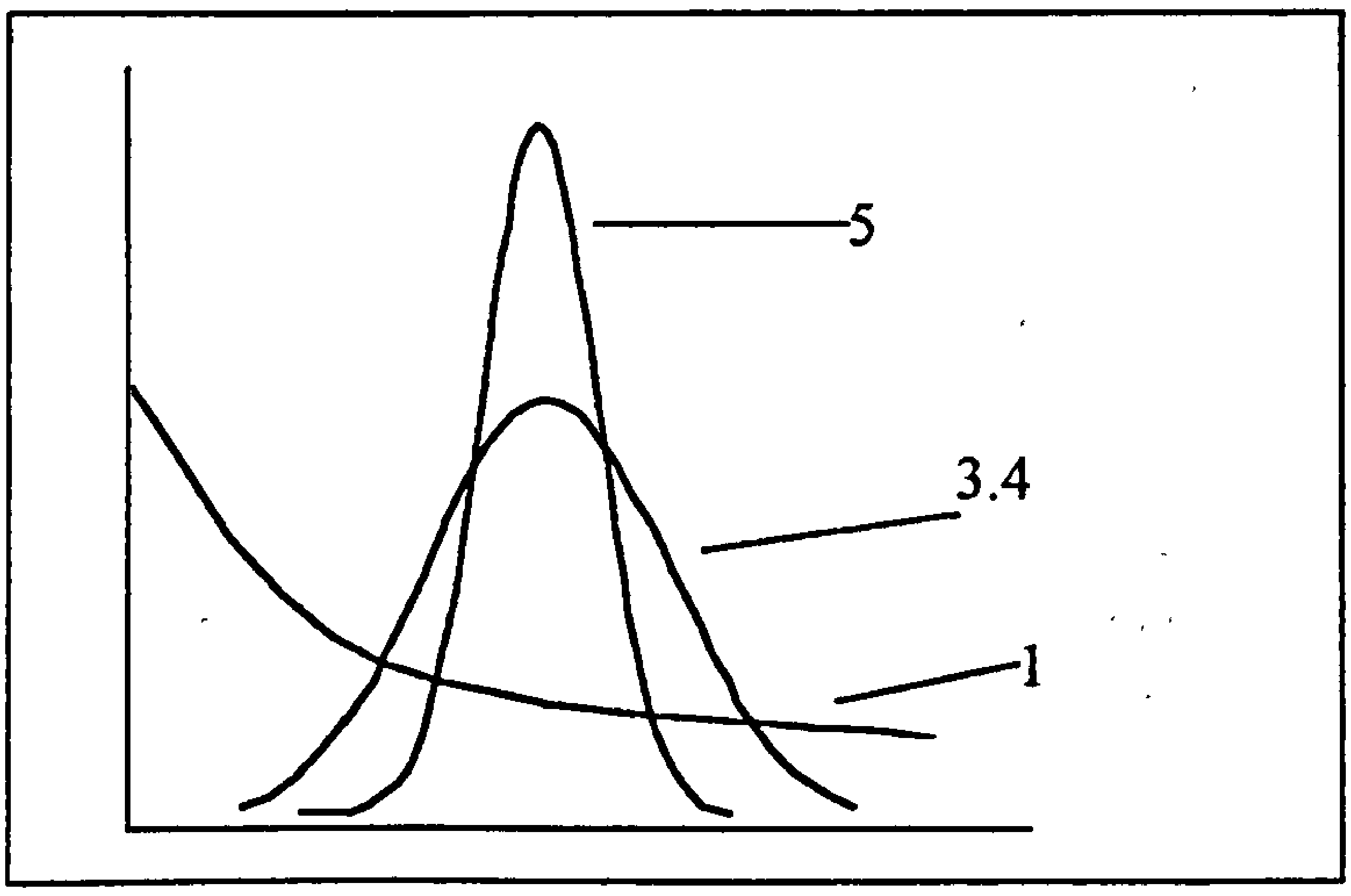
Table 6: Parameters used in the Task Performance Resource Constraint Model

MODEL PARAMETERS	SYMBOL
Linear work rate / Learning rate	$a\ (\eta,\beta)$
Initial level of knowledge / Head start	$b_o\ (\eta,\beta)$
Jumps in knowledge / Short cuts	$b\ (\eta,\beta)$
Time between work rate changes	$\Delta t\ (\eta,\beta)$
Common cause factor	$k\ (\eta,\beta)$
Task requirement / task standard	$W\ (\eta,\beta)$
Resource consumption rate	$r\ (C_b, dc)$
Initial resource capacity	$X(\eta,\beta)$

As can be seen in Table 6, each symbol is followed by a bracket containing two other symbols. These symbols represent the values needed to express the probability distribution for each parameter. For the resource consumption rate, C_b represents the basic rate of consumption and dc refers to the deviation coefficient associated with this parameter. This is a linear parameter and is not affected by jumps forward or short cuts. For all the other symbols, η and β refer to the scale and shape factor in a Weibull distribution respectively. This distribution is widely used in reliability analysis as its probability density function is capable of exhibiting a number of different shapes (Loa 1997 Chapter 3 p.13 & Appendix B).

In brief, the scale factor of a Weibull distribution is similar to the mean value - it gives an indication of the scale of the distribution. The shape factor is more complicated - values equal to or less than 1 tend towards a random value, the value 3.4 approximates to a normal distribution and values equal to or greater than 5 are strongly deterministic - showing a sharp peak around the scale factor. Examples of these are shown in Figure 30 and the relevant equations used to define the Weibull function are shown in Appendix 4.

Figure 30: The Weibull Distribution



The next section discusses the inputs, processing and outputs of the original TPRC model.

5.3.4 THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL PROGRAM

5.3.4.1 Inputs to the Original Program

The inputs to the program are based around the parameters in Table 6 with a few additions. The actual format of the input is given in a text file similar to that shown in Figure 31.

Figure 31: Input to the TPRC Model Program

W (η,β)	Number of data points
a (η,β)	Frequency of data point collection
b (η,β)	Number of Iterations
X (η,β)	b_o Initial level of knowledge (η,β)
r (C_b,dc)	Δt, Work rate change (η,β)
	k, Common cause factor (η,β)

Many of these values are represented in Figure 29. For example, if W is given the values of 100, 6.7, this indicates that there is a small amount of variance surrounding the value 100. This would be used when the task involves moving 100 metres or can be used to represent a percentage of task completion.

a (η,β) represents the task speed. If this is given the values 1, 1.0, this indicates that the speed is 1 unit of task per unit of time but there is a larger amount of variance about the value. This may be 1 metre per second, 1 mile per hour etc.

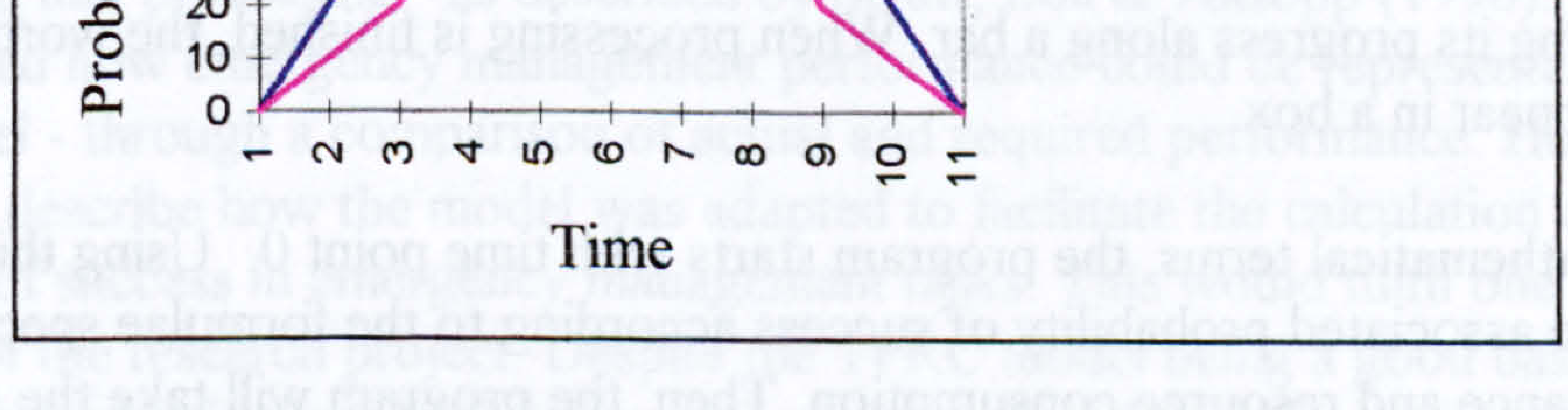
b (η,β) represents a jump forward or a short cut. Therefore, this would indicate progress in excess of the normal speed defined by "a" and is defined by a vertical line on the task performance graph shown in Figure 29. $b_o(\eta,\beta)$ represents a jump forward at the beginning of the task - indicating a head start.

X and r are linked parameters as they relate to resources available and the resource consumption rate. These may represent available air or water (and therefore breathing rate or speed of water use). They may also be represented as time, whereby the resource consumption rate would have a one to one relationship with the time axis.

The number of data points that are collected when outputting the final data are shown in the second column. This indicates the number of probability values that are selected - with respect to time. Given that the final output of the model is a probability of success curve, a larger number of data points in the same length of time (along the x axis) results in a smoother, more accurate curve. However, due to the memory limitations of the computer, this was given an upper limit of 200 points. Therefore, there would be 200 pieces of data recorded for each calculation.

The next value is linked to this concept as it specifies how often a data point is collected. For example, this may be every time unit (0,1,2,3) or every 2 time units (0,2,4,6) etc. Sometimes, the task completion and resource availability are expected to take over 200 time units. If 200 data points were recorded for every time unit, the crucial data would not be recorded by the analysis. In this case, we must sample over a greater duration so must stretch out the time between the collection of points. Therefore this value may be 2 (collecting points at 0,2,4…400), 3 (collecting points at 0,3,6…600). Ideally this should be as low as the data demands - to get the best possible level of accuracy in the curve - as demonstrated by Figure 32, comparing the same data using 3 points or in 11 points respectively.

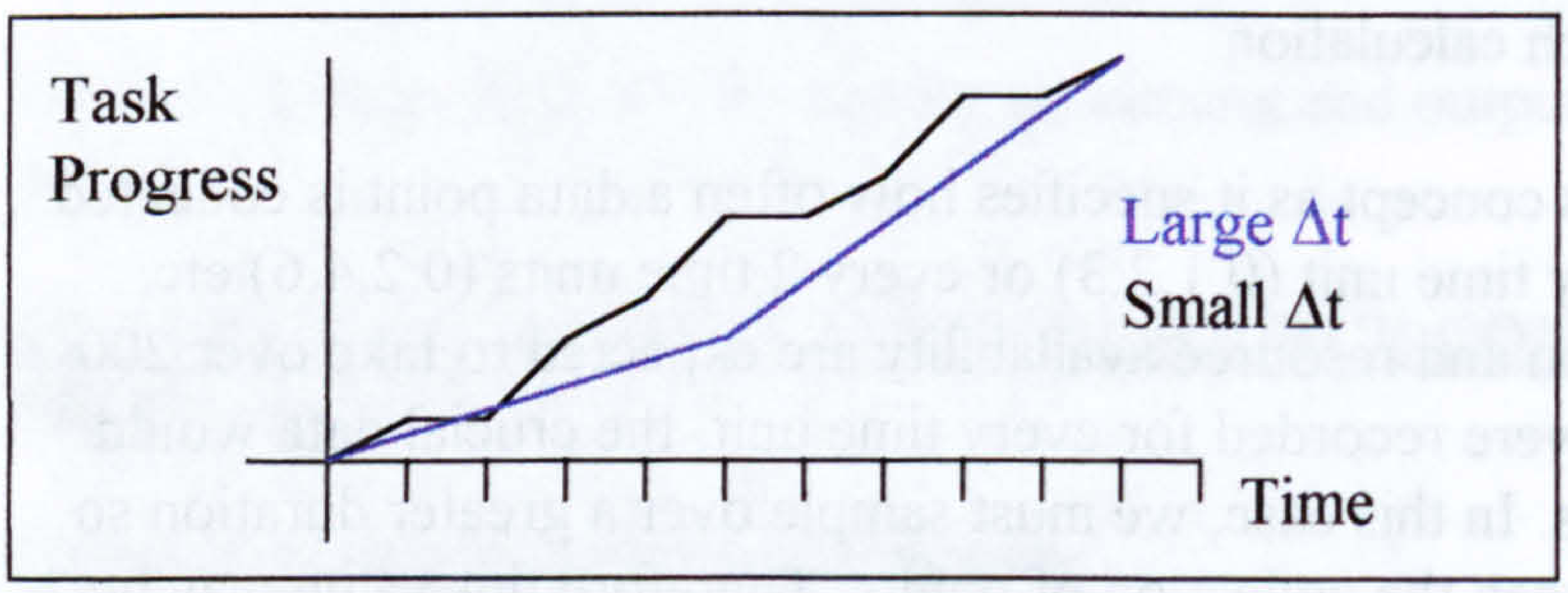
Figure 32: Demonstration of the Impact of Number of Data Points in Probability of Success Functions



The next value reflects the number of Monte Carlo iterations to be carried out. For each iteration, the program will run through the task performance and resource constraint variables - choosing a value from each distribution and eventually producing a probability of success curve with respect to time. The more times that the program runs through this procedure, the more variations that will be incorporated into the final values - therefore producing a more accurate curve. This is limited by hardware capabilities more than software and it is found that the higher the number, the longer the processing takes.

Δt reflects how often the work rate "a" changes within its distribution over time - that is, the consistency of the speed. A small value indicates that the work rate changes often within its distribution, only working for a small sample of time before the rate is chosen again from the distribution. A large value indicates that there is a large time value before the speed changes - indicating a more consistent level of speed. These can be demonstrated in Figure 33.

Figure 33: The Impact of Δt on Work Rate



Note that, as shown in Figure 33, just because the rate of change of work is faster for the small Δt does not mean the overall work progress is faster.

k can affect the overall speed of the task. This has been compared to motivation. If given a scale factor of 1 with a highly deterministic shape factor, this will not affect the other parameters. If given a scale factor value greater than 1, this indicates that the person doing the task is more motivated and therefore, works quicker, increasing the task speed, "a".

5.3.4.2 The Processing of the Original Task Performance Resource Constraint Model Program

Once these values have been inputted into the text file as appropriate, the file is saved and the program is loaded. This involved a Delphi (Visual Pascal) program - with a button labelled "Run". On clicking on this with the left mouse button, the program will run - indicating its progress along a bar. When processing is finished, the words "run complete" appear in a box.

In mathematical terms, the program starts with time point 0. Using this, it calculates the associated probability of success according to the formulae specifying the task performance and resource consumption. Then, the program will take the second time point and repeat the process. The probability of success is calculated again and so on until the specified number of data points (up to 200) has been collected. The program will repeat this whole process until all the iterations have been carried out and then, for each time point, will give the average value produced. This will then output the values of the time points and the probability of success associated with each one. This result is shown in the next section.

5.3.4.3 The Outputs from the Original Task Performance Resource Constraint Model Program

The program outputs the data to a text file, in which it displays two columns of data. These can then be loaded into a spreadsheet (e.g. Excel) to allow graphs to be plotted. The data obtained takes the form of Table 7.

Table 7: Output from the Task Performance Resource Constraint Model Program

1.0	0.00
2.0	0.03
3.0	0.09
4.0	0.18
5.0	0.30
6.0	0.44
7.0	0.59
8.0	0.72
9.0	0.82
10.0	0.90

The column on the left represents the time points at which the data was taken. So if the frequency of data collection had been 4.0, the values reading down this column would be 4.0, 8.0, 12.0 etc. The values in the right column represent the probabilities of success associated with that point in time. The probability of success has been calculated considering the probability of task completion as well as the probability of still having available resources as shown in Figure 29. This concludes the description of the original model as designed by Strutt, Loa & Allsopp (1996).

5.3.5 ADAPTATIONS OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL FOR THIS PROJECT

5.3.5.1 Introduction

Up until this point, this section has only described the original model's development and processing - as described by Strutt, Loa & Allsopp (1996). Section 6.2.2 outlined how emergency management performance could be represented in the TPRC model - through a comparison of actual and required performance. However, this section will describe how the model was adapted to facilitate the calculation of probability of success in emergency management tasks. This would fulfil one of the main objectives of the research project. Despite the TPRC model being a good basis for a performance evaluation mechanism as outlined in Section 5.3.2, there were a few changes that were necessary before this could be achieved.

5.3.5.2 Removal of Motivational Element, k

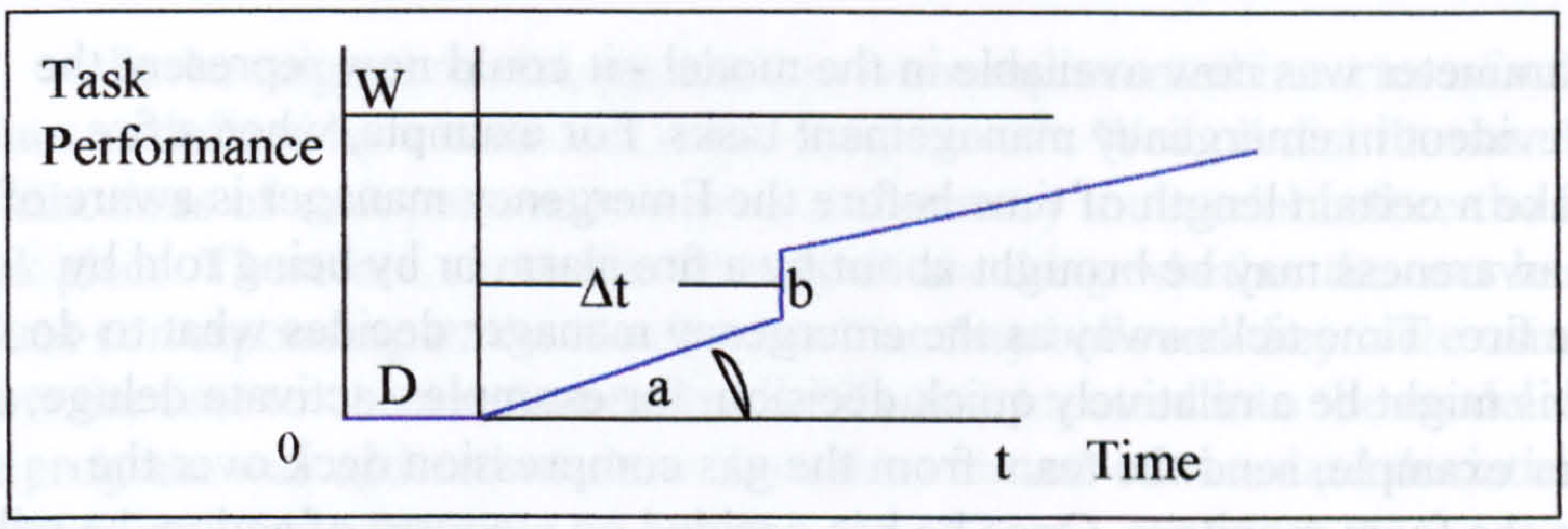
Firstly, the current emphasis of the model was based on a positive attitude towards task completion. For example, as stated in the previous section, the common cause factor, k, had to be a positive value greater than 1. The concept behind this was the idea of performance increasing due to high motivation but was a late addition to the original model concept - only being added in Loa (1997). As all the inputted values were required to be positive, it could only increase task performance. In an emergency, there are many factors that are likely to decrease task performance, such as confusion or stress; therefore, this was taken out of the equation returning it to the original form used in Strutt, Loa & Allsopp (1996).

5.3.5.3 Representation of Physical Parameters and Incorporation of the Delay Concept

At the initial stage of developing the TPRC model to measure human reliability, it was thought that the critical factors would be "required knowledge" and "available knowledge" (rather than "required performance" and "actual performance" as illustrated earlier in the text). However, assessment of emergency management indicated that although it relied on cognitive decision-making, it was the observable physical actions that provided the impact on the risk. Although deciding on a plan of action was an important objective; unless the plan was implemented, it would have no impact on the outcome of the emergency. Therefore, the main function of the TPRC model in evaluating emergency management skill would be to assess the probability of success in the physical tasks.

Using the TPRC concept to represent emergency management tasks, the mitigation of the emergency management team is defined in terms of task progress and the escalation is defined in terms of resource consumption. On re-examination of the task performance aspect of the TPRC model (as shown in Figure 29), it was notable that although there were facilities to represent jumps forward in progress or an initial "head start", there was no method of representing the reverse - a delay in the initiation of the task. In a real-life or simulated emergency, it is usual that the escalation (or resource consumption) starts before any of the mitigation activities (or task progress). This could only be represented by a step backwards (-b), a "jump forward" in the initiation of resource consumption or a new parameter indicating a delay on the time axis before task progress started. Therefore, the simplest method was to represent this concept as delay parameter D (η,β) as represented in Figure 34 (as adapted from Figure 29). (Though, it should be noted that as described in Section 5.3.5.4, η and β were changed as the input parameters to be the mean and x, the coefficient of variation (σ/μ).

Figure 34: New Task Performance Model showing Delay Term



Therefore task performance rate and overall performance achieved would have a value of 0 (represented by the blue line) until the delay had been completed - that is, the physical activities had begun. Like all the other values used in the model, D has a distribution value associated with it. Therefore, this can represent the variance or uncertainty associated with the delay value. In terms of the program's use of the parameter, each iteration of the Monte Carlo simulation will choose a value of D from the distribution specified. It will then treat the resource consumption rate as before (starting the count at t=0) but will not start to progress the task performance parameter until t has reached the value of D. The task performance rate will then be calculated as in the previous version of the program. On the next iteration, another value of D will be chosen from the distribution and this will be repeated until all iterations have been processed.

In mathematical terms, the equation shown in Appendix 4 defining the original TPRC model gives the Task Progress rate as follows:

$$\mathbf{W(t) = \sum_{i=1}^{n}(a_i \,.\, \Delta t + b_i) + a_{n+1} \,.\, (t-t_n)}$$

To incorporate the delay factor, this was changed to be:

$$\mathbf{W(t) = \sum_{i=n_D}^{n}(a_i \,.\, \Delta t + b_i) + a_{n+1} \,.\, (t-t_n)}$$

Where $n_D = D/\Delta t$ (n_D is an integer and Δt is the time step for the summation process)

As consistent with the rest of the original program, D was chosen from the Weibull distribution at random with scale parameter η and shape parameter β and the values were given by:

$$\mathbf{D = \eta . (-\ln(R_i))^{1/\beta}}$$ where R_i is a random number between 0 and 1.

In terms of the rest of the equation, the resource consumption rate was unaffected, starting at the origin (i=1).

Given that this parameter was now available in the model - it could now represent the delays that were evident in emergency management tasks. For example, when a fire starts, it would take a certain length of time before the Emergency manager is aware of it. This situation awareness may be brought about by a fire alarm or by being told by someone near the fire. Time ticks away as the emergency manager decides what to do about the fire. This might be a relatively quick decision, for example - activate deluge; or more complex, for example, send the team from the gas compression deck over the bridge to activate the foam monitors. Once he has decided on a course of action, he will then need to communicate it - this may involve telling the control room team to flick a switch or may involve passing on messages to a number of different parties. There is then another delay until these people react to the orders and follow them. As far as the fire is concerned, there has been no change up until the point the team act upon it. Although in strategic terms, much planning may have been carried out in this time, no progress concerning the physical emergency has been made and so using the TPRC model, this time is all included in terms of the delay parameter.

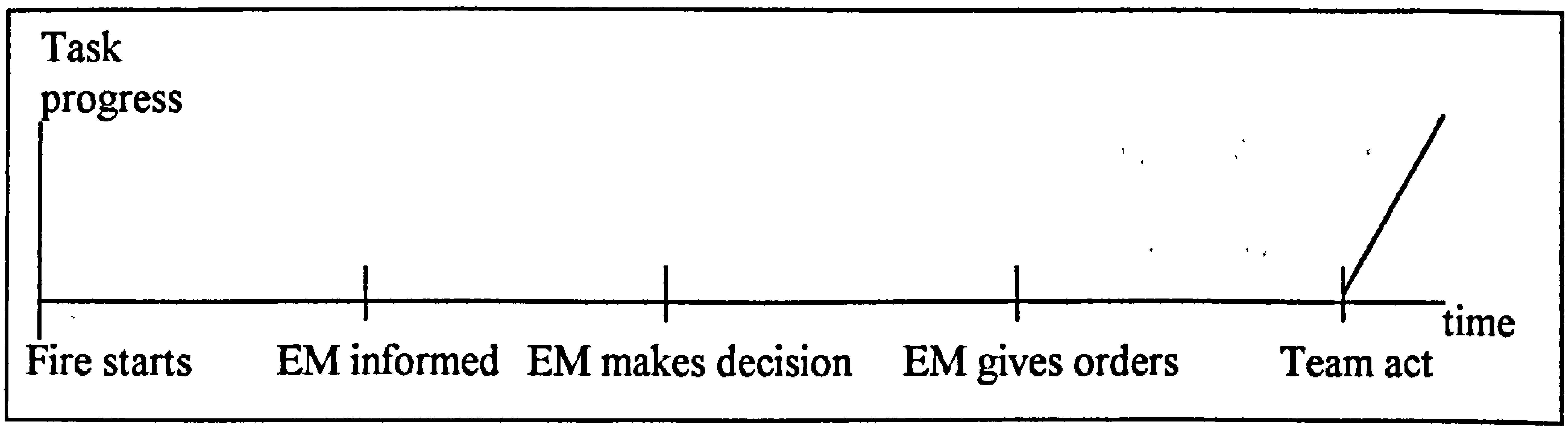
This concept is called SADCAR, whereby the phases from the initiating event are described as:-

- Situation Awareness
- Decision
- Communication
- Action, and
- Response.

These are as described in the example. The term "response" refers to the system's response to the team's action. That is, if deluge was activated, was the fire put out or diminished in any way or was it as powerful as ever?

Therefore, the delay term shown in Figure 34 can be described in more detail using Figure 35.

Figure 35: Representation of Task Performance Graph for Emergency Management Tasks



Other examples of the delay parameter are described in Section 5.4.2.1.

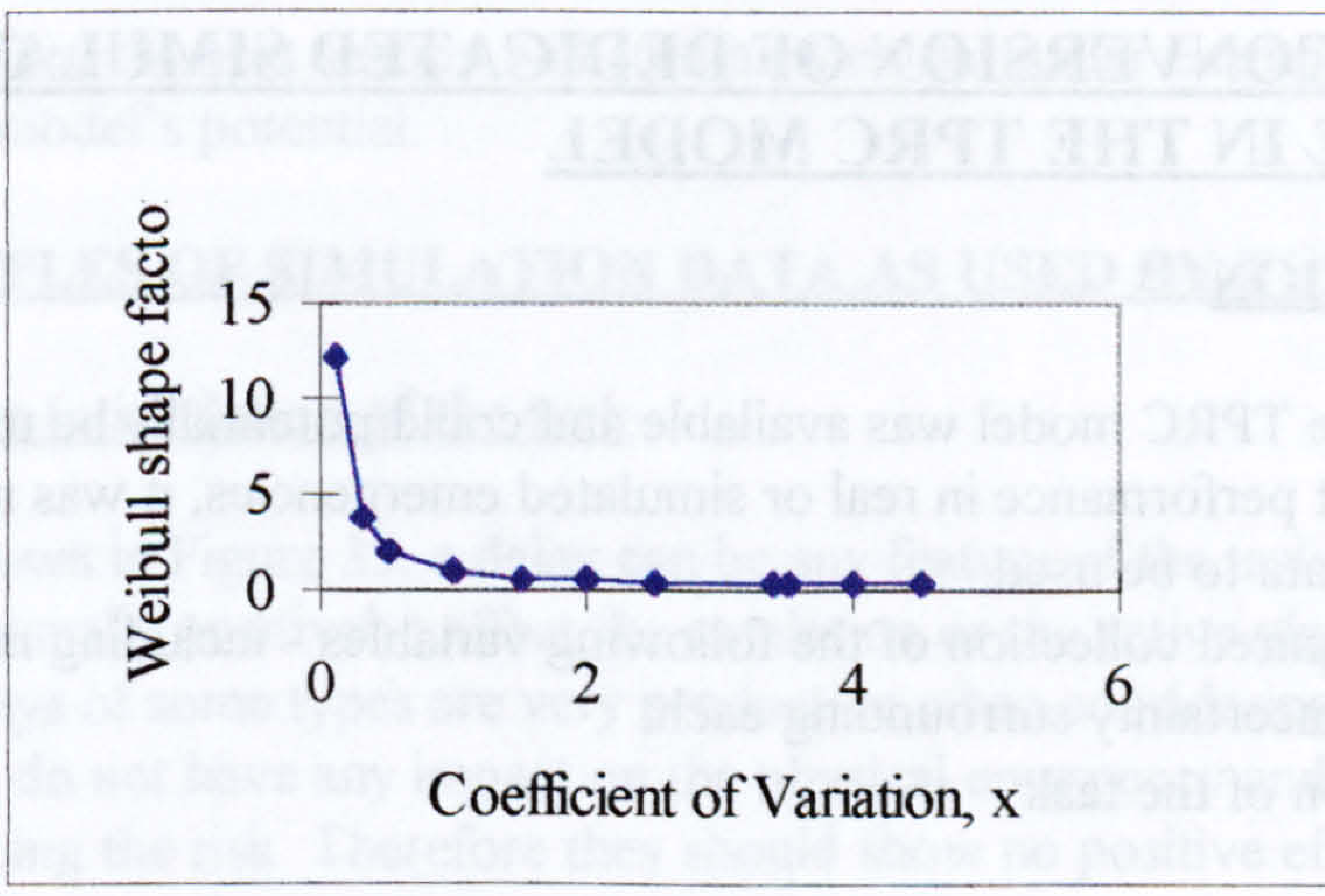
5.3.5.4 Use of the Coefficient of Variation

In the original model, parameters were represented in terms of a distribution of values as defined by a scale and shape function of a Weibull distribution. However, the distributions of each parameter were not shown by the model before the final processing took place. Therefore, there was no way of checking whether the user had put in the values corresponding to the distribution that they believed they were using. Therefore, to allow the user to check whether the distribution inputted into the model was as expected, the program was updated to show the values + and - 2 standard deviations of the mean for each inputted parameter.

Also, instead of inputting Weibull values, the model was adapted so that the user could input a mean value and a value, x, the coefficient of variation (σ/μ). This was added more for simplicity than any other reason. In general, the data obtained from the emergency management exercises gave strong indications of a mean value and implications of the variance surrounding it. It was less obvious to estimate the shape of the distribution. Therefore, it was simpler to describe these data in terms of a coefficient of variation. This was not expected to be a permanent change to the model but as an additional option to expand the model's capabilities - so that the user could input Weibull or coefficient of variation (or in the future other distributional parameters) values as desired.

The relationship between the value x and the Weibull shape factors are shown in Figure 36, and the equations linking these are shown in Appendix 4.

Figure 36: The relationship between the value x and the Weibull shape factor



Given that these changes were made, the listing of the final program is shown in Appendix 5 (Original program shown in Loa 1997). .

This concludes the section on adaptations made to the model in this research project. These were required to facilitate the analysis of the impact of emergency management on risk reduction. Therefore the following section will describe in more detail how the data were collected and adapted for input into the model including specific examples.

5.3.5.5 Independence of the Task Performance and Resource Constraint Parameters

During the research leading to the model development (described in Loa 1997), it was thought that the tasks considered in future research would involve dependence between task speed and resource consumption. The example used involves a diving task – where the quicker the task is carried out, the quicker the resources are consumed – in this case, volume of air. For this reason, there was a parameter "a" linking the calculation of the task progress rate calculation with that of the resource consumption rate. As stated in Loa (1997) and shown in Appendix 4, "This fractional increase in the rate of resource usage is dependent on the work progress rate through the parameter a. This dependency is assumed to be inversely proportional to a, hence the factor η_2 /a. This strict proportionality is moderated through a further random factor". The formula for the resource consumption rate included :

$$\mathbf{Cr_i = X.(1+2.R_4.dc.\ \eta_2 /a_i)}$$

However, during this research, it was identified that many emergency management tasks were independent. Also, where there was dependence between task and resource consumption rate, it could not always be established whether this relationship was "inversely proportional". Therefore, for simplicity – and in most cases, a more accurate representation of the relationship, the parameter ($\mathbf{a_i}$) was set to 1 – therefore ensuring independence of the two equations. This issue could be readdressed within the equation and the program for future research, as described in Section 10.7.1.2.

SECTION 5.4: CONVERSION OF DEDICATED SIMULATION DATA FOR USE IN THE TPRC MODEL

5.4.1 INTRODUCTION

Given that the TPRC model was available and could potentially be used to evaluate management performance in real or simulated emergencies, it was necessary to collect the relevant data to be used.
To run the model required collection of the following variables - including mean values and the variance or uncertainty surrounding each:

- Delays in initiation of the task
- Speed of the task
- Frequency of changes in task progress speed
- Task performance required
- Resources available to complete the task } which were used to determine the time
- Resource consumption rate } available

Ideally, the scenario content and timings should be designed based on realistic behaviour - of on-site emergency management teams, casualties and fire escalation.

However, these were not usually validated so collection of the real data was often useful in the modelling process. This included collection of design information on the installation and relevant equipment, human psychological, physiological and physical data (as shown in Chapter 6) as well as information extracted from the exercise. Given that the emergency manager and his team were attempting to manage the exercise as though it was real, their behaviour can be assumed to be a realistic representation of emergency management team behaviour. Further to this, as these exercises were used for assessment of competency in emergency management, it must be assumed that the emergency manager and his team were working to the best of their ability.

The behaviours that were observed in the scenario as occurring at a specific moment in time were assigned a deterministic value on input to the model (e.g. deluge is activated when the control room operator presses the relevant button). This can be described as a purely objective process. However, some behaviour is imaginary, and so is assigned a possible time within the possible time bracket and assigned a more uncertain value - giving a distribution of believable figures. For example, if at 05.00 minutes into the scenario, the medical team leave the control room and at 15:00 minutes, they report that they have located and are treating one of the casualties, it must be assumed that the casualties were located at some point in the 10 minute time period. However, the scenario organisation team does not normally record the exact point in time so this is assigned a mid-point value (e.g. 10 minutes) with a distribution not exceeding a width of 5 minutes on either tail. It is recognised that this choice of variance currently relies on a degree of expert judgment - which involves understanding of the events and tasks involved as well as knowledge of the mathematical processes occurring in the model. Therefore, the model is not entirely objective, which somewhat contradicts the purpose of the research. However, this issue will be discussed more in Chapter 7, when the problem is addressed through the concept of performance parameter data.

Therefore the next section will comment on particular examples of each variable to clarify the model's potential.

5.4.2 EXAMPLES OF SIMULATION DATA AS USED BY THE MODEL

5.4.2.1 Delays in initiation of the task

As shown in Figure 35, a delay can be any feature of the task that does not directly (and usually positively) affect the escalation or the active physical processes. Although delays of some types are very productive when considering the overall incident, they do not have any impact on the physical emergency and so they are not actually reducing the risk. Therefore they should show no positive effect on the probability of success in emergency management tasks.

Delays in action can be due to team strategy discussions, "time-outs", reading procedures or manuals, phone conversations, making tannoys or at the more negative end of the scale, panicking, crying or ignoring the current problems. Although the team strategy discussions and time-outs may result in a better response once they have been completed - while the team are engaged in conversation, the incident continues to escalate. The only circumstances where the communication actually affects the escalation of an incident is in a social emergency as opposed to a physical emergency - for example, terrorism, sabotage or bomb threats. In this case, the communication is considered to be an action but the reaction to such communication is dependent on the individual differences of the terrorist/saboteur, therefore is nearly impossible to model.

Delays are also caused by the time taken in making a decision. The longer an individual thinks about a problem, choosing options and running through some "mental simulations" - the longer the incident is left to escalate. Although the resultant decision may be a good one, it may be too late for it to have an impact. For this reason, Naturalistic Decision Making is promoted in emergency management training - resulting in quick and timely decisions based on good situation awareness and experiential pattern-matching (See Section 2.3.6.1 for comments on the Kaempf and Militello 1992 reference).

Similarly, delays could be used to represent multiple tasks. For example, if a system would only work after three different buttons have been pressed, the action of pressing the first two buttons can be represented as a delay. Until the final button has been pressed, the system will not be activated. This could be represented as the success in 3 separate tasks. However, as the individual button-pressing tasks do not produce an objective physical result, they do not have any impact on the eventual outcome of the emergency. Only the combination of 3 tasks would make a difference by starting a process that will produce an objective physical result. Therefore, these are grouped together as a delay.

Most of the delays that have already been discussed can be minimised so that they do not slow the emergency management process. These can include the design of technology and the careful planning of discussions or tannoys to ensure that all immediate actions have been initiated. However, there are some issues that will produce some delay no matter how efficient the emergency management team are. As shown in Figure 34, there is a delay before the team are aware of the problem, then delays before deciding on a plan of action and communicating this to the relevant parties. On receiving the communication, there is likely to be a delay before the action is initiated - depending on the complexity of the task and the preparedness of the individual. For example, if the task involves pressing a button in the control room, it is likely that the delay will be very small. If the task involves getting a medical team halfway across the platform with the relevant equipment, it is likely to take some time. The only way in which these delays can be limited is by alerting all relevant teams to stand by at the beginning of the incident. System or organisational delays are another aspect that cannot be changed by emergency management at this level. These include:

- Delays between the control room operator pressing the relevant button and initiation of deluge, shutdown, blowdown
- Delays before fire or gas leaks initiate the detection alarm.
- Processes that occur outside of their control - for example, assigning a crew to a fast rescue craft or a helicopter before attending the incident

5.4.2.2 Speed of the task

Once the physical task is proceeding, it has a certain mean speed of progress. These can include human and technological speeds. A few of the relevant speeds that need to be considered are listed as follows:

- Helicopter flight
- Personnel mustering
- Medical team resuscitating casualties
- Fire team searching in low visibility conditions
- Divers ascending
- System blowing down
- Technician isolating valve

As it can be seen, many of these do not readily produce values for "speed" or even "task to be completed" as will be discussed in Section 5.4.2.4. For example, there is no "speed" of resuscitation - it is simply carried out until it produces an impact on the casualty. For modelling purposes, if the performance requirement is a distance to be covered, the distance is calculated and then a mean speed of movement is used.

5.4.2.3 Frequency of changes in task progress speed

This is not a critical attribute of the model when it is used in emergency management as usually it is very uncertain (for example, the point at which a fire escalates) or relates to changes in the features of the task (for example, helicopter take-off compared to normal flight speed). Therefore this may use a very large value to ensure that there is no change of speed recorded in the modelling process or a very small value so that the number of changes made will result in an average value.

5.4.2.4 Task performance required

This represents the performance standard necessary to successfully complete the task. This may be a distance to be covered, a system state to be obtained or a number of casualties to be rescued. However, as shown in Section 5.4.2.2, some tasks cannot be measured in terms of quantitative values. Some are simply measured in terms of percentage. For other tasks with more complicated time-contingent processes, the estimated distribution of time taken to achieve the task is given as the performance goal. In this case, the speed of the task will have a one-to-one relationship with time. For example, imagine that it takes 20 minutes to blow down the platform. In this case, if the time base is in minutes, the task will be called 20 and the speed will be 1. If in seconds, the task will be 1200 and the speed will still be 1.

5.4.2.5 Resources available to complete the task

Resources often refer to the amount of equipment or personnel available to assist in the task. However, by their increased intervention, the task action speed is faster therefore increasing the probability of success in the task. Therefore, these aspects are included as part of the speed parameter.

In the model, resources refer to a quantity that is gradually being consumed as time goes on. Once consumed, if the task is not completed, it will be failed to some extent. In most cases, the critical resource in an emergency is time itself. Usually tasks must be completed before "it is too late" for example, due to fire impingement, death of casualties or structural collapse of the platform. Therefore, the resource is often calculated in terms of time - for example, the estimated distribution at which point the resources will have expired. In this case, resource consumption rate will have a one-to-one relationship with time, as described in Section 5.4.2.4.
Other resources are as follows:

- water/foam - which are consumed as a fire-fighter uses an extinguisher;
- breathable air - being consumed by divers, in breathing apparatus or in a room filling with smoke.
- food - not normally a key feature in these sorts of emergency. However, for a longer-term incident, having enough food to last until rescue occurs is extremely important. This would be particular relevant when considering natural disasters, such as famine and flood as well as "psychological" emergencies, such as kidnapping or terrorism.

5.4.2.6 Resource consumption rate

This involves the speed at which the resources are consumed. As stated in Section 5.4.2.5, this is often calculated in terms of time, whereby this will have a one to one relationship with time. For the more unusual cases, it is necessary to calculate consumption rate - for example, the speed of air consumption by a diver or foam consumption in an extinguisher. This will then be applied according to the time base used - for example, 25 litres/minute.

5.4.3 CONCLUSION

This section has described how the simulations can produce data that can be used in the TPRC model. Each of the model parameters has been described in turn, including the type of simulation data that could be applied in each case. Therefore, it is now necessary to describe an example of how the TPRC is applied using emergency simulation data.

SECTION 5.5: AN EXAMPLE OF THE TPRC MODELLING FROM DEDICATED SIMULATION DATA

5.5.1 INTRODUCTION

Now that the method has established how data are collected from the scenario and combined with theoretical data for use in the TPRC model, this section will work through an example of such use.

In total, there were 5 offshore scenarios and 9 onshore scenarios. A video recording of the actions taking place in the emergency management room allowed a transcript of events to be produced, so these were prepared for each scenario to facilitate TPRC and other analyses (transcripts available on request from the author, brief descriptions of each scenario are shown in Chapter 8). Each scenario contained at least 10 decisions that potentially influenced the emergency's outcome - and could be modelled using the TPRC technique. To represent all of these results would involve displaying in excess of 140 probability of success curves. Following this, it would be necessary to consider the impact of parameter changes - such as changes in the delay, task speed, resource availability - to compare the observed outcome with the best possible and worst possible outcomes. Overall, this would involve more than 1000 sets of results that would add little to the project other than to illustrate the scope of the model's use. Therefore, this section will use a few examples that adequately demonstrate the capability of the model in representing parameter change and a number of different types of task to show its flexibility. After working through these examples, further examples will be shown in Chapter 9. This is to ensure that the reader is not confused by a large number of different decision analyses at this point.

5.5.2 EXAMPLES OF THE TPRC METHOD BASED ON THE CRANE DRIVER SCENARIO

The examples shown here are taken from Offshore Scenario number 2 (full transcript shown in Appendix 6). This involves a methanol leak resulting from a dropped methanol tote tank. An extract of the transcript is shown in Table 8.

Table 8: Extract taken from the Methanol Tote Tank Scenario transcript

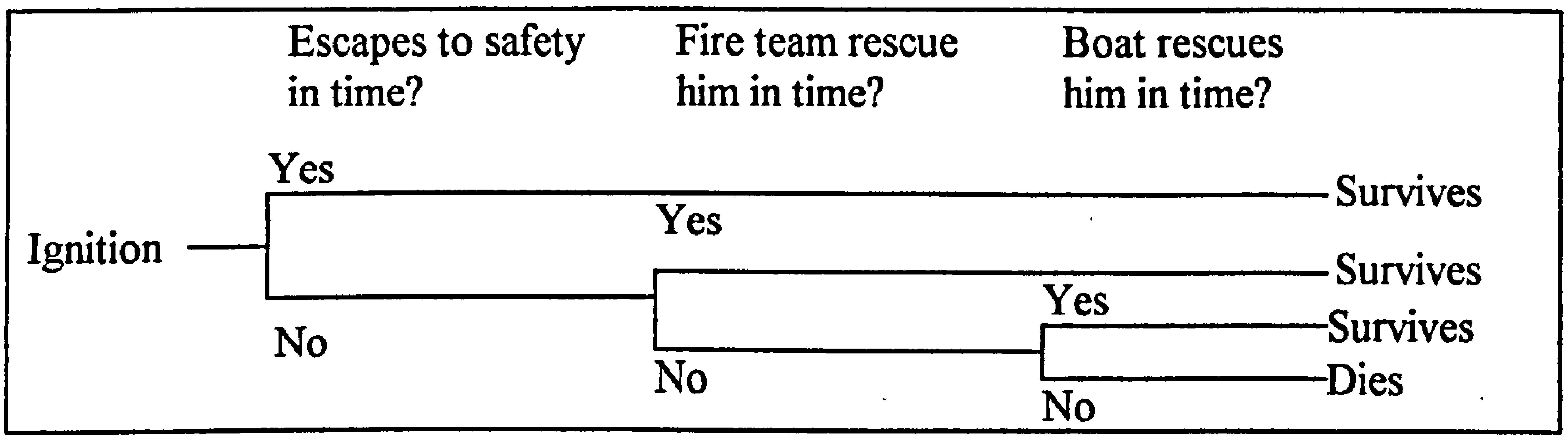
Time	Event
0:00:00	ASSUME INCIDENT OCCURRED
0:00:01	CD: Control room, Deck
0:00:03	call ends (CD)
0:00:05	CRO: Control, call back
0:00:06	call ends (CRO)
0:00:07	CD: Yeah, just to warn you, we've had a bit of a knock, moving these tote tanks around, the wind took the load and there was an edge-on, an edge-on knock, pretty hard, I'm just going to have a look now.
0:00:18	call ends (CD)
0:00:18	PS: Okay, stop all hot work, please CRO on the tannoy
0:00:21	Announcement ends (PS)
0:00:22	CRO (tannoy): Attention all personnel, attention all personnel, all hot work is to cease immediately, all hot work is to cease immediately, all hot work permits to be returned to the control, return all hot work permits to the control room, thank you.
0:00:34	tannoy ends (CRO)

As stated earlier, the announcements by the emergency management team are not an accurate representation of when the event occurred. Even in a real incident, it would take some time before the team were aware of the situation. Therefore, if an event could have occurred within a long duration of time, a reasonable value is chosen and large standard deviation can be given to the value in the model. As mentioned in Section 5.4.1, this introduces a degree of subjectivity into the process, which was not intended. However, this issue will be discussed in more detail in Chapter 7, when the problem is addressed through the concept of performance parameter data.

To establish the overall performance of emergency management, a number of issues must be taken into account - for example, rescuing casualties, fire-fighting, mustering, ordering helicopters. The TPRC can calculate the probability of success in each individual task - thus producing an overall impression of performance. Using the methanol leak scenario, the probability distributions associated with three tasks will be examined, they are:- the probable escape of the crane driver from the crane given ignition of the methanol, the probable rescue of the crane driver from the crane before he is overcome by fire; then, given that the crane driver jumps into the water, the probability that he will be rescued before he dies of his injuries.

In Section 2.4.3.5, it was discussed that the event tree method could potentially be used to structure the concepts relevant in research - by identifying the tasks that had an impact on risk reduction. However, it was noted that most of the quantification applied to this technique relied on expert judgement. Given that the TPRC model had the potential to quantify the probability of success in these tasks, it is possible to link the two techniques together. Therefore, this could produce an overall perspective of the incident using a known technique - with time-contingent probabilities of success as quantification. Therefore, an event tree summing up some of the critical paths of this example is shown in Figure 37.

Figure 37: Event Tree of the Crane Driver's Options



As it can be seen, the crane driver has a number of chances to escape the emergency situation. He can risk running through the fire to the muster point. He can wait in the crane cabin until the fire team rescue him, making it safe for him to move from the cabin to the safe haven; or, as a last resort, he can jump from the crane cabin (situated at the side of the platform) into the sea. In this final case, his main chance of survival involves being rescued by the standby vessel. Therefore it is necessary to consider each branch in turn.

1. The fire ignites 1:36 min into the scenario. The muster is started 61 seconds later. At 3:06 minutes, the crane driver reports that he is stuck in the crane cabin due to the escalating fire outside it. It can not be ascertained from the scenario whether or not he attempted to escape, but assuming he did, it is likely to have occurred between the start of the muster and before he reports that it is impossible to leave his cabin (NB. it may have occurred before the fire ignited but then he was driven back into the crane when ignition occurred). Therefore, the time from the ignition to the point at which he reports being trapped is given as the resource - the time available to escape safely over the methanol laydown area. As these tasks involve data that cannot be observed in the simulation, there are certain types of supporting data that are required. These will be discussed in the following chapter. For now, we can take the walking speed to be approximately 0.7m/s (from Pheasant 1987), given that he is likely to be slowed by the fire as well as the fact that he must climb down from the crane pedestal. From the diagrams of the platform, the distance from the crane cabin to safety can be given as approximately 25 metres, depending on the escalation of the fire as well as the route taken. Therefore the main parameters used into the model were:
Delay = 61 (0.2), Speed = 0.7 (0.1), Distance = 25 (0.3), Time Resource = 84 (0.05) - (uncertainty value x given in brackets)

2. Given that the crane driver either did not attempt to escape, or was unsuccessful in this attempt and was driven back to the crane, the next possible solution is to be rescued by the fire team. The fire ignited at 1:36 min into the scenario. The fire team left the control room for the area at 2:20 min. At 3:20, the control room operator tells the crane driver to stay in the crane and wait for the fire team. At 4:30, the fire team leader tells the crane driver to stop swinging the crane. At 5:04, the standby boat reports someone falling into the water. At 6:50, the fire team get to the crane cabin and discover that no one is inside. Therefore, we must assume that the crane driver finds that the heat is overwhelming and that he makes his escape sometime between 4.30 and 5.04. This is the resource limit - the time at which the fire team should have been able to make a rescue if the task was to be successful. As the fire team do not confirm the crane driver is missing until 6:50. It must be assumed that it would take them this long to successfully reach the cabin. This cannot be taken as simply moving through the area at a constant speed as the fire-fighting is the critical task and it is probably not constant - therefore the time taken in completing this task is used as the intended performance requirement of the task - as described in Section 5.4.2.4. Therefore the main parameters were:
Delay = 44 (0.05) Speed = 1 (0.1) Task = 270 (0.2) Time Resource = 189 (0.04) - (uncertainty value x in brackets)

3. Given that the crane driver jumps into the water between 4.30 and 5.04 minutes into the scenario, the standby boat sees him and starts to report that they have launched the rescue craft at 5:04 minutes. It is likely that this is not an immediate reaction (i.e., delay $\neq 0$). At 6:48, the standby boat reports that they have him in sight but have not yet picked him up. At 11:02, the radio operator tells the production supervisor that the fast rescue craft has picked up the man and they are heading back to the main vessel. He adds that he is in a bad way. It is not known how long he has had this information. As for the man's expected survival, it can be assumed that he has suffered burns and smoke inhalation (causing him to jump) as well as any injuries from the fall and the risk of cold

water shock and hypothermia. Although there is no way of knowing how long he might survive, certain theoretical information can provide a reasonable estimate of this (as described in more detail in Chapter 7). 2-3 minutes was taken to be the time at which the cold-water effects could occur (disregarding any other injuries). Being that it is assumed that he had no lifejacket, he could have muscle spasms and cramp leading him to sink beneath the surface before the rescue craft can find him so 2.30 min is taken as the resource limit. Based on additional information, the recommended distance for the standby boat to be from the platform is 200m and the approximate speed of the fast rescue craft is 25 knots /13m/s. Therefore, it can be assumed that the standby vessel and its fast rescue craft is capable of rescuing a person within 1 minute. However, as the probability of success must be based on the actual figures obtained from the simulation, it must be assumed that the vessel either had to move at a slow speed while manoeuvring round the platform or that the man was difficult to find. Either way, the "observed" data must be used, so it can be assumed that the man was rescued 7:00 minutes into the scenario. Therefore the main parameters were:
Delay = 19 (0.1) Speed = 1 (0.1) Task = 116 (0.02) Resources = 150 (0.07) - (uncertainty value x in brackets).

For each of these three examples, it was checked that the distributions of the input parameters produced were not contradicted by the scenario times.

SECTION 5.5.3: CONCLUSION OF THE TPRC EXAMPLE

Although the probability of success curves represent external physical tasks, they are influenced by the management decisions. For example, if the crane driver had been told to evacuate the methanol laydown area before the fire ignited, the problem may not have occurred. However, the crane driver may have been able to prevent the ignition so his presence was necessary. Also, it must be noted that a muster was suggested at 1:15 min into the scenario but was not actually started until 2:37 min. Decreasing this delay would definitely improve the crane driver's probability of escaping. Assuming that the crane driver could not escape on his own, one would hope that the fire team could get to the site before the crane driver is injured. This again would be improved by an earlier initiation of the muster. However, if it can be assumed that nothing can prevent the crane driver being forced to jump into the water, his chances must be improved there. If this had been predicted, the standby vessel could have been alerted so it could position itself at a safe distance from the platform but on the correct side to facilitate a good view of the incident. This could also allow information to be passed on the emergency management team on the state of the fire. However, these are issues that will be discussed with respect to the graphs produced by the modelling process. The results for all three examples will be discussed in Chapter 8. Further to this, additional analyses will be illustrated to demonstrate the flexibility and scope of the model as well as the extent to which the results were analysed.

5.6: CONCLUSION

Therefore, this section concludes the general use of the Task Performance Resource Constraint model from the introduction of the original model to the adaptations made to it to apply it to the research problem and an example of its application. Therefore, the following chapter will move on to discuss the supporting data that were required for model processing.

Chapter 6

SUPPORTING DATA FOR TASK PERFORMANCE RESOURCE CONSTRAINT MODEL ANALYSIS

SECTION 6.1: INTRODUCTION

As described in Chapter 5, many of the data cannot be collected from the observation of the scenario alone. Such data should have been collected when designing the scenario to ensure that it is realistic or is at least based on valid and reliable performance models. However, often the scenario design process is less formal and is more focused on providing a good test for the emergency management candidate than ensuring a totally realistic incident. For the most part, this is sufficient. Whether every detail of the incident is realistic or not, if the candidate has been successful, he can be deemed competent. It is unlikely that a candidate will focus on the realism of rescue and muster timings while he is under test. Therefore, in general, the model will estimate the times at which events occurred based on observation of the scenario. However, this model should ideally be able to predict probability of success in any simulation task or real-life scenario - given particular information about the task and resources involved. Therefore, there are certain amounts of theoretical data that should be collected.

Chapter 5 focused on the individual parameters used by the model - suggesting methods by which certain tasks and resources could be represented. This chapter will focus on particular scenario types, considering the task parameters that are typically important (e.g. casualty rescue, fires) as well as the relevant factors that affect these parameters (e.g. weather). Strutt, Loa & Allsopp (1996) considered a search and rescue mission for a diver - which shows the mitigating effects of experience and fitness. Therefore, this section will include data relating to some of the most common tasks in emergency management - mustering and other human movement tasks, rescue, escape and evacuation, administering first aid to casualties, a fire/explosion/gas leak incident, the mitigating effects of weather, and the use of the onshore emergency services. For each of these, the following sections will discuss how the data can be implemented in the TPRC model, examples of data collected and alternative methods of collecting data that have not been included.

SECTION 6.2: MUSTERING AND OTHER HUMAN MOVEMENT TASKS

There are a number of tasks that are affected by human movement - either as a delay in the task (e.g. crossing the control room to activate a shutdown,) or as the task itself (moving around the platform to get to the lifeboat stations, climbing ladders, rowing an unenclosed life raft or swimming to the rescue vessel). These data are obtained either through experience (collection of muster times) or are built up through information on human performance capabilities (e.g. average walking speed of healthy individual / running speed of Olympic athlete). These capabilities could also be established through anthropometric and biomechanical data (Pheasant 1986) or the study of exercise physiology (Reilly et al 1990) and reaction times, though this method could be criticised for simplifying the problem through decomposition of the tasks. Some data may also be gathered from the "time studies" of Taylor (1964). His method of Scientific Management established that work was to be carried out in a particular way and taking a specific length of time. Although this was under pressure, it also provides information on the human potential to carry out tasks at speed - as would be required in emergency conditions. For example, from the study of anthropometry, Table 9 gives the tempo, pace and speed of walking for a typical adult (Pheasant 1987).

Table 9: Walking: tempo, pace and speed for a typical adult

	Tempo	**Length of pace**	**Speed**	
	Steps / Min	**Millimetres**	**Metres/Second**	**Miles/Hour**
Very slow	60	400	0.4	0.9
Slow	80	540	0.72	1.6
Average	110	740	1.36	3.0
Fast	130	870	1.89	4.2
Very Fast	150	870	2.18	4.9

From observations of offshore simulations, Kværner (1997) uses the following walking speed data:

- 1 m/s on level walkways/corridors
- 0.8 m/s on stairs
- 0.3 m/s on ladders (allowing for time taken getting on and off the ladder).

No variances are given for these values but the environment (slippery, unsafe or uneven terrain), visibility (foggy/smoky/lighting), type of clothing, any injuries, characteristics of any item being carried (weight, bulkiness) and individual differences (risk perception, fitness) will mean that there is an implicit degree of uncertainty surrounding these values. Therefore, they are most appropriately represented using a distribution rather than a point value.

As well as these "performance shaping factors", the length of time taken to muster depends on the situation (e.g. routes available), the number of people and the size of the platform. In normal circumstances (i.e. not the offshore environment), this may also consider the type of people who may be involved, for example, children, elderly or disabled people. In the case of the offshore environment, there are recommendations specified for the employment of people with regard to health (UKOOA 1986). These recommendations make it possible to assume a reasonable level of fitness and mobility of all personnel under non-emergency conditions.

Data on muster times from Technica (1991 cited in Kværner 1997) gives:

- 7-10 minutes for a large northern platform with 100 POB - installed 1983
- 10-15 minutes for two large northern platforms with 140-170 average POB, installed 1982 and 1987.

- 7-10 minutes for 3 small southern platforms with 30-50 average POB, installed 1967-76.

These were taken from normal drills so do not include the time taken to raise the alarm or any problems due to blocked or hazardous routes. Kværner (1997) assumes it takes 2 minutes to raise the alarm though this is apparently not based on any real data. Modelling of the muster should also consider delays caused by sleeping shift-workers to dress and collect survival equipment and technicians making their place of work safe. Completing the muster check would also be delayed by any missing (assumed injured) personnel (Kværner 1997). Pauls (1988) and Nelson & MacLennan (1988) provide useful evacuation models based on flow rates, which would be more appropriate for large crowds moving through small passageways or doors.

The work of Bellamy & Brabazon (1993) should also be noted in this section. The following equation was found to conform to real data on evacuation rates of an onshore installation in the event of a toxic release:

$y = 14.12(\chi)^{0.5}$

where χ = the numbers to be evacuated

y = the evacuation rate (numbers evacuating per hour)

It is not known whether this can be generalised to other situations. However, they suggest that the critical aspects positively influencing muster speed are training and the provision of unambiguous information.

SECTION 6.3: RESCUE, ESCAPE AND EVACUATION

These issues are normally considered as a task - to be carried out before the platform becomes uninhabitable. However, they may also contribute to the idea of a limiting resource, where the task would be to fight the fire so that the helicopter can land - or to ensure that the muster is complete and all personnel are in the correct place to be evacuated. In general, this information can be gathered from technical information on the vehicles involved, the distances from the relevant installations and previous experience.

As far as helicopters are concerned, the Coastguard Agency (1996) specifies the following requirements:

1. To launch within 15 minutes of call-out by day and within 45 minutes of call-out by night.
2. To be able, in still air, to reach any incident within 100 nautical miles of the coast within 2 hours of call-out by night.
3. To be able, in still air, to reach any incident within 40 nautical miles of the coast within 1 hour of call-out by day.
4. To be able, in still air, to reach any inland part of the UK within 2 hours of call-out by day or night.
5. They should have a declared maximum operational range, without refuelling, of at least 200 nautical miles from the base.

The Coastguard Agency 1996 Statistics show that Item 1 was attained on all except 2 of 638 occasions (HM Coastguard 1996) so this is a realistic delay to be applied in the model.

Table 10 shows relevant statistics for some of the main helicopters in use.

Table 10: Helicopter Statistics for use in modelling of emergency management

Type	Seats Available	Speed (in still air)
Bell 212	11	100
Bell 214	18	125
S76	8	150
365N	11	145
bo105	4	105
Sea King	18	110
Wessex	10	90
S61N	24	110

(Kværner 1997)

Therefore, given the distance from the helicopter bases to the installation and then to the nearest safe haven or onshore hospital, one can calculate the time taken to evacuate the platform - or just one casualty.

Kværner (1997) suggests that it takes 5 minutes to load or unload survivors into a helicopter and taking off takes 1 minute. These data could all be used in the model to assess the probability of successful evacuation before the casualty dies or before structural collapse occurs.

Other mitigating features (cited in Kværner 1997) that could affect the model parameters are:

- Helicopter size and weight - the platform helideck must be capable of accepting the helicopter if it is intended to land.
- Additional equipment requirements - Winches are required when it is too hazardous to land on the platform, or when picking up people from the water or standby boat. Also, infrared cameras are useful when searching for people in the water.
- Weather conditions - These can have a critical impact on helicopter operations. Icing (up to 5000 feet and down to temperatures of -10°C), high wind (up to 60 knots) and low visibility (300 feet cloud base and 0.5 nautical miles horizontal visibility) are acceptable. Beyond these limits, take-off, flight and landing may be hazardous (Free 1987).

The helideck can be impaired by fire or platform conditions. Kværner (1997) suggests impairment is caused when:

- smoke is above 0.05% by volume
- thermal radiation is over 5kW/m^2
- there is an un-ignited gas leak on the platform (which could be ignited by landing the helicopter)

Other evacuations can use lifeboats, life rafts or ladders to the sea. Technica (1991 cited in Kværner 1997) suggests the following times for evacuation by lifeboat, based on typical data from a large manned platform:-

- roll-call and donning lifejackets - 4 minutes
- boarding the boats - 5 minutes
- launching boats - 10 minutes

Wilson (1991) suggests that embarking a 50 man TEMPSC (totally enclosed motor propelled survival craft) can take from 1 minute and 45 seconds to 3 minutes 30 seconds. However, Mills & Coleshaw (1998) add that while data from trials indicates that 45 fit personnel can load a free-fall lifeboat in 4 minutes, to load a single casualty into a lifeboat and secure him for launch can take between 2 to 3 minutes alone! Given that the lifeboat has been launched successfully, the time taken to get a safe distance from the installation must be added - this value can be influenced by good organisation of the standby vessels.
For a baseline value, Wilson (1991) states that the performance criteria for a TEMPSC are to achieve a speed of 6 knots in calm water. BHP (1994) state that their standby vessels can travel at a speed of 25 knots and the recommended standby distance from the platform is 200m. Therefore, it can be assumed that the standby vessels can have an influential effect on the rescue.

Design of the craft is a key mitigation factor for a successful evacuation. It is necessary to ensure that the craft protect the evacuees from the environment - both the water, cold and any smoke. Other mitigating factors include the number of lifeboats and ensuring they are filled to the correct capacity - as well as the prevailing conditions. There should also be reliable launching systems as well as a good clearance of the platform structure to reduce the chance of collision in bad weather (Boef 1992a & b, Førland 1992). Also the craft should be self-righting (Wilson 1991). Where contact with the elements is necessary, survival suits can significantly affect the success of a lifeboat evacuation by protecting the evacuees from the cold (Førland 1992). Also, if they are likely to enter the water, lifejackets are critical. The probability of surviving immersion is affected by the number of people requiring rescue, rate of people entering the water, clothing worn, number of rescue craft, sea state, temperature and visibility.

SECTION 6.4: ADMINISTERING FIRST AID TO CASUALTIES

For the model, it is necessary to establish how long it takes for someone in a hostile environment to be affected by the situation and, if injured, how long it takes them before they are incapacitated by the injury (and therefore unable to save themselves) or killed. This is normally taken as a resource - where tasks must be carried out before it is too late for the casualties. The tasks may include rescue, resuscitation or treatment to enable their recovery. Therefore, when the task is to evacuate, first-aid can be treated as a mitigation process depending on the severity of the injuries, the ease of locating the casualties and the risks to the rescuers. First aid may also be treated as a task in itself.

However, even considering the issue of predicting "effects of hostile situations on probability of survival" is often considered taboo as this has been compared with the torture of Jews in the 2nd World War, which was said to be carried out in the name of science. Moral and ethical boundaries need not be broken to give the data required by this research - at least, no further than medical science already breaks these by recording forensic evidence, animal experimentation or extraordinary stories of survival. Although these are usually complicated to a non-medical person, an expert in medical and statistical knowledge should be able to collate these data to produce distributions of values for survival times given particular conditions. However, caution should be taken to ensure that these values are not used as though they were all-inclusive. For example, just because no person has yet survived a body temperature of lower than 56.5°F does not mean it is not possible - and so emergency management decisions should not be taken on the basis of the known data - but on a distribution surrounding it.

In the model, the effect of the injuries on the casualty provide the resource - whereby treating their injuries and rescuing them from further harm are the tasks. In general, detailed knowledge about medical conditions and their probable survival is beyond the scope of this research. Therefore, this section will concentrate on some of the likely serious conditions that may occur in an offshore emergency.
These include 3 main types of injury:

- Trauma
- Heat and Cold Injuries
- Injuries due to exposure with chemicals

and for each of the following sections, it will discuss the general first aid that can be applied to mitigate such injuries.

6.4.1: TRAUMA

Life-threatening trauma injuries include everything from head injuries to internal injuries and blood loss. Research by Dumire and Peitzman (1998) state that death due to trauma occurs "in a trimodal distribution relating to the time interval from the injury":-
"Immediate deaths (50% of trauma-related deaths) occur at the time of injury and are generally a result of severe head or cardiovascular injury. Early deaths (30%) occur in the first few hours following injury as a result of major torso or head injury. Late deaths (20%) result from infectious complications or multiple organ system failure."
They suggest that although some of these fatalities can only be prevented by reducing the severity of the original injuries, many can be prevented by early treatment and fast access to advanced care facilities.

Streger (1998) suggests that in a mass casualty incident, 75-85% of the fatalities occur within 20 minutes of the event, usually before the emergency services arrive.
The interactions between the systems in the human body make modelling very difficult. For example, a combination of apparently minor injuries may result in a very serious condition through mitigating circumstances. For example, a small cut to part of the arm may just require a plaster. However, a slashed wrist is potentially fatal. Also pre-conditions may cause extra problems. For example, haemophilia would increase the risk of severe injury if a small injury was sustained. Angina or heart disease would increase the risk of heart attack due to shock.

It is also very difficult to link external physical causes to the resulting injury. For example, the severity of a head injury cannot be measured in terms of "pressure of impact" or "height of fall" as it relates to damaging very specific areas of the brain. Skinner et al (1996) suggests that a high energy impact can be defined as "a fall from equal to or greater than 6 metres" or being hit by a car travelling equal to or in excess of 20 mph. However, the modelling of this would be complicated, so this research will use estimates of the expected survival time from specific injuries. Some injuries are instantly fatal - and in these cases, no emergency management can make a difference. Some are so minor that there are likely to stop of their own accord - without any medical intervention. However, in emergency management, the main type of injury of importance is one that is potentially fatal if intervention is not rapid.

However, for certain medical problems, using distributions of the results and a large amount of data for each factor could give valid indications of the potential of human survival. The most obvious measurable quantity is blood loss as shown in Table 11.

Table 11: The Body's Reaction to Blood Loss (St. John's Ambulance 1997 p.78)

Approximate Volume Lost (assuming adult has approximately 6 litres (10 pints) in total)	**Effect on the Body**
0.5 litre (1 pint)	Little or no effect, this is the quantity normally taken in a blood-donor session
2 litres (3½ pints)	Hormones such as adrenaline are released, quickening the pulse, and inducing sweating. Small blood vessels in non-vital areas, such as the skin, shut down to divert blood and the oxygen it carries to the vital organs. Shock becomes evident.
3 litres (5 pints)	As blood or fluid loss approaches this level (half the normal volume of the average adult), the pulse at the wrist may become undetectable. The casualty will usually lose consciousness; breathing and the heart may fail.

Of course, this can only be calculated on the rate of blood loss - which is dependent on the location and extent of the injuries (e.g. loss from veins, femoral arteries or lacerations). This cannot be calculated in the same way as one would calculate flow rate from an oil pipe as the rate of internal bleeding cannot be seen or measured. Willett et al (1996 cited in Skinner et al 1996) give examples of the expected blood loss resulting from a fracture as shown in Table 12.

Table 12: Estimated Blood Loss caused by Fractures

Site of Fracture	**Blood loss (litres)**
Humerus	0.5 - 1.5
Tibia	0.5 - 1.5
Femur	1.0 - 2.5
Pelvis	1.0 - 4.0

For an open fracture, the loss is two or three times greater.

The St. John's Ambulance (1997) suggests that if a casualty is unconscious after 3 minutes of an incident possibly involving a head injury, the rescuer should suspect a more serious injury.

In most emergencies, it is best to "assume the worst and hope for the best". Therefore in the model, often the survival times from trauma are chosen pessimistically - perhaps giving mean values of as low as 3 minutes before the casualty is beyond help, depending on the predicted severity of the injuries. However, this depends on the purpose of the model's use. If this is used to determine what actions should be taken in an incident, if the pessimistic values are assigned and this indicates that the casualty has no chance of survival, then this may erroneously lead the emergency management team to not attempt a rescue. However, if this is used to dictate how fast such a rescue should be, the pessimistic values will force a quick decision, therefore resulting in a greater probability of success. Ideally, of course, these values should not be optimistic or pessimistic - however, with data that are not fully understood, such as these, it would be impossible to obtain. Therefore, these are normally assigned a wide distribution to cater for the levels of uncertainty involved.

Many trauma injuries can be mitigated by first aid. Some injuries are too severe to allow any assistance to be useful, for example, decapitation. Others may be extremely severe but quick intervention can make a difference, for example, amputation of a limb, electrocution or coronary thrombosis. Some injuries can only be treated slowly and carefully - for example spinal injuries, though in these cases, the difference between life and death may be defined by other issues - for example, serious bleeding or problems with respiration.

Streger (1998) suggests that a patient in triage should be categorised in less than 60 seconds. This indicates that it is possible to make a reasonable diagnosis in that amount of time - so we can reasonably expect this of an offshore medical officer as well. Often, the most serious injuries are easy to see, therefore quick action is possible. With trauma injuries, the main treatments involve resuscitation (if necessary), preventing further loss of blood, and treating for shock. Again the treatment depends on the injury. A small injury will require less bandaging than a large injury. Resuscitation can provide results quickly after some effort or not at all. Therefore, the mitigating factors include the number of casualties and the severity of their injuries, the number of skilled rescuers, the available equipment and the conditions. Hazardous conditions can be a risk to the rescuer as well as the casualty. So if a casualty falls due to the dizziness caused by smoke inhalation, they could die of a combination of the effects. Also, cold conditions can speed up the onset of shock. Therefore the times to complete such tasks are inherently variable - based on individual differences of the casualty and their injuries, and the skills and equipment available to the first-aider. Therefore, any estimation of the time taken to carry out first aid times should have a reasonably wide distribution.

Calculating the survival time for specific injuries and time to carry out medical tasks is beyond the scope of this research. If carried out in the future, the author recommends that this should only be carried out by a medical researcher who can understand the technicalities of the human casualty as well as the sensitivity of the issues involved. In any case, caution should be taken when using these values once obtained and they should not be taken as all-inclusive. For example, if an emergency manager made the assumption that someone would not survive after 3 minutes in freezing cold water based on model data, they may wrongly decide that there is no need to attempt a rescue.

6.4.2 HEAT AND COLD INJURIES

In general, there is an optimum ambient temperature for human action and an optimum core body temperature - generally listed as 37°C (98.6°F) (St. John's Ambulance Association 1997). Outside of this boundary, it is unpleasant, and, at the extremes of human tolerance - potentially fatal. This section includes the injuries due to contact with fire, though the injuries are often due to gas inhalation, so they will be considered in the "Injuries due to exposure with chemicals" section. The main injuries due to the cold in the offshore environment are due to falling or jumping into the water.

Medical and forensic journals record extreme and unusual cases of survival or death. For example, some people have died of hypothermia with core body temperatures of 95°F whereas there are records of people surviving a core body temperature of 56.5°F (McWhirter 1999, Hope 1999). This is far below 60°F-, which is, somewhat surprisingly, the temperature at which the State of Alaska medical organisation (1996) recommend that CPR (cardio-pulmonary resuscitation) should not be attempted.

Although such medical data is useful, it cannot be directly transferred to the model, as we are more concerned with the body's response to the environment in which it exists. For example, although we may know that a person can potentially survive body temperatures of 56.5°F, it is more useful to establish how this body temperature relates to the surrounding temperature - and so, given an approximate value of the surrounding temperature, we can calculate the time at which the environment would "win over" the person, whereby their body temperature sink below this value.

The Guinness book of records (McWhirter 1999) has descriptions of extraordinary survival stories, including people who have survived 18 days without food or water, 2 days in a freezer (in sub-zero temperatures) and people who survived 8 days at 39°c (102°F). In a disaster where an aeroplane crashed in the Andes, it was 10 days before some of the survivors died, in conditions of -40°F, whereas some survived to be rescued 82 days after the crash. This demonstrates the variance of survival capabilities in the human species and, again, could potentially be included as data in a model. A model that could be used to predict these data has been developed by the Defence and Civil Institute of Environmental Medicine in Canada for hypothermia (Tikuisis 1995, Tikuisis & Keefe 1996, Tikuisis et al 1997, Tikuisis 1998). The model considers ambient temperature, clothing, sea state, level of immersion as well as information about the person's physical characteristics. For example, it gives an estimated survival time of 4.8 hours for a healthy normal sedentary individual immersed in a heavy sea condition at 5°c wearing a shirt and anti-exposure suit. Despite this, passengers from the Estonia disaster survived the cold water much longer than the model would have predicted - believed to be due to their strong mental attitudes.

Regarding short-term exposure, the Sea-Marshall homepage (1999) suggests that the physiological effects of cold water are as follows:

- After 2-3 minutes - Initial shock responses, skin temperature falls, decreased breath-holding ability, muscle spasms followed by hyperventilation, loss of manual dexterity.
- From 3-5 minutes - Losing swimming ability.

Boating Basics (1999) give predictions of times at which exhaustion and death occur in cold water as shown in Table 13.

Table 13: Predicting impact of water temperature on humans

Water Temp (°F)	**Exhaustion/Unconsciousness**	**Expected time of survival**
32.5	Under 15 minutes	15-45 minutes
32.5 – 40	15-30 minutes	30-90 minutes
40 – 50	30 - 60 minutes	1 - 3 hours
50 – 60	1 - 2 hours	1 - 6 hours
60 – 70	2 - 7 hours	2 - 40 hours
~~70 – 80~~	~~3 - 12 hours~~	~~3 hours - Indefinitely~~
Over 80	Indefinitely	Indefinitely

Although not based on critical data as in the Tikuisis model, this can provide useful information for our modelling in terms of a resource. If it possible to rescue everyone before these limiting times, we can hope for a good probability of survival. Pheasant (1987) gives an interpretation of the effects of wind chill using the equation below:

$K_o = (10\sqrt{V} + 10.45 - V)(33 - T_a)$, where
K_o is the wind-chill factor
V is the air speed (m/s)
T_a is the air temperature (°C)
The interpretation of these factors given by Pheasant (1987) is shown in Table 14.

Table 14: Interpretation of wind-chill index (from Parker & West 1973)

K_o	Interpretation
<90	Hot
90 to 150	Warm
150 to 300	Pleasant
300 to 500	Cool
500 to 700	Very cool
700 to 900	Cold
900 to 1100	Very cold
1100 to 1300	Bitterly cold
> 1300	Exposed flesh freezes
> 1650	Exposed flesh freezes in one minute
> 2150	Exposed flesh freezes in 30 seconds

As far as people falling into the sea are concerned - there are other causes of injury. Firstly, there may be injuries leading the person to jump into the sea - for example, caused by fire on the platform above. The fall can cause trauma injury, which could be fatal in itself or could lead to drowning as the casualty becomes unable to swim. Shock is likely to occur due to the cold water - particularly if they are jumping from hot conditions, as in a fire. However, there is also some chance that someone falling into the sea can die of burn injuries - due to radiation from the fires above or fire on the sea surface. The effects of cold water can be mitigated through the use of survival suits. Weather conditions obviously affect the probability of survival - not only through temperature and sea conditions, but because fog can cause low visibility - slowing down the rescue attempts. Also survival can be improved by making the person more visible (i.e. by wearing bright orange clothing) and by improving the ability of the searchers - for example, by having more people assigning to searching, or by the use of transmitters. Once rescued, the best treatments include insulating the casualty from further heat loss, rewarming with humidified oxygen as well as the use of intravenous methods (Journal of the American Medical Association 1992). .

The Guinness Book of Records (McWhirter 1999) states the highest body temperature that a human has survived is 115.7°F / 46.5°C. Living human tissue is burnt when its temperature reaches 43°C (Pheasant 1987). The St. John's Ambulance (1997) states that:

- A partial thickness burn of 1% must be seen by a doctor.
- A partial thickness burn of over 9% will cause shock to develop and the casualty will need hospital treatment.
- Any full-thickness burn requires hospital treatment.

The main cause of heat injuries in an offshore incident are due to fires.
Kværner (1997) gives the levels of radiation intensity and the effect they have on humans as follows:

- 5 kW/m^2 - limiting escape actions lasting more than a few minutes in normal offshore clothing. At this level, the pain threshold for exposed skin is reached in about 15 seconds. Second-degree burns on exposed skin would be expected after about 2 minutes.
- 12.5 kW/m^2 - limiting escape actions lasting a few seconds. At this level, the pain threshold is reached in about 4 sec, and second degree burns on exposed skin in about 40 sec.
- 37.5 kW/m^2 - is taken as the criterion for immediate fatality. At this level, the pain threshold is virtually instantaneous, and second-degree burns occur in about 8 seconds.

Given that the radiation intensity can be estimated at particular locations within a fire or explosion from fire models, this can be used to predict the expected times at which the people involved will be affected. However, Purser (1988) has reviewed a great deal of data from research into the injuries caused by fire and heat. Apart from the influence of gas inhalation, injuries can be caused through a heightened blood temperature, burns or heat damage to particular organs - such as the respiratory tract. There is a relationship between the air and contact temperature and the severity of the injuries - as one would expect. Using the interaction between all the relevant variables (smoke obscuration, heat, toxic gases), Purser (1988) calculated that incapacitation due to an armchair fire would occur after 4 minutes of exposure. His models and data can also be used to relate to the types of fire that occur offshore.

Saving people with burn injuries is complicated - mostly because it usually involves risk to the rescuers. Either the fire must be controlled or put out - by which time the casualties may be beyond help; or the rescuers must protect themselves to the best of their ability and then remove the casualties from the environment. Fire injuries are a combination of burns and toxic gas inhalation - which will be discussed in the next section. Treatment of burns involves cooling the related area, prevention of fluid loss and infection where the burns are deep, and of course, treatment for shock. Again, these tasks have varying degrees of success - so must be represented by a distribution of time values

6.4.3 INJURIES DUE TO EXPOSURE WITH CHEMICALS

The data on the impact of chemicals on the personnel can be combined with the possible leak rates/chemical production rates to identify when the deadly concentrations would be reached. This can therefore be used to establish a distribution of times at which personnel in a specific area are seriously injured or dead - and therefore can give an estimate of how fast a rescue must be (and what protective equipment the rescuers must use). The impact of these chemicals on the personnel can potentially be mitigated by use of deluge, ventilation, quantity and location of chemicals and personal protective equipment (breathing apparatus, chemical suits) - depending on the characteristics of the chemical.

Obviously there are many hazardous chemicals and it is recommended that the reader refers to the published information on each specific chemical involved. For example, there are safety data sheets, produced by NIOSH (1994), with reports from the Health and Safety Executive (1992) on industrially used chemicals or the U.S. Army (1998) for those used in warfare or by terrorists. Chemicals have two main influences in an emergency - firstly, their impact on the personnel involved and secondly - their impact on the system, for example, flammable gas causing an increased escalation which will be considered in Section 6.5.

The safety data sheets typically include descriptions of the substances, their hazards and their means of action (e.g. flammable, irritant on skin, carcinogenic). Sometimes there are also recommendations for how the chemicals should be stored and transported and any precautions that should be taken. Most importantly for the modelling process, the documents give limits of concentrations that are acceptable over different durations (e.g. 8 hours and 15 minutes) and those which are deemed to cause "immediate danger to life and health". These values are based on animal and human research whereby the effects of concentrations over time are tested. Although the IDLH value itself may not indicate the concentrations at which life is at risk (as this is a limit value representing acceptability and ideally this should be set below the limit at which life is at risk), the research contained in the IDLH documents gives valuable insight into the levels

of concentrations whereby acute or long-term effects would be sustained. IDLH documents typically give a value for:-
LD_{50}, which is the "calculated dose of a substance which is expected to cause the death of 50 percent of an entire defined experimental animal population"
LC_{50}, which is the "calculated concentration of a substance in air, exposure to which for the specified length of time is expected to cause the death of 50% of an entire defined experimental animal population".
For this research, the value of LC_{LO} (Lethal Concentration Low) is also relevant as it expressed the lowest concentration of a substance in air, other than LC_{50}, that has been reported to have caused death in humans or animals. The reported concentrations may be recorded for periods of exposure which are less than 24 hours (acute) or greater than 24 hours (subacute and chronic). These values give us the relevant information to calculate the direct risk to human life.

Apart from the direct risk caused by exposure to the chemicals, certain chemicals may have an impact on the system and risking human life through this - for example, flammable chemicals causing fire and structural damage, leading to platform collapse - however, this will be considered in Section 6.5.

Most of the offshore incidents involving chemicals do so through exposure to fire. There is also the probability of damage from radioactive substances or contact with substances such as acids. In general, the implications of these are the same as for burns, shown in Section 6.4.2. Therefore, this section will concentrate on the products of combustion producing the most significant effects - Carbon Monoxide, Hydrogen Cyanide and Lack of Oxygen (Hypoxia). To assess the probable time of survival involves 3 main issues - the speed of concentration change in the atmosphere, the rate of uptake by the individual, then the rate of impact on the individual's behaviour. The speed of concentration change relies on the actual environment - for example the severity of the fire or gas leak, as well as the characteristics of the environment - enclosed, ventilated or open air. These issues will be considered in Section 6.5. The speed of uptake of the chemicals depends on their characteristics, concentration, and duration of exposure as well the human behaviour - for example, activity leading to increased respiration. Given this, the impact on the individual depends on its toxicity as well as the speed of uptake.

Carbon Monoxide is a colourless, odourless tasteless gas, which is extremely flammable. It enters the human body by inhalation, and then causes its toxic effects by bonding with haemoglobin (preventing Oxygen from bonding with haemoglobin) to produce Carboxyhaemoglobin (COHb). This therefore decreases the concentration of Oxygen reaching the tissues of the body. NIOSH (1994) recommends that the value for the "Immediate Danger to Life and Health" Concentration is 1200ppm. However, the same document comments that a 30-minute exposure to 1200 ppm will produce a COHb of 10-13%, which is thought to only result in a slight headache. Therefore, these values are clearly too low to give an indication of lethal or incapacitating doses.
In Table 15, Kværner (1997) gives values of COHb that are more likely to relate to our study

Table 15: Temporary Refuge Impairment Criteria (Kværner 1997)

Severity	Narcosis	Body Temperature °C	Obscuration
Human Factors Effects	15% COHb.	39	1 dB/m
Significant Effects (Impairment)	30% COHb.	40	N/A
Potential Fatalities	50% COHb.	41	N/A

In Table 16, Kværner (1996) also suggests likely reactions to Carbon Monoxide in terms of parts per million of the gas.

Table 16: Effects of Carbon Monoxide (Kværner 1996)

Carbon Monoxide Concentration (PPM)	Effects
1500	Headache in 15 minutes, collapse in 30 minutes. Death in 1 hour
2000	Headache in 10 minutes, collapse after 20 minutes Death in 45 minutes
3000	Maximum "safe" exposure limit for 5 minutes. Danger of collapse in 10 minutes.
6000	Headache, dizziness in 1-2 minutes. Danger of death in 10-15 minutes.
12800	Immediate effect, unconsciousness in 2-3 breaths. Danger of death in 1-3 minutes

Purser (1988) shows that the time to incapacitation involves a combination of the %COHb and the level of activity. For someone carrying out heavy work, 2% COHb can result in incapacitation within 1 minute; whereas if at rest, 2% COHb results in incapacitation after approximately 4 minutes. Naturally, we would expect an individual to try and escape a hazardous environment, so paradoxically, it is likely that the heavy work involved in escaping the environment will also speed up the toxic action.

Purser (1988) suggests the following "Stewart equation" is a good approximation of the %COHb resulting from short-term exposure based on the volume of air and CO concentration:

$$\%COHb = (3.317 \times 10^{-5})(\text{ppm CO})^{1.036}(RMV)(t)$$

where

CO = CO concentration (ppm)

RMV = volume of air breathed (L/min)

t = exposure time (min)

This shows some potential in being used to estimate the "survival time" as the %COHb levels define the distributions at which incapacitation and death occur, RMV can be estimated from normal human responses and CO concentrations can be calculated from the characteristics of the fire as discussed in Section 6.5 - for example, Initial CO concentrations in smoke are estimated to be in the range from 0.1% for well-ventilated fires to 5% for under-ventilated fires. (Kværner 1996).

Unlike Carbon Monoxide, Hydrogen Cyanide produces rapid effects on the brain - by diminishing the ability of the body to use oxygen when it reaches the tissues. NIOSH (1994) gives the IDLH as 50 ppm. However, Purser (1988) notes the effects of higher concentrations, citing values of 100ppm after 20-30 minutes, 200ppm after 2 minutes as the levels that cause incapacitation (from Kimmerle cited in Purser 1988). McNamara (cited in Purser 1988) notes that there was a report of a survival from accidental exposure to 444ppm, though 539ppm is given as the 10 minutes LC_{50}. Purser (1988) estimates that from 80 -180ppm, unconsciousness will occur at between 2 to 30 minutes based on the following equation:
$t_{Icn}(\text{min}) = \exp(5.396 - 0.023 \times \text{ppm HCN})$ where $t_{Icn}(\text{min})$ is the time to incapacitation in minutes.

Hypoxia is not only caused internally - due to displacement in the tissues by HCN and CO - but also due to the lowered Oxygen content in the inspired air, due to the fire (Purser 1988). Oxygen levels that drop to 15% causes increased breathing, faulty judgement and rapid onset of fatigue. Levels below 10% cause rapid loss of judgement, followed by unconsciousness, leading to death within a few minutes. In these conditions, escape actions would need to take a few seconds if the individual is expected to survive. (Stenaas 1991 cited in Kværner 1996).

For hypoxia, Purser (1988) gives the time to loss of consciousness ($(t_{Io})\text{min}$) as:
$(t_{Io})\text{min} = \exp\,[8.13 - 0.54(20.9 - \%O_2)]$

Carbon Dioxide is also toxic and is universally present in fires (Purser 1988). However, its main effects are caused by interaction with the presence of the other toxic gases as it causes hyperventilation. The increased rate of breathing increases the rate of uptake of CO and HCN. A level of 3% is said to double the respiratory minute volume (RMV) and 5% is said to triple this rate. Unconsciousness is said to occur after 2 minutes for a level of 10% (Purser 1988). However, Purser (1988) calculates the effect of Carbon Dioxide on the speed of uptake of the other toxic gases as shown in the following equation:

$$VCO_2 = \frac{\exp\,[0.2496 \times \%CO_2 + 1.9086]}{6.8}$$

Obviously, a fire would produce combinations of these gases resulting in an interaction between the effects. In general, additive effects of the gases are likely. However, the mathematical calculation of the degree of these effects is not fully understood so caution should be taken before using these specific values without consideration of various factors (Purser 1988).

Of course, there are other mitigating factors. Smoke obscuration of over 1% is judged to be impassable by people without personal protective equipment (Kværner 1996). This may be assisted by using guidance systems - perhaps powerful lights or audible alarms. Training and practice through drills will also improve the speed of exit from a smoky situation. Certain medical problems may make a person more likely to suffer quickly in a toxic gas environment - for example, asthma or lung problems. Breathing apparatus can provide some protection against the chemical effects of toxic gases and their irritant effects. Whole chemical/fire-protective suits also provide protection against the heat. The average man walking at 4 mph consumes 40 l/min of air. Based on this, depending on the size of the cylinder and the degree to which it is compressed, a cylinder can provide between 11 and 48 minutes of air (Paterson 1993).

SECTION 6.5: FIRE/EXPLOSION/GAS LEAK INCIDENT

For modelling of a fire/explosion/gas leak incident, it is necessary to understand the nature of the materials involved. This information may include:

- the chemical characteristics of the materials - for example, the temperatures at which ignition is likely, the behaviour of the material once ignited.
- the probable size of a leak - for example, the amount of chemical in a fixed container, the pressure of a pipeline, the likely size of hole in a pipe.
- the behaviour of a leak or fire - escalation rate, probability of explosion or impingement on other systems.
- means of control - isolation of leak, blowdown of pipes, deluge to control spread and escalation and cooling to prevent further impingement
- mitigating factors - weather conditions, wind direction, location of and relationship between critical systems

Due to the number of variables, often this is very difficult to predict and model. In general, it is applied in the TPRC model as follows:

- A task - such as attempting to control a fire through deluge or fire fighting. Success in the task means the fire has been extinguished.
- A resource - which may be the time at which a fire is expected to impinge on another system, in which case, it is intended that the controlling task (defined above) is successful. Once it is known that the situation is beyond control, the time at which the fire is expected to cause structural collapse or impairment of the temporary refuge is a resource, in which case the task involves the evacuation of all personnel.

The numerical values assigned to these parameters are largely unknown - though possible information can be estimated using models.

Since the Cullen Report (1990), the required survival time of the temporary refuge has been specified. It is now required that the walls are resistant to explosions and fires to ensure that they are safe long enough to ensure a successful evacuation. These are normally specified in terms of fire type and time (e.g. J30 means the wall can resist a hydrocarbon jet fire for 30 minutes).

Obviously, this requires great understanding of the characteristics of the fire that is likely to occur. Ramsay et al (1994) provides information on the probably leak rates over time from a 30mm hole in an oil pipe. This gives a maximum value of 40 kg/s, leading to flames of up to 70 metres high. With or without ignition - blowdown and isolation were found to have a significant impact on the leak size and resulting flame height - normally gaining control after 16 minutes. Chamberlain (1998) has carried out detailed experiments on offshore fire hazards - including unconfined and confined crude oil jet fires and pool fires. This mainly focused on identifying the temperature variance across the area. It included the impact of deluge - however, despite specifying "early" and "late" activation of deluge, the times at which these were initiated were not published.

Again, the details of such research are beyond the scope of this project. Nevertheless, it may be necessary to refer to such data to establish the likely behaviour of fire and gas leaks for input into our model.

Fire and gas escalation are mitigated by weather conditions as well as effective safety systems. Safety systems include alarms (decreasing the delay before controlling actions are taken), shutdown and blowdown systems as well as fire-fighting equipment, such as deluges and portable extinguishers. Such systems can be assessed in terms of their impact on the fire (task speed) in terms of quantities available, reliability, duration of use as well as the effects of use on the fire. This may also include the impact of passive fire systems - for example, fire-retardant designs, enclosures of corridors and even pre-planned design parameters - like a re-consideration of the inventory of hazardous materials. Table 17 shows some information on the extinguishers available for use on an offshore platform (Taken from Paterson 1994).

Table 17: Extinguishers used in the offshore industry

Type of extinguisher	Capac.	Duration	Range	Comments
Water extinguisher	9 litres	60-90 sec.	Maximum range 8m, most effective 3m	Best cooling properties of all extinguishers. Most useful against solid fuel fires. Not to be used on electrical fires or flammable liquid fires - as the fire can be intensified and spread by the water.
Foam extinguisher	9 litres	60-90 sec.	Maximum range 5m, most effective 3m.	Excellent smothering properties and most effective against flammable liquid fires by forming a blanket. Not good against a free-flowing liquid fuel which is alight, or with fuel spilling down a vertical surface. Not to be used on electrical apparatus
Dry powder extinguisher	4.5-13.5 kg	15-40 sec, depending on size.	Range: 10-15 feet (3-4.5m). depending on size.	Most suitable extinguisher for inflammable liquid fires and can be used on electrical fires. Acts more quickly than foam. Has no cooling properties so re-ignition may occur.
BCF Vaporising Liquid Extinguisher	1-7.5 kg	10-20 sec, depending on size	6-20 feet (2-3m), depending on size	Similar to dry powder
CO_2	1.5 - 7.5 kg	10 - 30 sec, depending on size	6 feet (2m)	It works by smothering fire and is useful against solid, liquid and gaseous fire as well as electrical fires.
Wheeled portable extinguishers				
Foam:	90 l			
Dry powder:	22-75 kg			
BCF:	22-68kg			
CO_2:	22-45kg			

These can be used to calculate the speed of fire fighting, which is also dependent on the numbers of people who are actively fighting the fire. There must be not only an adequate supply of extinguishers but also breathing apparatus and personal protective equipment for the fire fighters. Water deluge rates have been cited as being between 10-

30 litres/min/m^2 (Kværner 1996) and 12-48 litres/min/m^2 (Vinnem 1989) and are a good method of fire control for 3 main reasons:

- they can be activated instantly from the control room, so can have an impact on the fire before it can escalate to a high degree.
- they allow control to occur without risking personnel going into the hazardous area.
- they can provide a continuous supply to a large area and do not require regular refilling as for portable extinguishers.

Therefore the models should be able to establish the times at which deluge can control a fire. However, very little research has produced formulae for the relationship between fire and deluge action. As stated before, there are many variables involved - temperature, wind direction, quantity of fuel all affect the outcome. Therefore, as this research does not have all the specific variables to make a complete outline of the characteristics of the fire, it will rely on published examples of fire behaviour.

SECTION 6.6: THE MITIGATING EFFECTS OF WEATHER

As shown in the previous sections, the weather can provide mitigation or worsening of a number of incidents. Fire can be adversely affected by strong winds blowing towards the temporary refuge or controlled with wet conditions. Fog can slow or prevent a rescue. Cold weather can lead to injuries through slipping on ice or hypothermia. The weather also affects the surrounding seas - their temperature and wave size - affecting the probability of rescue of a man overboard or successful launch of the lifeboats. Extreme weather such as large waves, hurricane force winds or seismic activity can cause incidents themselves - through structural damage to the platform or by vessel collision.

In general, there is a large body of research into weather, facilitating the prediction of extreme conditions in specific areas. Designers are required to build an installation for the extreme conditions including wave height and seismic activity in the area. Woo & Muirwood (1986) have carried out a study on seismicity in the North Sea. Time of day also affects the probability of rescue - Night time would makes all tasks more difficult due to the reduced visibility. Brand (1988) gives the climatic conditions in the North Sea as follows:
Sea temperature: 16°C to 5°C (occasionally 2°C)
Ambient temperature: 25°C to 5°C
Wind Speed: + Force 10
Wave Heights: Occasionally + 30 metres
These should all be considered when establishing variables for the TPRC model. They may affect the mean value or increase the uncertainty in the distribution.

SECTION 6.7: ONSHORE EMERGENCY SERVICES

Although this project focuses on the offshore industry, this model should ideally be generic enough to cater for all future emergencies. Therefore, this section considers the effects of involvement from the emergency services. In an offshore incident, emergency management would involve initial intervention from the medic and fire fighters - then eventually by external vessels. Onshore, it is possible to rely on the emergency services to help within a shorter amount of time.

The Patient's Charter (Department of Health 1996) specifies two performance standards for ambulances:
1. An ambulance must arrive at the scene within 8 minutes for 50% of all calls.
2. An ambulance must arrive at the scene within 14 minutes (19 minutes in rural areas) for 95% of all calls.

Further to this, it states that patients in the Accident and Emergency department should be seen and assessed within 5 minutes of arrival. Rescue EMS Magazine (1991) states that on arrival in triage, a patient should be categorised in less than 60 seconds (cited in Streger 1998).
Data from a number of regions indicates that this is possible. However, the latest data from the London Ambulance Service (1999) do not meet the first two requirements. These data can be used to provide a resource - where the task is to stabilise the casualty until the emergency services arrive, or to get the plant safe in time for their arrival. They can also be used as the expected delay - for example, when the casualty does not receive proper treatment until the ambulance has arrived and the paramedics have started work. The impact on emergency management produced by this delay in arrival may be alleviated by emergency services communicating the necessary information to novice rescuers to give the remedial treatment required before they arrive. Also, the on-scene commander can improve efficiency by providing adequate information to the emergency services to ensure that they bring the right equipment and can find the site easily. If weather or on-site conditions were likely to slow the emergency services, it would also be helpful to assign resources to direct the traffic or clear the route. For example, lighting the route in fog or applying salt to melt the ice.

SECTION 6.8: CONCLUSION

This concludes the chapter including the details of the data to support the model. Although this does not contain all of the potential data that can be applied, it provides useful examples, as well as guidance to obtaining further data. The thesis will now move on to discuss the method to obtain "performance parameters" from the scenario data.

Chapter 7

COLLECTION OF PERFORMANCE PARAMETER DATA

SECTION 7.1: INTRODUCTION

Up to this point, the data available for the research include:

- timings from escalation models
- design data on installations, for example, distances and routes
- estimated timings of human survival in hazardous conditions
- speed (and therefore timings) for human performance in various tasks
- speed (and therefore timings) for machine performance
- specific timings of management and external tasks and events observed in the dedicated simulations

These data are adequate for TPRC processing of the probability of success in events observed in a simulation. However, the objectives, as stated in Section 1.2, discuss the impact of change in emergency management skill and the assessment of generic (novel) emergency situations through the application of performance parameters. Therefore, these issues will be discussed in this chapter.

At this point, the delays introduced by a change in emergency management skill or a generic (novel) emergency situation can only be ascertained by expert judgement. This introduces a degree of subjectivity into a technique that has the potential to be completely objective. It is known that the delays are rarely zero, however beyond that fact, it is difficult to establish realistic estimations of delays as input for the model.

The use of performance parameters involves building up collections of timings observed in the scenarios so that these can be generalised and applied to novel situations, whilst maintaining a degree of objectivity. For example, in the same way that Pheasant (1987) used the measurements of human limbs, heights and strengths to assist designers in the recommended sizes and functions of tools; distributions of the times taken to carry out emergency management tasks could be built up from the simulation data.

These performance parameters could potentially be used:-

- in the TPRC model to estimate the optimal and worst-case scenarios - using the longest and shortest observed delays, and compare these with the values observed in the scenario - therefore contributing to the third objective of the research
- in the TPRC model as a basis for testing novel designs - therefore contributing to the third objective of the research
- in the TPRC model for novel or generic emergency management situations - therefore fulfilling the fourth and final objective of the research

- as raw data, to be used by designers or emergency planners to estimate the best and worst response times
- to build up distributions to represent particular types of data- and distinguish between the onshore/offshore industry, pre-emergency and post-emergency reactions or levels of competency
- to reduce the reliance on expert judgment in the TPRC model - therefore increasing the objectivity and reliability of the technique

These issues will be considered in Section 7.3 & 7.4. However, the following section will first consider how the performance parameter data can be collected.

SECTION 7.2: COLLECTION OF THE PERFORMANCE PARAMETERS

7.2.1 COLLECTION OF GENERIC AND SPECIFIC PERFORMANCE PARAMETERS

The performance parameters can reasonably be separated into two different types:-

- generic data - including "time to give a tannoy", "time to respond to a radio call" and "time to make an announcement".
- context-based scenario-specific data - which were of 3 different types including estimates of escalation times (e.g. "methanol spill discovered to fire ignited") estimates of task times (e.g. "fire team arrive - foam monitor activated") estimates of times involved in specific management tasks (e.g. "fire ignited - deluge activated")

In the case of the scenario-specific performance parameters, it would be unusual to have a sample of more than one for all of the scenarios. This related to the type of scenario and type of actions taken in response to specific events. However, if enough scenarios were analysed, these could be used to build up distributions of timings in the future. As this project was restricted by the numbers of scenarios available, this was beyond the scope of the project.

As these values were based on simulations and the real events did not actually occur, there is no guarantee that they are accurate. Further to this, as the observer could only record data received by the emergency management team, the "imagined" events may have occurred some time before as specified by the scenario organisation team. Therefore, these values are predominantly "assumed" and may bear no relationship to the average time taken by the events in a real situation. Nevertheless, the simulations are designed to be realistic and therefore the timings should also be "within reasonable limits" and would therefore fall within the distribution of time values associated with the real events. For these reasons, caution and discretion should be taken when using the one-off scenario-specific data - using a broad variance to compensate for the uncertainty surrounding the values. Ideally, any real incidents relating to the type of incidents used in the simulations should be incorporated into the distribution.

However, 14 scenarios had enormous potential for producing a large amount of generic data. The generic performance parameters were defined as shown in Appendix 7. Timings for announcements, radio calls, tannoys, phone-calls and any relevant delays were included. The results are shown as frequency distributions in Appendix 11. These generic performance parameters could be used like the decomposed descriptions of movement in Chapter 6 that assess how long it takes to cover an area based on the speed of walking. Therefore, it is no longer necessary to observe an actual scenario or to use expert judgment to obtain the delays taken by management action. Using the data built up from dedicated simulations, it would be possible to estimate how long it takes to receive information, make a decision and communicate it to the relevant team based on the times taken in giving radio calls, making announcements and the delays between them.

Ideally these data could include cognitive information - such as the time taken to make a decision. However, this information is not observable and so cannot be included in an objective collection of information. It can only be built up and assumed through distributions of alternative timings, for example, the time taken to respond to an announcement, Therefore, the performance parameter data collected were based only on communications, actions and responses.

7.2.2 CATEGORISATION OF DATA

Given that the data were obtained from different sources, it was considered to be useful to categorise them - in case the differences between groups were found to be important in the future.
The groupings include:

- distributions in terms of scenario
- distributions in terms of emergency manager - C, E, L & P
- distributions in terms of industry - offshore / onshore (which also corresponded to distributions in terms of team)
- distributions for pre-incident and post-incident timings
- distributions representing the assessed level of competency (recorded for the onshore group only)

Comparisons between the data for each category may identify particular characteristics of the category - and would justify why performance parameter data cannot be generalised from one category to the other. For example, pre-incident radio calls may be much longer than post-incident calls - therefore normal radio conversations cannot be used to predict the time taken in an emergency conversation. Likewise, offshore teams may be more familiar with particular procedures than onshore teams - therefore the times taken by these particular procedures cannot be generalised from one environment to the other.

Competency ratings were recorded for 8 of the onshore scenarios using questionnaires as described in Appendix 9. These allowed the recording of the assessor's judgment of the performance for each scenario - either "highly competent", "competent", "notable shortfalls" or "fail". Categorisation of these groups would indicate whether more competent teams produced different timings for specific tasks. It also would indicate whether the assessor is influenced by the team's use of time during the incident and therefore, if this can be used as an objective method of competency assessment in the future.

The differences between teams or emergency managers may identify particular styles of emergency management practice through emphasis on different methods. For example, a team using a crew resource management approach may result in longer informational calls from the scenario organisation team than those using a command and control approach. However, in this research, there were only two groups which differed in terms of their working environment (onshore vs. offshore) and, in this case, their attitude towards emergency management approaches was not recorded.

The grouped distributions for the scenarios are shown in Appendix 8. These include the scenario-specific parameters for all of the scenarios with the addition of the generic performance parameters for Offshore Scenario 2. The summaries of the parameter data (e.g. means, standard deviations) are then grouped by type (e.g. offshore vs. onshore, pre-incident) in Appendix 10.

SECTION 7.3: USING THE PERFORMANCE PARAMETERS IN THE TPRC MODEL

The Performance Parameter data could be used in a number of separate ways in the TPRC model. These are as follows:

- Using the scenario-specific data, the TPRC can reproduce the same task or escalation for different conditions or a novel scenario.
- Building up a task time from specific or generic performance parameters to test a new design
- Building up a task time from generic performance parameters to estimate the average response in a novel situation.
- Using the extremes of the performance parameter distributions to establish the fastest and slowest time.
- Choosing the generic performance parameter from the closest distribution (e.g. scenarios defined as highly competent, offshore scenarios etc) to represent the most likely response time from that category of task.

For example, if the scenario-specific data gives a distribution for "time between leak and ignition", a novel task can be plotted for this escalation time. Alternatively, the scenario-specific data may represent "time from start of incident to getting the fire team to the helideck" which could be used for a range of different speeds of escalation or different tasks. This improves the objectivity of the whole technique by removing the reliance on experts to provide estimates of values. This concept is best described through the use of an example, as shown in the following section.

SECTION 7.4: EXAMPLE OF PERFORMANCE PARAMETER USE IN THE CRANE DRIVER SCENARIO

Using the example scenario of the crane driver and the methanol tote tank, the performance parameters can be collected from the simulation data.

The expected amount for the time taken by can be calculated from the times taken as follows:

- passing on a message from the crane driver to the control room,
- passing the message from the control room operator to the OIM
- for the OIM to respond with an suggested action, then
- for this suggestion to be relayed back to the crane driver

These parameters provide an estimate of how long it could take for the team to realise the crane driver's circumstances then to order him to the safe haven.

This information can then be used in the TPRC as a possible delay in the initiation of his movement from the crane and can potentially be used for other similar situations. If distributions of the values can be produced, we can establish the minimum delay (indicating an optimal performance), an average delay, or a very long delay (perhaps caused by repetition of unintelligible radio messages or delays in response). This could be used to define the worst possible and best possible outcomes from the situation. This can then be compared with the observed outcome - hence giving an indication of the quality of the performance.

The extract of such a transcript (as shown in Table 8) is shown again in Table 18.

Table 18: Extract from Methanol Tote Tank Scenario Transcript

Time	Event
0:00:00	ASSUME INCIDENT OCCURRED
0:00:01	CD: Control room, Deck
0:00:03	call ends (CD)
0:00:05	CRO: Control, call back
0:00:06	call ends (CRO)
0:00:07	CD: Yeah, just to warn you, we've had a bit of a knock, moving these tote tanks around, the wind took the load and there was an edge-on, an edge-on knock, pretty hard, I'm just going to have a look now.
0:00:18	call ends (CD)
0:00:18	PS: Okay, stop all hot work, please CRO on the tannoy
0:00:21	Announcement ends (PS)
0:00:22	CRO (tannoy): Attention all personnel, attention all personnel, all hot work is to cease immediately, all hot work is to cease immediately, all hot work permits to be returned to the control, return all hot work permits to the control room, thank you.
0:00:34	tannoy ends (CRO)

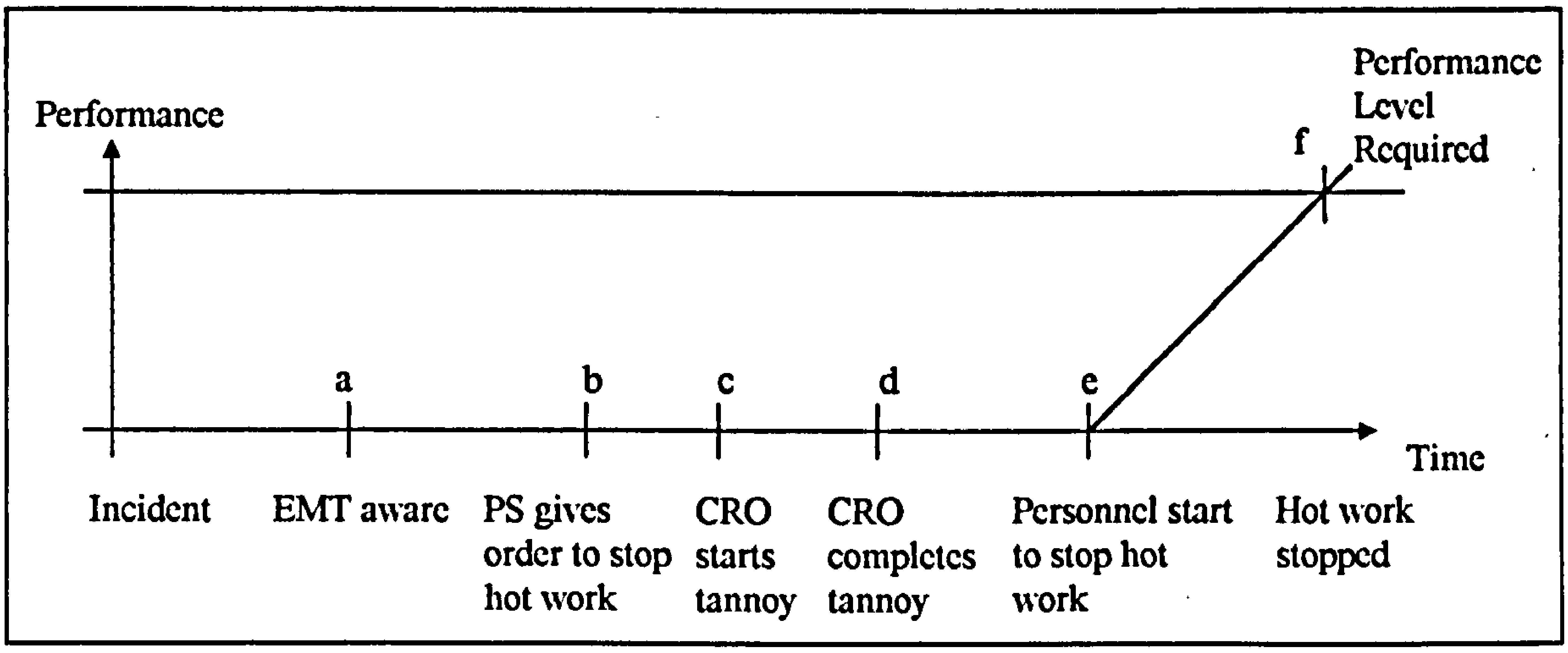
Consider Table 18. As the incident is fictitious, we can only assume when the initiation of events took place if it had been real. The first indication of an incident is when the scenario organisation team call the emergency management team on a hand-held radio. Therefore, the actual time at which the incident occurred is assumed retrospectively - given as 1 second before the call was started. Therefore, in generic data terms, it takes 1 second from the incident to the crane driver (CD - scenario organisation team) to start to call the control room. This call does not give any information about the incident or ask any questions. It merely starts the communication process. It is therefore a non-informational call that lasted 2 seconds. It takes 2 seconds from the end of this call for the control room operator (CRO - emergency management team) to start to respond to this call. His reply confirms the start of the communication process and also gives no information regarding the incident. This is therefore a non-information call that lasted 1 second. It takes 1 second for the crane driver to reply, which he does so with a lengthy call about his predicament. This call is therefore an informational call, which lasts 11 seconds, and so on. Considering the content in more detail, the Production Supervisor (PS) orders the CRO to stop all hot work using the tannoy. From the end of this order, it takes 1 second for the CRO to start this process. Therefore, using just this section of the scenario, we can obtain the generic data as shown in Table 19.

Table 19: Generic data obtained from section of Methanol tote tank scenario shown in Table 18

BEHAVIOUR	RAW TIMES (in seconds)	MEAN and SUM	STANDARD DEVIATION	MIN, MAX
Total time to deliver a message	17	17 (n=1) 17	-	-
Scenario organisation team's informational calls	11	11 (n=1) 11	-	-
Scenario organisation team's non-informational calls	2	2 (n=1) 2	-	-
Emergency management team's non-informational calls	1	1 (n=1) 1	-	-
Scenario organisational team's calls	2, 11	6.5 (n=2) 13	6.363961	2, 11
Emergency management team's calls	1	1 (n=1) 1	-	-
Non-informational radio calls	2, 1	1.5 (n=2) 3	0.707107	1, 2
Informational radio calls	11	11 (n=1) 11		
Total radio calls	2, 1, 11	4.666667 (n=3) 14	5.507571	1, 11
Delays between radio calls	2, 1	1.5 (n=2) 3	0.707107	1, 2
Announcements	3	3 (n=1) 3		
Information known in SOT - EMT told	18	18 (n=1) 18		
Time to initiate following orders (calling others outside)	1	1 (n=1) 1		
Incident - start first tannoy	22	22 (n=1) 22		
Length of tannoy	12	12 (n=1) 12		
Incident - start of first call out from CR	5	5 (n=1) 5		
Incident - start of first call into CR from incident site	1	1 (n=1) 1		
Incident - start of first informational call into CR from incident site	7	7 (n=1) 7		

Even from such a small section of the scenario, there are some useful data available. For example, it can be established that it took 12 seconds to deliver a tannoy. In this case, it is a non-informational tannoy as it gives an order but provides no information on the nature of the incident. Therefore, in terms of management tasks, 12 seconds is a possible duration for a non-informational tannoy. In terms of the TPRC, it would just be represented as part of a delay. However, as the tannoy provides an order, it also initiates actions outside of the control room. In terms of the TPRC, stopping the hot work should prevent further escalation of the incident. Therefore assuming that there will be another delay until the personnel carrying out the hot work can initiate their response, this will eventually result in the given task being implemented. In terms of the TPRC and SADCAR, the progress will look like Figure 38 (comparable to Figure 35).

Figure 38: TPRC Progress Graph in Stopping Hot Work



From Figure 38, it can be seen that there are a number of contributory delays before the actual task is carried out. The timing from points a to d is measurable. The actual timing of the incident as well as points e and f must be established. In a dedicated simulation, these are fictitious but based on the observed reactions; so reasonable estimates may be obtained for these values. For example, it took 1 second for the CRO to respond to the PS's order to stop all the hot work. Therefore it is possible that it also took 1 second for the personnel working on the hot work to react. The time taken to actually complete stopping the hot work (i.e. ensuring all equipment is safely switched off) is not recorded and cannot be estimated from the current amount of data. If a future scenario involved a technician calling in to say that the hot work is now stopped, this would provide an estimate of the duration of this task and would be recorded in scenario-specific data for that purpose.

Taking these ideas further, the generic data distributions can be built up and used as best and worst examples of timing. In our small sample of data, there were two non-informational calls - one of 1 second, one of 2 seconds. Therefore using the distribution from this sample, the average length of a non-informational call is 1.5 seconds; the shortest is 1 second and longest is 2 seconds. In combination with data from other distributions, this can be used to establish the average, shortest and longest delays before actions are initiated.

Also, these generic management tasks are independent of physical design parameters. For example, there is no reason why giving the order to muster should take longer for a bigger platform. Therefore, time taken in "ordering the muster" could be used from a scenario based on one installation for a scenario based on another installation. The actual "mustering time" could either be calculated from muster modelling programs, real data or built up based on numbers of people, distance and average walking speed. Therefore, given the design parameters (from either a real installation or a future concept for an installation), it is possible to apply the TPRC model to given tasks in the environment. This would make it possible to assess the impact of design changes on risk - hence fulfilling one of the objectives of the research

SECTION 7.5: PARAMETER USE OUTSIDE OF THE TPRC MODEL

The use of performance parameters is not confined to application in the TPRC model. As raw data, it can be used in its own right as a benchmark for performance. This could be used for a number of purposes, including the following:

- for assessment - therefore defining the times taken by highly competent, competent or failed emergency managers to react to particular situations so assisting in the assessment of other emergency management candidates
- for design - to ensure that designers are aware of the times taken to respond to particular situations and therefore new technology takes these times into account
- for emergency planners - to take the times taken into account when writing emergency management procedures

SECTION 7.6: LIMITING THE USE OF EXPERT JUDGMENT IN THE MODEL

One key feature of the addition of performance parameters is its potential to rectify one of the weaknesses of the current TPRC method. In Sections 5.4.1 and 5.5.2, it was noted that expert judgment was sometimes required to define means values and/or variance for some of the parameters. Most of the parameters used in the model could be obtained objectively using physical data from other research, so this would not cause too much of a problem for these data. However, the delays as defined by the management tasks were one of the main areas where these data could not be obtained from an alternative source.

The main focus of this research was to use simulation data in the model - therefore relying on this as the only source of management-based delays. As stated earlier, it could not be determined whether the delays observed (as determined by the scenario organisation team) were based on those that would be observed in a real situation. Also, it could not always be determined when certain events occurred (due to recording only the "emergency management team" side of the activities). Therefore, when it was necessary to represent these delays in the model, this required a wide distribution to be applied to the data - as defined by expert judgment. If distributions of the times taken by management decisions / actions or delays could be collated - as was the purpose of these performance parameters, this could provide a source of data for these observed parameters. Consequently, this would therefore reduce the reliance on expert judgment potentially producing an entirely objective technique.

SECTION 7.7: CONCLUSION

This section has demonstrated how simulation data can be applied to a number of analyses outside the scope of its original scenario. Using distributions of large numbers of data, possible timings of human responses can be estimated for use in design, risk assessment or theoretical research. In this case, 9 onshore and 5 offshore scenarios were used to produce data - resulting in over 17,000 pieces of data contributing to the 46 generic performance parameters. These could then be applied in the TPRC model, to test the impact of optimal, average and poor performance on the outcome of emergency as will be demonstrated in Chapter 9. This chapter concludes the sections on the method The previous chapters described the scenario arrangements for the research, the original TPRC model and the changes made to facilitate assessment of the impact of emergency management on risk reduction, plus the supporting data required. This chapter has introduced the concept of performance parameters, which collates the simulation data to be used in novel situations. Therefore, this report will now move on to illustrate the results that were obtained - initially starting with the results of the TPRC model as defined in Chapter 5.

Chapter 8

TASK PERFORMANCE RESOURCE CONSTRAINT MODEL RESULTS

SECTION 8.1: INTRODUCTION

This section will present the results as obtained from the TPRC model as described in Chapter 5.

As stated earlier, there were 14 simulations used - 5 offshore and 9 onshore. All 14 scenarios were prepared for TPRC analysis. This involved producing a full transcript of the scenario (an example of which is shown in Appendix 6) then a collection of the relevant timings involved in decision-making tasks. The scenario-specific timings (as introduced in the previous chapter) are shown in Appendix 8. The timings of generic tasks were incorporated into the development of the generic performance parameter distributions. As this involves a considerable amount of data, the means, standard deviations, maximum and minimum values are given in terms of categories in Appendix 10. The frequency distributions for the total post-incident data are shown in Appendix 11.

This chapter will focus on how the TPRC model can represent the impact of changes in the key parameters by using tasks taken from one scenario – Offshore Scenario 2, as described in Section 5.5.2. Once this has been used to explain how the technique works, this chapter will include additional examples taken from the other scenarios. There will also be use of the TPRC to examine aspects of a real situation then comparison with other quantification techniques. In addition to these examples, it should be noted that the TPRC results from Offshore scenario 1 (the helicopter crash) have been presented in Lyons et al (1998) shown in Appendix 12.

SECTION 8.2: TASK PERFORMANCE RESOURCE CONSTRAINT (TPRC) MODEL RESULTS

8.2.1: INTRODUCTION

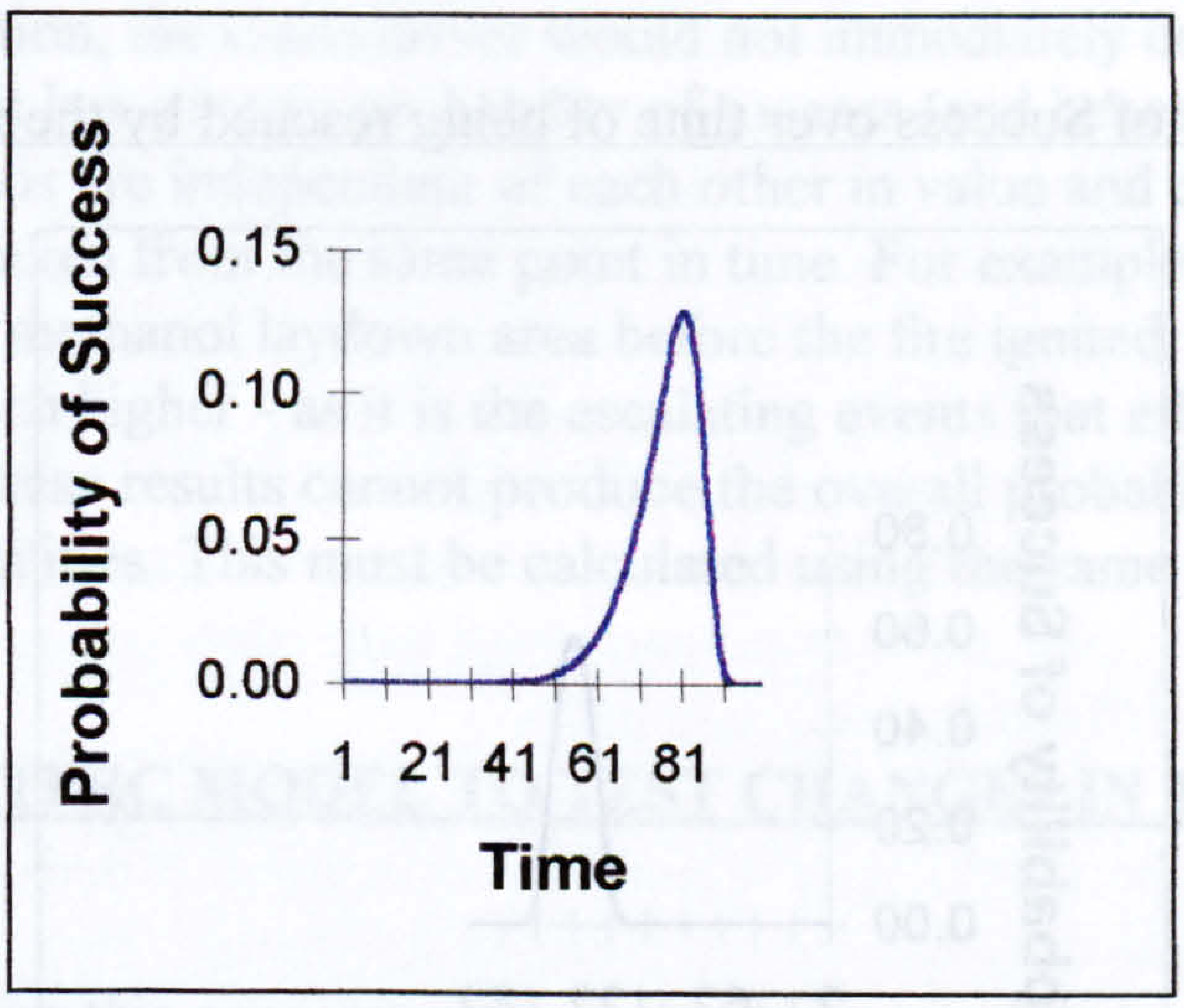
The results show the TPRC graphs for each of three events - the crane driver escaping over the methanol laydown area, being rescued from the crane by the fire team and by being picked up by the fast rescue craft - in each case, before the crane driver dies of his injuries. Following this, the report will continue by speculating on using different variables for input to the TPRC model given the same situations - and therefore illustrating the impact each variable has on the probability of success.

8.2.2: TPRC MODELS OF THE METHANOL LEAK INCIDENT

This incident clearly involves many factors - activating deluge, putting out the fire and ensuring that the fire does not escalate and impinge on other parts of the installation. However, one of the main tasks involved is to save the crane driver. In the first instance, the leak is the problem. The crane driver investigates this so is still in the area when the ignition occurs. For some reason, the crane driver cannot escape to safety and seeks refuge in the crane cabin. Before the fire team are able to get to him, he is overcome by smoke and flame and is forced to take the only other escape from the flames by jumping into the sea. Of course, in many cases, the events that occur in the scenario have already been specified. Therefore, perhaps any intervention made by the emergency management team would have made no difference. However, in this case, the crane driver was given no encouragement to leave the area himself (being told to stay and wait for the rescue). Also, once the crane driver was in the water, the standby boat made an immediate decision to launch - without any intervention by the emergency management team, who, at this point, were still unaware of what had happened.

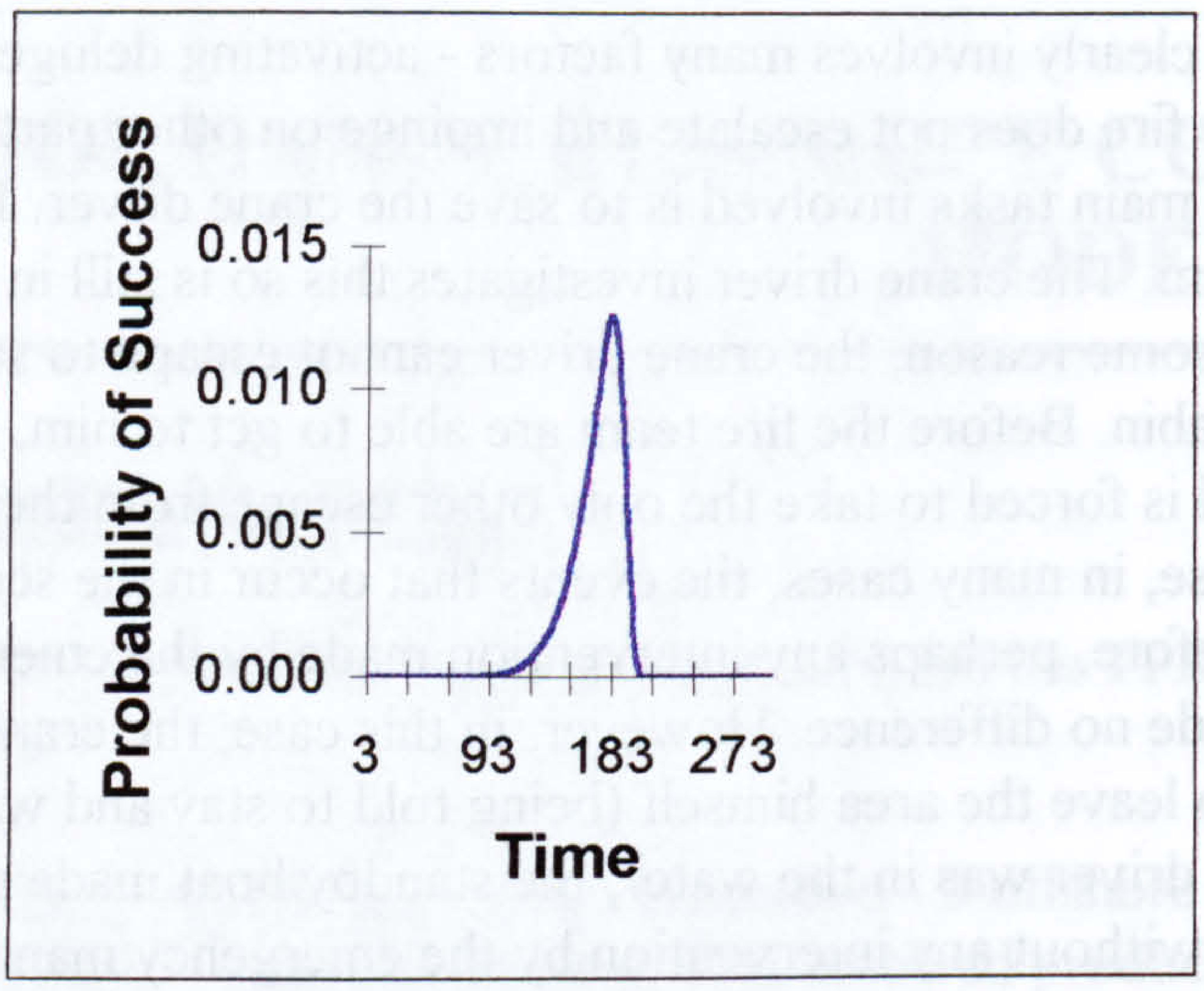
Therefore the TPRC results of the crane driver managing to escape over the methanol laydown area before being incapacitated by the smoke and fire are as shown in Figure 39.

Figure 39: Probability of Success over time of Crane Driver's escape across the deck



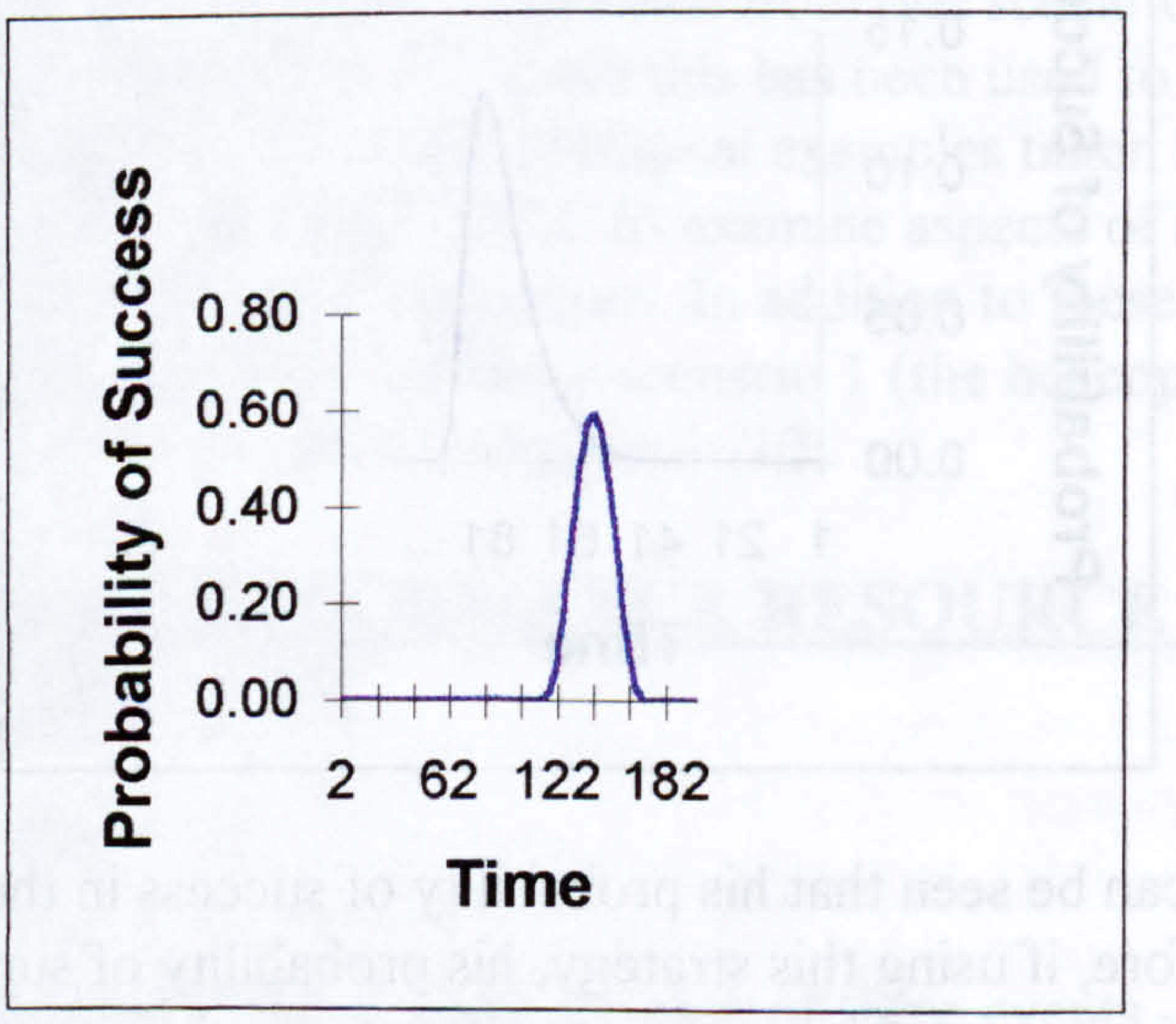
From this, it can be seen that his probability of success in the task has a maximum value of 0.13. Therefore, if using this strategy, his probability of survival is small and he would be ill advised to attempt this escape. As the information is not available, we must assume that either he did not attempt the escape or his attempt failed and he was driven back to the crane cabin. Given this, his next hope of rescue involves relying on the fire team to subdue the flames, to access the crane cabin then to lead him to safety. The probability of success with respect to time of the fire team reaching the crane driver before he is overcome by fire is shown in Figure 40.

Figure 40: Probability of Success over time of Crane Driver's rescue by the fire team



This time the maximum probability of success is even smaller - 0.013. This indicates that the fire team have very little chance of reaching the crane driver in time now that he has been driven back to the crane and the fire has escalated. So the crane driver is forced to take the extreme measures of jumping into the sea. Given that he survived the fall, he now relies on the speed of the standby boat crew and the fast rescue craft to rescue him before he dies of his injuries, hypothermia or drowning. For this, the TPRC results are shown in Figure 41.

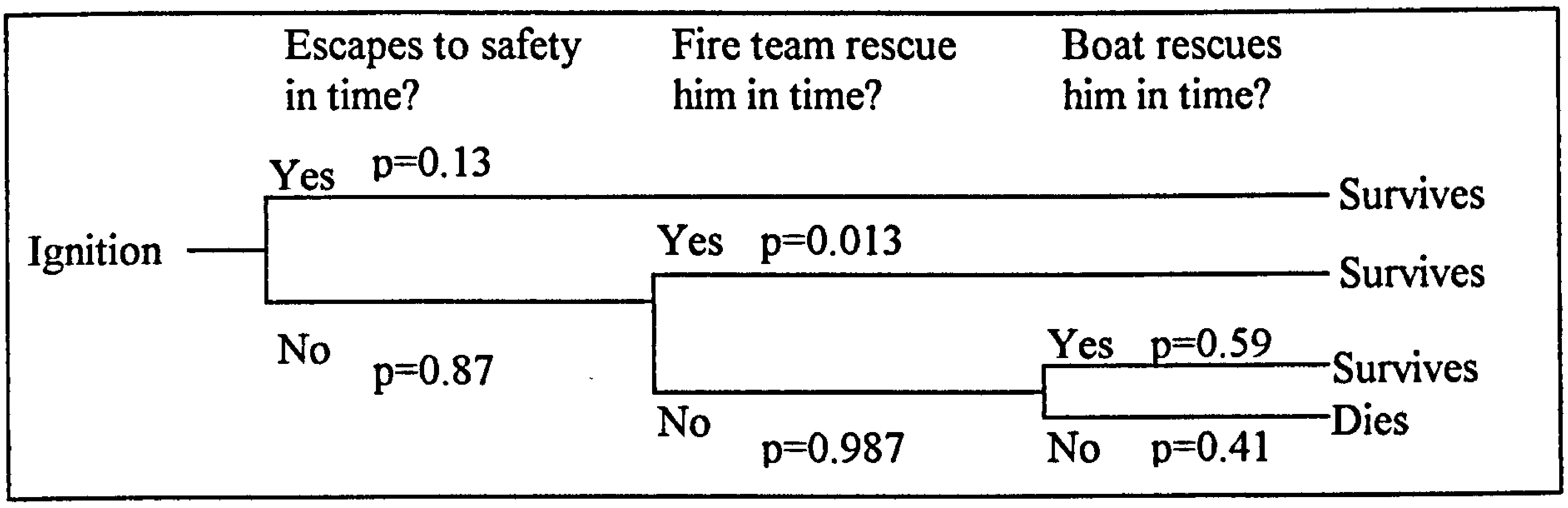
Figure 41: Probability of Success over time of being rescued by the fast rescue boat



Here, the probability of success is much more favourable. The maximum probability of success is given as 0.59. Therefore, the chance is better than a random "50:50" chance though is by no means optimal.

Given that these values can be obtained, consider the event tree shown in Figure 42. This is repeated from Figure 37 with the addition of the maximum probabilities of success obtained in the model.

Figure 42: Event Tree of the Crane Driver's Options including Probabilities



Firstly it should be noted that these provide the maximum probabilities of success for each aspect of the task not the average value. Also the probability of success functions relate to time - and the timing of each distribution does not have the same starting point.

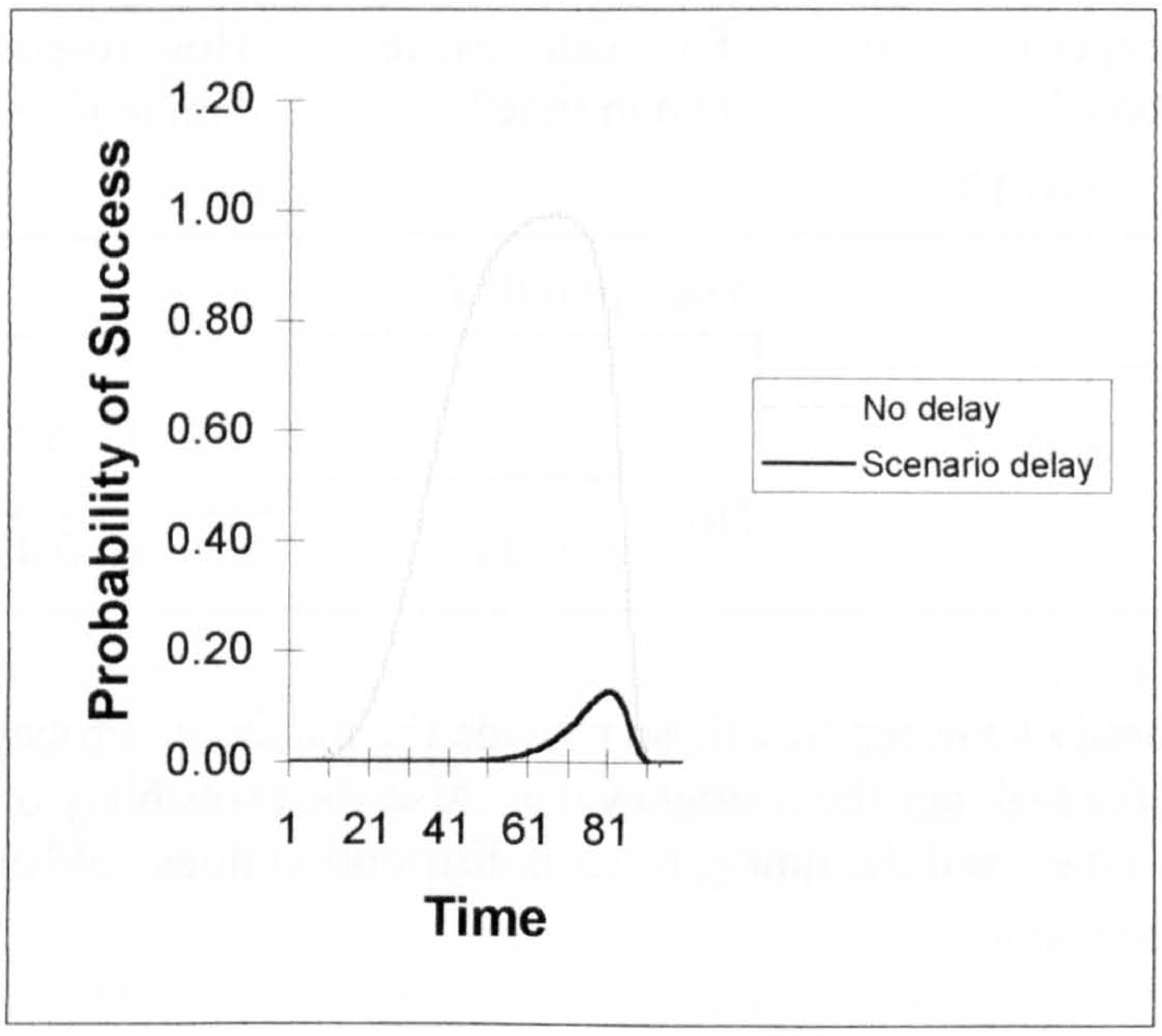
Also, caution should be taken that these results are not used in decision-making. Given the initial situation, the crane driver would not immediately consider jumping over the side just because it has a larger probability of success (and hence survival) in these graphs. These decisions are independent of each other in value and can only be compared with other solutions taken from the same point in time. For example, if the crane driver had escaped over the methanol laydown area before the fire ignited, the probability of success should be much higher - as it is the escalating events that effectively reduce his chances. Therefore, these results cannot produce the overall probability of survival by the product of the probabilities. This must be calculated using the same time base for all three distributions.

8.2.3 USE OF THE TPRC MODEL TO TEST CHANGES IN THE PARAMETER VALUES

Therefore, using this same scenario, it should be possible to use the TPRC model to test how changes in the parameter values (through changes in the emergency management team's reactions or the emergency situation) affect the outcome. This can be used to assess the impact of changes in emergency management skill and design affect the risk and will therefore fulfil the 3rd objective of the research.

Therefore, in the first example, this considers the optimal potential for the first situation - the escape of the crane driver. In this case, the same starting time was used but rather than waiting for the muster to start, the crane driver attempted the escape immediately at the point when the leak ignited. Therefore, instead of a delay of 61 seconds, the delay is now taken as 0 (0.05). This may be too optimistic - as was discussed in Chapter 7 regarding performance parameters. However, it provides some idea of the maximum probability of success in the situation - as shown in Figure 43.

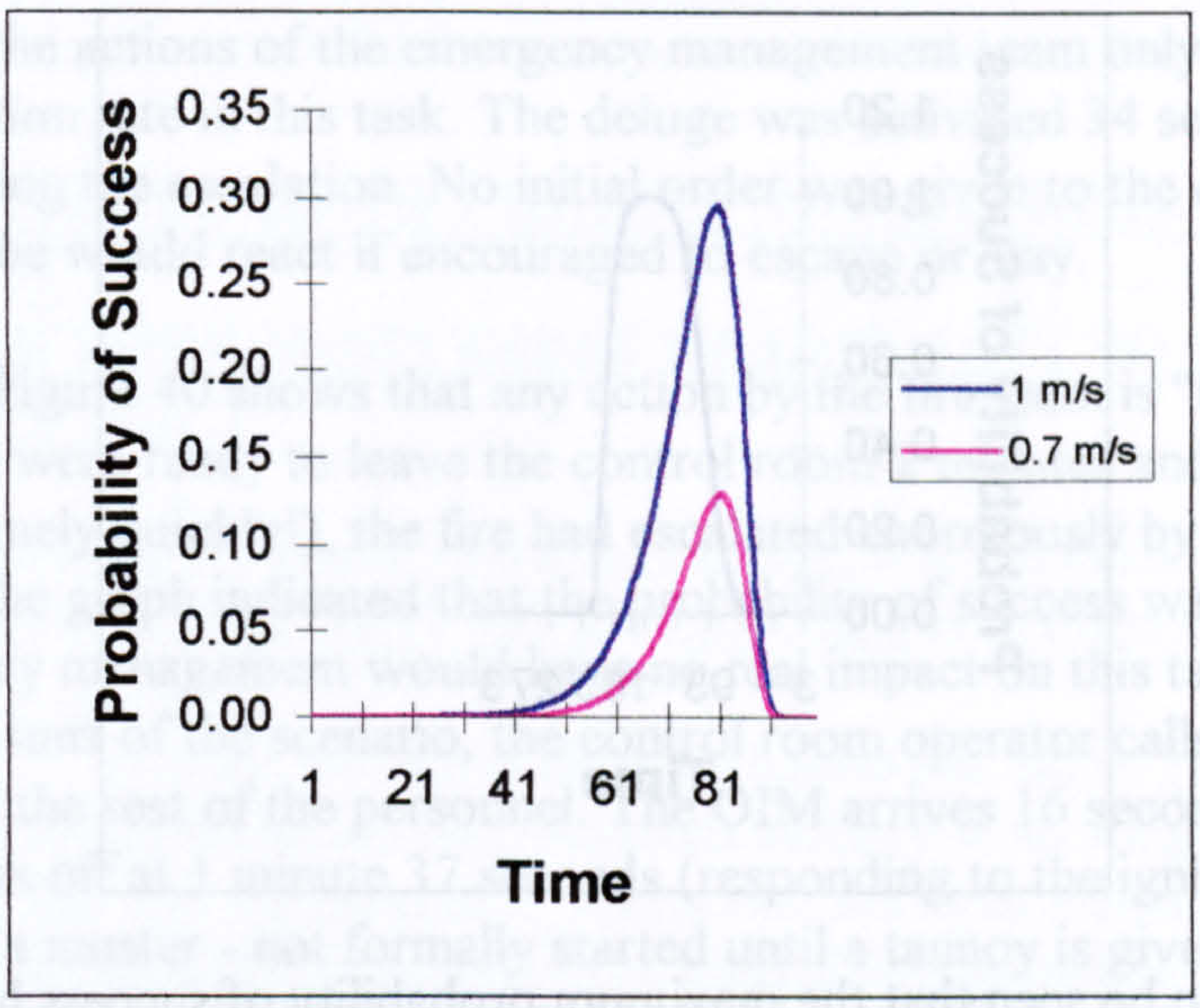
Figure 43: Probability of Success over time in escaping over the deck - comparison between the observed delay and no delay



From Figure 43, it can be seen that the probability of success is greatly increased by early initiation of the task - up to 0.99. If there is no delay in attempting to escape, the fire has not escalated to a significant level to hinder the crane driver's progress. Therefore he is almost certain to successfully escape across the deck without help from the fire team. If the emergency management team had been able to predict this course of events, they could have ordered the crane driver to leave the area once the leak had been detected. This would have significantly reduced the probability of injury to himself - as well as to the fire team who were sent to rescue him. In this case, our emergency management team failed the crane driver - they were more concerned with other issues and this example has illustrated how much difference that could make.

Consider also the crane driver's speed of movement. If he left at the same point (with the delay of 61 seconds) but moved considerably faster, what influence would this have on his probability of success. Using a speed of 1m/s (0.1) instead of 0.7m/s, the TPRC results were as shown in Figure 44.

Figure 44: Probability of Success over time in escaping over the deck showing change in speed

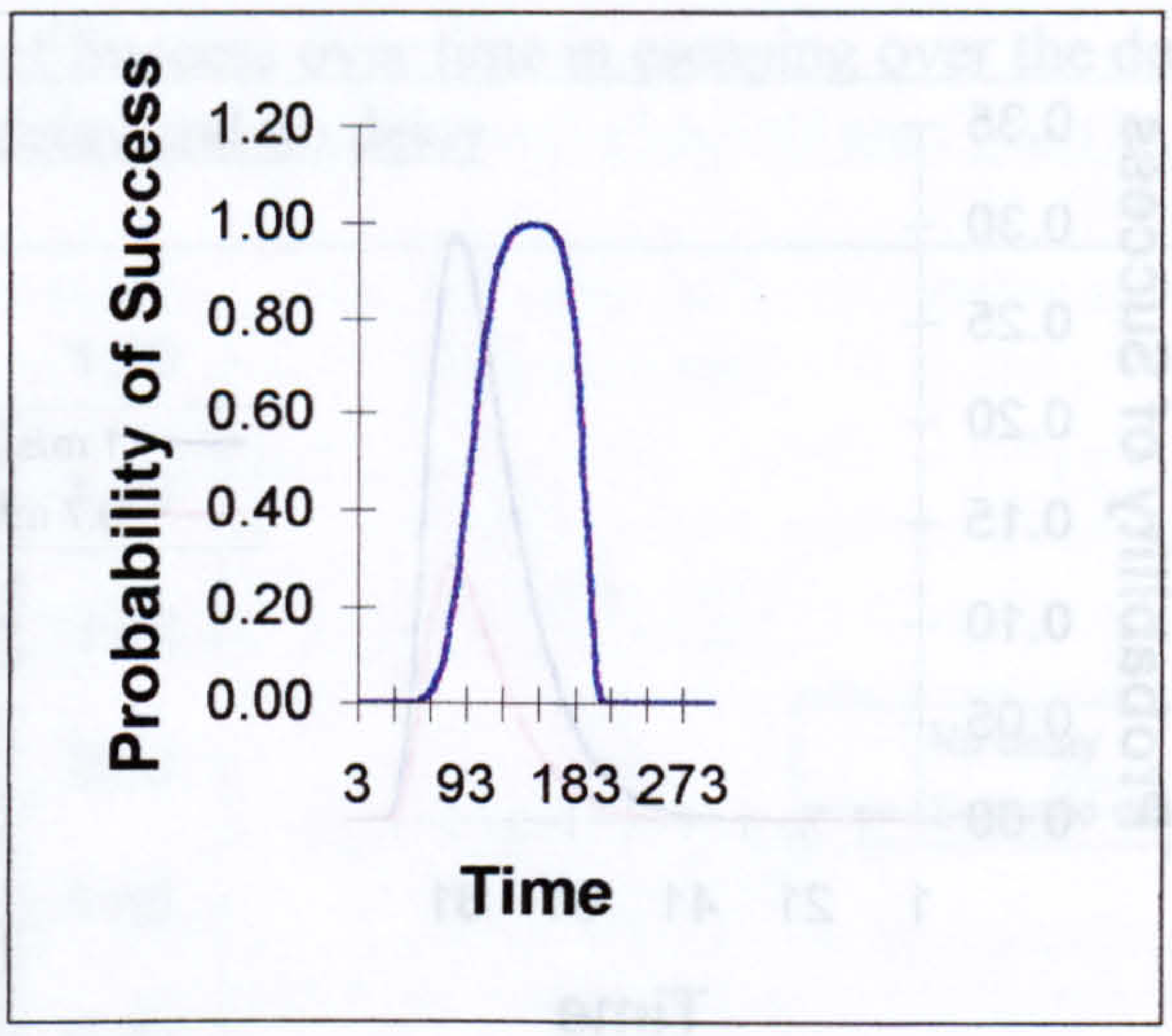


Note that an increase in overall speed has improved the probability of success by more than half - now giving a maximum value of 0.3. Despite this, the influence of the resources is clear. Although the graph of 1 m/s starts rising before the 0.7 m/s graph - both decrease to zero at the same point. This is consistent with the concept of risk - that when the resource limit has been reached, the task progress will be prevented.

This is also consistent with observations from aircraft evacuations - that fit young men are often the first evacuated from an aeroplane - and therefore the most likely to survive. Although there are other contributory factors, such as determination or even aggression, it is likely that they can react faster (low delay) and move faster than other types of passengers - resulting in a higher probability of success in evacuating (Muir et al 1996).

There are further changes that could be made. The resources (time) are determined by the speed of escalation of the fire. If this could be controlled to a greater degree, this would give the crane driver more time until he is overcome by the heat and smoke - possibly enough to facilitate his escape. So if the TPRC uses the observed scenario times (including the 61 second delay) but with a resource time of 189 (0.05) - the point at which the crane driver found the heat so unbearable that he jumped into the water - the TPRC results are as shown in Figure 45.

Figure 45: Probability of Success over time in escaping over the deck with increased time resources



Again, it can be seen that the maximum probability of success has been greatly increased (peaking at 0.997). By increasing the resources either by controlling the fire or providing the crane driver with increased protection against the fire - his probability of success in escaping over the methanol laydown area is extremely high.

However, the maximum probability is not the only consideration. One of the main virtues of this model is that it produces a distribution of values over time. Currently, there are no performance standards that can be related to the TPRC model. For example, if a probability of success of 0.75 or better was considered "acceptable" - this model could provide us with the amount of time at which the task was on or above this limit. This results in a probable time frame for a task to be successfully completed. For example, in Figure 45, the probability of success is above 0.75 for 75 seconds (between 108 and 183 seconds). However, in Figure 43, the probability of success is above 0.75 for 37 seconds (between 44 and 81 seconds). This indicates that the time window for a successful result is greater for Figure 45.

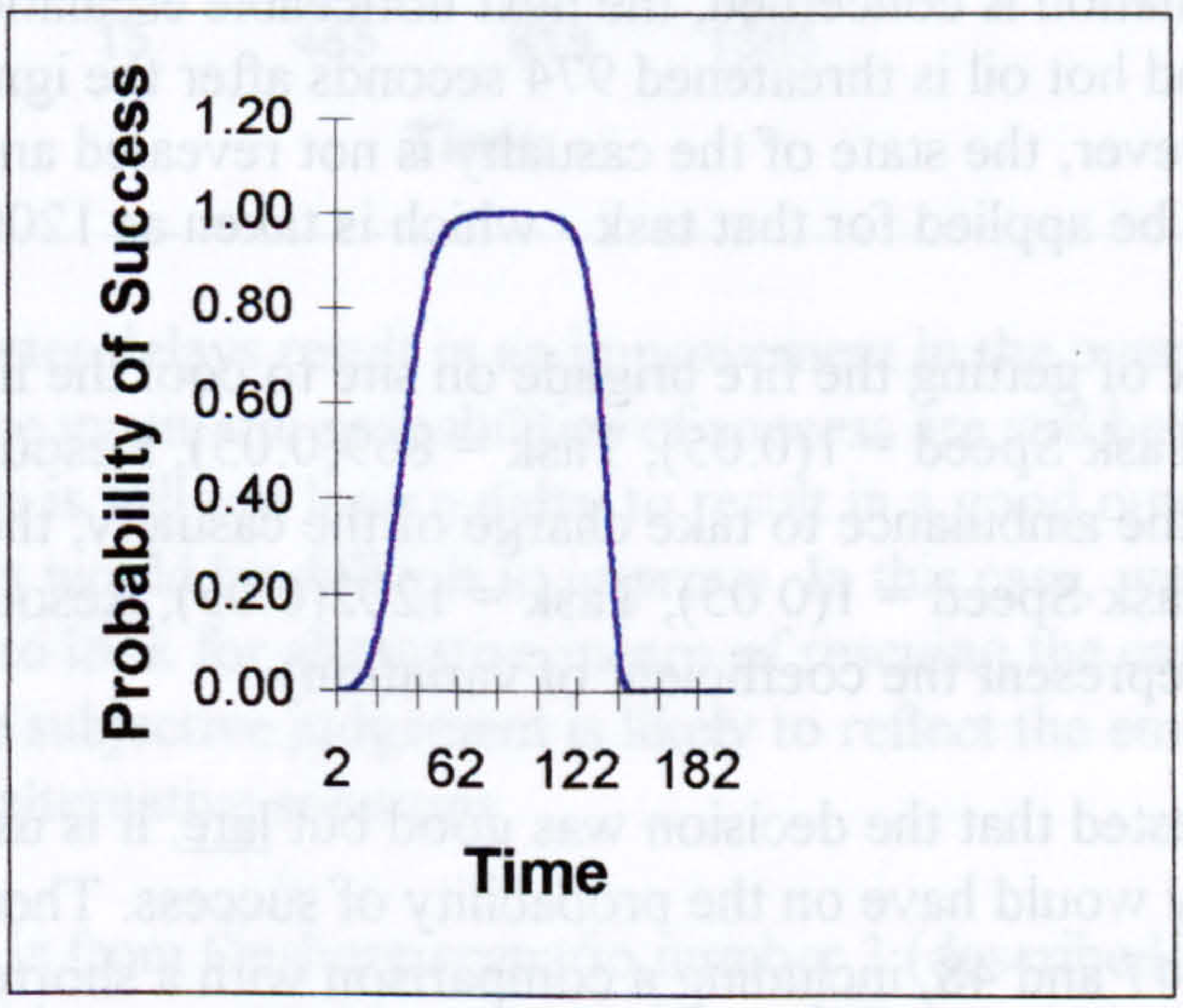
In each of these graphs, the influence of resources, delays and task speed can be seen. These results also seem to have validity when considering our knowledge of emergencies and emergency management. If the escalation rate is slowed, it increases our chances of a successful rescue - hence reducing the risk. If the delays in action are shortened or the actions are speeded up, it increases the probability of success in the task, again reducing the risk.

However, this task is greatly influenced by the crane driver's perception of reality - rather than reality itself. One might expect his decision to be based on his perception of the comparison between his probability of survival if he does try to escape and if he does not. If he perceives the chances of success in escaping to be low - he is unlikely to attempt it. Consequently, if he perceives the chances to be high, he is likely to attempt the escape, even if these perceptions later turn out to be wrong. In graphical terms, if no attempt is made, the delay is assumed to be greater than the resources and therefore the probability of success will have a maximum value of 0.

Therefore the actions of the emergency management team only affected the resource consumption rate in this task. The deluge was activated 34 seconds after the leak ignited - slowing the escalation. No initial order was given to the crane driver so we do not know how he would react if encouraged to escape or stay.

However, Figure 40 shows that any action by the fire team is "too little too late". Although the team were ready to leave the control room 2 minutes and 20 seconds into the incident (extremely quickly!), the fire had escalated enormously by the time they had reached the site. The graph indicated that the probability of success was extremely low; therefore emergency management would have no real impact on this task. However, it is notable that at the start of the scenario, the control room operator calls the OIM to the control room - not the rest of the personnel. The OIM arrives 16 seconds later. The platform alarm goes off at 1 minute 37 seconds (responding to the ignition). This, informally, signals a muster - not formally started until a tannoy is given. However, if the muster had been started at the same time as the OIM was called - this would have shortened the delay in rescue as well as calling the crane driver away from the site before the ignition occurred. Therefore, the delay would be even shorter than that shown in Figure 43 - increasing the probability of success even more. To represent this, we have to consider the crane driver's probability of success if he attempted to leave the area as soon as he found the methanol had leaked (45 seconds into the scenario). This is shown in Figure 46.

Figure 46: Probability of Success over time in escaping over the deck before leak ignites



As suggested, the probability of success is even greater than in Figure 43 - when the crane driver did not attempt the escape until the leak had ignited. The actual maximum value was given as 0.9999, occurring between 92 and 94 seconds after the leak was discovered. On the graph, it appears that the probability is 1. However, this would not be possible using statistical models of reliability such as the TPRC model.

This has shown a worked example of how the TPRC model is used and how it demonstrates understandable and realistic results. At this point, this appears to have successfully fulfilled 3 out of the 4 objectives. However, to demonstrate the scope of its use, the following section will illustrate a number of different examples.

SECTION 8.3: ADDITIONAL EXAMPLES OF TPRC MODELLING

8.3.1 EXAMPLES OF TWO SIMILAR TASKS FROM DIFFERENT SCENARIOS

The first example is from the first onshore scenario - where the incident involves a hot oil leak that ignites (description in Section 4.9.6). The TPRC analysis of two tasks are shown:
- getting the casualty to the ambulance before it is too late for him.
- getting the fire brigade on site before the diesel and hot oil tanks are threatened.

As far as the management team are concerned, both tasks are one and the same - putting out the priority one and priority two calls.

In the questionnaire study (see Appendix 9 for details), the assessor stated that the decision to make priority one and two calls (phoning for ambulance and fire brigade) was a good one but was late.

From the transcript, it was observed that the calls were not completed until 202 seconds after the leak had ignited. It was then 869 seconds before the fire engines were on site and were actively involved in cooling the area. It was 1202 seconds before the casualty was safely in the ambulance. As both of these tasks involve sub-tasks of different speeds - for example, travelling, setting up equipment, they are used in the TPRC model as the actual time with a speed of 1 unit/second - as described in Section 5.4.2.4.

As far as the fire escalation is concerned, the next noticeable escalation point is the time at which the diesel and hot oil is threatened 974 seconds after the ignition. This is taken as the resource. However, the state of the casualty is not revealed and so an arbitrary escalation point must be applied for that task - which is taken as 1200 seconds after ignition.

Therefore for the task of getting the fire brigade on site to cool the fire, the data are:
Delay = 202 (0.05), Task Speed = 1(0.05), Task = 869(0.05), Resources = 974(0.05)
For rescuing getting the ambulance to take charge of the casualty, the data are:
Delay = 202(0.05), Task Speed = 1(0.05), Task = 1202(0.05), Resources = 1200(0.1)
(Figures in brackets represent the coefficient of variation)

As the assessor suggested that the decision was good but <u>late</u>, it is useful to see what impact a shorter delay would have on the probability of success. Therefore, the results are shown in Figures 47 and 48, including a comparison with a shorter delay of 60 seconds.

Figure 47: Probability of Success in setting up cooling before diesel and hot oil are threatened - comparison between delays

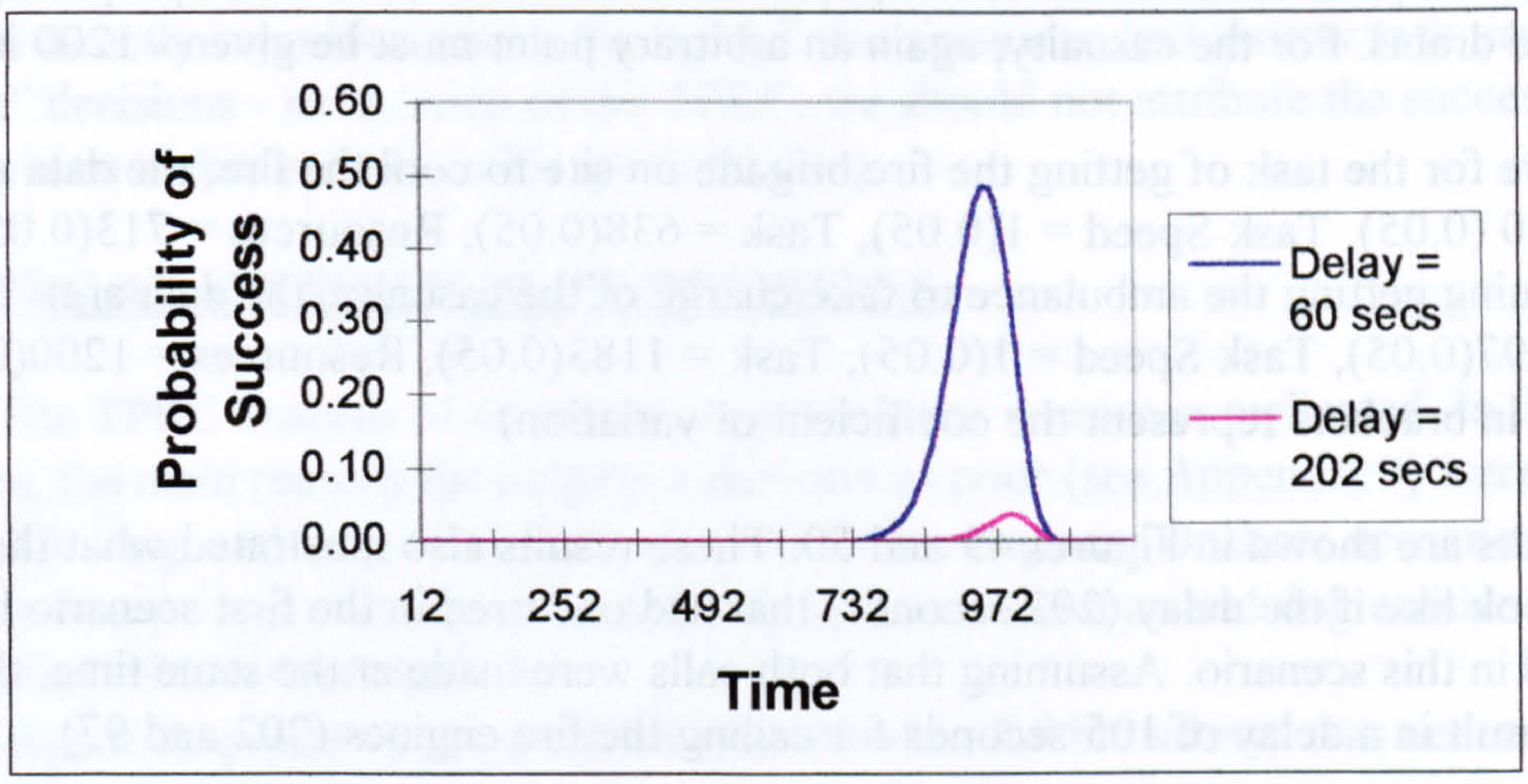
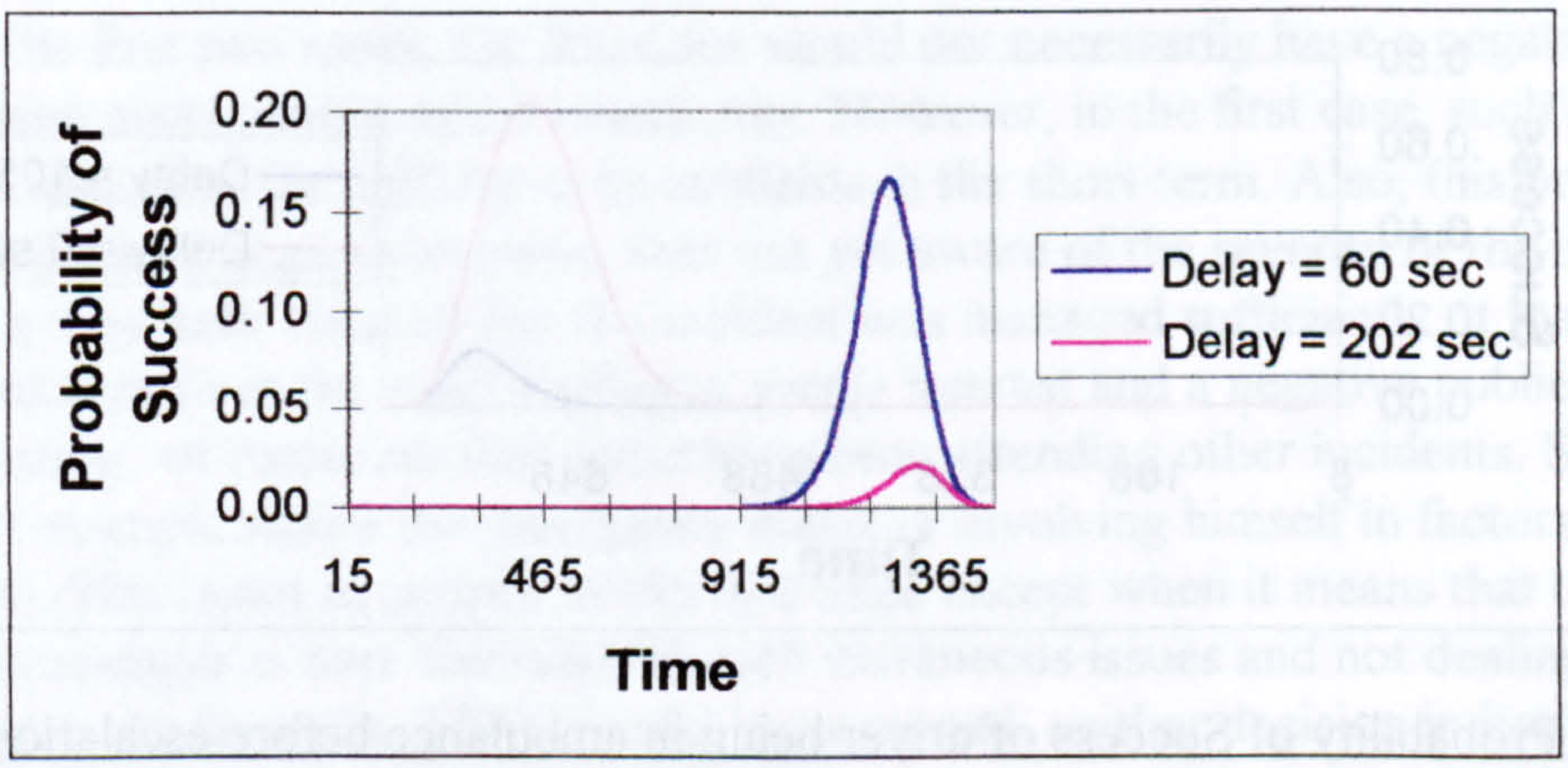


Figure 48: Probability of Success in evacuating the casualty before escalation - comparison between delays



As expected, the shorter delays result in an improvement in the overall probability of success. However, the maximum probabilities of success are still below 50% - suggesting either that 60 seconds is still too long a delay to result in a good outcome, or that the success of these tasks would be difficult to improve. In this case, we would expect the emergency manager to look for alternative means of rescuing the casualty and controlling the fire and therefore subjective judgement is likely to reflect the emergency manager's flexibility in seeking alternative solutions.

The second example is from Onshore scenario number 3 (described briefly in Section 4.9.8), where the incident starts with a tanker driver falling and hitting his head. The loading hose of his propane tanker then proceeds to leak propane. Considering the same task as in the first example (making the priority one and priority two calls), the assessor judged the decision as good and early and the candidate was judged as highly competent overall (see Appendix 9).
The calls were completed 97 seconds after this accident occurred. 1 second later, the propane ignites. Therefore, as far as the events are considered, the fire engines were

called before a fire had actually started! The fire engines arrive 638 seconds after being called and the ambulances arrive 1183 seconds after being called. For the fire engines, the escalation point is measured as the point where a fireball occurs and propane goes down the drains. For the casualty, again an arbitrary point must be given - 1200 into the incident.

Therefore for the task of getting the fire brigade on site to cool the fire, the data are:
Delay = 0 (0.05), Task Speed = 1(0.05), Task = 638(0.05), Resources = 713(0.05)
For rescuing getting the ambulance to take charge of the casualty, the data are:
Delay = 97(0.05), Task Speed = 1(0.05), Task = 1183(0.05), Resources = 1200(0.1)
(Figures in brackets represent the coefficient of variation)

The results are shown in Figures 49 and 50. These results also illustrated what the graphs would look like if the delay (202 seconds) that had occurred in the first scenario had also occurred in this scenario. Assuming that both calls were made at the same time, this would result in a delay of 105 seconds for calling the fire engines (202 and 97)

Figure 49: Probability of Success of fire engines being on site before fireball occurs

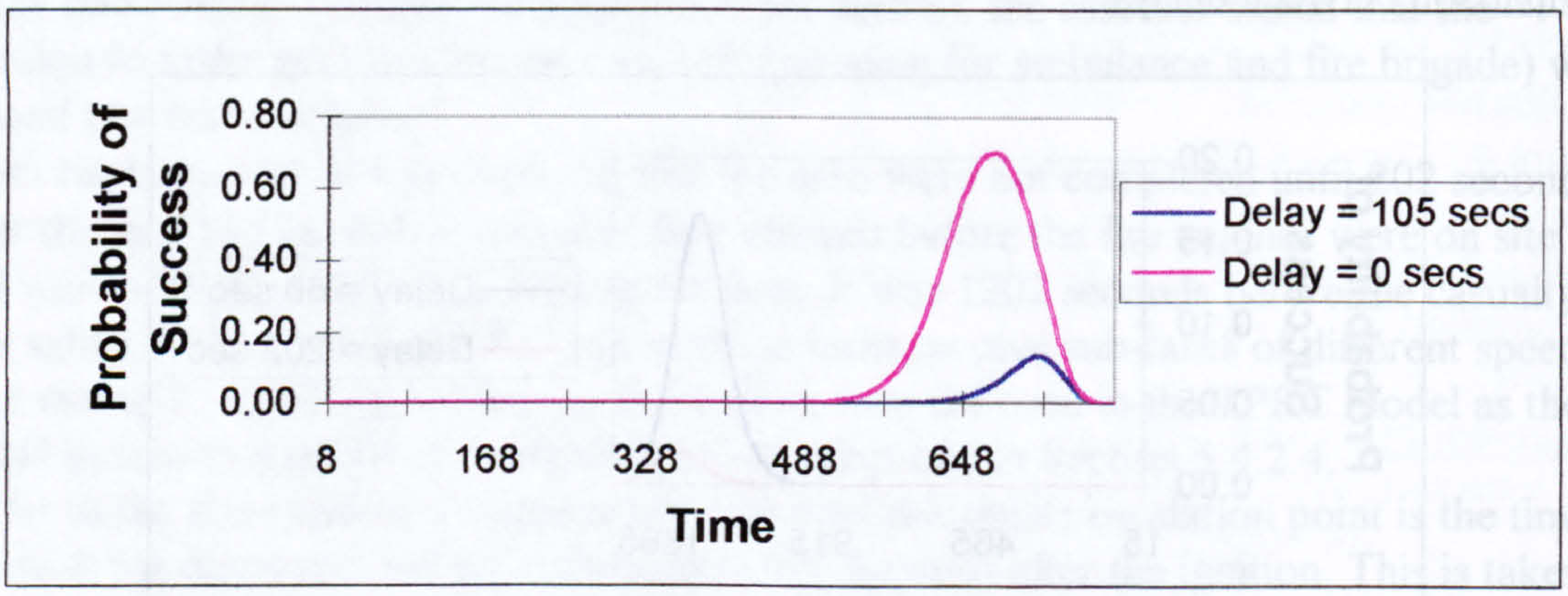
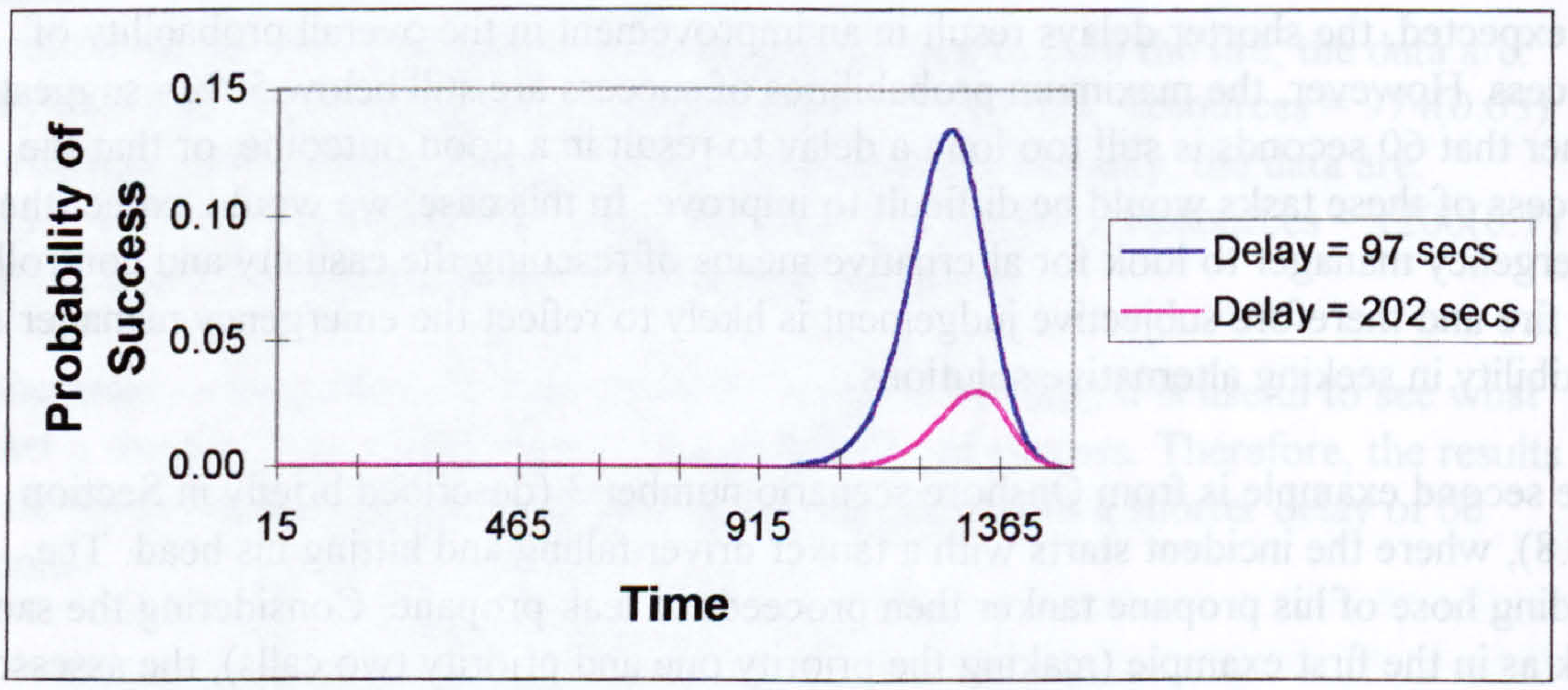


Figure 50: Probability of Success of driver being in ambulance before escalation occurs



As before, the shortest delays result in the greatest improvement in probability of success. However, from the two tasks, it is apparent that the fire engines are more likely to be successful than the ambulance team. When comparing the two scenarios, it is also noticeable that the ambulance and fire engines took a different length of time to reach their destination. In general, this is a realistic occurrence. Availability, distance and road conditions are likely to affect their time of arrival. However, comparing the two scenarios directly is problematic as the "early" decisions also had shorter task times than the "late" decisions - so in terms of the TPRC, we should not attribute the success of the early decision maker entirely to his quick thinking.

8.3.2 TPRC ANALYSIS OF POOR DECISIONS

The TPRC analysis of decisions judged as poor is more complicated. In this set of scenarios, the main reasons for judging a decision as poor (see Appendix 9) were:

- overkill - e.g. ordering 10 ambulances and 10 fire engines (Onshore scenario 4).
- unnecessary - e.g. ordering an ambulance to rescue the man and dog outside the complex (Onshore scenario 5)
- inadequate response - e.g. partial blowdown when full blowdown was necessary (Onshore scenario 4)
- errors of omission - e.g. not protecting the surrounding area from column depressurisation (Onshore scenario 4)

In the first two cases, the decisions would not necessarily have a negative effect on the overall management of the emergency. However, in the first case, such a large number of resources are unlikely to be available in the short term. Also, this order was placed when the emergency manager was not yet aware of the severity of the incident. Although it may have ensured that the incident was managed sufficiently, it may also have caused a panic in the nearby villages, media interest and a negative public response to the "wasting" of resources that could have been attending other incidents. Similarly, the second example shows the emergency manager involving himself in factors outside of his concern. This is not as serious as the first issue except when it means that the emergency manager is over-focusing on such extraneous issues and not dealing with the main incident. As far as the TPRC model is concerned, neither decision in itself would negatively affect the overall management of the emergency. The successful rescue of the man and dog could also benefit public relations. Perhaps this is one example of where the subjective assessment shows inconsistencies with the public opinion or objective measures of success.

As far as the inadequate response or errors of omission are concerned, the TPRC is much easier to use. An inadequate response may be represented similarly to the concept of delays discussed in Section 8.2.3. In some circumstances, a partial blowdown means that the plant is not as safe as it would be following a full blowdown. Therefore, the risk of escalation has not been abated. This is comparable to the performance shortfall shown in Figure 16. If the desired level of performance is never attempted, how can it be achieved? Similarly, if a task is not attempted at all, the probability of success can be only left to a minimal chance of it being completed accidentally. Therefore technically, this can be used in the model with an "infinite" delay.

For example, assuming the task of protecting the surrounding areas takes approximately 2 minutes (no data are available for this task so this is an arbitrary figure), it is necessary to protect the area until the column is depressurised - at 16.30 minutes into the scenario. As this task was not attempted at all during this time, we can apply a delay exceeding the resource limit, which in this case was chosen to be 1000. Therefore the data inputted are as follows: Delay = 1000(0.05), Task Speed = 1(0.05), Task = 120(0.05), Resources = 330 (0.05) (Figures in brackets represent the coefficient of variation).

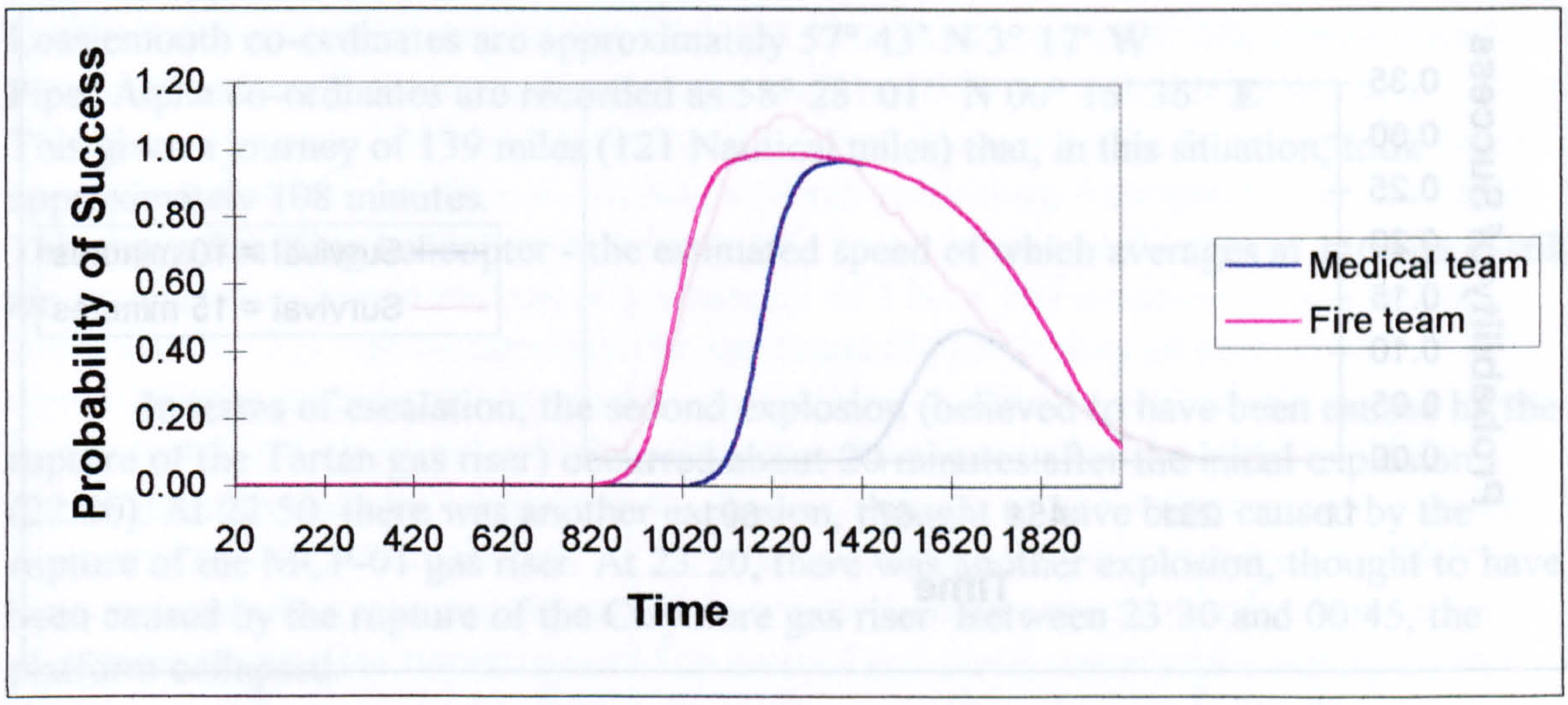
In this, the probability of success never increases above the origin - following the time (t) axis. This reflects the probability of success in a task that was never attempted.

8.3.3 ADDITIONAL EXAMPLES FROM THE OFFSHORE SCENARIOS

In Offshore scenario 3, a technician has explosion injuries as well as flash burns. The TPRC model can be used to plot the probability of success over time of getting the medical team to the casualty before he deteriorates. From the transcript, the production supervisor is told over the phone that there is an injured person in the GCD control room. The phone-call ends 5.08 minutes into the scenario and he informs the rest of the team 20 seconds later. A medical team are despatched 6.52 minutes into the scenario but due to the fire team leader's difficulties in gaining access, they do not arrive on site until 20 minutes into the scenario. Although, it is not known how long it will take before the casualty's condition deteriorates with these combination of injuries, it will be taken to be 30 minutes. It is notable that the fire team have been in the GCD control room for a few minutes before the medical team arrive. Therefore, it would be better to have a "multi-skilled" fire team that are also knowledgeable in medical skills. Obviously, to a certain degree, this will be the case. However, if we assume the medical team arrive on site at the same time as the fire team, it is not know how much difference this makes to the probability of success.

Therefore, taking the task of getting there as a unit task (time taken in the whole process rather than time to get from A to B), the data inputted for the "scenario" medical team are as follows:
Delay = 412(0.05), Task Speed = 1(0.05), Task = 788 (0.05), Resources = 1800 (0.1) (Figures in brackets represent the coefficient of variation). The data inputted for the medical team (assuming they were with the original fire team) are as follows:
Delay = 126(0.05), Task Speed = 1(0.05), Task = 879 (0.05), Resources = 1800 (0.1). The results are shown in Figure 51.

Figure 51: Probability of Success in getting to the casualty before he deteriorates - comparison between medical team and fire team timings

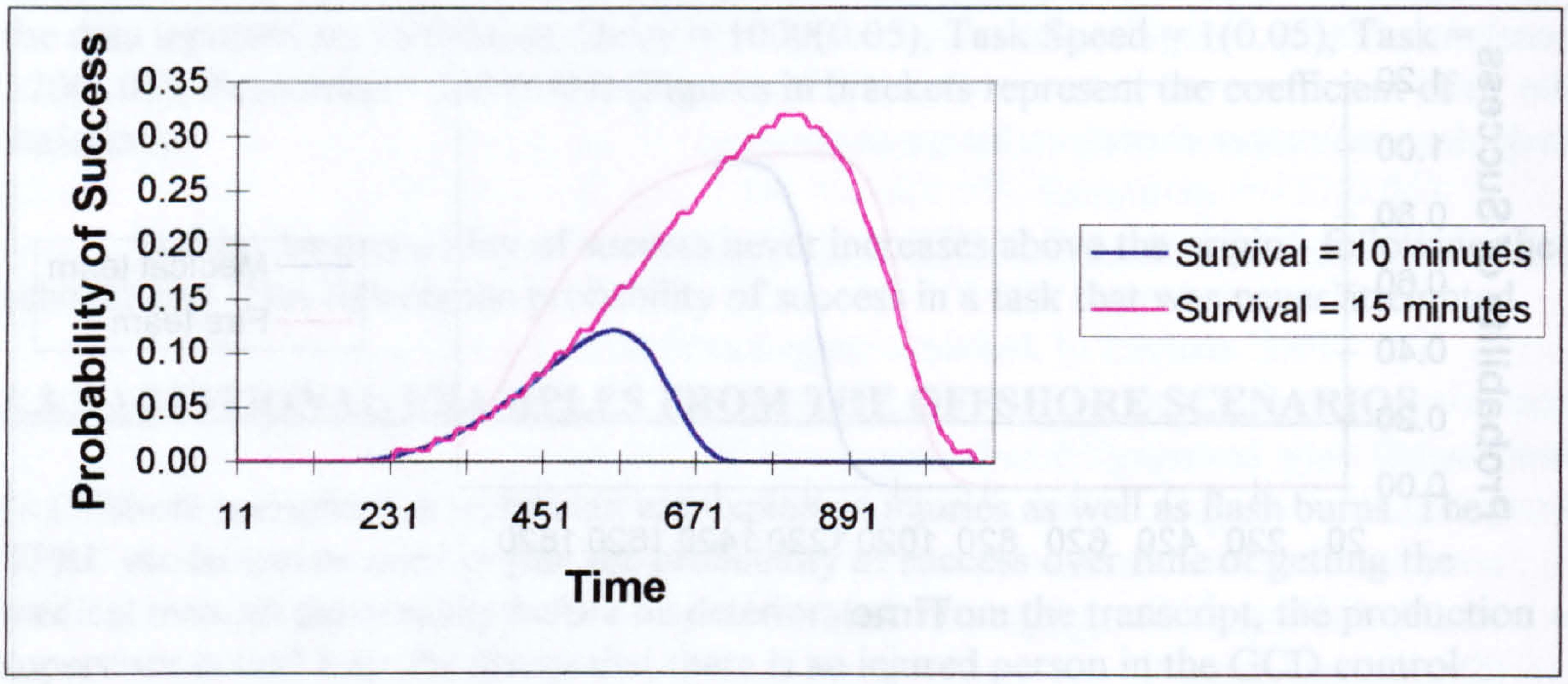


From Figure 51, it can be seen that there is very little difference between the two tasks. The fire team has a much greater task on their hands, as they are required to clear the route to the site on the way. For this reason, the maximum probability of success is 0.99. This is only slightly greater than the probability of success obtained by the medical team - which had a maximum at 0.97 - however, again it can be seen that the time window for success has been changed - where the influence is shown at the leading edge of the curve.

In Offshore scenario 4, there is a fire in the HV switchgear room. This initially starts with a smoke alarm and a technician is sent to investigate. However, he is overcome by smoke and does not attend the muster. It is not known exactly when this occurs but his last communication to the control room ends at 1.42 into the scenario and he is known to be missing from the muster at 3.50 minutes. Therefore this value is uncertain between these two points. The fire team leave to search for the missing people at 5.27 minutes into the scenario (therefore delay is between 102 and 230 seconds). 19 minutes into the scenario, the search teams find him and mouth-to-mouth is performed. Using the data from Table 16, it is not unreasonable to expect collapse and/or death after 10-15 minutes. Therefore, these 2 values will be applied in the model.

Delay = 166(0.1), Task Speed = 1(0.05), Task = 813 (0.5), Resources = 600 (0.1)
Delay = 166(0.1), Task Speed = 1(0.05), Task = 813 (0.5), Resources = 900 (0.1)
(Figures in brackets represent the coefficient of variation).
The results are shown in Figure 52.

Figure 52: Probability of Success in reaching the technician before he is seriously injured through smoke inhalation



From this graph, it can be seen that neither option gives the technician a particularly good probability of survival. Because the task of locating him takes so long, his chance of survival (depending on the concentration of smoke inhaled and actual exposure time) has a maximum probability of survival of 0.32.

This concludes the section on examples from the offshore scenarios observed in the research. However, as specified, the model should also be capable of representing data from real incidents. For this reason, the following section will use a task that occurred in the Piper Alpha disaster and was recorded in sufficient detail to facilitate TPRC analysis.

8.3.4 USING THE TPRC MODEL FOR EXAMINING THE PIPER ALPHA DISASTER

The TPRC model was intended to be a predictive and analytical tool for assessing the impact of emergency management on risk reduction. At this point, all of the data that had been applied were obtained from models, simulations or theoretical knowledge. To ensure the model was capable of incorporating data from real emergencies, this section will use data recorded in the Public Inquiry into the Piper Alpha disaster (Cullen 1990). Therefore, this could assess the probability of obtaining the outcomes that occurred, given the situation. This could therefore establish where the actual outcome lay based on the optimal and worst-case scenarios - and consequently whether the emergency was managed poorly or well.

Not all the details of times were recorded in the report - usually because the people who were most likely to know the information did not survive the disaster. Therefore, the information that is known to be the most accurate is that which was recorded by those external to the emergency, that is, the onshore rescuers. Therefore, using the Cullen (1990) report, it is possible to determine the following points.

The initial event - the explosion - occurred somewhere around 22:00 hours.

Between 22:04 and 22:08, maydays were sent out.
Rescue helicopter (137) left Lossiemouth at approximately 22:22 and arrived at Piper Alpha at approximately 23:30
Lossiemouth co-ordinates are approximately 57° 43' N 3° 17' W
Piper Alpha co-ordinates are recorded as 58° 28' 01" N 00° 15' 36" E
This gives a journey of 139 miles (121 Nautical miles) that, in this situation, took approximately 108 minutes.
This was a Sea King helicopter - the estimated speed of which averages at 110 Kts in still air.

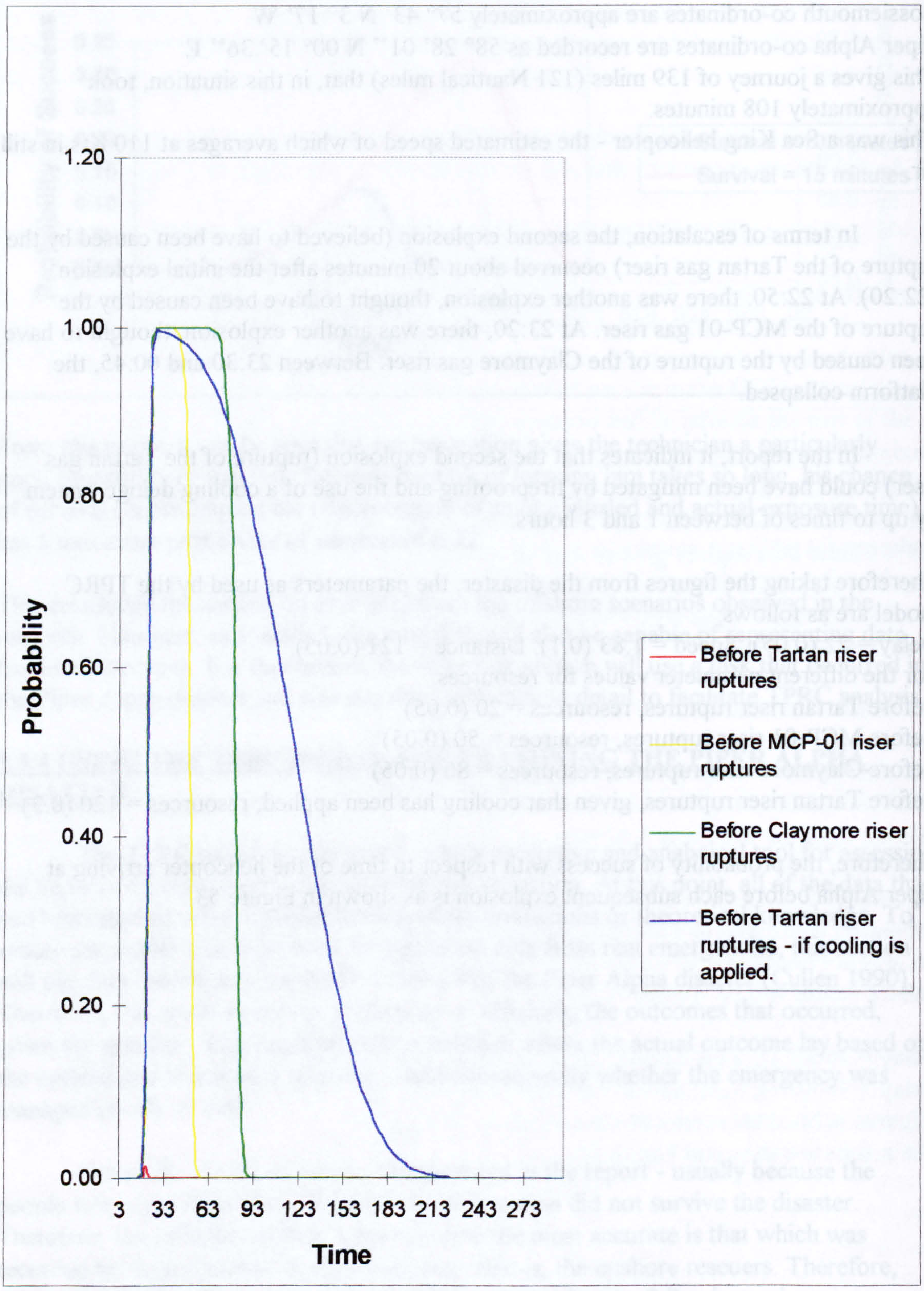
In terms of escalation, the second explosion (believed to have been caused by the rupture of the Tartan gas riser) occurred about 20 minutes after the initial explosion (22:20). At 22:50. there was another explosion, thought to have been caused by the rupture of the MCP-01 gas riser. At 23:20, there was another explosion, thought to have been caused by the rupture of the Claymore gas riser. Between 23:30 and 00:45, the platform collapsed.

In the report, it indicates that the second explosion (rupture of the Tartan gas riser) could have been mitigated by fireproofing and the use of a cooling deluge system by up to times of between 1 and 3 hours.

Therefore taking the figures from the disaster, the parameters as used by the TPRC model are as follows:
Delay = 22 (0.05), Speed = 1.83 (0.1), Distance = 121 (0.05).
For the different parameter values for resources:
Before Tartan riser ruptures, resources = 20 (0.05)
Before MCP-01 riser ruptures, resources = 50 (0.05)
Before Claymore riser ruptures, resources = 80 (0.05)
Before Tartan riser ruptures, given that cooling has been applied, resources = 120 (0.3)

Therefore, the probability of success with respect to time of the helicopter arriving at Piper Alpha before each subsequent explosion is as shown in Figure 53.

Figure 53: Probability of Success of Rescue Helicopter 137 arriving at Piper Alpha before escalation events.



From Figure 53, it can be seen that the scenario that actually occurred on board Piper Alpha had a maximum probability of success of 0.01 (shown by the peak in the red line). Therefore, Rescue 137 was the first helicopter on scene and could not have arrived earlier than the explosion caused by the rupture of the Tartan riser. The events then escalated leading to the subsequent ruptures of the MCP-01 and Claymore risers. However, if cooling had been applied to the risers, this was predicted to have increased the time of the initial rupture to 1-3 hours (if not preventing it altogether). In the TPRC model, this was represented using a mean of 2 hours (with a coefficient of variation of 0.3 to represent the estimations of a minimum of 1 hour and a maximum of 3 hours). From Figure 53, it can be seen that this increased the probability of success of R137 arriving at the platform to a maximum approaching 1. This indicates that if such cooling had been applied, there was a high probability of the first helicopter arriving before escalation occurred. In practical terms, this also indicates that the helicopter would have a greater probability of approaching the helipad without danger and was more likely to have successfully evacuated some of the personnel. In emergency management terms, it also demonstrates the importance of fire control and on-site emergency management - rather than reliance on the onshore support for evacuation. In terms of this research project, this demonstrates how the TPRC model can be used with real data - and how it can provide support to emergency plans or recommendations - such as those shown in the Cullen (1990) report. This is potentially a form of validation for the TPRC model - however, just because a probability of success has been produced does not mean that the figures are an accurate representation of risk – a problem that is observed for many new techniques. Therefore, the following sections compare the results obtained using the TPRC model with results obtained from other QRA and HRA models, in this case, HAZAN and HEART

SECTION 8.4: COMPARISON OF TPRC MODEL WITH OTHER QUANTITATIVE RISK ASSESSMENT METHODS

As discussed in the literature review, there are many different techniques of Quantitative Risk Assessment and Human Reliability Assessment. However, whilst these are available for use to quantify the probability of error or failure of systems in different circumstances, what the user requires from a technique may become overlooked. Quantitative Risk Assessment often requires the probability of failure – such as the failure of a valve or switch. Human Reliability Assessment aims to provide values of a similar type towards Quantitative Risk Assessment. However, instead of failure, it provides the probability of error – which when considering the term "reliability" may equate to be the same thing. This research aims to clarify the link between these two aspects – that human error may or may not lead to human failure and human failure may or may not be caused by human error.

The TPRC model has aimed to quantify the probability of success with respect to time in emergency management tasks. Therefore, to consider the role of this model, it was considered useful to compare this with other methods of QRA and HRA – and the best way to do this is to consider how other techniques would approach the crane driver scenario presented – what quantitative results they would produce and what these results represent.

Many of the techniques described in the literature review perform quantification using the opinions of a group of experts. If these techniques were to produce comparable results; in this case, the group must be knowledgeable in the probability of success in specific emergency management tasks - and ideally, the relationship of this probability with time. This is expected to be problematic - both in identifying people with the skills as well as obtaining reliable results from them. Therefore, it is necessary to focus on more objective techniques to compare with the TPRC results.

Therefore, for this, it made sense to identify the techniques that :-

a. produced quantitative values
b. had an objective structure so that these values were not entirely produced by the expert judgment of the user
c. considered the impact of time
d. could represent some or all of the aspects important in an emergency

For this, the most appropriate QRA and HRA techniques were considered to be HAZAN and HEART respectively.

Therefore, this section will demonstrate how these techniques would fare when considering the tasks shown in the crane driver scenario described earlier, as follows:

- Crane driver's escape from the crane
- Fire team's rescue of crane driver from the crane
- Crane driver's rescue by the fast rescue craft

These results can therefore be compared with the results obtained by the TPRC model. Notably, the TPRC model provides values for probability of success with respect to time that could potentially be used in another technique – such as the Event Tree Analysis as shown in Section 5.2.2. Therefore, it was not considered necessary to compare the TPRC with a whole hazard or error identification techniques – but only that part of the technique from which the numbers are calculated. If the TPRC methodology was seen to take greater account of the issues that are known to affect the outcome in a real situation – and incorporate the effects into the calculation, then it could be considered as successfully fulfilling the objectives of the research. Therefore, this section will concentrate on comparing the extent to which relevant issues are taken into account in the calculation process.

8.4.1 HAZAN

HAZAN (or HAZard ANalysis) is the method by which quantitative methods are applied to safety problems. In general, this provides a structure to identify and use the frequencies and consequences of events – to make safety-oriented decisions. Whilst the use of the term HAZAN is occasionally used to refer to the combined process of hazard identification and quantification; within this research, in accordance with the former description by Kletz (1999), it refers only to the process of quantification – providing the numbers to represent probability of failure for pre-identified hazards.

Ordinarily, HAZAN uses past data (such as mean failure rate) to estimate the probabilities to be incorporated into its quantification process. In some cases, the human data of this kind can be estimated (such as the number of times an operator will press the wrong button) from trials based on the proportion of successes to failures within the total number of trials. However, to analyse a less typical example, such as in the emergencies described in this research, it is necessary to resort to the more generic descriptions of human failure rates – For example, as cited in Section 2.4.3.1, "When complex and rapid action is needed to avoid a serious incident, the probability of failure is 1 in 1" (Kletz 1999).

The next level of human failure rate defined in the Kletz (1999) methodology is "1 in 10" for "in a busy control room where other alarms are sounding, the telephone is ringing, people are asking for permits-to work, and so on". However, where there is doubt in the description of the tasks, it is recommended that the higher value of 1 in 1 is used.

Therefore P(failure) = 1 is the value suggested as a standard value for the human failure rate in such situations and whilst this is most probably defined with operational tasks (such as activating valves etc.) in mind, no other values are given for more physical tasks, such as those described in the crane driver scenario. In HAZAN analysis, the normal implication of a "p(human failure) = 1 result" is that fully automatic systems should be installed to avoid relying on human action in such circumstances – clearly not something that could be done in these circumstances.

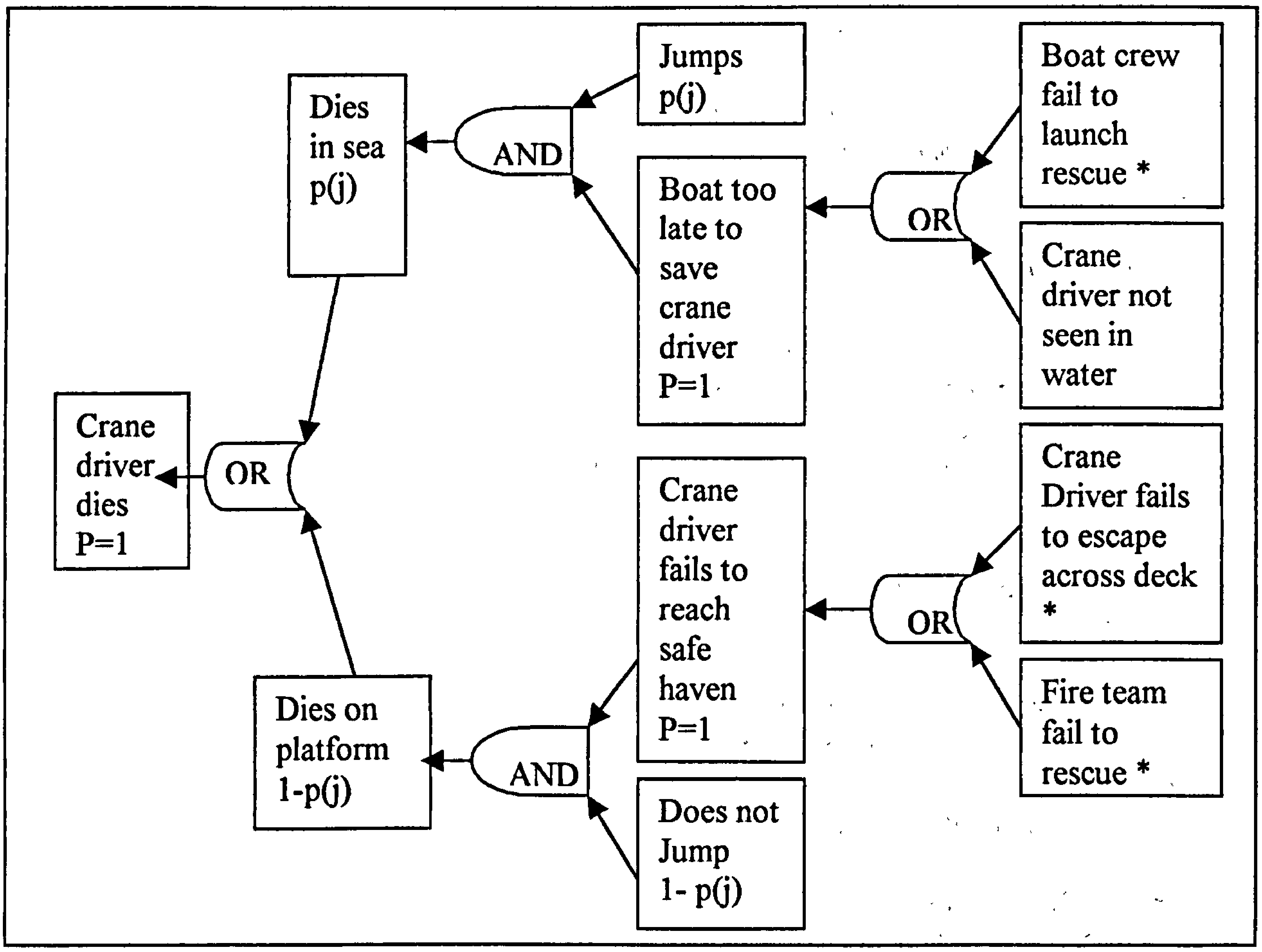
Consider the decisions listed as follows :-

- Decision to launch fast rescue craft
- Decision by fire team to attempt to rescue crane driver
- Decision by crane driver to attempt an escape from the crane.

All are motivated to avoid the death of the crane driver – which would be described as a serious incident.
All require rapid action to avoid this outcome.
The complexity of the actions required would be more difficult to assess – the first two tasks involve preparation of equipment and then a search and rescue in hazardous conditions. The final decision would be made under life-threatening conditions and involving potentially life-threatening actions.

As the HAZAN quantification technique does not provide any distinction between the levels of complexity, it is reasonable to assign the definition of "complex and rapid action is needed to avoid a serious incident". Given that no mean failure rate can be estimated for our novel crane driver situation from past data, it would be necessary to use the suggested values – p(failure) for the decision = 1 . Therefore as no action can result if the decision has failed, the probability of failure for the actions resulting from these decisions must also be 1. These are marked with * within the Fault tree in Figure 54.

Figure 54: HAZAN Analysis of the Crane Driver scenario



As it can be seen, it is the values given for the probability of failure in these decisions that affect the overall probability of failure – leading to a certain failure in the task, no matter what values are assigned to other parts of the tree.

Whilst the intention behind the numbers was probably to obtain "conservative" values of probability of success when considering emergency management tasks – within the method of HAZAN as it stands, there are no means by which to succeed in these tasks. Therefore, if we consider the situation whereby mean failure rate for the physical tasks was known – the tasks would still fail leading to the death of the crane driver based on the guaranteed failure at the decision-making stage.

This is linked to the concepts of error and failure – in that a failure in the decision leads to no action being taken – an error in the decision may lead to action with deficiencies. However, while there are no data from other sources to alleviate this problem, the use of this method to obtain realistic values of risk for emergency situations should be carefully considered.

Whilst this section considers comparing the HAZAN methodology with the results obtain from the TPRC model, it is useful to consider where the TPRC results could be used with a similar Fault Tree structure.

For this scenario, the TPRC method produced:-

- Probability of Success/Time Function of the Crane Driver escaping across the deck
- Probability of Success/Time Function of the Fire Team rescuing the Crane Driver on the deck
- Probability of Success/Time Function of the Fast Rescue Craft rescuing the Crane Driver from the water.

As discussed previously in Section 8.2.2. (and shown in Figure 42) with regard to event trees, there are problems with using the TPRC in combination with other methods.

With using Fault trees, there are three issues that must be addressed :-

- Converting the Probability of Success / Time function to Probability of Failure / Time function.
- Calculating the probability of the decision leading to the attempted action
- Calculating the conditional probability through the tree when using time-dependent functions as opposed to point values.

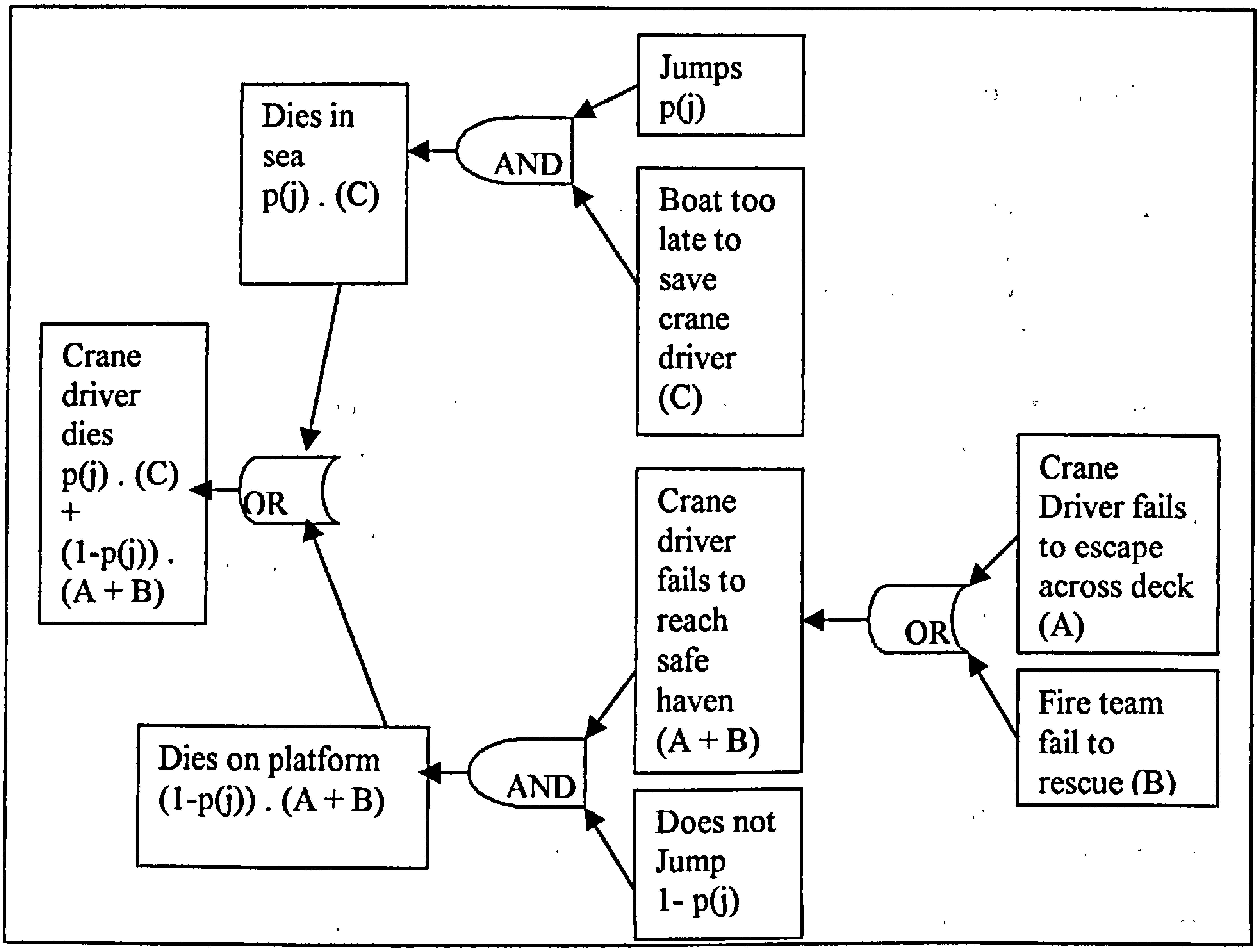
The first problem is addressed by using the formula:-
Probability of Failure = 1 – Probability of Success

Calculating the probability of the decision was considered beyond the scope of this research – as it involves more examination of the cognitive aspects of emergency management – as will also be discussed in Section 10.7.2.4. Only the time taken in making the decision is considered in the model as it contributes towards the delay in the action. The decision may be linked to the perception of the probability of success – where the crane driver considers which option maximises his survival. However, while we cannot assume this, or even that the decision-making process will be rational, these values can not be estimated. However, it should be noted that in every case, if this probability was known, it would always decrease the Probability of Success/Time function – as the Probability of making a decision would always be less than 1.

Calculating the conditional probability involving time functions is more of a mathematical problem – producing an overall probability/time function for the eventual outcome - as will be discussed in Section 10.7.1.4.

Therefore, to avoid the complexity of these issues, the fault tree shown in Figure 55 represents the probability of failure/time functions for each task GIVEN that the decision to attempt the task has been taken. These are shown symbolically (as A, B and C) to demonstrate how the TPRC model may not produce the pessimistic values shown by the HAZAN technique. However, it should be remembered that the calculation of conditional probability (for example, A+B) is not as simple as portrayed.

Figure 55: TPRC Contribution to Fault Tree Analysis of the Crane Driver scenario



Therefore, while the HAZAN methodology admits that the levels of reliability are probably not really as low as this, no alternative values, weightings or shaping factors are provided within the original methodology description to improve these estimates.

Whilst some techniques are aiming to rectify this, none yet encompass the impact of delays, speeds of action, escalation rates or situation-specific features - issues that clearly have an impact on failure and success in a real incident. The TPRC model is able to distinguish between these critical aspects.

Because the TPRC model is capable of producing a probability of success or failure function based on information obtained directly from the task, it removes the need for historical data, which, in such specific circumstances, is likely to be unavailable. Ultimately, it could be suggested that (once the issues of conditional probability with time-dependent functions and the probability of decisions have been addressed) the TPRC values could be incorporated into the HAZAN technique – providing more realistic values than suggested in the original HAZAN methodology. This again goes to show that the TPRC model does not aim to replace other techniques or QRA – but provides supporting data where previously, there may be none available – or TPRC can provide data where there are no means of estimating a risk value through other techniques. Also, because of the TPRC's ability to incorporate changes in emergency management skill or design, these changes can be represented in the fault tree to look at their eventual impact on the overall risk value.

8.4.2 HEART

Like the TPRC model, HEART was developed for reliability engineers to assess the probability and consequences of human unreliability within a system. More specifically, HEART was designed to identify error-likely situations, to estimate the type of error that was most likely to occur and to quantify the impact of the effects. Therefore, it can be seen that HEART is already considering a different type of aspect – unreliability defined as "probability of error" as opposed to "probability of failure".

The HEART method involves the use of the basic description of the operator's understanding of the task to define a value for the probability of error, which is then modified by the error-producing conditions of the working environment.

HEART's data source is reliant on the observations and knowledge of its author. The TPRC model involves the use of a basic structure, on which observations and knowledge can be used to refine the data. Also, the use of source data for both models means that neither relies solely on the expert judgement of the user and therefore the results of the model for a given situation should be reproducible with a high degree of reliability. Of course, in this stage of development, the reliability of the TPRC model would depend on the extent to which the users researched the source data

Despite these differences in structure and the sources of data, HEART shows the greatest potential out of all the HRA techniques for examining emergency situations – and despite the focus on error rather than failure, it seems possible that HEART can produce meaningful data that could be applied to our problem. Because the different error-producing conditions are represented with different numerical factors, there is the chance that the critical attributes of an emergency situation could be reflected in the error-probabilities. Therefore, this could achieve two of the original goals of this research – to assess the probability of success in emergency management tasks and to reflect the changes in emergency management skill.

As already discussed previously, time is a critical aspect of emergency management success and it should be noted that "a shortage of time available for error detection and correction" is a key error-producing condition and the generic task associated with the highest level of unreliability is "totally unfamiliar, performed at speed with no real idea of likely consequences". Whilst neither of these reflect the numerical values of real time as the TPRC model does, the fact that they are included should be considered in HEART's favour. On the other hand, HEART manages to give quantitative value to factors that clearly have impact on the probability of failure/error in an emergency – such as "high-level emotional stress" but that are not currently reflected in quantitative terms in the TPRC model. Whilst it is suggested that such a condition would affect the speed of Task Progress in the TPRC model, it is not yet known to what extent.

Another feature of HEART that could be considered a positive attribute is the fact that it quotes not just the nominal value for Human Unreliability but also the 5th and 95th percentile boundaries. These values could be used to reflect the uncertainty associated with the value – and could potentially be used with Monte Carlo simulations to produce probability of success distributions comparable to those inserted into the TPRC model.

Therefore, this section will continue with an example of how the HEART approach could be used by a reliability engineer to assess the human unreliability associated with the crane driver's rescue and escape tasks.

The first task involves choosing the generic error probability. This choice is somewhat difficult. It is not know whether this should consider the whole unique context of the emergency situation or the fact that all of these issues would have been practised in drills and simulations. Therefore, it could be considered that all three tasks – the crane driver's escape, the crane driver's rescue by the fire team and also his rescue by the fast rescue craft could be considered the same type of tasks.

Therefore, the first choice of value for all three tasks would be represented most appropriately by level A described as follows:
Totally unfamiliar, performed at speed with no real idea of likely consequences:
0.55 (0.35 - 0.97)
The second choice would be represented most appropriately by level E described as follows:
Routine, highly practised rapid task involving relatively low level of skill:
0.02 (0.007 - 0.045)
In each case, the first value is the average and the values in brackets represent the 5th and 95th percentiles.

Given these distributions of generic error probabilities, it is also necessary to incorporate the effects of the relevant error producing conditions. In Section 2.4.4.2.2, it was suggested that many of the HRQ techniques view emergency management tasks in a pessimistic light (also as verified in the description of HAZAN in Section 9.4.1) therefore they should be used with caution.

However, when using HEART, it could be argued that pessimistic results were due to the temptation to include a large number of error producing conditions when evaluating emergency management conditions - resulting a probability of failure or error tending towards 1. To produce the most accurate results, Kirwan (1994) suggests that this evaluation should include a small number of error producing conditions. In this case, only the minimum relevant error producing conditions that are evident in this scenario and many other emergency situations will be used.
These are:

- Time pressure (x 11)
- Ambiguity about performance standards (x 5)

However, Kirwan (1994) also recommends that Time Pressure is not used in conjunction with Category A Generic Error Probabilities.
Given the values (as defined by the generic error probabilities above) and using the most optimistic and pessimistic views, the results obtained then depend on the proportion of effect assessed by a user. Table 20 represents the scope of results that would be obtained using HEART to quantify the probability of failure in the described tasks.

Table 20: HEART Quantification of the Probability of Failure for the Emergency Management Tasks

Probabilities of Failure for Emergency Management Events		
	Values for routine highly-practised rapid task involving low level of skill (E):	Values for totally unfamiliar task, performed at speed with no real idea of likely consequences (A):
(If proportion of affect is 1.0 for all parameters)		
5th Percentile	11 x 5 x 0.007 = 0.385	5 x 0.35 = 1
Median	11 x 5 x 0.02 = 1	5 x 0.55 = 1
95th Percentile	11 x 5 x 0.045 = 1	5 x 0.97 = 1
(If proportion of affect is 0.4 for all parameters)		
5th Percentile	5 x 2.6 x 0.007 = 0.091	2.6 x 0.35 = 0.91
Median	5 x 2.6 x 0.02 = 0.26	2.6 x 0.55 = 1
95th Percentile	5 x 2.6 x 0.045 = 0.585	2.6 x 0.97 = 1
(If proportion of affect is 0.1 for all parameters)		
5th Percentile	2 x 1.4 x 0.007 = 0.0196	1.4 x 0.35 = 0.49
Median	2 x 1.4 x 0.02 = 0.056	1.4 x 0.55 = 0.77
95th Percentile	2 x 1.4 x 0.045 = 0.126	1.4 x 0.97 = 1

NB: Values of greater than 1 are shown as 1 as specified in the HEART methodology.

From these results, it can be seen that the possible range of probabilities of error that could be assigned to these three tasks range from 0.0196 to 1, depending on the interpretation of the task with regards to familiarity and the proportion of effect of the error producing conditions. The expert judgment technique used in HEART would be expected to produce only one range of values - for example, one of the six ranges represented in Table 20. These ranges demonstrate the scope of the method by illustrating how the task could be interpreted by different experts.

It should be noted that none of these calculations have taken account of the physical parameters involved in three very different tasks, such as the distances to be covered or escalation speed. Therefore, these can only have an impact on the probabilities if they are taken into account with the proportion of effect. In essence, HEART requires that an objective measure of a physical parameter must be converted into a subjective measure of an abstract parameter. For example, whereas the TPRC model uses real time and distance, HEART would use "time shortage" as a fixed error-producing condition of x11. Therefore, could it be assumed that the proportion of effect for this reflects "real time" in its calculation and in which case, there is a possibility that this be developed to be more objective.

Many of the results above show that the probability of error is 1, therefore we could assume that error is guaranteed. However in the context of this work, what does that mean?
Firstly, is the error in the decision-making process or in the physical process?
In real terms, this may mean that the crane driver will fail to make the decision to escape and will stay in the crane. In terms of his probability of survival, this dictates that he fails in the task but it does not dictate that he will not survive – it is just beyond the scope of the "escape" task. This is where the fault trees shown in Figures 54 and 54 are so relevant - from the two branches - probability of survival would be dependent on escape and/or being rescued.
Otherwise, this value may indicate that there is one guaranteed error in the decision-making process. This may mean running in the wrong direction. Again, this will just decrease his probability of success in surviving, but does not guarantee failure.
Conversely, the error could be in the physical process. This may involve a fall. Again, this does not necessarily constitute failure in the task – but may increase the probability of it. Ultimately, HEART has not provided the answer to the question – in this situation, what is the probability that the crane driver escapes or is rescued? Whilst HEART may provide a more deeper representation of the probability of error, it can not fulfil the requirement of a Quantitative Risk Assessment where the probability of failure is the necessary input.

Therefore, the TPRC model appears to be more successful than HEART when examining physical tasks and evaluating the impact of changes in physical parameters within these tasks on the probability of success. Of course, this is because one of the intended objective of the TPRC model is to examine task failure – and, as discussed in Section 8.4.1, like HAZAN, HEART is designed to assess the probability of error. Probability of error is not, as such, the probability of human failure – and therefore this may reflect the probability of errors in decisions – something that the TPRC model does not yet incorporate. Ultimately, these techniques are measuring different things but, as suggested in this research, it is the probability of task success produced by the TPRC model that should be the intended data required for risk assessment of emergency situations and not the probability of error as obtained from HEART. This concept will be discussed in more detail in Section 10.7.2.4.

These analyses conclude the comparison of TPRC results with those obtained from other methods of HRQ and QRA.

SECTION 8.5: CONCLUSIONS

This Chapter has shown the basic potential of the TPRC model in assessing probability of success in emergency management tasks. As risk is defined by the probability of an event as well as its consequences - these probability of success / time functions illustrate part of the risk equation. As the results show the effects of parameter change on the probability of success curve, these show the impact of emergency management on risk.

The results shown in this chapter illustrate the following successes of the methodology.

- It is capable of assessing tasks observed in an emergency scenario with a high degree of objectivity
- Quantitative values representing "probability of success with respect to time" were produced given data on tasks and resources present in an emergency situation
- The methodology produced appropriate changes in the probability of success in response to changes in the inputted parameters
- The methodology is potentially capable of representing and analysing any emergency management task - real or simulated, including novel designs or situations
- In comparison to other methods of QRA and HRQ, this method produces probability of task success not the probability of error as produced using other HRA techniques
- Particularly in comparison with HEART, the TPRC methodology was found to produce results more representative of the emergency situation
- The TPRC model has been shown to be capable of providing quantitative values for other established techniques – such as event tree and fault tree analysis – and more representative values than those suggested in the original version of HAZAN for emergency situations.
- As the TPRC model can represent the impact of changes in emergency management skill and design, these can now be used in conjunction with Fault Trees and Event Trees to be reflected in the overall risk values.

Overall, this suggests that the TPRC model has been used to successfully achieve three of the four objectives of the research. The TPRC model will be discussed further in the following chapter with respect to performance parameters.

Chapter 9

PERFORMANCE PARAMETER RESULTS

SECTION 9.1: INTRODUCTION

The fourth and final objective states the requirement of defining performance parameters that can be applied to evaluate generic emergency situations.

As stated in Chapter 7, it was suggested that these performance parameters could be used as follows:

- in the TPRC model to estimate the optimal and worst-case scenarios - using the longest and shortest observed delays, and compare these with the values observed in the scenario
- in the TPRC model as a basis for testing novel designs - therefore contributing to the third objective of the research
- in the TPRC model for novel or generic emergency management situations
- as raw data, to be used by designers or emergency planners to estimate the best and worst response times
- to build up distributions to represent particular types of data- and distinguish between the onshore/offshore industry, pre-emergency and post-emergency reactions or levels of competency
- to reduce the reliance on expert judgment in the TPRC model - therefore increasing the objectivity and reliability of the technique

These were then recorded as shown in Section 7.4 for the 14 scenarios. These were separated into scenario-specific and generic data, which will be analysed in the following sections.

SECTION 9.2: SCENARIO-SPECIFIC PERFORMANCE PARAMETERS

The scenario-specific data are recorded in Appendix 8. The timings of these data would be difficult to analyse in detail. As these timings are dependent on the scenario in which they occur, they usually only occur once in the whole data set. Therefore, they represent only one point value of the estimated timing of this particular task or event. As stated in Section 2.4.1, one of the weaknesses of certain HRA and QRA techniques is the assumption that point values are representative of a distribution. This project aims to move away from this deterministic approach. Therefore, the scenario-specific data that have been recorded in this project represent point values from within distributions of values. At this point, these timings should therefore be used with caution. They should only be used in the modelling process if the data cannot be built from realistic physical data or estimated from any other source. Currently, they often represent the timings of tasks and events that were estimated by the scenario organiser - someone who was not necessarily knowledgeable about the technical processes involved. Although it is hoped that these were based on the scenario organiser's research into the scenario, they are still biased by his judgement. Overall, until distributions of the scenario-specific data can be built up using further scenarios or real-life data, these are only to be used where no reasonable estimate of timing can be made and where the analysis is experimental rather than forming a basis of critical decisions.

SECTION 9.3: GENERIC PERFORMANCE PARAMETERS

As described in Chapter 7, the generic performance parameters could be used to build up distributions of values. Each generic performance parameter was defined carefully to ensure that the collection method was objective - and these definitions are shown in Appendix 7.

As there was too much information to record the generic information for each scenario, this is collated in Appendix 10 in terms of numerical descriptions of the distribution with respect to categories, which are:

- post-incident offshore data
- post-incident onshore data
- pre-incident onshore data
- pre-incident offshore data
- post-incident onshore data - scenarios rated as highly competent
- post-incident onshore data - scenarios rated as competent
- post-incident onshore data - scenarios rated as having notable shortfalls
- post-incident data (onshore and offshore)

For these, data on the frequency of event (number of times observed), mean timing (average length of event) and sum of timings (amount of time taken up by these events per scenario) were all recorded. The standard deviation gave an indication of the spread of variable's distribution for each category. Also, the maximum and minimum values were supplied to provide values for the events having the longest and shortest duration respectively.

The final category (post-incident data (onshore and offshore) was expected to be one of the most useful collections of data - as it had a broad distribution representing emergency management performance parameters from both industries. Therefore this is also presented as frequency distributions as shown in Appendix 11.

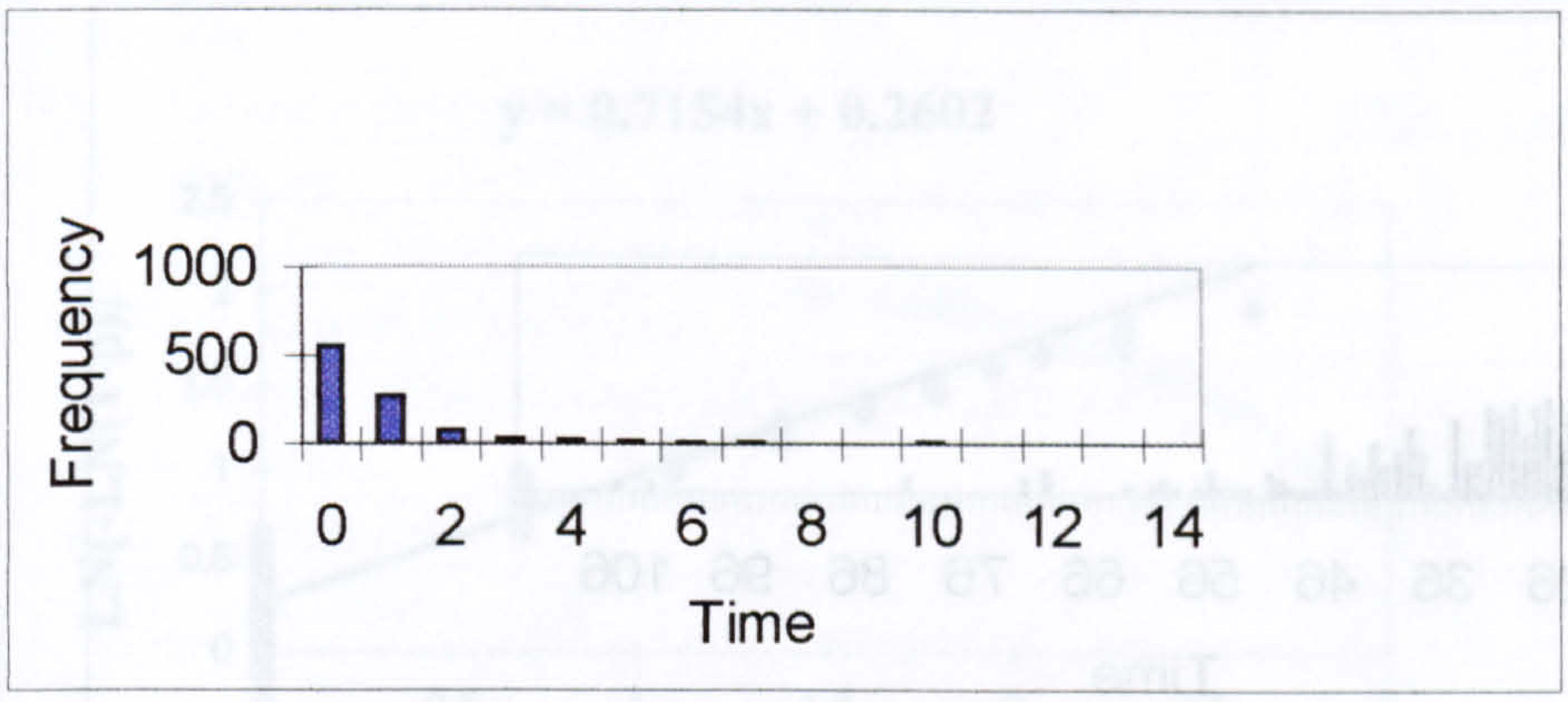
As the generic data were collected to build up distributions to be used in future analyses, it would be necessary to choose the data that best fit the given situation. This would be particularly important if it was found that the distributions recorded were not representative of the data required by the analysis. To establish this fact, it would be necessary to statistically evaluate the differences between the data recorded. For example, in some cases, it may be necessary to represent the responses of a competent or highly competent emergency manager. In this case, it may be inappropriate to use a distribution that also incorporates data from a scenario assessed as being poorly managed - which might bias the distribution. If it was found that timings from scenarios of different levels of competency produced different timings, it would be inappropriate to use data with "notable shortfalls" to represent a "competent" or "highly competent" level of performance. Alternatively, if the average time to make a phone call in a "highly competent" scenario was found to be significantly shorter than in a "competent" scenario, using the highly competent timings would give an optimistic view of the delay produced by making a phone call.

However, despite the large numbers of data that were recorded in the research, these were actually supplied using a small number of people (2 teams of approximately 6 people each - depending on the criteria set by the scenario). Therefore the data cannot yet be expected to represent the full population of offshore or onshore emergency management teams. It was intended that these data should be developed in the same way that Pheasant (1987) used his data so the individual differences would be incorporated rather than separated in the distributions. For this reason, the statistical analysis of differences between the distributions has not been carried out within this research. In future, it is recommended that ANOVAs are carried out, considering the differences between the categories as follows:

- distributions in terms of scenario
- distributions in terms of emergency manager - C, E, L & P
- distributions in terms of industry - offshore / onshore (which also corresponded to distributions in terms of team)
- distributions for pre-incident and post-incident timings
- distributions representing the assessed level of competency

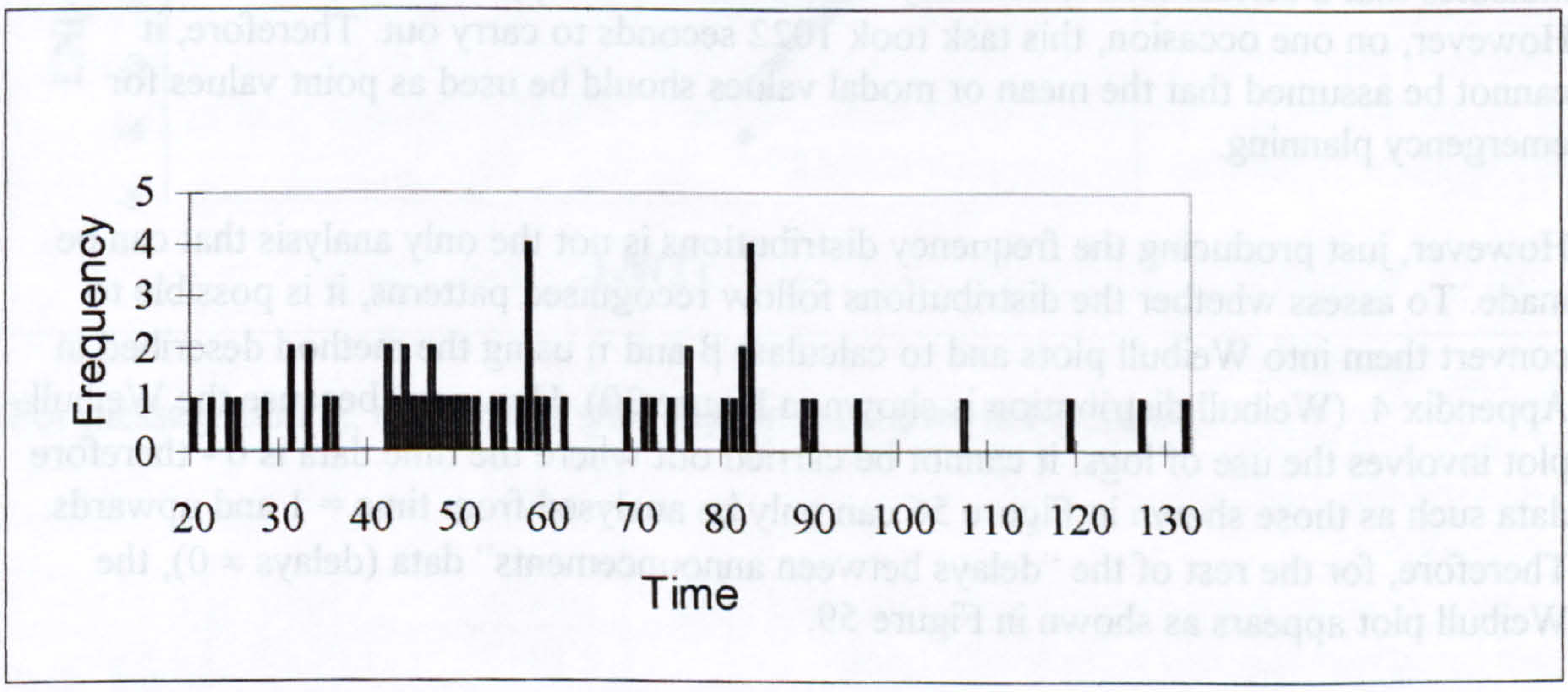
The impact of individual differences can only be reduced by using large numbers of individuals such as the amount used by Pheasant (1986) in his anthropometrical study. However, even at this stage, most of the data fall into normal or skewed distributions therefore it is likely that they already represent the population to a high degree. As there are a large number of data for some of the performance parameters (up to 2648 data pieces in the "radio calls" parameter), these are potentially useful for TPRC analysis to give probable means, variances and an indication of the shape of the distribution.
For example, Figure 56 displays the frequency distribution for the times taken in responding to an announcement.

Figure 56: Frequency distribution of delays in responding to announcements



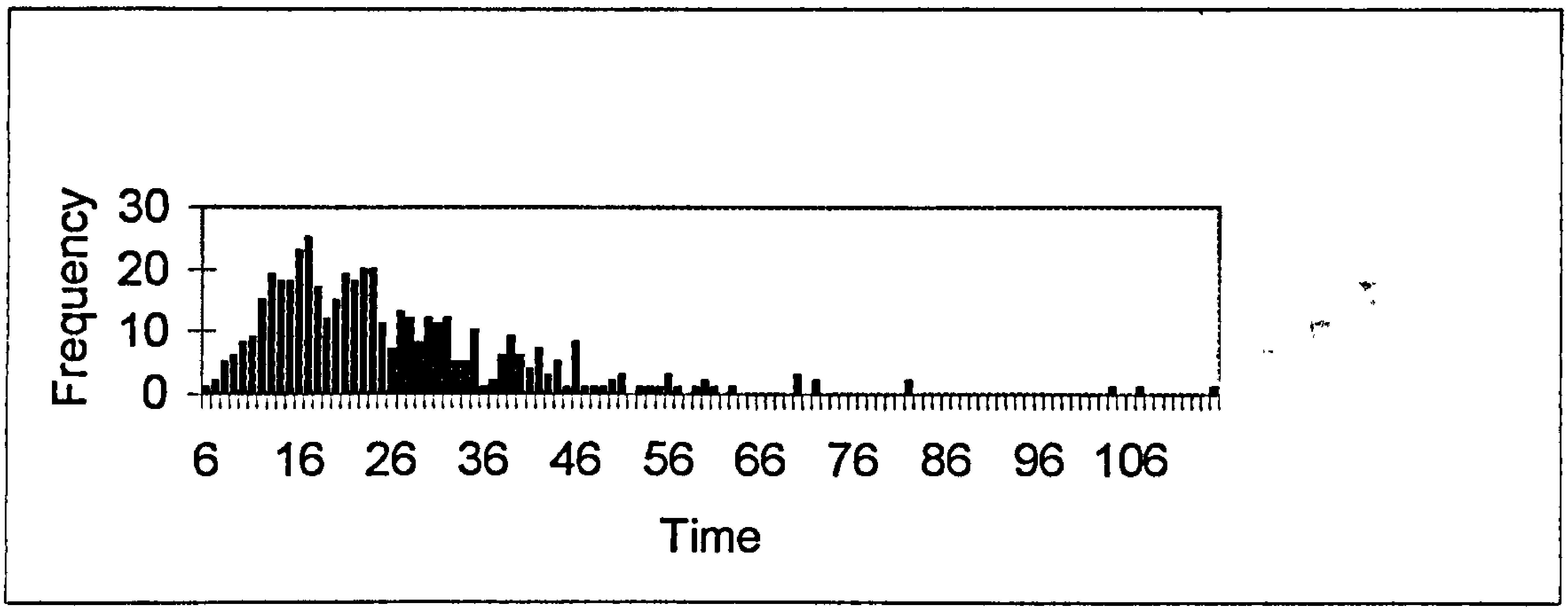
From this, it can be seen that the majority of announcements are acknowledged within the first 2 seconds. This may mean that someone is answering a question or merely responding to their name. Some delays are 3,4 or 5 seconds long; but although the maximum delay is 14 seconds, it is rare that anyone takes longer than 7 seconds to respond. In contrast, Figure 57 represents the frequency distribution of time-out length. This is apparently bi-modal, with the maximum frequencies being observed at 58 and 83 seconds respectively. As the longest observed time-out was 132 seconds, this may illustrate the amount of time that is taken to re-organised and re-focus one's team - perhaps less than might be thought! However, on the negative side, this also indicates that the physical emergency is being allowed to escalate for this length of time without any additional interventions. Therefore, it should be ascertained that all the possible physical interventions have been set in action before a time-out begins.

Figure 57: Frequency Distribution of Time-Out length



Finally, Figure 58 represents the frequency distribution of messages (i.e. two way communication from initial contact to completion of message content)

Figure 58: Frequency distribution of timings of messages

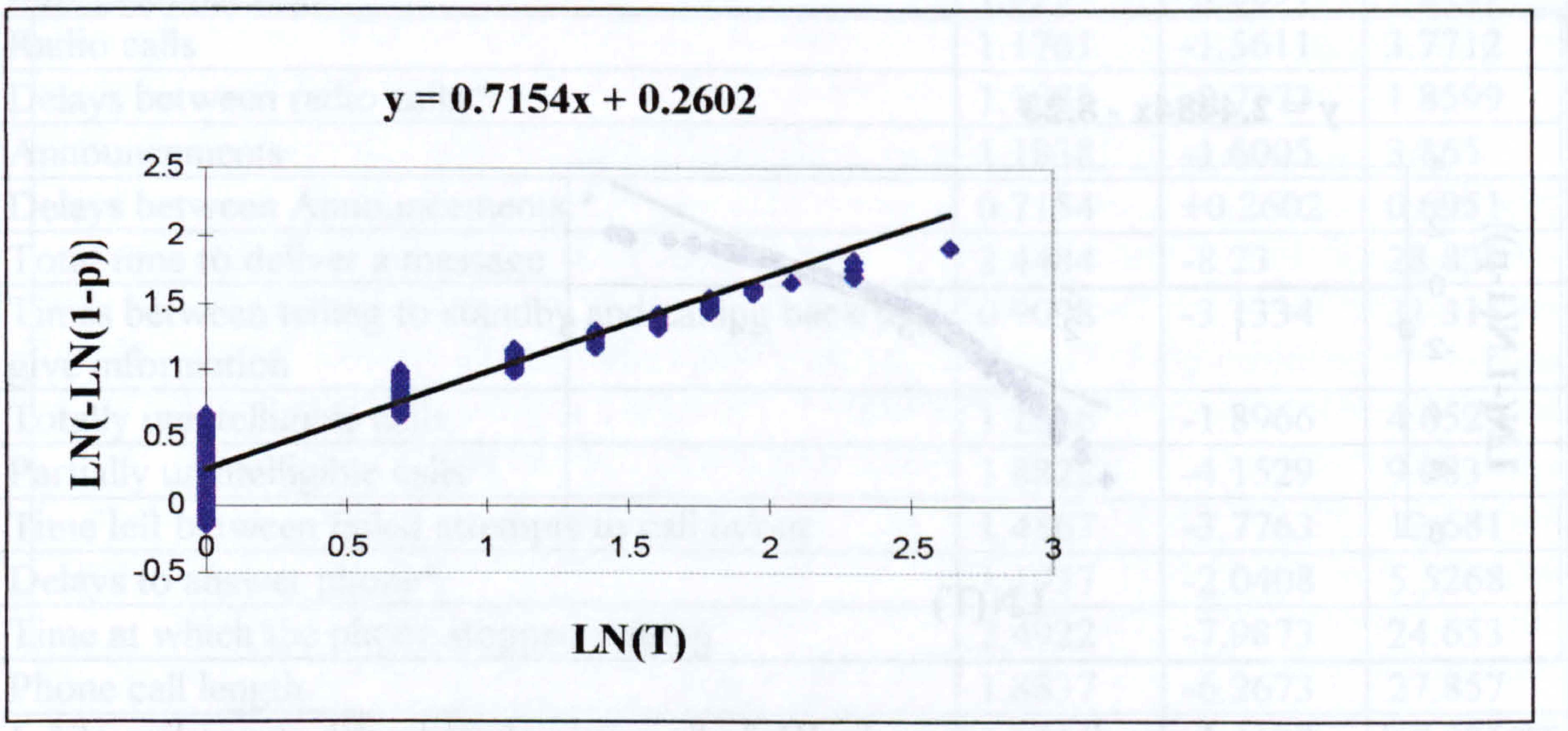


Although Figure 58 does not show a normal distribution, it can be seen that the largest frequencies (18-25) are grouped around the 13-24 area. From this, the average time taken to give or receive a message can be assumed.

As shown in Appendix 11, many of the distributions have a peak value (mode) and a spread surrounding this value. For some of the distributions, the mode is obtained for the smallest time value. In this case, as the time values increase, the frequency values decrease. The later distributions only have a small amount of data and often show only 1 data point for each observed time value. Therefore, for these parameters in particular, further data must be collected before the patterns can be established. Some distributions are apparently bimodal - for example, time out length, which may be influenced by the characteristics of the scenario. The tails of the distribution are particularly relevant to this research. For example, consider the distribution of "passing information from the emergency management team to the scenario organisation team". This distribution indicates that a certain task is normally carried out within approximately 200 seconds. However, on one occasion, this task took 1022 seconds to carry out. Therefore, it cannot be assumed that the mean or modal values should be used as point values for emergency planning.

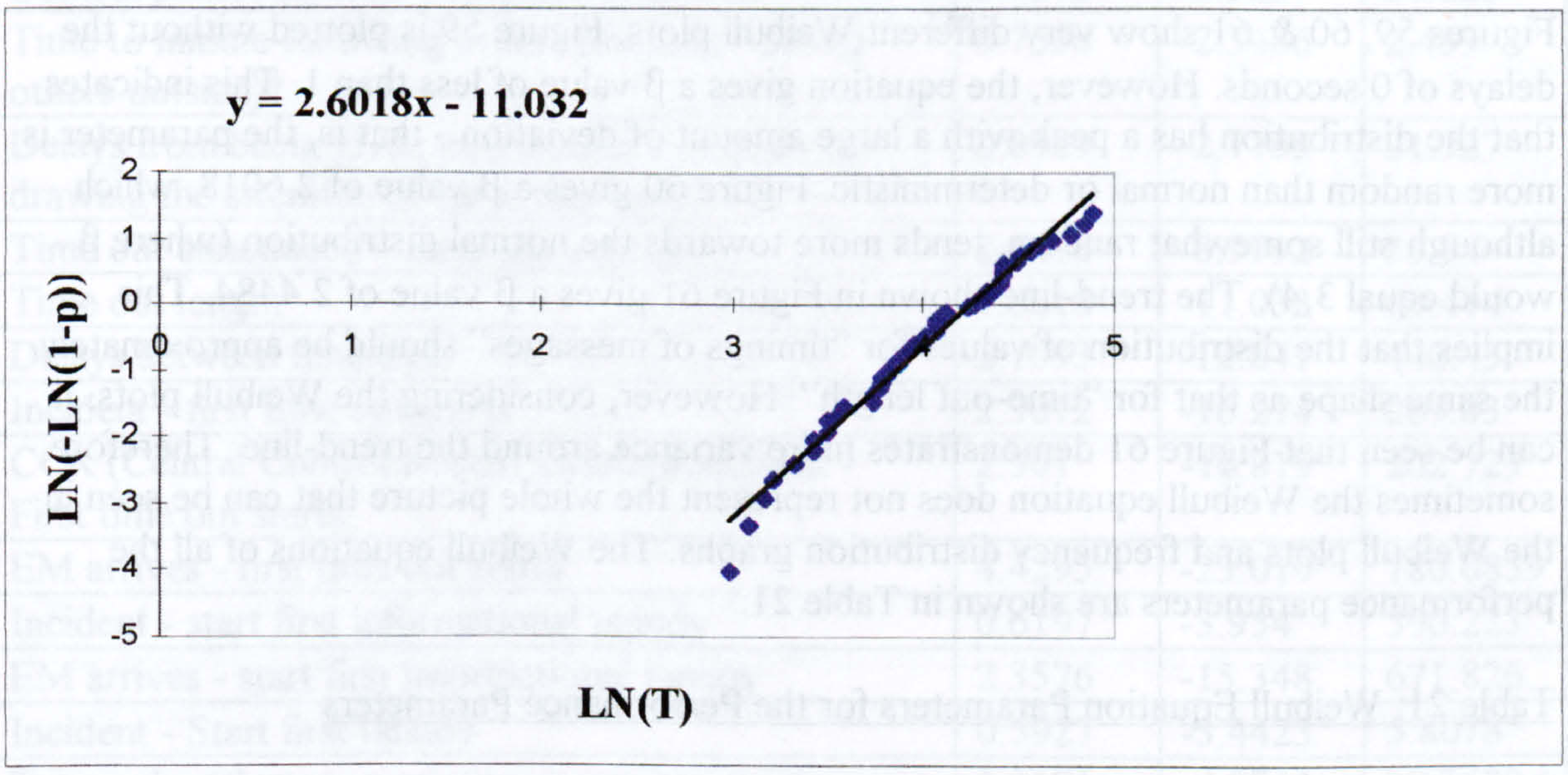
However, just producing the frequency distributions is not the only analysis that can be made. To assess whether the distributions follow recognised patterns, it is possible to convert them into Weibull plots and to calculate β and η using the method described in Appendix 4. (Weibull distribution is shown in Figure 30). However, because the Weibull plot involves the use of logs, it cannot be carried out where the time data is 0 - therefore data such as those shown in Figure 56 can only be analysed from time = 1 and upwards. Therefore, for the rest of the "delays between announcements" data (delays $\neq 0$), the Weibull plot appears as shown in Figure 59.

Figure 59: Weibull plot of Delays between Announcements



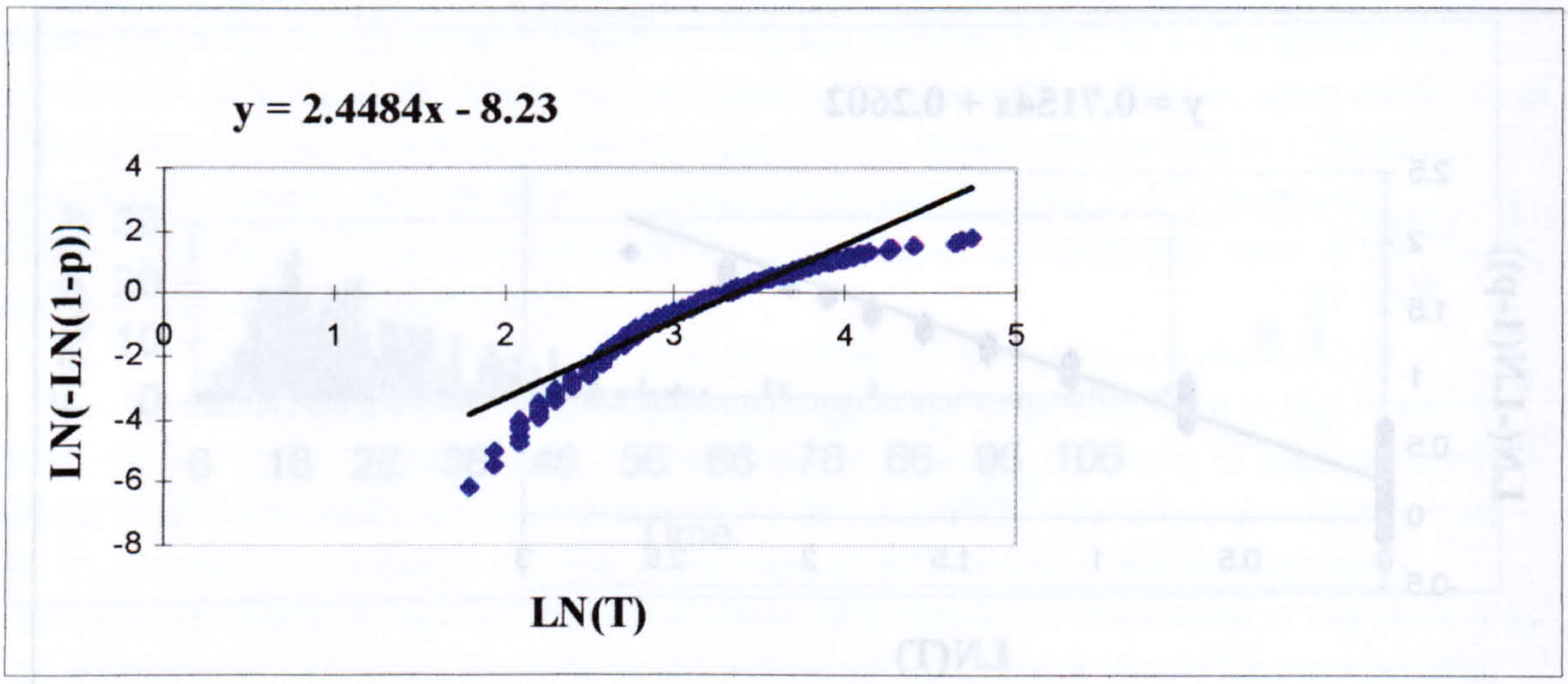
For time-out length, the Weibull plot appears as shown in Figure 60.

Figure 60: Weibull Plot of Time-out length data



For message timing, the Weibull plot appears as shown in Figure 61.

Figure 61: Weibull plot of timings of messages



The equation on each graph represents the Weibull equation based on the trend-line of the data. The gradient is the shape factor (β) and scale factor (η) can be calculated from the intersect (-β ln η) (See Appendix 4 for details). As shown in Figure 30, if the gradient was 3.4, the distribution would be approximately normal. As it tends to smaller numbers, the distribution is more random.

Figures 59, 60 & 61 show very different Weibull plots. Figure 59 is plotted without the delays of 0 seconds. However, the equation gives a β value of less than 1. This indicates that the distribution has a peak with a large amount of deviation - that is, the parameter is more random than normal or deterministic. Figure 60 gives a β value of 2.6018, which although still somewhat random, tends more towards the normal distribution (where β would equal 3.4). The trend-line shown in Figure 61 gives a β value of 2.4484. This implies that the distribution of values for "timings of messages" should be approximately the same shape as that for "time-out length". However, considering the Weibull plots, it can be seen that Figure 61 demonstrates more variance around the trend-line. Therefore, sometimes the Weibull equation does not represent the whole picture that can be seen in the Weibull plots and frequency distribution graphs. The Weibull equations of all the performance parameters are shown in Table 21.

Table 21: Weibull Equation Parameters for the Performance Parameters

Parameter	β	**-β ln η**	η
Scenario organisation team's informational calls	1.5746	-1.2466	2.2071
Scenario organisation team's calls - non-informational	2.1254	-1.2466	1.7977
Emergency management team's calls - informational	1.8417	-3.3636	6.2115
Emergency management team's calls - non-informational	2.1845	-1.0037	1.5833
Scenario organisation team's calls	1.165	-1.7341	4.4304
Emergency management team's calls	1.2464	-1.3846	3.0371

Non-informational calls	2.1433	-1.1204	1.6866
Informational calls	1.655	-3.2697	7.2109
Radio calls	1.1761	-1.5611	3.7712
Delays between radio calls *	1.1883	-0.7373	1.8599
Announcements	1.1838	-1.6005	3.865
Delays between Announcements *	0.7154	+0.2602	0.6951
Total time to deliver a message	2.4484	-8.23	28.829
Times between telling to standby and calling back to give information	0.9098	-3.1334	31.315
Totally unintelligible calls	1.2336	-1.8966	4.6529
Partially unintelligible calls	1.8822	-4.1529	9.083
Time left between failed attempts to call in/out	1.4867	-3.7763	12.681
Delays to answer phone*	1.1937	-2.0408	5.5268
Time at which the phone stopped ringing	2.4922	-7.9873	24.653
Phone call length	1.8837	-6.2673	27.857
Information passed from EM to SO	1.0461	-4.4138	67.9852
Information passed from SO to EM	1.6978	-6.2497	39.6884
Time to initiate following orders (control panel work)*	0.7847	-1.9298	11.697
Incident - Control panel responds*	0.2965	-0.3884	3.7059
Control panel response - operator response*	0.7578	-2.583	30.223
Time to initiate following orders (moving / calling others outside)*	0.7538	-2.3456	2.459
Delays from being given information externally to drawing the attention of the group to it	0.8989	-2.7755	21.927
Time out announced - Time out started*	2.5476	-8.9792	33.94
Time out length	2.6018	-11.032	69.414
Delays between time-outs	2.1093	-12.841	440.45
Incident - first time out starts	2.9072	-16.274	269.83
CCR (Central Control Room) aware of incident - First time out starts	2.301	-12.819	262.723
EM arrives - first time out starts	4.4295	-23.019	180.6839
Incident - start first informational tannoy	0.6197	-3.954	590.223
EM arrives - start first informational tannoy	2.3576	-15.348	671.826
Incident - Start first tannoy	0.5927	-3.4423	5.8078
Tannoy length	1.2171	-4.0713	28.3629
Time between tannoys	0.6144	-3.7357	437.117
Incident - start of first call out from CCR	0.8029	-2.7019	28.939
Incident - start of first call into CCR from incident site	0.5445	-1.7855	26.554
Incident - start of first informational call into CR from incident site	0.6453	-2.528	50.28
Incident - EM arrives	1.0899	-4.7645	79.162
Incident - call EM	0.953	-3.6768	47.37
call EM - EM arrives	1.0259	-3.49	30.0308

EM arrives - EM's first response	0.6675	-1.9963	19.899
Incident - EM's first response	1.0304	-4.0574	30.021

* - include delays of 0 seconds

As can be seen in the column of β values in Table 21, only one value exceeds 3.4 (the value indicating a normal distribution). This was the parameter "OIM arrives - first informational tannoy" and is apparently deterministic (See Appendix 11 for frequency distribution). However, there are only 5 pieces of data in the distribution, so this is unlikely to be meaningful. Therefore, the data are predominantly random. From the frequency distributions shown in Appendix 11, most are approximately logarithmic in appearance. However, a cluster of values with a long tail will give a low β value consistent with our results. If we consider the data obtained from large samples, there appears to be a surprising relationship between the parameter type and β. For example, "delays between announcements" involves relative simple "response to questions" timings. Nevertheless, β is 0.7154, indicating a high level of randomness. In contrast, the β value for "message length" is 2.4484, indicating more of a tendency towards a clustered distribution. We would expect this to be random due to the large variation in content of a message. However, as shown in Figure 61, the trend-line is not necessarily representative of all the features of the data.

Given that the data have been analysed and the various distributions have been collated (where appropriate), the next section can illustrate how this information can be applied in the TPRC model.

SECTION 9.4: USING THE PERFORMANCE PARAMETERS IN THE TPRC MODEL

This project has now collated a large body of data including the following:

- Physical data on emergencies, their escalation and mitigation (from literature)
- Physical data on human physiology with relation to physical task speed and injuries (from literature)
- Technological specifications on rescue craft (from literature)
- Physical design data of installations (from site-specific literature)
- Scenario-specific estimations of emergency timings (from the dedicated simulations)
- Distributions of timings for generic performance parameters applicable in emergency management (from the dedicated simulations)

In the previous chapter, the TPRC model demonstrated how a time contingent assessment of probability of success could be produced for tasks where the resource-time and task progress-time relationships can be plotted. It was also noted how changes in the variables could affect the outcome - particularly the impact of an initial delay. Out of all the contributory variables, the delay is the easiest to improve. That is, the task goal is normally a fixed objective - as defined by the incident. The task speed is typically defined by the limits of mechanical or human physical ability. The resources are usually a feature of the incident, for example, speed of escalation. Therefore, emergency action can only improve the influence of these variables on the probability of success to a small degree.

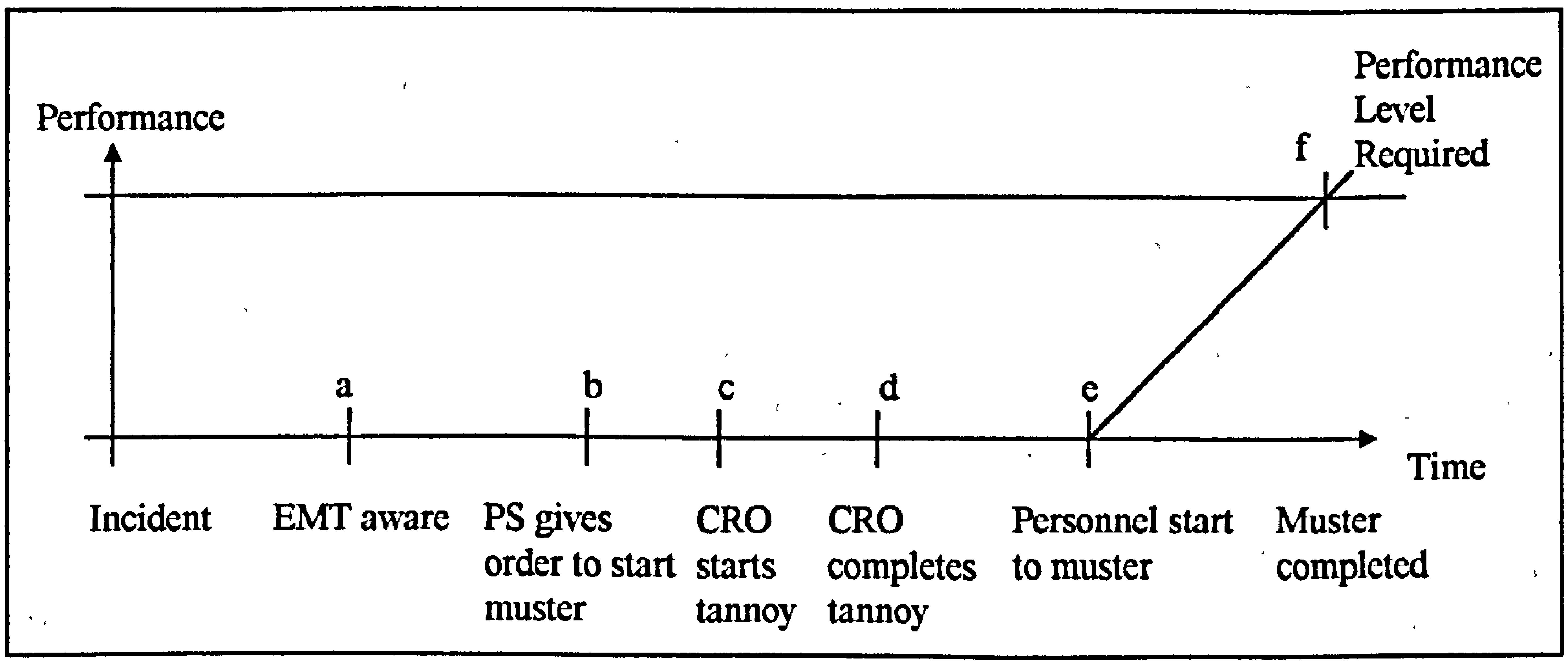
To produce a significant change, most factors should have been changes prior an emergency - for example, changes brought about by design, training or the allocation of resources. These might include reducing the distances to rescue by providing a close helicopter-launching site, speeding up rescue personnel through fitness training and selection, slowing escalation by providing improved safety systems.

However, the delay in action is a key contributory factor - and is strongly influenced by the actions of the management team. Most of the tasks involved in an emergency are outside of the emergency manager's direct control. The management team can only pass on information and make recommendations, but it is the on-scene personnel that carry out the actual mitigating actions. Therefore it is the responsibility of the emergency management team to ensure that they limit their delays to a minimum to facilitate the probability of success in each task. As stated in earlier chapters (Figures 35 & 38), the delay in action is made up of a number of sub-tasks:- informing EM, EM makes decision, EM gives orders, team act. This is known as SADCAR - situation awareness, decision, communication, action, response. Making a "good and timely" decision is a critical aspect of emergency management. These "good decisions" are intended to produce a positive outcome - which is something that cannot be defined until the system or incident responds. Also, because decision-making is a cognitive process, it is not something that can be observed or recorded in this context. Therefore, as an emergency management is best assessed in terms of the emergency's outcome, an emergency management decision is best assessed in terms of the actions that it produces.

For example, returning to the methanol tote tank scenario, the crane driver is initially thought to have tried to escape from the crane by running across the methanol laydown area. In our given example of the TPRC results, the delay before he attempts to make his escape is 61 seconds - corresponding to the start of the muster.

To illustrate how the generic performance parameters can be used to give data for a novel situation, we can use this part of the scenario. However, instead of the Production Supervisor ordering to stop the hot work (as shown in Figure 38), he immediately orders a muster. This can be shown in Figure 62.

Figure 62: TPRC Progress Graph in starting Muster



Taking the extract used previously, as shown in Table 8, the generic and scenario-specific performance parameters for the process can be considered. In this case, the generic performance parameters were taken from the offshore post-incident distributions shown in Appendix 11. These produce the possible sets of values as shown in Table 22.

Table 22: Possible Timings for Delays between the Incident and start of the Muster

Parameter	Original Scenario Measures	Minimum parameter value	Average parameter value	Maximum parameter value
Incident (assumed) - start of first call into CR from incident site	1	1	36.6	86
Scenario organisational team non-informational call	2	1	1.77	5
Delay between calls	2	0	1.51	21
Emergency management team non-informational call	1	1	1.35	6
Delay between calls	1	0	1.51	21
Scenario organisational team informational call	11	1	8.97	39
From end of call - PS gives order	0	(Scenario specific - 0)	(Scenario specific - 0)	(Scenario specific - 0)
Announcement	3	1	3.32	43
Time to initiate following orders (call others outside)	1	1	27.46	126
Length of tannoy	12	1	16.67	40
Tannoy ends - Personnel start to muster (Assumed)	(Scenario specific - 0)	(Scenario specific - 0)	(Scenario specific - 0)	(Scenario specific - 0)
TOTAL TIME	34	7	99.16	387

In Table 22, the first column represents the figures that were shown in the scenario relating to stopping the hot work in response to the incident. However, because the modelling process must now examine starting a muster, some changes must be made. The time between receiving the information and the production supervisor giving an order is based on a cognitive process. The production supervisor decided that the hot work must be stopped. This is the closest approximation to a decision to start a muster that is available in this sample of data; therefore, the same timing must be used. Similarly, the timing between ending the tannoy and the external people starting the muster is assumed. As this occurs later in the scenario, the timing is taken from that point - in this case, 0 seconds. This produces a total time of 34 seconds from the incident to starting the muster. Given that in this scenario, it was assumed that the crane driver attempted to escape when the muster was started, this can also be used in the TPRC model of his escape.

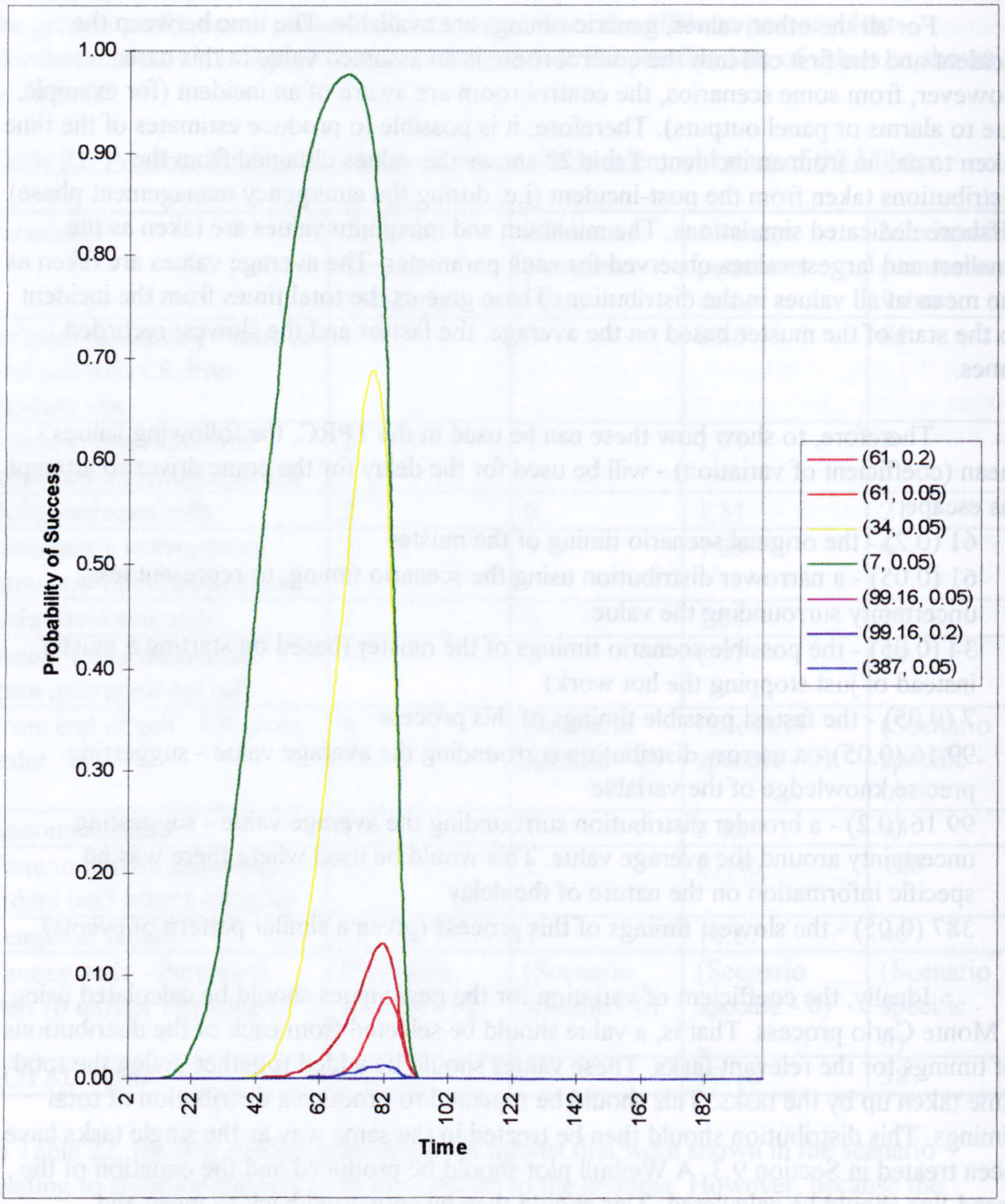
For all the other values, generic timings are available. The time between the incident and the first call into the control room is an assumed value in this case. However, from some scenarios, the control room are aware of an incident (for example, due to alarms or panel outputs). Therefore, it is possible to produce estimates of the time taken to call in from an incident. Table 22 shows the values obtained from the distributions taken from the post-incident (i.e. during the emergency management phase) offshore dedicated simulations. The minimum and maximum values are taken as the smallest and largest values observed for each parameter. The average values are taken as the mean of all values in the distribution. These give us the total times from the incident to the start of the muster based on the average, the fastest and the slowest recorded times.

Therefore, to show how these can be used in the TPRC, the following values - mean (coefficient of variation) - will be used for the delay for the crane driver to attempt his escape:

- 61 (0.2) - the original scenario timing of the muster
- 61 (0.05) - a narrower distribution using the scenario timing, to represent less uncertainty surrounding the value
- 34 (0.05) - the possible scenario timings of the muster (based on starting a muster instead of just stopping the hot work)
- 7 (0.05) - the fastest possible timings of this process
- 99.16 (0.05) - a narrow distribution surrounding the average value - suggesting precise knowledge of the variable
- 99.16 (0.2) - a broader distribution surrounding the average value - suggesting uncertainty around the average value. This would be used where there was no specific information on the nature of the delay.
- 387 (0.05) - the slowest timings of this process (given a similar pattern of events)

Ideally, the coefficient of variation for the new values should be calculated using a Monte Carlo process. That is, a value should be selected from each of the distributions of timings for the relevant tasks. These values should be added together giving the total time taken up by the tasks. This should be repeated to produce a distribution of total timings. This distribution should then be treated in the same way as the single tasks have been treated in Section 9.3. A Weibull plot should be produced and the equation of the trend-line should be calculated. This should then be converted back to mean and coefficient of variation values (using the equations in Appendix 4) and applied in the TPRC model as above. However, in this case, it is necessary to illustrate the differences between the parameters and so this process is not followed. All the other variables are kept constant and as are follows:
Speed = 0.7 (0.1), Distance = 25 (0.3), Time Resource = 84 (0.05) - (uncertainty value x given in brackets)
The results of the TPRC model for these values are shown in Figure 63.

Figure 63: TPRC results for crane driver's possible escape across the methanol laydown area - the effects of various possible delays based on performance parameters



Obviously, the best probability of the success was when the delay was based on the minimum (fastest) values. These values are probably too optimistic to represent a realistic time to pass on the information. For example, the shortest recorded tannoy was 1 second - which would surely not be enough to pass on the relevant information. Nevertheless, this information was obtained by observation of previous scenarios so at some point there must have been a tannoy that was that short. This delay produced a maximum probability of success of 0.98. The second shortest delay resulted from an estimation of event timings if the production supervisor had ordered the muster at the point where he stopped the hot work. This resulted in a maximum probability of success of 0.69, which is also a reasonably acceptable value. As stated in Chapter 9 (Figure 39), the scenario data produced a maximum value of 0.13. With such a low probability of success, it would be foolish for the crane driver to risk the attempt. However, if the production supervisor had started the muster at the same point that he stopped the hot work, the crane driver should have attempted to muster as well. This would have increased the probability to 0.69 and if it was successful, it would have prevented the further consequences. The crane driver would not have been trapped in the crane and therefore would not be forced to jump into the water, requiring rescue by the fast rescue craft. However, the fact that the production supervisor did not give the order to muster does not indicate poor emergency management. Using average values from all of the other factors, it can be seen that both the 34 second (possible muster timing) and 61 second (actual muster timing) values were faster than the estimated average value of 99.16 seconds. This indicates that the crane driver's failure was not due to the emergency management team's tardiness, but more due to the task involved and the escalation of the situation. The maximum delay inputted was 387. This resulted in a maximum probability of success tending towards 0. Although this was calculated from the slowest times to carry out the sub-tasks, this does not indicate that it was the slowest possible time to complete the task. If this was expanded to include delays in passing information from SO to EMT or, internally, or problems with totally or partially unintelligible calls, this could potentially be much longer. In theory, this could be infinite. If the emergency management team were not informed that there was an incident, it is unlikely that the muster would be called. Similarly, if due to their own incompetence, they did not respond appropriately to the crane driver's call, the probability of success in the task would be 0.

The relevance of uncertainty has not been discussed in the results. However, here it can be seen that when the delay was 61, a broader distribution of inputted values (0.2) lead to a higher probability of success than a narrower distribution (0.05). Therefore in this case, the variance has acted in the favour of the crane driver.

In Section 7.3, it was also suggested that the TPRC could be used to test new designs using the data from simulations. Given the same situation as shown in Figure 63 (description of task in Figure 62), we can imagine our crane driver has a greater or lesser distance to cross the methanol laydown area to safety. Changing the distance would also normally affect the resources. For example, if the given distance is reduced for the crane driver, it is also reduced for the fire. Therefore, a shorter distance may result in a faster escape but it will also result in a faster escalation. In our current scenario, the distance is approximately 25 metres. Figure 64 represents the TPRC results from half this amount (12.5m) and double this amount (50m) including the effects on task as well as escalation (resource consumption). This was carried out for the possible scenario delay (assuming the Production Supervisor started a muster at the point at which he stopped the hot work) and the average delay based on the generic performance parameters.

Figure 64: Results of TPRC for crane driver's possible escape across the methanol laydown area - the effects of changes in distance

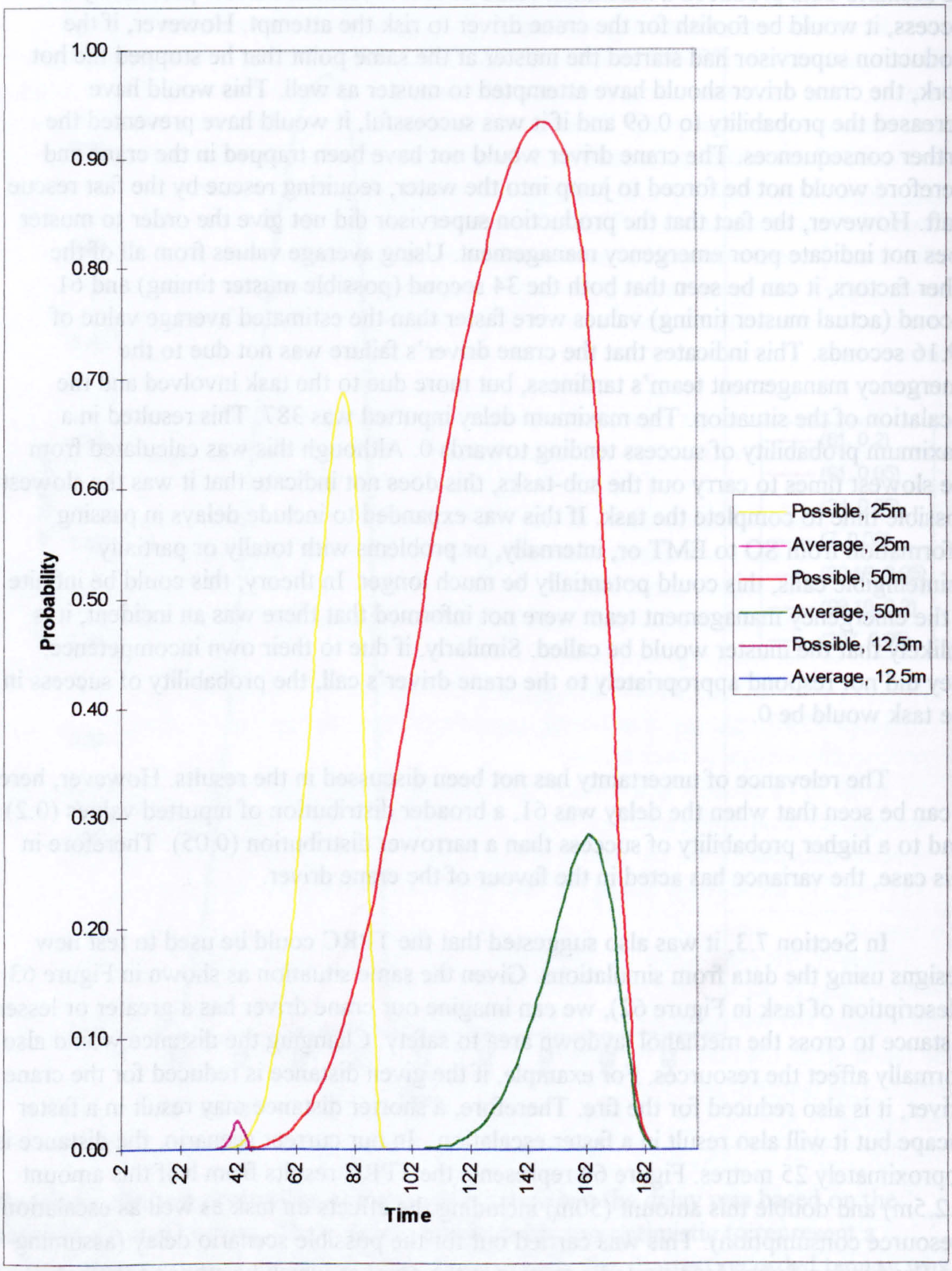
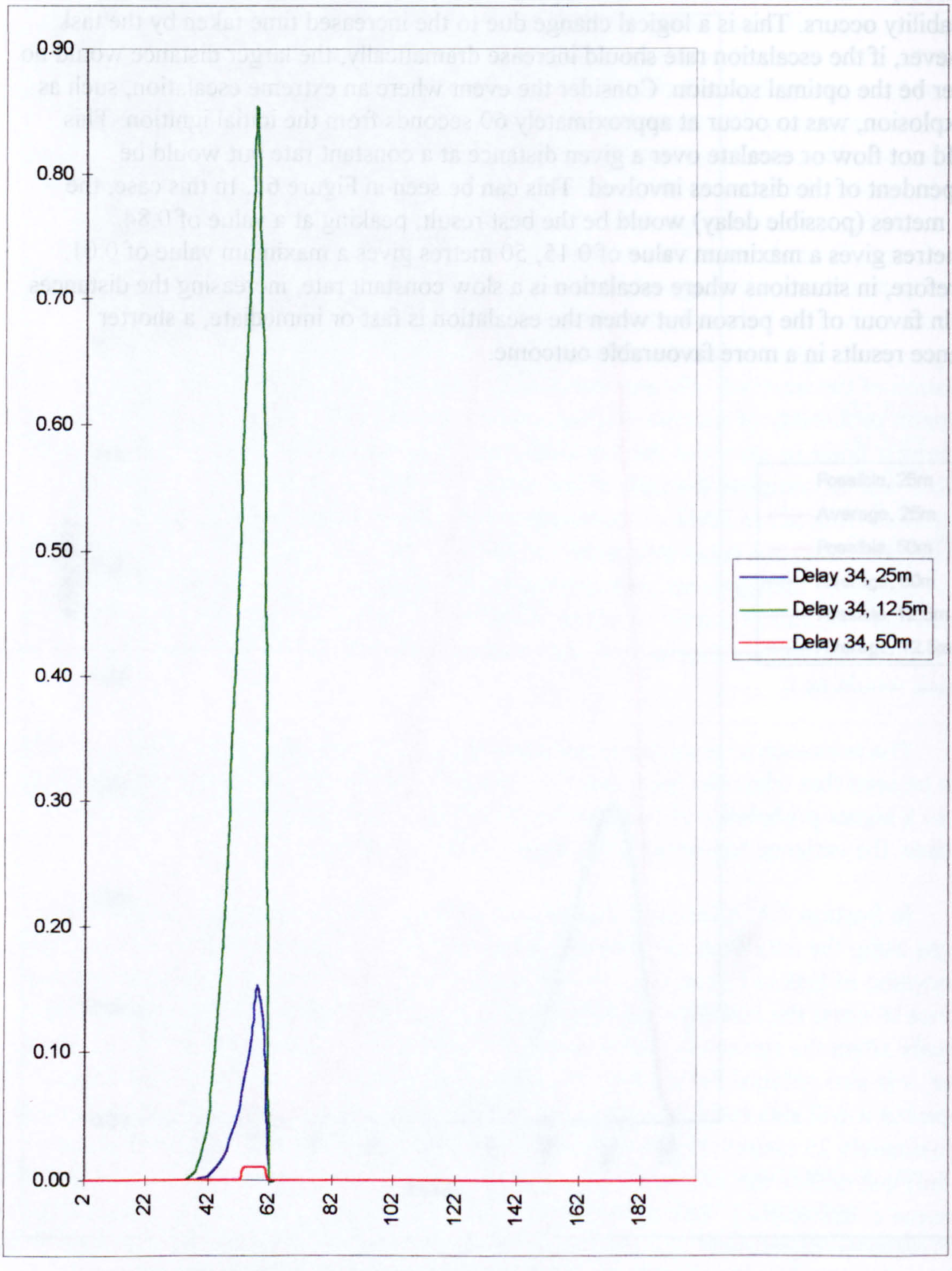


Figure 64 illustrates that greater distances improve the probability of success in this task. The 50-metre distance combined with a delay of 34 (0.05) resulted in a maximum probability of 0.93. With a delay of 99.16 (0.05), this is decreased to 0.28. When this is compared with the original distance of 25 metres, a delay of 34 (0.05) produced a maximum of 0.69 and a delay of 99.16 (0.05) produced a maximum of

$2x10^{-6}$. Therefore, the increase in distance clearly improved the crane driver's probability of escape. However, when this was decreased to 12.5m, a delay of 34 (0.05) produced a maximum probability of success of 0.03, a delay of 99.16 (0.05) reduced this 0. However, an increase in distance also increases the time at which the maximum probability occurs. This is a logical change due to the increased time taken by the task. However, if the escalation rate should increase dramatically, the larger distance would no longer be the optimal solution. Consider the event where an extreme escalation, such as an explosion, was to occur at approximately 60 seconds from the initial ignition. This would not flow or escalate over a given distance at a constant rate but would be independent of the distances involved. This can be seen in Figure 65. In this case, the 12.5 metres (possible delay) would be the best result, peaking at a value of 0.84. 25 metres gives a maximum value of 0.15, 50 metres gives a maximum value of 0.01. Therefore, in situations where escalation is a slow constant rate, increasing the distances acts in favour of the person but when the escalation is fast or immediate, a shorter distance results in a more favourable outcome.

Figure 65: Results of TPRC for crane driver's possible escape across the methanol laydown area - the effects of changes in distance in relation to a fast escalation (explosion)



It should be noted at this point that the escalation rates in this example were essentially artificial - based only on the scenario organiser's interpretation of events. Although, these should ideally be based on realistic escalation information, this cannot be guaranteed. Also, the idea that escalation would increase at a constant rate relating to distance may not be the case. This example was included only to demonstrate that changes in design could be applied to a TPRC of a given situation.

SECTION 9.5: USING THE PERFORMANCE PARAMETERS AS RAW DATA

As suggested in Section 7.5, the use of performance parameters is not confined to application in the TPRC model. As raw data, it was suggested that the performance parameters could be used as a benchmark for performance, for three main purposes:

- for assessment - therefore defining the times taken by highly competent, competent or failed emergency managers to react to particular situations so assisting in the assessment of other emergency management candidates
- for design - to ensure that designers are aware of the times taken to respond to particular situations and therefore new technology takes these times into account
- for emergency planners - to take the times taken into account when writing emergency management procedures

For example, consider factors that change with the level of competency awarded. One key result was the difference in time-out length. The mean values are as shown in Table 23.

Table 23: Mean values of Time-out length for Levels of Competency

Highly Competent	Competent	Notable Shortfalls
83 seconds	61 seconds	56 seconds

This may indicate that longer time-outs are associated with higher levels of competency. Therefore, this may mean that longer time-outs influence the assessor to award higher levels of competency. However, it may indicate that time-out length can be used as an independent assessment method.

Similarly, another indication of competency may be the number of "negative" events per scenario / hour - such as the number of times that the phone was not answered and stopped ringing. However, in this case, there were not enough data available to make this assumption - occurring on one occasion for the highly competent scenarios but not occurring at all for the scenarios with notable shortfalls. This is contradictory to the expectation and, as it is unlikely that competency and "number of phone-calls not answered" are closely linked, this requires more data to assess the likely frequency of unanswered calls.

It is likely that the raw data both for scenario-specific and generic performance parameters are useful for designers and emergency planners. This might be through application of performance parameters in other techniques - such as the timeline analysis or Microsaint (as discussed in Sections 2.4.4.2.5 and 2.4.4.2.6). For example, if it is known that it takes a specific length of time to receive information and deliver messages (considering maximum and minimum times), a designer can ensure that the delay caused by these tasks are not detrimental to the outcome of the incident. A designer can ensure that a system allows a certain length of time for a human to cancel a process (for example, security locks on exits, halon firing) or that areas are protected to a certain degree to allow rescue or intervention (e.g. a temporary refuge or bridge access must last long enough for the personnel to use it).

Likewise, an emergency planner can use these values to design emergency procedures. If it is known that a person can carry out certain actions within a known length of time, the procedures can be designed to make the best use of the expected time available. For example, if the design is such that certain tasks must be done within a limited amount of time and the length of time taken to carry out these tasks can be estimated, the tasks can be ordered and prioritised accordingly.

For example, in Offshore Scenario 1, it takes 13 seconds from the helicopter crash to the activation of the Level 3 shutdown. This is a reasonably quick human reaction and it is hoped that it will result in immediate action of the systems involved. In this case, it would be intended that any escalation that would be caused by leaving the systems active have been abated by this quick reaction. This is something that must be considered by designers. That is, if the system would only be effective if activated 1 second after a helicopter crash, this is clearly an unrealistic expectation of the emergency management team. Also, if the designers suggest that the system must be activated within 30 seconds of the incident to be effective, this would indicate that it should prioritised as such in the emergency procedures - perhaps indicating that this should be done before starting the muster or calling for a medical team.

Although this has briefly described the use of performance parameters as raw data, it is expected that with the large number of examples shown in Appendix 8 that this could be used for a large number of different scenarios.

SECTION 9.6: CONCLUSIONS

Overall, this demonstrates the potential of the performance parameters, both in their own right and when applied in the TPRC model. This has fulfilled the fourth and final objective of the research.

In general, this suggests that the TPRC method can be used to quantify the impact of emergency management on risk reduction. The performance parameters add a new dimension to the model by allowing it to use distributions of data recorded from simulations to represent the reactions of an emergency management team. This reduces the reliance on expert judgment to define the values for the delay parameter in novel situations. Therefore, this methodology can realistically be expected to fulfil the objectives of the research.

Chapter 10

CRITIQUE OF THE METHOD

SECTION 10.1: INTRODUCTION

This chapter includes a critical analysis of the methodology, initially starting with a description of how the method developed, problems that occurred along the way therefore guiding it to being the method it became. Following this, there will be a critique of the final method in terms of the scenario arrangements that were set down for the research, limitations of the model as well as other issues relevant to the data collection and analysis.

SECTION 10.2: INITIAL STATE OF THE RESEARCH

When this research first began, it was thought that the objectives would be

- to examine the tasks and associated cognitive processes involved in emergency management
- to identify the behavioural features of good emergency management
- to link these aspects to quantitative risk assessment through development of mathematical models

These would therefore result in the identification of observable, objective and quantifiable benchmarks to assist in the emergency management assessment process. It would also allow aspects of emergency management to be incorporated into quantitative risk assessment and human reliability assessment.

At this point, the TPRC (Task Performance Resource Constraint) model was being developed within the department to examine the probability of success in human-based tasks. However, it had only been demonstrated with a limited scope in terms of specific tasks and industries (Loa 1997). Obviously, it was hoped that this concept would be useful in the research - whether it should remain in this form or be used as a basis for a new model. Initially, it was anticipated that the TPRC model would be developed as a Human Reliability Quantification tool by incorporating the impact of Performance Shaping Factors from THERP (Swain & Guttman 1983) and Error Producing Conditions from HEART (Williams 1986) into its calculations. There was also some speculation that the model could be applied to the emergency situation purely in terms of cognitive aspects, for example, the probability of success in making a good emergency management decision.

SECTION 10.3: INITIAL DEVELOPMENT OF THE DESKTOP SIMULATION METHOD

However, the goals outlined above were just the initial plans and, at that time, it was difficult to see how such objectives could be met. This was particularly the case as there was an absence of useful emergency management data, and no guarantee of data for the duration of the research. The only source of emergency management data was from the literature, such as those recorded in accident investigations, public enquiries and anecdotal reports.

Therefore, the initial focus was to develop a methodology for assessment of simulated emergency exercises in industry that:

- examined decision-making in an emergency situation
- differentiated between good and bad emergency management strategies and decisions
- produced a quantitative result based on objective measures that could be useful for HRA or QRA.
- did not rely on the provision of external resources (for example, access to emergency management teams), but could still be useful if such resources became available
- was simple enough to be used with novice emergency managers but also beneficial for those with more expertise (and therefore could be used to quantify the impact of training)
- was fully repeatable
- was scientifically valid, reliable and ethical
- was consistent with real-life knowledge of emergencies and emergency management therefore could represent all the relevant features for a post-hoc analysis of a real incident (and potentially be validated in this way)
- could be developed to incorporate additional factors, different contexts or situations.

Also, given that this was in the early stages of the research, it was important that it should produce results quickly. This would reduce the risk of investing too much in a method that was later found to be ineffective.

In the early stages of the research, there was no obvious way of obtaining "real" data on decision making from real emergency managers. Also, the relevant literature rarely reported enough detail to provide the basis for such a method. Therefore, the desktop simulation was developed. This could fulfil the objectives stated above in the following ways:

- It was based on a "board-game" format, using a grid to represent the relevant physical area, and has specific rules for escalation and personnel behaviour. Therefore, it was cheap, easily repeatable but with the potential for development.
- This involved the use of a "building fire" simulation so that even novice emergency managers could make a reasonable attempt at control and organisation - though those with more experience could also use this to test their skills. In addition, more simulations could be developed to include different situations and contexts.

- This could incorporate a methodology to investigate the cognitive aspects of emergency management. Using a post-hoc questionnaire, it would be possible to analyse the attitudes towards the decisions made.
- This method was consistent with the real-life concepts of an emergency - in that escalation could be mitigated through the correct human intervention. Also, there were penalties attached to making late decisions - which allowed the concept of time pressure to be incorporated
- Use of a board game can be considered an ethical test of emergency management decision-making.
- As discussed in Chapters 2 and 3, real emergency management is often assessed in terms of the physical outcome - in terms of numbers of fatalities, survivors, casualties, assets and environmental damage. Therefore, this seemed to be a reasonable premise on which to base an objective, quantitative measurement of success. This would be consistent with real-life knowledge of emergencies and could distinguish between good and bad emergency management strategies. To be a totally objective assessment of management skill, it would be necessary to compare the actual outcome against the best possible and worst possible outcomes. Bearing these points in mind, the success in the desktop simulation was measured in terms of % survived (those evacuated from the building) and % safe area (where the fire was controlled). These were both observable quantifiable outcomes relating to the success of the strategy chosen. Given that the escalation of an emergency (if little or no mitigation took place) is linked to time - the speed of success was also an important aspect. If the people were evacuated just before the building was destroyed in a real incident, there would have been more chance that this strategy would have failed (due to the variability in the behaviour of an escalating fire). Therefore, both the evacuation and safe area parameters linked to a time axis - and the most successful strategies were defined in terms of the quickest evacuation/control.

This method was initially tested using "attitude-based strategies" - such as people-oriented, selfish etc. In terms of results, the desktop simulation showed face validity - in that the strategies thought to be effective (people-oriented) showed faster evacuation and better control of the escalation than those that were <u>not</u> thought to be effective (selfish or denial strategies). Therefore, this indicated that objective outcome-based evaluation of emergency management skill had the potential for development.

However, this desktop simulation demonstrated some problems in its infancy - mainly the amount of organisation involved in running the game (monitoring real moves, recording the moves and using the prescribed rules to analysing the responses of fire and people). Therefore, it was decided that this should only be progressed using a computer-based simulation. Also, at this point in time, dedicated simulations in the offshore industry (as described in Chapter 4) became available for observation.

SECTION 10.4: DEVELOPMENT OF THE METHODOLOGY FOR ASSESSMENT OF SIMULATED EMERGENCY EXERCISES IN INDUSTRY

Initially, it was not certain how the dedicated simulations would affect the research. There was a possibility that these could be used just to enable development of the desktop simulation - perhaps by making it offshore specific. It quickly became clear that observation was not sufficient to gain the maximum benefit from this experience. Therefore, it was arranged that remaining simulations could be recorded using a video camera. Unfortunately, there was no opportunity for change of the scenario organisation or any flexibility to gain additional data on the cognitive aspects of the decision-making - for example, by interviewing the emergency managers or allowing them to talk-though their thoughts using the videos. Once the recordings were complete, again, it was not certain how they could be integrated with the previous desktop simulation research - if at all.

Therefore, attempts were made to analyse the success of emergency management in the dedicated simulations in the same way as it was analysed using the desktop simulations. This was problematic as the dedicated simulations were more complex than the desktop simulation - involving more complex objectives than those that could be defined in terms of % evacuated or % area. Similarly, it would have required considerable effort in developing the desktop simulation format to incorporate the context of offshore emergency simulations. Whilst the analytical aspect of the desktop simulation was already adequate, focusing on the context aspect would not have been particularly beneficial - particularly when contextual data could be obtained from the dedicated simulations themselves.

Therefore, at this point, it became logical to return to the TPRC model and identify whether it could use its particular features of merit (e.g. the incorporation of uncertainty into the inputted parameters and producing a probability of success/time function); the same <u>concept</u> as the desktop simulation (i.e. objective outcome-based assessment) but be used to incorporate the <u>context</u> of the dedicated simulations (multiple tasks and objectives in an offshore/onshore situation).

This could therefore incorporate some of the positive aspects of current methods of QRA and HRQ (e.g. the task representation used in the time-line analysis, probability of success linked to time available versus time required as used in techniques such as HCR). However, it also could eliminate some of the problems associated with the current methods (e.g. reliance on expert judgement or statistics for error probabilities, pessimistic view of probability of success in emergency situations, decomposition or inappropriate categorisation of tasks, the specific impact of real-time on outcome and the use of point values as opposed to distributions of values).

At this point, it was decided that the desktop simulation would require considerable work before it could be an effective research tool and so it was left at this stage of development. In addition, the dedicated simulations were expected to provide a wealth of data with greater validity than the desktop simulation was likely to produce within the time-scale of this project. Therefore, the desktop simulation was available for development if, for some reason, the analysis of the dedicated simulations could not be used within the research. As it happened, there was no need to return to the desktop simulation. For that reason, this part of the research is shown in Appendix 2 so that it does not distract the reader from the main focus of the research.

Therefore, from this point onwards, the research had two main focus points:

- To develop the TPRC model to incorporate the critical aspects of the desktop simulation in terms of outcome-based assessment
- To identify the key features in the videos of offshore simulations that relate to tasks, their objectives, escalation points and outcomes with respect to time.

One of the most important aspects influencing the probability of success identified in the desktop simulation was the impact of an initial delay in the initiation of the task. The original TPRC model was designed to look at jumps forward in knowledge but was not able to represent tasks that had not been initiated immediately at the point when the resources had started being consumed. As in the objective outcome-based assessment, tasks have a physical and observable effect (e.g. movement towards an exit, activation of equipment to extinguish a fire) and it is usual that escalation is progressing before these tasks have actually been initiated. Therefore, in terms of the physical aspects, decision-making and communication all contributed to delays in the emergency management tasks. Therefore, it was required that the TPRC model should be adapted to incorporate these factors as described in Chapter 5.

Given these changes, a number of tasks from the offshore simulations were analysed using this technique. As most physical tasks required data that could not be obtained from the scenario alone, it was necessary to obtain the relevant design information (distances from platform to shore, from relevant places on the platform (slug catcher to safe haven, GCD deck to control room etc)); human physiology information (walking speed, tolerances); and environmental information. Some of these are described in Chapter 6.

However, it was still thought that this concept would be linked to the subjective assessment of emergency management for use in the benchmarking of performance and the cognitive aspects of emergency management performance. Therefore, as a second set of scenarios became available (this time based on an onshore installation), it was decided that the subjective data should be recorded in some way. It was required that this did not disrupt the normal simulation procedure so the pilot study involved the use of brief questionnaires. It was possible that these could be expanded for future sets of scenarios if they yielded interesting results. However, the main results of this aspect of the research revealed little more than the wide difference between the subjective assessments of characteristics associated with good emergency management and the estimated physical outcome of the emergency actions. In any case, no future scenarios were available within the research period so the questionnaires were not developed beyond the pilot stage. Therefore, this section is shown in Appendix 9.

It was notable that the observations from the dedicated simulations contributed data primarily to the delay aspect of the model. Therefore, it was speculated that these could be used to build up a database of emergency management response times. Initially, it was thought that the average reaction for specific situations could be assessed - for example - from the awareness of an ignition to the point at which the fire team are called. However, it was difficult to categorise these to produce more than one point value without losing the specific context of the situation. Therefore, these were recorded for each scenario as examples of possible timings - possibly to be built up into distributions in the future. However, many HRA techniques use decomposition of tasks to the generic level - and this would also be possible for the observable parts of a delay. For example, although the "the awareness of an ignition to the point at which the fire team are called" parameter is very specific, it would be made up of generic parts including "length of radio call", "delay between radio calls", "length of announcement" etc. In addition, whereas each scenario provides no more than one timing for the specific performance parameters, it can sometimes provide more than 100 values for the generic performance parameters - giving greater insight into the characteristics of the parameter's distribution.

These parameters are comparable with the idea of the "time and motion" study, but rather than physical tasks, they relate more to communication tasks - of which there are no recorded estimations for emergency management skills. Therefore, given the estimations of the parameters involved in a novel emergency management task, it is possible to make an estimation of how long a delay can be expected before the required action is initiated. The concept of both specific and generic performance parameters are recorded in Chapter 7, which then continues by demonstrating how these can be applied in the TPRC model.

SECTION 10.5: CRITIQUE OF THE SCENARIO ARRANGEMENTS

Unfortunately, the scenario arrangements were fixed for the duration of the research project. This meant that the environment, people involved, equipment, procedure and, type and number of scenarios were all pre-defined. It was only possible to obtain data within this scope. The original scenario arrangements were extended to allow the presence of an observer in the emergency management room, and to allow this observer to use a video camera. Later in the project, it was also possible to allow questionnaires to be given to the emergency management candidate and assessor. However, as the simulations were run on a tight schedule, it was specified that these questionnaires should take up a minimum length of time, so that they did not delay the debriefing. Therefore the questionnaires, as shown in Appendix 9, were shorter than would have been hoped to enrich the research.

As suggested in Section 2.3.6.1, it is questionable whether simulations have good external validity - That is, it is not known whether the observed behaviour is representative of behaviour that would occur in a real emergency. For example, although the stress of being under test may affect the performance, does it affect it to the same degree that a real emergency would? However, it would be unrealistic to design a research project that relied on the "convenient" occurrence of an emergency that could be recorded and analysed in the same way as these simulation data have. Therefore, it was necessary to rely on simulation data for the duration of the project. However, the techniques should be capable of using real data, such as those shown in Section 8.3.4 from Piper Alpha, so that this could be used as a means of validation. Therefore, the behaviour produced by the simulations was assumed to be "real".

Other than this issue, it was not possible to identify how much research went into the design of the scenarios. Although the scenario organizer was known to have gathered installation-specific information to design the relevant scenarios, it was not known how realistic this information was. For example, the scenario organizer may have designed the scenarios based on the QRA and conversations with senior members of staff. He also may have walked around the installation to estimate the duration of certain tasks. However, this research has established that the timings involved in an emergency scenario rely somewhat on engineering and medical principles. Therefore, producing realistic timings for all the tasks and events is problematic. Also, as there was no specific procedure of scenario design, it is not possible to determine the accuracy of the results. As mentioned earlier, the scenarios were designed to be a realistic test - not necessarily a perfect representation of a real incident. Therefore, some of the installation-specific timings that are recorded as "scenario-specific performance parameters" may not be based on realistic data. These values were applied in the TPRC model therefore the output of this would also be affected

Another problem was caused by the use of one main assessor. As stated in Section 3.5.4, it is recommended that at least 2 assessors are used. However, in this case, only one assessor was available to answer the "assessor" questionnaires. As shown in the results shown in Appendix 9, the levels of competency may be more orientated towards "behaviour correlating with good decision making" rather than the decision-making itself. As there was only a sample of one assessor available to answer the questionnaires, it is impossible to say if this is a general trend in emergency management assessment. Ideally, the other assessors (including the scenario organiser) should have answered the assessment questionnaires, to identify whether the views were consistent through the whole assessment team.

Other than this, the assessment procedure created the following problems for scientific reliability.

1. As he is an expert in emergency management, the assessor would try to compare the responses that were made by the emergency manager with the responses he would expect to see. However, frequently, the assessor would have the "brief" of the scenario as given to him by the scenario organizer. Therefore, he was aware of the escalations and problems that would occur in the scenario. The emergency manager does not have the luxury of this foresight. Knowing this, it would be almost impossible for the assessor to try and predict the responses by someone who did not have the same amount of information that he had. This is likely to cause some bias as the assessor can plan emergency interventions that would mitigate the events that he already knows will happen.

2. In this research, the main assessor was from the same organization that trained the candidate in emergency management skills, often being the trainer himself. The training process would involve passing his own judgment of good emergency management on to the candidate. Therefore, during the assessment, the candidate would be expected to copy this style of emergency management to achieve a high competency rating. This may be counter-productive if the candidate has developed an effective emergency management style that may be contradictory to the style taught by the assessor. For example, consider the emergency management styles described in Section 2.3.4. An assessor who expects a crew resource management approach is unlikely to be satisfied by the use of a bureaucratic approach - and vice versa, although in reality, both may be effective methods of managing an emergency and optimising the outcome.

OPITO (1998) state "The HSE has indicated, where industry-wide training standards are appropriate, they should be developed in conjunction with established, independent bodies with the expertise and the capability to monitor standards". Therefore, in general, the choice of style and the definition of competency with regard to assessors is defined subjectively through their previous emergency management experience. Therefore, it would be difficult to use the assessor's results as validation for the TPRC model. However, questionnaires and subjective assessment are no longer the main issue in this research and, in general, most of these problems would be rectified by running dedicated simulations that were designed using scientific criteria. Unfortunately, this option was not available during this project. However, the recommendations for running dedicated simulations for research purposes are shown in Chapter 12.

SECTION 10.6: CRITIQUE OF THE DATA COLLECTION METHOD

Other than the questionnaires, which will be discussed in Appendix 9, there are two main data collection techniques. One involves extracting the data from the scenario. The other is predominantly a research technique, involving collection of data and technical information as well as information on human activities and tolerance limits. This section will examine both of these in turn.

10.6.1 DATA COLLECTION FROM THE SCENARIO

The first data collection technique consists of recording the scenarios on video then transcribing the data. This was a long and slow process. Recording the words, actions and timings for all members of the group would often require small sections to be rewound and replayed more than once. When there was overlap between conversations or fuzzy radio calls, this was even more difficult. This made the process a lot more tedious - a 30-minute scenario sometimes taking over a week to transcribe. Also, due to the nature of the method, it is vulnerable to particular errors.
The following errors may have occurred:

- Mishearing the words - Mishearing the words may be caused by unusual accents, use of terms that are unknown to the author, volume or fuzziness due to the distance from the microphone or using lowered voices, quality of the video-recording or due to the acoustic quality of the original radio message.

- Recording the wrong words in the transcript - This may be caused by mishearing them (as above) or a typing error.
- Recording the wrong timing - This could be due to a typing error or noting down the wrong time from the stopwatch. For example, it takes a finite time between an event occurring on the video and the observer looking at the stopwatch. These data are digitally displayed and are recorded to the nearest second, which occasionally results in a 0 value. If it takes more than half a second to look from the video to the clock, there is a possibility that a larger value will be obtained.
- Recording the written communication wrongly - No information was communicated solely using written information therefore this consideration was not deemed necessary. In the event that this had occurred, the written messages would be recorded in real time as for announcements. However, in the event that this had been an issue, errors could be caused by not being able to understand the person's handwriting. It could also be due to obscuration (by people standing in front of the camera) or due to the size of the handwriting in relation to the frame. It could also be due to the position of the writing in relation to the camera. Again this could be caused by typing errors - though it should be noted that there was no written information recorded in the transcripts.

The use of video recording is generally considered to promote the use of objective techniques. There is no room for interpretation of events and conversations that are recorded both visually and audibly. However, as the scenarios were only transcribed by the author, there is no guarantee that errors were not made. Simply getting someone else to read through the transcripts and compare them to the videos is unacceptable, as the reader would be biased by expectancy effects. That is, they would expect to hear the words that are in the transcript and so any ambiguity in the words on the video will be resolved using the transcript rather than by the reader's interpretation. As the transcription process was so long and slow, it was not deemed possible to get an independent verifier to produce transcripts for the same scenarios. Therefore, any errors produced by the data collection remain in the research - though these are likely to be rare due to the contextual relationship of the data provided by conversations.

10.6.2 DATA COLLECTION FROM THEORETICAL INFORMATION AND OTHER MODELS

This considers the data that were collected from theoretical information and models - such as fire models, casualty models and estimations of human performance (e.g. Walking speed).

This data collection technique was limited by the skills of the researcher, the flexibility of the organizations involved as well as the available research that has been undertaken in the area. Ideally, the timings of the main tasks should be estimated through walk-throughs. For example, working out how long it would take the fire team to reach the helipad by actually walking the distance. Although this is likely to be altered by the circumstances, it gives a realistic indication of the timing. However, for escalation of fires, the effects of mitigation and injuries, no real try-outs can be attempted. Therefore, it is necessary to rely on models and theoretical information.

Chapter 6 illustrates the main data that were collected for this research, including information on human performance, injuries and fire escalation and mitigation. Although there is much more information available, this is often difficult to extract from the relevant source; for example, the relevant medical information on survival time in relation to specific trauma injuries is recorded in medical journals. This describes case studies of exceptional survival as well as unexpected death due to complications. However, without an in-depth understanding of the description of the injuries as well as the understanding of the medical techniques, it is difficult to recreate this in a form that is usable for the TPRC model. Even where models are available, they are often inaccurate due to the effects of personality and individual differences. For example, there is a model predicting survival time from cold-water immersion (Tikuisis 1995, Tikuisis & Keefe 1996, Tikuisis et al 1997, Tikuisis 1998). This uses information on clothing, ambient temperature, sea state, level of immersion and information about the subject, such as fitness and body fat content. As stated in Section 6.4.2, their original model predicted a survival time much shorter than that of the surviving passengers of the Estonia disaster. This suggests that the TPRC model's use of distributions to represent variability is an important asset. However, it creates problems when choosing the correct values to be used, as will be discussed in Section 10.7.4.1.

Similarly, the behaviour of fire is changed by the amount of fuel, oxygen, weather conditions, ambient temperature and the effects of mitigation. Although there is a large body of information about particular types of fire, there is no model that provides all-encompassing rules for escalation.

Therefore, the data collection technique relies on extracting the information from the correct sources. This often requires considerable understanding about the relevant subject areas - including medical, biological, chemical or engineering information. Even then, not all of the relevant information has been collected by the various disciplines. As research continues in these areas, overall knowledge increases. Therefore, as this model relies on external data, it is limited by the progress of other research. Although this guarantees a certain degree of flexibility and an ability to incorporate new ideas and new models, it also applies limitations to its current use.

SECTION 10.7: CRITIQUE OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

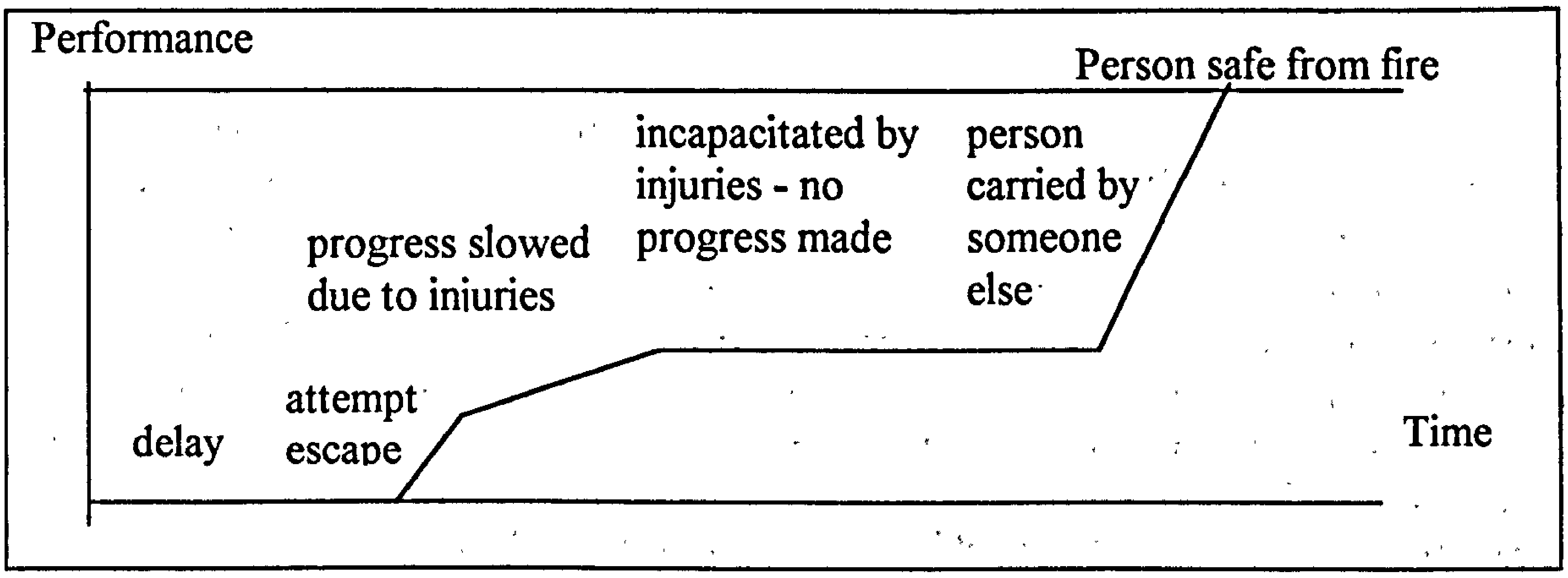
10.7.1 CRITIQUE OF THE MATHEMATICAL LIMITATIONS OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

The TPRC model is based on mathematical theories such as calculus and statistics. Therefore, it has been assumed that there are no weaknesses in mathematical validity or reliability. However, in its current role, there are a number of inadequacies when representing the emergency management situation.

10.7.1.1 Multiple Tasks and Multiple Resources

Firstly, the TPRC model is only capable of modelling a single task progress rate and a single resource consumption rate. These must both be linear, and are sampled from the same distribution for the whole analysis. However, the nature of emergency management is such that there may be a change in progress speed for the task. For example, the speed of a person escaping from a fire may be affected by his injuries. First there is likely to be a delay, while he becomes aware of the situation and decides what to do, then he may travel quickly through the fire, then may become hindered by his injuries due to the fire and smoke. In certain circumstances, he may become too seriously injured to continue and may then be rescued by someone else. For this, the task progress rate would be similar to Figure 66.

Figure 66: Task Progress Rate of Escaping the Fire



Although there is variability in task progress speed used in the model, these values are taken from the same distribution. To be accurate, each of these sub-tasks should be represented by different speed distributions. Because the TPRC model cannot yet represent sub-tasks, it also cannot represent multiple tasks working towards the same goal. For example, if we use the same example, the performance objective is to get the person (the casualty) to safety. If the casualty travels only half the distance to safety, they will not be successful in the task. If the rescue team travels only half the distance towards the casualty, it will not be successful in the task. However, putting these two tasks together results in a high probability that the rescue team will find the person and the task will be completed, as shown in Figure 66. These two tasks are independent of each other and would be represented as such on a TPRC graph. Modelling this using the current TPRC model would require prior processing of the information to obtain one progress rate to represent both tasks. Ideally, the TPRC model should be capable of considering such situations.

This problem is further complicated by the use of dependent tasks. For example, multiple tasks that work towards the same goal but produce an additive effect. These would include having extra people in a search and rescue team (therefore decreasing the area that each person must search) or using more than one fire control system, like deluge and hoses. These might be represented on TPRC task graphs similar to those shown in Figures 67 & 68.

Figure 67: Task Progress Rate of Search and Rescue

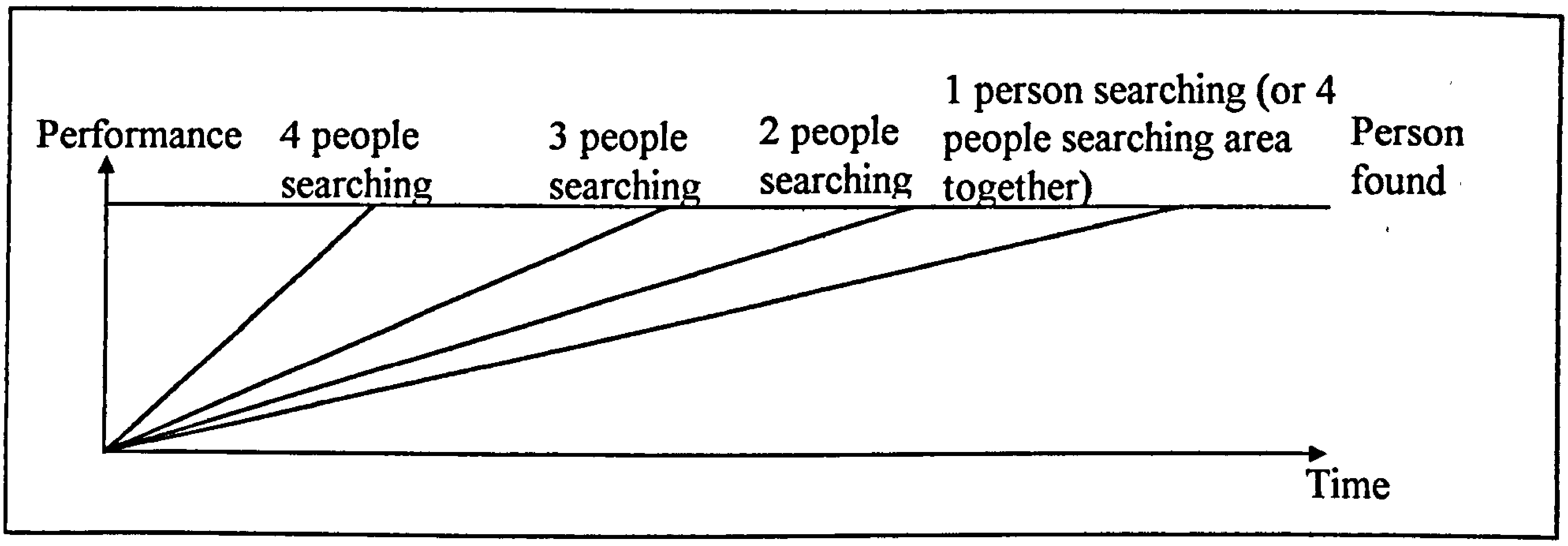


Figure 67 represents the effect of numbers of people in a search team on the search progress rate. If the four people all move round the area together, they would be searching the area at the same rate as one person searching. If they all split up and each take a section of the area, their individual task rate would be the same but the amount of work to be achieved by each is a quarter of the original total. However, if TPRC models are carried out on the tasks of individuals, searching different areas, we might assume that only one of them would successfully find the casualty. As these tasks are dependent on each other, they should be added together so the group performance is considered. In the current TPRC model, this would be calculated by multiplying the original task rate by the number of people searching. However, this assumes that all people move at the same speed and have the same proportion of the area to cover. It also would be difficult to estimate the effects of adding extra searchers later in the process. In the current TPRC model, there is no method of inserting the individual task progress graphs into the model and having it produce a probability of success curve based on the combination of these data.

Figure 68: Task Progress Rate of Fire-fighting

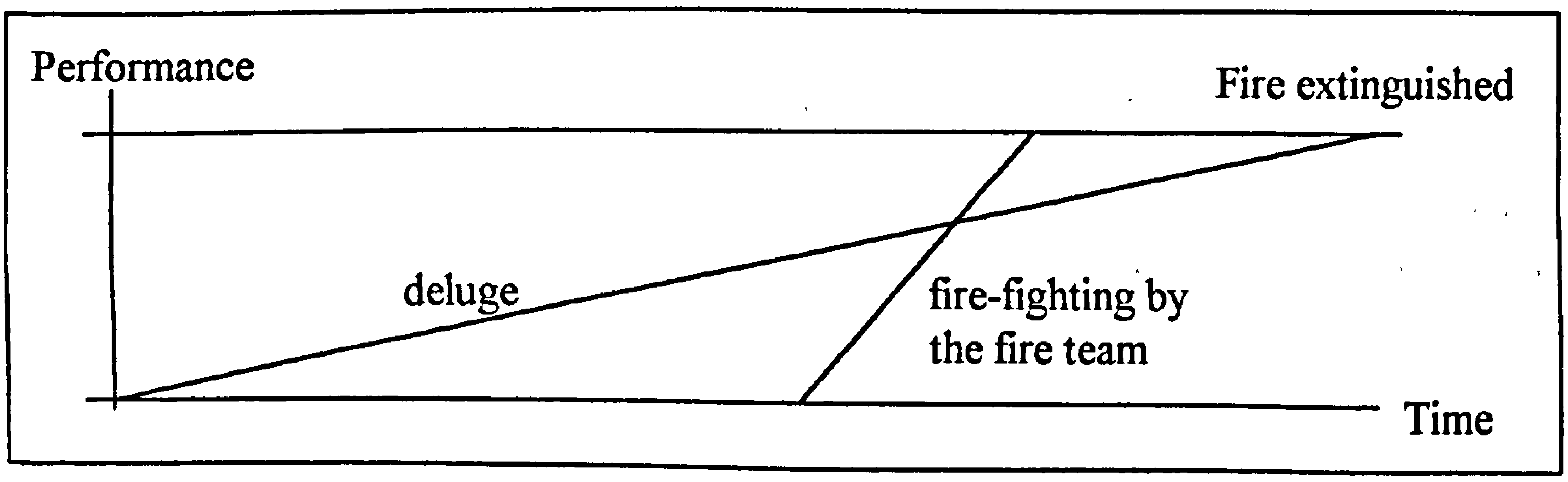


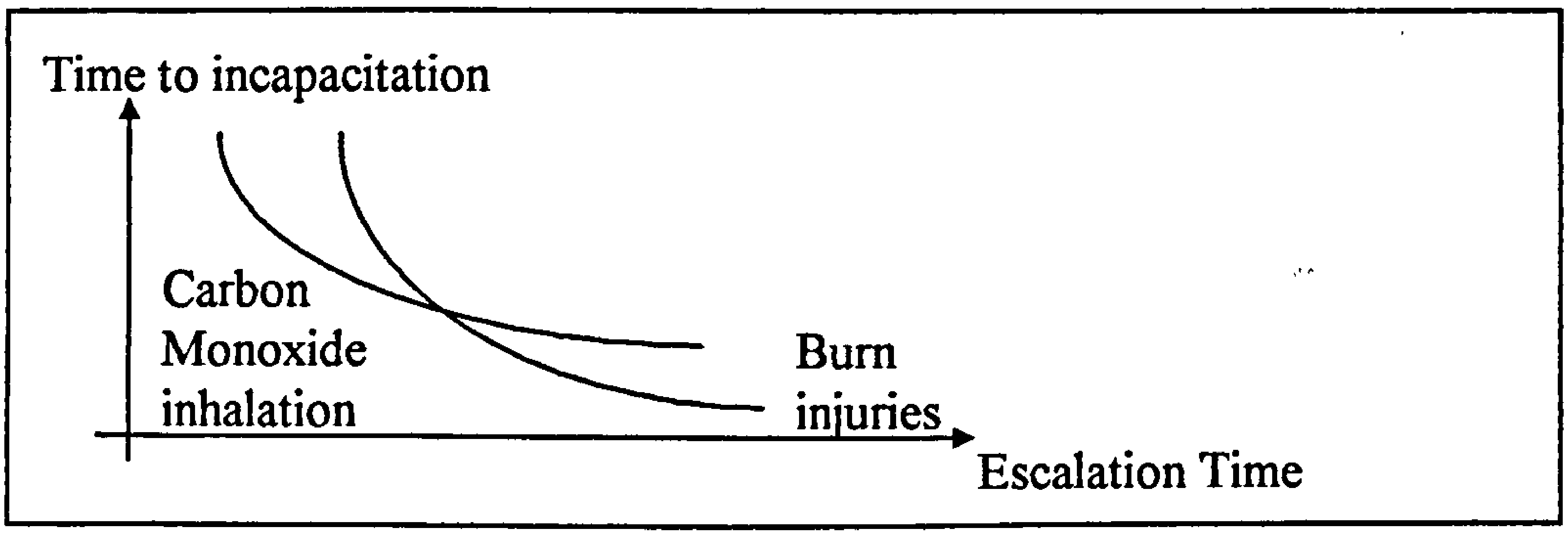
Figure 68 shows an example of how different types of methods can be used to fight a fire. The progress rates in the graph show how the progress would be for each individual task - not the combination of the two tasks together. The deluge is activated right at the start of the fire, but only has a limited effect. However, the fire team take a long delay, as they collect equipment and travel to the incident site. Once they start the hoses, their impact on the fire is significant. If these were considered in this way, it would appear that it is pointless to use deluge, as fire hoses are more effective. Clearly, this is not the case. Unlike the previous search and rescue example, the two fire-fighting methods cannot easily be added to represent the increased task progress rate. In this case, the current TPRC model would have to use one task progress rate to represent the whole process. This relies on the knowledge of the user to estimate the effect of the combined tasks and to have a task progress rate that reflected this estimation.

The next point considers the limitations on the resource consumption rate. This value produces the time available to complete the task and is a linear variable. This may not be an accurate representation of resource consumption. For example, fires are known to escalate in area, temperature and toxic gas production in a non-linear manner (Peacock et al 1996, 1998; Bukowski 1997, Lie 1989, Chamberlain 1996). Currently, this is catered for by the TPRC model by allowing the user to calculate the time at which the fire would have reached an "escalation point". This converts the escalation distribution into the linear concept of time.

It should be possible to reproduce the results of fire models as resource consumption rates or to, at least, obtain more accurate distribution types, such as the use of exponential distributions. These would represent a more accurate view of the situation, which would be reflected in the TPRC results.

Apart from this, there may also be multiple resource constraints - similar to the concept of multiple tasks, as shown in Figures 67 and 68. For example, the task may involve rescuing a person from a fire before he dies of his injuries. Therefore, the resource limit is the point at which the person is incapacitated (or killed) by the effects of smoke and fire. Figure 69 represents possible, albeit simplistic, resource consumption rates of both factors (based on information from Purser 1988,1989).

Figure 69: Resource consumption rates of smoke inhalation and fire injuries



Both concepts are more complex than can be shown in Figure 69. However, this adequately demonstrates the problem. Like the example shown in Figure 68, these two issues cannot be considered in isolation. In the early stages of escalation, incapacitation is caused more quickly by smoke inhalation than by burn injuries. However, as the fire escalates, incapacitation by burn injuries becomes faster - and therefore is of greater concern. Obviously, this suggests that non-linear graphs should be used in the resource consumption rate but also that both issues should be considered. As the escalation time progresses, it is necessary to consider the main factor contributing to incapacitation (initially smoke inhalation then burn injuries). As both factors act on the individual at risk, it is necessary to produce a resource consumption rate that can incorporate the effects of all the factors involved.

10.7.1.2 Interaction between Task and Resource

In Section 5.3.5.5, it was stated that the dependence of the task performance and resource constraint model was removed from the original model described in Loa (1997). This was to cater for the independence in emergency management tasks observed in many examples. However, it was noted that often there is an interaction between task and resource and therefore this should be something that the model is capable of incorporating.

For example, if the task involves putting out a fire and the resource limit is defined by the "point at which the fire becomes unbearable for the fire-fighters", the two factors interact. Therefore, they cannot be seen as independent issues. If the task is carried out early in the escalation process, the escalation limit point is extended (delayed). However, if the task is delayed, the escalation limit is brought forward, making the point at which the fire becomes unbearable earlier. Therefore, the relationship between the two factors should be established prior to processing. Unlike the original model, it could not always be an "inverse relationship" between the two rates. Therefore, generally, this concept should be avoided in the TPRC model until the relationship can be calculated then input into the model.

The resource consumption rate is defined by the fire escalation. Therefore, as the task involves fire fighting, this escalation is also implied within the task. Therefore, to model this example using the current version of the TPRC model, the escalation must be assumed to be such that no task was attempted (i.e. the worst case scenario). Although this would artificially result in a lower probability of success function, in most cases, this is preferable to assuming low risk associated with the task. However, it does run the risk of being overly pessimistic about the probability of success in emergency management situations - which was a criticism for many of the other HRQ methods.

10.7.1.3 Sources of Variance

There is also some concern over the source of the variance used in the inputted distributions. Distributions can be used because the data can be any value within the distribution or can be used to represent the user's uncertainty about the inputted value. For example, the distributions of performance parameters represent a known distribution of values - from which the value can be chosen. However, the user may not know the appropriate value to be used in the model. To compensate for this lack of knowledge, the user picks a possible value and chooses a distribution to cater for all the reasonable values - thereby introducing the problems of subjectivity into the process. Both could result in the same inputted distribution for different reasons. This emphasized the issues of uncertainty and variability. Bartlett et al (1996) clarifies the difference as follows - "Uncertainty represents ignorance about the precise value of a particular parameter... variability represents inherent variation in the value of a particular parameter within the population of interest". Currently, these are both represented by the same distribution parameters. To indicate the quality of the results, these should be separate in future versions of the model.

10.7.1.4 Conditional Probability

Currently, the TPRC model is capable of modelling tasks and resources that are independent. However, many tasks are only carried out because previous tasks failed or succeeded – therefore, there should be a link between their respective probability of success curves. In our example, we assumed that the crane driver tried to escape before he was driven back to the crane to await rescue by the fire-team. He was unable to remain there so jumped into the sea, awaiting rescue from the fast rescue craft. Each of the subsequent tasks is based on the failure of the previous task. If the first task was successful, there would have been no need to consider the other two tasks.

Using single point probabilities in the laws of conditional probability, it is possible to work out the probability of a particular event given that another event has occurred, using the product rule. For example, the event tree shown in Figure 42 gives the maximum probabilities of success for each of the three tasks - these could be multiplied together to produce an overall probability of success - however, this only represents the maximum - not the full scope of the function.

Therefore ASSUMING that the escape and rescue failed and that he jumped into the sea, what is his probability of sea rescue? Using the TPRC model, this would be difficult to calculate. The model produces probabilities for events that relate to time and each curve may be started at a different point in time. Therefore there is no point value of probability that could be chosen. Similarly, considering the Fault Tree shown in Figure

55, what is the overall probability of the Crane Driver's death? Of course, additional data are necessary to establish this – including the probability of making the decisions to attempt to escape over the deck, for the fire team to attempt a rescue or for the crane driver to jump into the sea. However, assuming these data are available, the calculation of (A+B) – probability of failure to reach the safe haven with respect to time – is still not an easy process. If this calculation is possible, it is unlikely that it could be represented as a simple function – but is more likely to be calculated as the addition of probability functions with respect to sections of time.

This will create problems if the TPRC model is to be used to provide a whole probability function for other techniques, such as event or fault trees, as shown in Sections 8.2.2 and 8.4.1.

10.7.1.5 Conclusion

Overall, these issues are the only inadequacies that are to be found with the mathematical design of the model itself and are only relevant if an "ideal" version of the TPRC model was desired. In most cases, the problems can be resolved through the application of subjective techniques - for example, the estimation of task / resource consumption speed under particular circumstances - which introduces an element which is not desirable in such an approach. The next set of issues involve the application of the model to human performance and emergency management, which will be discussed in the next few sub-sections

10.7.2 CRITIQUE OF THE APPLICATION OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL AS A HUMAN RELIABILITY ASSESSMENT TECHNIQUE

There are a number of problems with using the TPRC model as a human reliability assessment technique. During this project, only its application in the assessment of emergency management tasks had been explored - not its potential as a general HRQ technique, if this was required in the future. However, certain problems that are likely to arise include specific features of the task, lack of human error identification and reduction techniques and dependence on cognitive decisions. These will be discussed in turn.

10.7.2.1 Features of the Task

In this model, the main features involve completing the given task within a time limit. The goal involves an objective target and task progress is measured over time. However, there is not yet any indication of the quality of the task progress. For example, consider a task that involves writing a university report. It may be specified in terms of word length and hand-in date. Therefore, these specify performance goals and time available. Therefore this can be measured on the TPRC model. However, if the specification is to hand in a good report (a subjective definition), this becomes more difficult to model. For example, the task progress may be good, in terms of the words being produced. Each unit sentence may be very good - but this does not indicate that the final result is acceptable. Even given unlimited time resources, the writer may not produce a good report. This would indicate a great deal of uncertainty about the performance goal to be produced. The assessor may be able to define exactly what the requirements are. However, it would still be difficult to determine the task progress speed. Therefore, producing the "probability of success" function for writing a good essay would be difficult. Where quality of a task is a critical issue, it is difficult to use the TPRC model. For example, performing heart surgery can be measured in terms of its outcome. A novice surgeon may complete all of the prescribed tasks, but without the precision of an expert. Both may go outside of the definition of "perfect" surgery. Therefore, the lowered precision of the novice would decrease his probability of success. However, because the TPRC model does not measure "precision", the curves of the expert and novice would be identical. The TPRC cannot take account of variables that are not prescribed in the task particularly if they are subjective to the participants or assessors. Up to this point, this has not been found to weaken the TPRC model's use in assessing emergency management as it used physical measures of outcome.

10.7.2.2 Lack of Human Error Identification Techniques

The TPRC model was not actually intended to be a complete HRA methodology. Its only focus was the quantification aspect of the process. Nevertheless, other than using alternative methods of HRA, there is no clear method of expanding the TPRC model to include HEI. The TPRC model is based on tasks and resources that were identified by a user. This then uses the values to produce probability of success curves. For example, although the effects of "action too late" are clearly shown by the model, "wrong action" must be identified by the user. For example, the TPRC model is capable of producing a probability of success for "running around the control room 3 times before the power fails". However, just because the probability of success is high does not mean that it is an effective strategy. Therefore, at this point, it requires some subjective judgment to identify the tasks and resources that are correct and implicitly linked.

For example, the TPRC model can also calculate the Probability of Success of rescuing the casualty before blowdown is complete. However, this task may not be related to this resource limit. Rescuing the casualty before he dies, or before the fire escalates, are more relevant resource limits if it is intended to produce a meaningful result. In general, the tasks and resources should be defined by experts with understanding of the critical situation-specific factors in the scenario. In emergency management, these would involve the occurrence of undesirable and irreversible consequences. For assistance with identifying the human error aspects of each situation, the author recommends the use of lists of "error modes" such as those used in THERP (Swain & Guttman 1983), SRK (Rasmussen et al 1981) PHECA (Whalley 1988) & HAZOP (Kletz 1974) - others cited in Kirwan (1992, 1998a, 1998b). However, if it is intended that the TPRC model will be objective, this should be taken into account when choosing HEI technique.

10.7.2.3 Lack of Human Error Reduction Implications

Like human error identification, the model provides little contribution to the field of human error reduction. Although, this was not one of the original intentions of the model, it is generally considered important if the model is to be applied in general HRA. In the TPRC model, the lowered success curves can be attributed to high escalation or low task progress rate. Therefore the main implications for an emergency manager would be to attempt speedy progress without delay. These implications do not provide any great insight into the subject, as most emergency managers would know this anyway. Similarly, the main implications for designers are to speed up task progress and to slow escalation, which again is not surprising. Therefore, the main implications are for the emergency manager to organise his team in such a way that he can ensure efficient progress. This involves ensuring that the relevant communication is flowing and that the emergency manager can keep track of the complex array of tasks and events. However, the emergency manager's main responsibility is to decide on the best course of action, which is a factor that will be considered in the next sub-section. However, one important consideration in identifying an error recovery methodology is to ensure its consistency with the TPRC model. If, as intended, the methodology is to be completely objective - ideally the error recovery mechanism should also be objective.

10.7.2.4 Dependence on Cognitive Decisions

Currently, the TPRC model uses tasks and resources. Each task has been based on a decision to carry out this task. However, despite the decision-making aspect being a critical aspect, this is not modelled explicitly – or represented within the numerical results obtained. This contributes an initial "condition" to the process – given that the decision to act (X) has been made, the probability of success in the action is Y. Based on the laws of conditional probability, unless the probability of making the decision was 1 (an extremely unlikely occurrence), this would act to reduce the overall probability of success in every case.

For example, the TPRC model is capable of calculating the probability distribution of rescuing a person before he dies. This assumes that someone makes the decision to actually attempt the rescue. However, although it may include the delay caused by making the decision, the TPRC model does not include the probability of making the decision itself. Therefore, the probability of success curves may be somewhat optimistic when we assume that the probability of making the decision has not been incorporated. However, the probability of making the decision may be linked to the objective probability of success. It seems reasonable to assume that the decision to act will be based on the actor's perception of their likely probability of success – if they believe that they are certain to succeed, this will increase their likelihood of choosing this option – if they believe they are certain to fail, they are unlikely to choose this as their first solution. This is a process that occurs not only at the beginning of the action – but continues right through it – as an actor decides whether the chosen course of action is STILL correct – or whether they should give up, change action or change some of the characteristics of the action, for example, speed up. It seems reasonable to assume that these beliefs are based to some degree on the objective characteristics of the situation.

However, it is not known whether a) the estimations of perceptions of success or b) the amount of objective information on which these beliefs are based – either involve rational processes. Therefore, the relationship between the calculated probability of success in the tasks and the probability of decisions to act can not yet be established.

As this issue of the contributed of cognitive aspects to probability of success is beyond the scope of this research, this problem could be rectified, for the time being, by using current HRA methods that identify and quantify the probability of cognitive errors (examples cited in Kirwan 1998a). Many quantification techniques rely on expert opinion and therefore would bring a certain degree of subjectivity into the process (Kirwan 1999), and unlike the TPRC, the quantification methods usually only produce a single point value to represent the human error probability. Therefore, our probability of success function could be multiplied by the relevant cognitive error probability, using the product rule. This would result in the probability of successfully making the right decision and the responding actions resulting in the desired outcome. However, ideally, the cognitive error probability should also be represented as a function with respect to time - which obviously complicates the technique. Here the decision to attempt task / continue attempting task or give up on task could change over time – and this should be represented in the model.

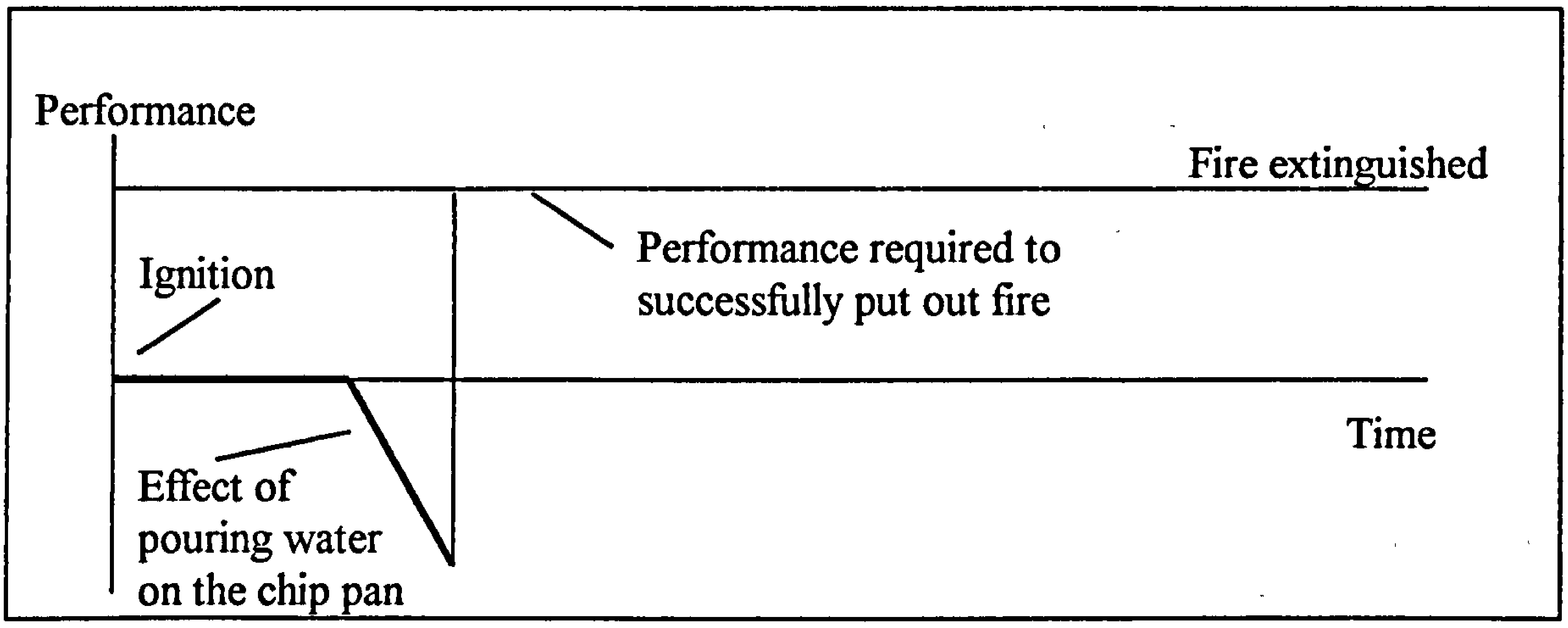
10.7.3 CRITIQUE OF THE USE OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL TO ASSESS EMERGENCY MANAGEMENT DATA

There are a few issues that are particularly relevant to emergency management that are not apparent for other aspects of HRA. Firstly, there is the problem of considering tasks that worsen the situation, and then there is the issue of "psychological" emergencies. These will be considered in turn.

10.7.3.1 Tasks that worsen the situation

Even in a domestic situation, it is reasonable to assume that pouring water on a fire will help to put it out. However, many chip-pan fires have resulted in serious injuries for people making this erroneous assumption. Similarly, in an industrial context, there are actions that will worsen the emergency. This situation is difficult to model in the TPRC model, as it is often the resources that are affected rather than the actions. If the task of "putting water on a chip-pan fire" is modelled with respect to putting out the fire, it actually has a negative gradient - resulting in more effort being required to put out the fire. This can be shown in Figure 70.

Figure 70: Task Progress rate for Actions that Worsen the Situation



However, as mentioned earlier, it is not possible to model multiple tasks in the model. Therefore, the rectifying "originally correct" performance cannot be performed following the wrong performance. Therefore, the TPRC model normally assumes the erroneous action has been carried out and then estimates the probability of success in rectifying it - with the increased escalation of the fire. If the mathematical aspects of the model can be adjusted, then this type of issue can be taken into account.

10.7.3.2 "Psychological" Emergencies

The scenarios that were used in the competency assessment mostly involved physical and technological emergencies. These include helicopter crashes, search and rescue, casualty management, process incidents etc. However, there are other types of emergencies that are not related to physical phenomena. These include terrorism, hijacking, bomb scares, sabotage or attempted suicide. The emergency management tasks that are required involve psychological and social skills - such as understanding when obedience or risk-taking behaviour is necessary, negotiation skills, out-thinking, empathy and many more. These are tasks that are impossible to define in objective terms and it is unlikely that a general probability of success is an appropriate measure for these situations. The resource consumption rate is often defined by humans (for example, time limit given before a hostage is murdered) and can be affected by mood or impulsive action. There may be no tasks that can mitigate the circumstances - such as suicidal person who cannot be dissuaded or physically stopped. However, it should be noted that the competency assessment is designed to test scenarios of this nature. Therefore if scenario data are available, a TPRC can be carried out comparing the "observed task time" with the "observed resource time" using a large value for the variance when it is to be applied to other situations. Also, if the scenario-specific performance parameters can be built into distributions, these can be applied in the same way. However, due to the difficulty in obtaining reliable objective measures of the outcomes of these types of emergencies, it would be difficult to use the TPRC for novel or theoretical situations.

10.7.4 CRITIQUE OF THE USER ASPECTS OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

Up to this point, the criticisms have focused on the functions of the TPRC model rather than its interaction with the user. In general, the user is expected to be someone with knowledge of mathematics (to understand the variance being used in the inputted distributions) and computing (to cope with using the 3 types of files involved in the modelling process). Normally, the users are expected to include those who require results to assist in emergency management decisions or design choices; and those who have a theoretical or practical interest in risk and reliability. For these reasons, there are two main weaknesses in the TPRC model - the subjectivity and the program design. These will be considered in turn

10.7.4.1 Subjectivity in the TPRC Model

In general, there are a number of elements of subjectivity in the TPRC model at this point. One main issue is choosing the relevant tasks and resource consumption rates - that are both significant in measuring the outcome of the emergency, and are inherently linked. For example, outcomes that are concerned with the survival of casualties or extinguishing fires are obviously important. Outcomes that are more concerned with non-emergency issues - such as keeping production active or, in the case of the onshore scenarios, ensuring residents are informed are informed about the incidents - are not as much of a priority.

The linking between tasks and resources are also important in the application of data in the TPRC model. For example, consider the crane driver example. Given that he has jumped into the sea, the logical indication of a successfully managed event is his survival - hence the use of the rescue by the fast rescue craft. The escalation of the fire on the platform no longer critically affects his chances (unless it leads to platform collapse!). Therefore considering the combination of tasks and resources in the TPRC model, "time to be rescued" should be limited by his survival time - not a fire escalation point. Although both could produce equally good TPRC results - only the former is meaningful. Therefore, these choices require some application of expert judgment.

Likewise, there is some subjectivity in applying the numbers to the process. Firstly, identifying whether the decisions are linked to the events (reactive) - or were based on an estimation of future events (proactive). This creates problems when applying the delay parameter as it requires some interpretation whether a decision was induced by a past event (therefore giving rise to a delay) or was attempting to mitigate a future possibility (indicating that a delay parameter is an inappropriate representation of the cognitive process).

Given that the user is likely to be affected by the results of a risk assessment - either financially (designers), physically or psychologically (operators at risk) - there will also be the temptation to bias the results in favour of the user's opinion. In general, this would be difficult in the TPRC model as it mostly uses objectively defined parameters, such as distance and human movement speed. However, from this research, it is clear that the delays of management have a large impact on outcome and; even when using observational data from scenarios, these may be biased by subjectivity. It was this reason, among others, that lead to the collection of performance parameters.

The TPRC model's use of variance is one of the issues that makes the model preferable to other models, yet it also gives rise to a weakness. Although variance can be objectively displayed, it is not as easily understood as a mean value. Earlier in Section 10.7.1.3, it was mentioned that variance was used to represent both variability as well as uncertainty. Therefore, as long as the mean values are correct, it is likely that the inputted variance would not be closely examined in an audit. As shown in Figure 62, increased variance can actually work to improve the probability of success. Therefore an unscrupulous person could use this in his favour - claiming that the broader distribution was used to represent his ignorance and uncertainty in the values. By presenting the results from an objective methodology such as this, it is unlikely that the reliability of the inputted values will be questioned. One option is to automate the variance - by allowing the program to estimate the values. However, this would remove an important feature of the program for those who have expertise in this area. Therefore, the main recommendation is to ensure the user is objective - perhaps by being an independent auditor.

10.7.4.2 Program Design

Currently, the program is not very user-friendly. Firstly, there is no visual representation of the distributions of inputted variables. Although the program gives numerical values for certain percentiles of the distributions (e.g. 95% or 99%), a plotted distribution would be more understandable. This would decrease errors or potential biases if this could be shown prior to the calculation of the probability of success. Once the distributions of the inputted variables have been accepted, there should be no return to the input screen to adjust the values in the user's favour.

Secondly, the use of three separate files is cumbersome. It is possible to design software to input the data, show the distributions of the inputted variables then process the data producing probability of success/failure curves. Some of these features were used in an earlier version of the TPRC model but it was necessary to revert to the original system when the program was updated for this research. Other improvements are suggested in Chapter 12.

10.7.5 VALIDITY OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

Overall, the Task Performance Resource Constraint Model shows a high degree of validity as a process. It has also been used with real data from the Piper Alpha disaster so has demonstrated that it has the potential to represent such a situation. In comparison with other methods of HRQ, it represents more consistency with current knowledge of emergency management and its impact on outcome – to produce outcomes that are of more use to Quantitative Risk Assessment. This is because the outcome of an emergency is measured in terms of physical characteristics - for example, survivors, assets etc. These physical characteristics are influenced by physical events - for example, escalation, mitigation and evacuation, which are influenced by physical capabilities. Many HRQ methodologies focus on non-physical characteristics, such as levels of stress or training and experience, therefore are incapable of representing the critical aspects that influence the outcome of an emergency - and by association, the risk that is reduced by emergency management. Although these methods may be useful at quantifying the probability of error (human unreliability) in events where the reliability is <u>not</u> strongly influenced by physical aspects, they do not produce reliable results when being applied to those that do. Often this is due to the issue of considering human unreliability as the probability of error as opposed to the probability of task failure – the latter being more appropriate to Quantitative Risk Assessment than the former. Whilst it is important to consider how and why human error arises, it is not always easy to consider how this impacts on the consequences in specific situations. In this way, the TPRC model does not yet incorporate the probability of errors, therefore it is not appropriate to compare the TPRC model and earlier HRQ methods as they are examining different aspects.

However, the model is only as good as the data used. As some of these were simulated data, (some of which were assumed due to the scenario arrangements), the quality of these data is questionable. Also, using the TPRC model in this role could lead to confusion in its objectives. The data are provided by scenario information, using assumed resource limits. In the scenario, it is possible to identify whether the task succeeded or failed - as these later events are also recorded. Therefore, it seems illogical to base a probabilistic analysis on information where the probability of success is already known to be 0 or 1. However, the main focus of this research was to produce a method that <u>could</u> use simulated or real data to objectively quantify the impact of emergency management on risk. In theory, the initial task would to be to prove that emergency management made <u>some</u> difference to risk - then to try and quantify the extent of this difference by comparing it with other levels of performance - as shown by comparing Figure 39 with Figures 43,44, and 45. It is not important whether the tasks were failures or successes in the scenario - the objective is to calculate the probability of failure or success and to see if these are consistent with real-life knowledge about emergencies. As shown later in Figure 53, the model is used to speculate on the probability of success that could have been achieved if the circumstances had been different – and if different actions had been taken. This was the goal of the model and can be used to analyse past circumstances or to test future options. These issues will be discussed further in Chapter 11.

SECTION 10.8: CRITIQUE OF THE PERFORMANCE PARAMETERS

There are three main criticisms with the concept of performance parameters; the quality of the data, the lack of cognitive data and the problems in application.

10.8.1 QUALITY OF THE DATA

Like the TPRC model itself, the performance parameters are only as good as the quality of the simulation that produced them. In this case, there were only two emergency management teams - one for the onshore industry, one for the offshore industry. In total, there were 4 emergency management candidates - 2 for each industry. 3 out of 4 candidates were assessed as being "competent", the other had "notable shortfalls". Therefore, in terms of the contributing data, it would be difficult to determine whether these are representative and predictive of all emergency managers and can be extrapolated to other industries. Ideally, statistical tests should be carried out to identify whether these showed significant differences between the groups for each of the performance parameters. However, for the scenario-specific performance parameters, there was usually only one piece of data for each. In the case of the generic performance parameters, it would be interesting to identify whether there were differences between the levels of competency (to see if certain tasks were performed faster by more competent crews - indicating efficiency - or slower by more competent crews - perhaps indicating quality and carefulness); the offshore and onshore crews (to identify whether there were differences in particular skills between the two industries) and pre- and post-scenario data (to show how the emergency situation affects the time spent on various tasks). This sort of analysis should probably be carried out in future research when more data are available.

In terms of the scenario-specific performance parameters, these were already known to have limitations. Until the scenarios or specific parts of the scenario have been repeated many times, it would be impossible to identify whether the parameters were reliable. Apart from this, many of the parameters were based on assumptions, rather than reliable information. For example, escalation points (such as the fire impinging on the diesel tanks) were imagined and may not have been based on real fire models. The observer/recorder must assume when these events occur to record them in the transcript. This brings a source of subjectivity into the process. Even the scenario organiser may not know when the fire is likely to impinge; therefore the events of a scenario may be very unrepresentative of a real situation. In general, it is recommended that the TPRC user refers to physical models of the events being examined (human movement, fire escalation, system shutdown) and to only use the scenario-specific performance parameters where no other data are available. In this case, the scenario-specific data should be used with caution. However, it could be assumed that these represent one possible point on a distribution; therefore the only problem lies in assuming what part of the distribution this is. Therefore, there is an increased reliance on expert judgment for the variance when using the scenario-specific parameters.

There are also limitations with the use of the generic performance parameters. Therefore, care should be taken to ensure that the most representative distribution should be used when trying to represent a novel situation in the TPRC model. However, as these distributions are based on so few data categories, they may not be entirely representative. Even so, these data are sometimes based on assumptions. These include:-

- Phone call length: It cannot be observed when the scenario organisation team pick up or put down the phone.
- Information known in SOT - EMT told: This is based on an assumption of when the SOT (scenario organisation team) know the relevant information
- Any data that assume a time between the incident and any other event: This incident is often an assumed event.

However, these are not always based on assumptions. For example, it may be obvious that the incident has occurred, for example, while having a normal radio conversation, the external caller suddenly screams that he has been sprayed with chemicals. It may be obvious that the emergency management team has determined the length of the phone call - by picking up the phone and slamming it down when they've finished speaking. In some cases, it may be obvious when the scenario organisation team (representing the on-scene commander or others) become aware of certain situations. For example, if one external team tells another external team, who passes this information onto the control room, it is obvious when the second external team learn this information.

In general, these problems can be rectified by adding data from scientifically designed simulations (as will be defined in Chapter 12) and, ideally, real emergencies.

10.8.2 LACK OF COGNITIVE DATA

One main criticism of the performance parameters is the lack of cognitive data, such as the timings involved in decision-making. The performance parameters involve observable tasks, which therefore excludes a separate category for cognitive tasks. This is unfortunate as the cognitive processing is one of the critical parts of emergency management. Currently, the performance parameters include many of the main management tasks involved in an emergency. These include communications and control room operations. However, the time taken in making a decision is, as yet, unknown. To make assumptions about the timings involved would not be able to take account of the complexity of the decision. Therefore, it is recommended that the scenario-specific performance parameter that is closest to the relevant decision may be used as a guideline. If desired, the action and communications timings could be removed from the performance parameters to leave only the estimated time taken by the decision. Also, the scenario-specific performance parameters could be categorised in terms of the complexity of the decisions involved, such as the SRK approach used by Moieni et al (1994). Some of these problems may be rectified using solutions suggested in Chapter 12.

10.8.3 APPLICATION OF PERFORMANCE PARAMETERS

This section is concerned with the application of the performance parameters - with particular regard to their use in the TPRC model. Some of the problems have already been discussed - with regard to subjectivity in choosing tasks and resources appropriate to the issues (as described in Section 10.7.4.1). However, the use of performance parameters brings additional issues such as:-

- Identifying the scenario-specific performance parameters appropriate to the situation.
- Knowing what generic performance parameters should be included when building up a task.
- Choosing the point value (i.e. the mean) and the levels of variance for unknown tasks.

The first of these is concerned with the choice of parameter that best fits the situation under test. For example, if the task specifically involves the time taken to drag a casualty out from a helicopter - could this best be approximated by the time taken to drag a casualty out from a helifuel fire?, or a crane? The former would best represent the fuel involved (and possibly the intensity of the fire) whereas the latter incorporates the idea that the casualty is trapped in a "vehicle". As with Section 10.8.1, this can be rectified by the collection of more performance parameter data - or, ideally, greater use of theoretical data and models.

The second of these relies on building up structures of emergency management tasks - in which the performance parameter data is used. Currently, this relies heavily on the structures that were used in the scenario - focusing on the tasks that were closest to those required by the analysis - as shown in Figure 63. However, this again introduces subjectivity into the technique and could be carried out using a structured framework - for example, a task or timeline analysis - to identify what performance parameters contribute to tasks. For example, for a competent emergency management team, what is the probability that the external team will be told to "standby" before being allowed to deliver a message? This information could identify the most probable structure for a task to ensure this is objectively defined. For example, this may include a typical number of informational / non-informational radio messages, delays and internal announcements before a particular physical task is initiated.

The third of these issues is similar to the problem of choosing a value for variance as described in Section 10.7.4.1. Because it is not yet known whether the performance parameters are representative of a population of emergency managers (either onshore or offshore), both the use of the current median values and variance of the distribution may introduce errors into the process. For example, consider the event whereby the current data are biased towards lower (faster) values of radio calls/announcements etc. then these values are applied in the TPRC model (or as raw data in a timeline or other analysis). Given that the whole distribution is affected, the median and slower values may be optimistic. Therefore, if an emergency planner or designer assumes the tasks can be carried out within these times and base their conclusions on these results, then they may be introducing risks into the equation.

SECTION 10.9: CONCLUSIONS

There are a number of criticisms that can be associated with the research. Many of these do not remove any value from the results and conclusions that were generated from the research. Many of these result in recommendations for future research and therefore suggest alternatives or easier methods than those that were chosen. In summary, the main issues include:

- There were inadequacies in the scenario arrangements - The procedure was fixed by external organisations so could not be adapted for the research. Therefore there was no recording of scenario organisation team data and the collection of subjective data was limited. Also, there was no guarantee that the scenario event timings were accurate. The number and type of scenarios were limited by availability and the use of external organisations. However, due to the emphasis on probabilistic approaches, each scenario represents one possible series of events and outcomes in an emergency situation, therefore provided a valid test of the methodology.

- The TPRC model was limited in that it could not easily be adapted for multiple tasks and multiple resources, non-linear progress rates or exclusively cognitive tasks. Most of these could be rectified by "rethinking" the task and defining it in different terms. Also, although the model provides a structure to be a totally objective technique, due to the lack of available data, this is not yet possible.
- The Performance Parameters were limited again by the scenario arrangements - by the numbers and types of scenario, the reliability of the scenario timings and the use of assumptions where observed data were not available. There was also the notable absence of cognitive data - as although this would be useful, it is essentially unobservable. Also, application of performance parameters in the TPRC model or elsewhere is somewhat reliant on subjective techniques.

Overall, some of these problems can be rectified by suggestions shown in this chapter and in general, do not take any credit away from the actual positive contribution of the research as will be shown in the following chapter. Other recommendations for future research are shown in Chapter 12. Therefore, taking these into consideration, this thesis will move on to the analysis of the results.

Chapter 11

ANALYSIS OF THE RESULTS

SECTION 11.1: INTRODUCTION

This chapter involves an in depth examination of the results shown in Chapters 8 and 9. This will start by looking at the Task Performance Resource Constraint Model, then will continue with an examination of the use of the performance parameters

SECTION 11.2: IMPLICATIONS OF THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL RESULTS

11.2.1 WHY WAS THE TPRC MODEL CHOSEN?

Traditional methods of Quantitative Risk Assessment involve the estimation of frequency and consequence of events. This usually produces a single point value to represent risk. There are many authors who consider this to be a dangerous oversight of the true nature of risk as often it is not clear whether the average or highest value has been taken (Richardson 1996, Power & McCarty 1996, Bartlett et al 1996). Quantitative Uncertainty Analysis attempts to rectify these inadequacies by providing a whole distribution of risk values. It is apparent that the concept of risk is too sensitive to be represented by single point values. However, it is rare that this influencing factor is incorporated into the analysis.

Risk is calculated from the probability (or frequency) of an event and the consequences of such an event. The Task Performance Resource Constraint Model examines one side of this equation - the probability of an event occurring, based on success or failure of particular tasks. This also incorporates influencing factors, particularly focusing on the effect of time on risk. Like the Quantitative Uncertainty Analysis techniques, it uses distributions of input values as opposed to single point values. Originally, this model was used to assess the effects of fatigue in stress-strain relationships - producing a function representing risk related to time. Following on from this, it was decided that this concept could also be used to test reliability (or probability of success) in human tasks by comparison of the time required and time available for certain tasks. Therefore, from being a probabilistic model of reliability, the TPRC model could now provide an input to the field of Human Reliability Quantification.

Apart from being able to represent distributions (and therefore taking account of some of the variability surrounding the values), the TPRC also manages to produce results where other HRA techniques are lacking. Firstly, as it uses generic user-defined tasks and resources, it can incorporate specific contexts[1]. Secondly, the types of tasks are not limited by set criteria - but, apart from those examples identified in Section 10.7.3 (such as psychological emergencies), can potentially be any physically-defined human behaviour [2]. Thirdly, and most importantly, as the distribution is related to a time base, it can represent the importance of time in the human reliability equation[3,4]. These features deal with some of the criticisms of other HRA techniques listed by Dougherty (1993)[1], Blackman & Byers (1995)[2], Reer (1994)[3], Kim & Bishu (1996)[4].

However, two of the key objectives of this project were to obtain objective data from emergency scenarios on management performance then develop a methodology to use these data to assess the probability of success in emergency management tasks. As time is one of the critical aspects of an emergency, it was necessary to choose a model that could assess human reliability with respect to small changes in time. Most of the Human Reliability Assessment techniques would consider time as a categorical as opposed to a continuous variable - for example "too early" and "too late". One of the best attempts to represent the continuous nature of time is shown in TESEO (Bello & Colombari 1980) - as discussed in Sections 2.4.4.2.7. However, this used pre-determined choices of "time available" - 2, 10, 20 seconds for routine tasks and 3, 30, 45 and 60 seconds for non-routine tasks. Therefore, these were fixed time values and could not use variable times as required by the user. It also was unable to assess the success of tasks over durations longer than 1 minute - such as some of the physical tasks that are present in an emergency. In comparison, many other HRA techniques would represent an emergency through application of "Performance Shaping Factors" (PSFs) (Swain & Guttman 1983) or "Error Producing Conditions" (EPCs) (Williams 1986). These would include such items as "time pressure", "unfamiliarity", "low signal to noise ratio", "complexity" and "duration of stress". These effects are usually assumed to be additive, which is reflected in the estimations of probability of failure. Consequently, most of these methods give pessimistic estimations of success for most emergency management tasks (Kirwan 2000). On the other hand, Reer (1994) developed a model using the concept of an "available time window". This compared the required time with available time for various tasks and based the probability of success based on this comparison. This model showed great potential for being developed into a emergency management assessment technique. However, it was based on decomposition of tasks to a specific number sub-tasks and therefore could not easily represent novel or complex tasks. Moieni et al (1994) progressed this by using data from simulations. However, their model produced the point values that are contradictory to the concept of risk as described at the beginning of this section. Given these facts, the TPRC Model appeared to have good potential for an emergency management assessment technique.

The Task Performance Resource Constraint Model provides a flexible time base to be chosen by the user. This could be used to express fatigue effects over years - but could also express probability of success in tasks that take seconds (for example, starting the deluge system before a gas leak ignites) minutes, or hours (completing evacuation before the installation collapses). It could include variances associated with the inputted values, which was highly appropriate to represent the variability evident in an emergency situation. Finally, despite the criticisms expressed in Section 10.7, it could also incorporate most types of task, whether carried out by machines or people. Also, given enough data from theoretical knowledge and scenario-specific knowledge - the TPRC model had the potential to be completely objective. For these reasons, the TPRC model appeared to be the most promising technique for the research.

11.2.2 HOW SUCCESSFUL WAS THE TPRC IN ASSESSING THE IMPACT OF EMERGENCY MANAGEMENT ON RISK?

To see whether this model had the potential to assess the effect of emergency management on risk, it was necessary to use it and examine the results. This could be carried out using data from accident investigations, which give the specific context and time data on particular failures and any attempted mitigation. However, our project intended to focus on data from simulations. As discussed in Section 10.5 - as simulations are considered sufficient to identify whether a person was competent in emergency management, they should also be capable of assessing whether a person's intervention is likely to have an impact on the simulated incident. That is, although the situation is artificial, it should contain all the important factors from a real incident - so a model assessing real emergency management and risk should also be able to assess a simulated version. It has been debated whether a scenario is "externally valid" producing a realistic estimation of behaviour in an emergency. In most research circumstances, the simulation technique is the best possible approximation of behaviour in a real-life incident - especially if it is designed based on a set procedure with a high degree of fidelity.

The following sections discuss the results that were obtained in the model - as shown in Chapters 8 and 9.

11.2.2.1 Initial TPRC Results

Chapter 8 illustrated the TPRC assessment of three emergency situations taken from a simulation. In the incident, a crane driver reports that a methanol tote tank dropped onto the methanol laydown area, resulting in a leak, which then ignites. The first situation is based on the assumption that, after a specified delay, he attempts to escape across the methanol laydown area. The second situation is based on the assumption that he waits for rescue by the fire team. It should also be noted that these are independent situations - he may have waited for rescue with or without the initial attempt to escape. Finally, the third situation is based on the fact that the heat becomes so overwhelming that the crane driver is driven to jump into the sea. He then awaits rescue by the fast rescue craft, which is launched from the standby vessel.

The first graph (shown in Figure 39) shows a probability of success function with respect to time for the crane driver's escape from the crane. Using timings estimated from the dedicated simulation, design data, escalation data and information on human movement speed, this function gave a maximum probability of 0.13. This indicates that attempting to escape under these circumstances would involve a substantial risk. The second graph (shown in Figure 40) showed the corresponding function for the fire team's rescue of the crane driver. This gave a maximum probability of 0.013. If we just compare maximum values, rescue involves 10 times more risk than attempting to escape. However, in the scenario, these involved two different time frames. The time to perceive the risk is likely to have produced a substantial delay in the escape task, whereas the rescue involves the fire team meeting at the control room before heading to the methanol laydown area to attempt the rescue. The third graph (shown in Figure 41) used information on expected survival time in the water, as well as estimated speed of the fast rescue craft. In this, the maximum probability of success was 0.59. These three graphs have shown that the TPRC model can represent different types of task involving different types of inputted data. In each case, a probability of success curve has been produced representing the maximum probability as well as the variance with respect to time.

The TPRC method is the only technique that can represent probability of success functions with respect to time for specific tasks including pre-determined variability parameters, based on either real, simulation and theoretical data - or a combination of all three. Therefore, the results are difficult to validate. Initially, the emphasis was on obtaining face validity. For this, it was necessary to show that where the inputted variables are adjusted, that the probability of success function changes in the expected manner. That is, where the time required to carry out a task is reduced, the probability of success values will increase. Likewise, where the time available is reduced, the probability of success values will decrease. Similarly, different strategies can be applied to the same problem - and the probability of success values can be calculated for each, identifying the best solution. Therefore it was necessary to examine this task using such changes.

Figures 43 to 46, aim to show this through using the examples with different parameter values. For example, in Figure 43, the escape is modelled with no delay compared with the delay that was observed in the scenario. Logically, no delay would result in an earlier attempt to escape the area. This earlier attempt would result in crossing through the fire before it had enough time to escalate to a dangerous degree, increasing the probability of success and decreasing the risk. This is consistent with the results that are shown in Figure 45 - where "no delay" increases the maximum probability of success up to 0.99. Therefore, this indicates that the model's use of delays is consistent with knowledge about real-life emergencies.

Figure 44 represents the impact of a change in average speed of the crane driver's escape. Consider, for example, if the crane driver is significantly fitter than average. This may increase his speed up to a degree where he has a significant chance of escaping the area before the fire has escalated to a dangerous degree. The model uses 0.7 m/s, which is a possible human movement speed, and this increased his maximum probability of success from 0.13 to 0.3. Although this is still not ideal, it may mean the difference between life and death. Again, the model's results are consistent with current knowledge about real-life emergencies.

Figure 45 does not involve any different action on the part of the crane driver but a change in escalation rate of the fire - hence increasing the time available to safely escape. This could represent a design change - for example, the application of better passive protection such as firewalls or, external control of the fire by use of the deluge. In this case, it is merely defined as taking 189 seconds to reach an unbearable temperature instead of 84 seconds. Consistent with knowledge about real-life emergencies, the model produces a higher maximum probability of success for longer escalation time than it does for a shorter escalation time.

In each of these cases as well as the examples shown in Section 8.3 (Figures 46 to 52), the model demonstrated an appropriate change in the probability of success curves. This suggests that the TPRC model provides a valid assessment of the impact of emergency management on risk. However, up to this point, this has only really discussed the maximum values. If these were the only issue, there would be little point in representing the whole curve. Consider, in particular, Figures 43 & 45. After the peak value, both return to 0 at the same point in time. Both of these results showed changes in the task performance rate (in which the delay is included) - not the resource consumption rate. Therefore the time available was not changed by the faster actions of the crane driver. Again, this is consistent with the general concept of emergency management. These issues will be discussed again in Sections 12.2.2.3 and 12.2.2.4.

Figure 42 attempts to show how the results from the TPRC model could be applied in another methodology - in this case, the event tree. However, this figure only shows the maximum probability of success for each function - not the entire function. Therefore if it was intended that this should be used as a total methodology, each function should be multiplied with respect to "real-time" - that is, the time at which each calculation was started should be brought together on one time axis. In this case, the probability of survival in the sea is conditional on failures in the other tasks (but obviously not catastrophic failure or the crane driver would not have lived to be able to jump!). Therefore, the functions shown in Figures 39 and 40 must also be inverted to produce probability of failure functions. This, consistent with the concept of the nature of risk as discussed in Section 11.2.1, would produce a function with peaks at the point when the maximum success of each progressive task occurs.

11.2.2.2 Comparison of TPRC Results with Questionnaires

The TPRC technique was also used to model the probability of success for tasks that were subjectively assessed in the questionnaires as shown in Appendix 9. As discussed in Section 10.5, the questionnaires were too brief to collect a large amount of subjective data on the scenarios. However, they were able to collect information, in particular, on the competency levels awarded and the assessor's opinions with regard to the speeds and quality of individual decisions. However, it must be stated that the probability of success in the tasks did not numerically relate to subjective competency ratings. As will be discussed later, this is probably because the two techniques were designed to assess different aspects of the same issue, as shown in the following points:

- The TPRC was designed to assess risk - and any mitigation that can be brought about by emergency management. The Competency Assessment Technique is designed to identify people who will make good and timely decisions in a real incident.
- The TPRC can identify the probability of success and failure in independent specified tasks. The Competency Assessment Technique can identify the skills of trying the right tasks in the right order at the right time.
- Whereas the TPRC model awards success based on the outcome, the Competency Assessment Technique awards success based on the attempts made.

Ideally, both methods should be supportive of each other. As discussed in Section 10.7.4.1, The TPRC model relies on expert judgment to recognize whether the decisions were dependent on certain events. Likewise, the Competency Assessment should involve some estimation of the probability of success and failure of the emergency manager's attempts based on the time taken to initiate communication and actions. Some of these issues will be discussed in Chapter 12.

11.2.2.3 Use of the TPRC model with Performance Parameters

Next, the TPRC model was used together with the Performance Parameters that will be discussed in Section 11.3. In Figure 63, the use of minimum, maximum and average delay values were compared with the values estimated from the scenario and more realistic than the zero value used in Figure 43. Again, these were found to be consistent with current knowledge about emergencies. However, this graph also represented a change in dimension that had not been considered in the earlier graphs - the use of the distribution spread parameter. In this case, the scenario delay of 61 was used with a more variable (0.2) and less variable (0.05) distribution. From the results, the more variable value gave a maximum probability of success of 0.13 whereas than the less variable value gave 0.08. This indicates that the delay chosen from a broader distribution resulted in a shorter delay overall when modelled. Although knowledge of the effect of variance could not easily be used to predict the direction of the outcome, some difference would be expected. Therefore, this is still consistent with knowledge about the effects of variance of inputted values on outcome. As the user only specifies the mean and variance of the distribution, the model chooses the values from the given distribution. As this is now using the normal as opposed to Weibull distribution for its inputted parameters, there is no reason to suggest that it would tend towards the upper values (longer delays) rather than the lower values (shorter delays).

Finally, Figure 64 represents the effects of a design change that affects both task and resource consumption. The change involves either an increase or decrease in distance of the area across the methanol laydown area. Therefore, the change would affect the distance across which the crane driver had to travel to reach safety. It would also affect the distance across which the fire has to spread to prevent the crane driver's escape. In this case, it was assumed that the escalation acted at a slow constant rate - for example, a slow spreading fire. Figure 65 represents how an escalation would affect the task if this was independent of design. For example, rather than a spread over an area, this may be an explosion. In both cases, it was not known by the author whether this was a realistic estimation of methanol leak/ignition behaviour. To produce a realistic example would require greater knowledge of chemicals and fire behaviour. Therefore, this example represents how such a situation could be modelled rather than an exact representation of a known situation. Nevertheless, the results show that an increased distance increased the probability of success in the task. This suggests that the slower escalation of the fire results in the initial delay becoming a less significant factor, when the person is moving at a speed defined by this specific speed distribution. Although this did not use exact escalation data, the model behaves appropriately in the situation - indicating that known escalation behaviour can be applied in the model interacting with design changes.

11.2.2.4 Use of the TPRC Model for examining the Piper Alpha Disaster

Section 8.3.4 represents how real data could be applied in the TPRC model by showing the probability that the first helicopter arrived at the platform before certain escalation events occurred. Using the known distance from Lossiemouth to Piper Alpha and the known speed of a Sea King helicopter, the task could be applied in the TPRC model. The delays were provided by the time between the incident and the point at which the helicopter was airborne - adding up to 22 minutes. The events from the incidents shown escalation points determined by the rupture of the different risers - Tartan, MCP-01 and Claymore respectively. Therefore, it was possible to use these values in the model to assess the probability of helicopter arrival (and therefore a means of evacuation or rescue) before the incident had escalated to a critical degree.

The TPRC model was successful in this analysis task. It shows that there was little possibility of getting the helicopter to the platform before the first escalation (rupture of Tartan riser) - as supported by the real events that were observed. This was something that the OIM should have known - and should have incorporated into his plan of action - by either attempting to apply cooling to the risers or by preparing for a sea evacuation. In comparison to this first value, the probability of success functions of the first helicopter arriving before the other ruptures are massively increased. However, much of the damage had been done at this point and the helideck was now dangerous to approach and use. Also, these escalations were likely to have been caused, or at least speeded up, by the initial rupture and are not independent of it. However, this was consistent with real-life - in that the helicopters had arrived by this point in time.

As stated in Section 8.3.4, the Cullen (1990) report suggests that these ruptures could have been delayed by up to 3 hours, if not prevented altogether, by applying cooling to the risers. Therefore, using the figures suggested as a potential resource consumption rate, the probability of success of getting the helicopters to the site BEFORE the ruptures could now be calculated (given that cooling has been applied). This would demonstrate how the TPRC model could compare actual events with the events that "could have been" if different actions had been taken. Clearly, as shown in Figure 53, this gives a high maximum probability of success - suggesting that, with the use of cooling, the platform could have been approached by a helicopter safely - potentially leading to a safe evacuation with minimal losses.

Again, this represents the model's potential in quantifying p(success) in real and imagined tasks. The results obtained were consistent with the real events, but this also shows how the tasks could be combined to make decisions. For the emergency manager, this indicates that he <u>must</u> make some intervention to avoid catastrophe - as the helicopters could not be relied on to make a clear evacuation before escalation in the given (real) situation. For emergency procedures' writers and planners, this indicates how early helicopters should be called in an incident - and the importance of self-sufficient emergency management - in this case, the application of cooling. It also brings together the importance of linking the concepts - that if the risers <u>are</u> cooled, this should give adequate time for the helicopters to arrive - something that, although is implicit in the Regulations and recommendations, is only made explicit when analyses such as these are presented.

In terms of the relationship with risk, it should be noted that each of the progressive escalation points resulted in a more serious outcome. Therefore, it should be noted that although the probability of failure for these will be nearly the same, the consequences will be different - resulting in an overall different value for risk.

11.2.2.5 Comparison of the TPRC Model with other HRQ Techniques

In Section 8.4, the tasks described in the crane driver scenario were analysed using two other techniques of HRQ, to compare the results with those obtained using the TPRC model. This comparison brought light to the issue of the definition of human unreliability – was it probability of failure (therefore being equivalent to the engineering definition of reliability) or the probability of error (more generally considered within the sphere of human reliability)? – and what was the relationship between these factors? The TPRC model considers unreliability as "probability of TASK failure" and it was only by carrying out these comparisons that the differences between TPRC and other methods became apparent.

It was observed that HAZAN produced a typically pessimistic view of emergency management – starting with the concept that there is a 1 in 1 probability of failure when "complex and rapid action is needed to avoid a serious incident". Section 8.4.1 demonstrated that this would lead to an overall probability of failure of 1 when applied in the Crane Driver example.

Although this result may lead risk assessment techniques to consider the initiation of an emergency as such a serious issue so to focus on preventing the initiating events; this also suggests that no intervention will produce a successful outcome. Therefore, by association, it would be assumed that no improvement of emergency management skills would produce a significant impact on the risk so there is no motivation to consider this as a viable option. In reality, this is clearly not the case.

However, this discovery should not lead to a "re-invention of the wheel" to identify techniques suitable for such analyses and fortunately, it was also demonstrated that the TPRC model could provide the probability of success functions to apply in a fault tree or event tree. In this example, the TPRC model was used to produce an equation to represent the overall probability of the crane driver's survival or death.

Using the same tasks, HEART gave distributions of values for p(error) from 0.0196 to 1. These were altered using changes in subjective, usually psychological, parameters - such as time pressure and ambiguity about performance - and expert judgments of their influence. The probability of error was not linked to the original physical factors that lead to these psychological factors - such as escalation speed, delays in the task or the definition of the task to be completed. Due to its disregard of physical data to calculate the probability of human unreliability in particular tasks and circumstances, again this did not seem to encompass the critical aspects of the emergency situation. It should be reiterated here that failures in emergencies may not necessarily be due to errors (for example, fast escalation leading to no opportunity for intervention). Errors may or may not lead to failure in the outcome (some things are due to luck!). HEART focuses on "error" - which does not consider the outcome of an error - therefore error quantification techniques, such as HEART, are not always appropriate to compare with an outcome-based risk methodology.

For example, many of the results obtained in the "crane driver" example give the probability of error as 1. From this, it can be assumed that the error is certain but in the context of applying these results into a more global quantitative risk assessment, it is not clear how this could be incorporated. Therefore, this result could even be seen as creating more problems than it solved. If there is a "certain" error, does it occur within the decision-making, communication or action processes – what is the nature of the error? Consider the following interpretations.

If it is assumed that there is a certain error in the decision making, this could be a complete failure to make a decision (something that would be difficult to define – even the absence of action could be due to a conscious decision!) or that he makes precisely one error within the decision.
In our example, this may mean that the crane driver will fail to make any decision and so it must be assumed that he stays in the crane OR he makes an error in the decision-making, for example, chooses the wrong direction. The former "absence of a decision" may eventually turn out to be the right decision – and by "unconsciously" relying on others to rescue him, he remains in the most obvious place to be rescued. This guaranteed error may lead to a higher probability of success in the rescue!
Therefore, neither of these errors give any indication to the probability of survival of the crane driver – The probability of error may be 1, but because there is no clear definition of how these errors manifest themselves or the circumstances in which the decision was made, the probability of survival is still unknown.

On the other hand, this error could be in the physical process. This may involve a trip or a slip - which if serious, could result in a total failure of the escape process or could delay the process slightly. Again, this does not necessarily constitute failure in the task – but may increase the probability of it. Ultimately, HEART has not provided the answer to the question – in this situation, what is the probability that the crane driver escapes or is rescued? Whilst HEART may provide a more deeper representation of the probability of error, it can not fulfil the requirement of a Quantitative Risk Assessment where the probability of task failure is the necessary input.

However, whether considering errors or failure, if it can be considered (as discussed in Section 10.7.2.4) that the actor would based his probability of survival on his perception of the physical situation and his estimation of the solution that optimised his chance of success, then this decision should be linked to the probability of task success such as that produced by the TPRC model. Based on this, the method of quantification in HEART would appear to also be inconsistent with the real-life knowledge of emergencies. For example, in a rescue task, would an error-producing condition (such as a low signal-to-noise ratio) have as much impact on the risk as whether the distance to the casualties is 10 metres or 100 metres? Even at a cognitive level, the physical attributes of a situation have an impact on the outcome – the stress caused by physical differences in the task are likely to influence the probability of error more than "global" error-producing conditions. Also, considering the lists of error-producing conditions, the quantitative influence of these may change within an emergency situation - for example, in general, "No obvious way to keep track of progress during an activity " currently assigned a weighting of 1.4, is likely to be more important than "a means of suppressing or overriding information which is too easily accessible" assigned a weighting of 9. Users may argue that these influences should be modified by the "proportion of effect". However, this almost defeats the purpose of having pre-specified values for error-producing conditions at all. It is likely that the values should be re-assessed for emergency situations. Similarly, HEART has many subjective parameters that could actually be represented by physical parameters - for example, time pressure can be measured through the relationship of time required and time available - possibly producing some formula of how this relates to perception of time pressure. Also, "ambiguity about performance standards" could be represented by uncertainty about the goal standard required.

In contrast, the TPRC model considers human unreliability as a failure - an error that has an objective and measurable impact on the outcome. Therefore the methods appear to be inconsistent with each other. In general, this makes it difficult to compare between methods – or to identify a method with the potential to validate against the TPRC model. Overall, this suggests that compared with these techniques, the functionality of the TPRC model is more consistent with the real probability of success in emergency management tasks as it considers physical parameters and is outcome-based.

11.2.2.6 Conclusions

Overall, it can be seen that the TPRC model can represent the impact of changes in variables on probability of success in various tasks. The results from all the changes described in Section 11.2.2 were shown to be consistent with the current knowledge about emergencies. For example, long delays, slow work progress and increase escalation (reduced time available) were all found to have an adverse effect on the probability of success of the task.

This helped to indicate the sensitivity of the concept of risk to particular variables. Risk is not a fixed concept but is changeable according to the details of a situation. In an emergency, probability of success is influenced by the events and circumstances of the situation, the actions taken and the timings. Often, even the maximum speed of the task is not sufficient to make an impact on the probability of success curve (As shown in Figure 44, the difference between 0.7 m/s and 1 m/s would not produce a maximum value tending towards 1). However, the "delay before taking action" appears to be much more significant. Although both of these factors influence the time taken to complete the actions, the initial point at which the gradient starts to rise (as defined by the delay) made more impact on the probability of success curve than the actual degree of the gradient (as defined by the task speed). Although, these examples only demonstrated limited changes, in reality, it is more likely that the delay will tend to zero than the speed will tend to maximum. For example, if this related to human speed, this would indicate the speed of an Olympic runner. The implications of this is that is it more important to start a task early than to carry it out quickly - indicating the important of "good and timely" decision making. As far as the resources are concerned, the conclusions are similar. The greater the length of time available, the greater the probability of success in the task.

As stated earlier, there was no model which could be directly compared with the TPRC model and so could be used to validate this technique. Therefore, initially, the main criteria of the model was to assess its ability to represent a large variety of different emergency tasks and to show face validity in the results. In this report, the author believes that this has successfully been completed. The Task Performance Resource Constraint model is logical in its construction - relating the times required for tasks and the times available. Where these timings produce a only small time window of opportunity, the resultant probability of success is small. Where the window of opportunity is large, so is the probability of success. However, in addition to this face validity, the TPRC model also showed its ability in assessing real data from the Piper Alpha disaster and was compared favourably other methods of HRQ - namely, HAZAN and HEART.

In general, the TPRC Model has the potential to provide an objective assessment of performance based on specified distributions of physical values. The probability of success that results from these values is based on mathematical equations. Currently, as noted in Section 10.7.4.1, there is a risk of bias through subjectivity in:

- choosing the task performance / resource constraint parameters to be measured.
- choosing the mean values and the degree of variance to be applied to each parameter where it has not been objectively specified

However, if a strict framework can be identified (specifying tasks that were known to be linked to resource constraints) and enough numerical data can be collected to build up distributions of performance parameters, both of these problems can be eliminated and the approach can be totally objective.

In this report, the model successfully demonstrated the probability of success in a large number of different emergency management tasks. Although the results were based a collection of simulation, theoretical and design data, the model successfully managed to produce a probability of success function relating to time. Where emergency management provided no or little intervention, the probability of success would be low. If emergency management provided appropriate and timely intervention, the probability of success would be high. Therefore, this application of the TPRC model can be considered to have successfully achieved the objectives of this research.

SECTION 11.3: IMPLICATIONS OF THE USE OF PERFORMANCE PARAMETERS

The concept of performance parameters was brought about to define timings for human activities based on the observation of dedicated simulations. These could therefore be used in planning, design as well as within the TPRC model - hence reducing

the reliance on expert judgment. These were intended to be predominantly management activities as opposed to physical activities that could be ascertained from drills and walk-through simulations. However, to aid in the processing of the TPRC model, the timings of physical activities that were used in the simulation were also included in data collection. Therefore, as the timings were considered reasonable enough to provide a realistic test for an emergency manager, they should also be reasonable enough to be used in preliminary data analysis.
For this reason, there were two types of data collection:

- Generic - timings of tasks that were not context-dependent, were observed frequently and could be expected to occur in any scenario
- Scenario-Specific - timings of tasks that were context-dependent, were usually only observed to occur once and would only occur in scenarios with a similar context.

As mentioned in Chapter 10, the timings of the scenario-specific tasks and events were based on the Scenario Organiser's imagination, organisational skills and knowledge of the process. The values were intended to represent the timings of tasks and events in a real emergency. However, as the physical events in the emergency were simulated, it was not known how realistic these timings were. This introduces a great deal of subjectivity into the data, which in turn makes the validity and reliability questionable. As this research is based predominantly on dedicated simulation data, which is a "subjective" representation of a real incident, it may seem unreasonable to particularly note the subjectivity of this aspect. However, these simulations were only intended to provide a reasonably realistic test for the emergency management candidate. If it is the intention of the TPRC user to model novel situations or new designs, it would not be advisable to use these data for this reason. They should therefore be used only as a last resort - when timings cannot be estimated from any other source. In this situation, the TPRC results of such analyses should not be used to make critical decisions - in terms of design, emergency management or any other factor. However, if it can be ascertained that the data ARE realistic and DO represent the specific task/resources as required by the analysis - they have some potential. It should be noted particularly that the total timing incorporate the time taken to make a decision - something that it not obviously captured by the use of the generic performance parameters.

However, this section will focus on the use of the generic performance parameters. These were not subject to the same criticisms as the scenario-specific performance parameters, because mainly:-

- they rely on observable tasks;
- they consist of management communications and actions as opposed to physical or technological behaviour

but particularly,

- they are in greater numbers so unusual timings are noticeable as they probably represent the "tails" of the distribution rather than being taken as the average value. Consider that if only one piece of data was recorded (as in the Scenario-specific performance parameters), this could represent an outlier, the median or some other point on the distribution. Building up a distribution reduces the risk of getting biased data.

This resulted in a set of 46 generic performance parameters (as defined in Appendix 7) - including the delays, times to carry out communications and times to pass on information. For each of the generic performance parameters, the data were collected into distributions. These distributions were collected with respect to:- candidates, pre vs. post incident, competency level of the scenario, as awarded by the assessor; and onshore vs. offshore, as shown in Appendices 10 and 11.

As discussed in Section 10.8, at this time, there are not enough data to be confident in the reliability of the generic performance parameters. They were from 2 teams - one offshore, one onshore. Therefore, although many of the parameters form distributions approximating to a "normal" shape, they cannot be assumed to be representative of the population of emergency managers and their teams for either industry. No statistics comparing the groups were carried out at this stage. However, it was possible to examine the distributions using a Weibull plot - to assess whether they fitted particular distribution shapes. This analysis found that most of the data tended towards being "random" as opposed to deterministic, which is what we would expect from human behaviour. Some of the frequency distributions were apparently logarithmic rather than normal. Often this was due to the low numbers (eg. delays of 0 or 1 second) in the parameter. Some of the parameters contained small numbers of data, therefore it would be beneficial to collect more data to ascertain the nature of the distribution. However, for the distributions obtained through large numbers of data, it is likely that these are a true reflection of the task. In general, these distributions could be used, either alone or in combination, to estimate the delays taken up in particular actions. These delays can then be used when designing systems to withstand hazards for a particular length of time, e.g. firewalls. They can also be applied to the emergency planning process - to assess whether certain actions would be effective if carried out after the minimum or most likely delay - or if, by this time, the actions are likely to fail.

When applying the distributions to other situations - whether in the TPRC model or other techniques, the choice of distribution is very important. In general, it is recommended that the user chooses the distribution closest to the required situation - for example, if one wishes to know the average time taken by a highly competent emergency manager to make a tannoy within an onshore emergency - it is best to choose the information from the onshore post-incident highly-competent data set. This is comparable to the recommended technique for using specific data. If the description of the data is vague, it is best to choose the highest level possible to ensure a broad spectrum of data. For example, if it could be a petrochemical incident of unknown type and could apply either onshore or offshore, it is best to choose it from the data obtained from the large total (post-incident) distribution, to ensure that the total variance is taken into account. As the larger distribution has been obtained from a larger amount of data, it is more likely to represent the population than a small potentially-biased sample.

Chapter 9 illustrated an example of how the performance parameters could be used in the TPRC model. To assess the performance by one particular emergency management candidate in one particular situation does not require the information about every other candidate in any other situation. However, if the TPRC model is to be used to assess design changes or novel situations, it would also be necessary to estimate the "average" response as well as the best and worst responses. This can be established through use of the performance parameters. The TPRC model uses a distribution for each inputted parameter. Therefore, when assessing novel situations, the management intervention (usually represented by an initial delay) can also be inputted as a distribution. For example, in one scenario, it may have taken 26 seconds to receive a message. However, using 26 seconds to receive a message in all future TPRC models would potentially lead to errors. If it was known that 26 seconds was a short time to receive a message and the average time was actually 60 seconds, this adjustment could be made.

Therefore, this really acted to show that the TPRC model could use such data rather than assessing the performance of the data themselves. The combination of model and performance parameters worked together to produce results that are consistent with knowledge of real-life incidents. Therefore, although there are some limitations, as were discussed in Section 10.8, it appears that the performance parameters (both generic and scenario-specific) are applicable in this research. As shown in Section 10.5, the performance parameters also have the potential to be used outside of this research project. For example, designers can assess how long an emergency evacuation can take using physical models. However, up until now, there was no information on what sort of delay could be expected by the passing of information. Therefore, if a design is given physical criteria (for example, survival time of 5 minutes), it can be established whether it is possible to carry out both management and physical tasks in this time.

SECTION 11.4: CONCLUSIONS

To summarise:

- The Task Performance Resource model demonstrated its success when assessing the impact of emergency management on risk. The relationship between an emergency management task and the escalation can be used to calculate a probability of success function with respect to time. If favourable changes in this relationship occur, this increases the probability of success respectively as has been shown for numerous simulation tasks and an example from the Piper Alpha disaster.
- The TPRC model is preferable to other methods of HRQ when assessing emergency management tasks for a number of reasons. Most HRQ techniques do not represent variability in the inputted variables and are restrictive when considering the effects of time. Also, some major emergencies <u>have</u> been managed successfully, yet many HRQ techniques remain pessimistic about the success of emergency management tasks or do not represent the physical values that most influence the outcome of the incident.
- The data from the questionnaires (as shown in Appendix 9) indicate that competency is strongly linked to the number of good decisions that are made in the scenario. As one scenario was marked as "competent" when there were 4 decisions considered to be "poor", this indicates that other emergency management behaviour (e.g. leadership, delegation) has a strong influence on assessment results.
- The Performance Parameters provide distributions for tasks and events that occur in an emergency. The reliability of the specific timings of events is dependent on the skills of the scenario organizer and there are generally only single examples of each one. The generic performance parameters involve observable management tasks and large distributions of these can be produced.

- The TPRC model can use the Performance Parameters to represent "poor", "average" and "good" times for a particular task. This can be used in novel situations or environments as well as using designs that are still at an early stage of development. Care should be taken to choose the most appropriate distribution for the situation.

This thesis will now move on to discuss the implications of these results, the contribution to knowledge as well as possible future research.

Chapter 12

DISCUSSION AND CONCLUSIONS

SECTION 12.1: INTRODUCTION

This chapter will discuss the implications of the results - both in terms of their contribution to knowledge as well as their practical application. This chapter also includes suggestions for future research. These will be split into sections according to the relevant area of the research - scenario arrangements, data collection, the TPRC model, questionnaires and performance parameters. Next there will be a general discussion to summarise the research, then finally the conclusion.

SECTION 12.2: SCENARIO ARRANGEMENTS

Ensuring that training simulations are as effective as possible as well as ensuring that quality data are obtained relies on a solid proceduralised method. Therefore, the structure of the scenario arrangements should be optimised to produce good results. As yet, there is no recommended procedure for planning and running dedicated simulations. As there is such variety in the type of simulation required, this is usually implied in the literature. As discussed in Section 3.5.3.4, UKOOA (1997a, 1997c) specify the frequency of simulations, some of the tasks that should be assessed as well as the qualifications of the assessors. OPITO (Institute of Petroleum 1998) specify the types of scenario as well as the performance attributes that should be examined. However, during this research, it became apparent that there were recommendations that could be made in terms of the scenario arrangements. Therefore, how the scenarios should have been arranged in this research (and therefore should be arranged for future research) will be described in this section.

The scenario arrangements should model the emergency manager's environment as closely as possible. All the relevant equipment and personnel should be available for use, or appropriate substitutes should be supplied. For example, in the current research, the alarm systems were simulated using a tape-recorded version. Therefore, it is not necessary to spend large amounts of money to produce an identical system where cheap alternatives are sufficient.

As discussed before, the scenario organization team should consist of people who are familiar with the particular installation. As a minimum, the Scenario organizer should carry out the following tasks:-

- Clarify the purpose of the scenarios - to identify if particular skills must be assessed - for example, team or individual assessment, testing of the emergency plan etc.

- Clarify the scope of the scenarios - define the number of scenarios that are required to fulfil this purpose.
- Collect relevant information about the installation including Quantitative Risk Assessment, Emergency Procedures, Installation Description and scale diagrams - and from this, identify a number of key emergency scenarios while referring to the purpose and scope as defined above.
- Talk to the installation personnel in different roles (those not included in the Emergency Management Team under test). Clarify details of scenarios including particular concerns associated with the scenarios as well as predicted courses of action.
- Estimate the timings associated with tasks and escalation. This could be carried out using a walk-through technique or through observation of platform drills (e.g. musters).
- Document the results. This could be carried out using an event tree approach as described in Section 2.4.3.5. The possible actions are then associated with certain task and escalation timings. A transcript of the timings of the events (escalation points) must then be produced, which should be accurate to the nearest second. As the timings of intervention are dependent on when the emergency management team order an action to take place, the duration of the relevant tasks should be recorded.
- At this point, it would also be useful to identify criteria for good / poor performance. That is, for each event or action, define details of what would reasonably be expected of a team and what would be considered an optimal performance.
- Verify that the scenario is realistic and a good test of emergency management skills using documentation and conversations with installation personnel (as before, those not included in the Emergency Management Team under test).

Therefore, the actual running of the scenario would consist of working to the transcript and event tree. Once particular tasks have been ordered, the scenario organiser can refer to the expected duration of the task and note the time that it is expected to end. For example, if blowdown is expected to occur 20 minutes after it was initiated, the scenario organiser should note down the time at which it was ordered and record its end time 20 minutes later.

Therefore, it is necessary for the scenario organiser to use a clock or stopwatch to keep track of the time. When particular events occur, the scenario organiser should make them known to his team to ensure that the intended information is returned to the emergency management team. This would therefore result in a realistic simulation.

Currently, the methodology only allowed the use of video recording in the emergency management team room. This was sufficient to note how the emergency management team deal with the information that they are given. However, certain aspects of the information may have been lost, through unintelligible radio calls or details of phone-calls that are not passed on to the rest of the emergency management team. In this research, it was necessary to assume when the events occurred, based on the actual messages that were sent to the emergency management team. Using a video camera in the scenario organization team room would assist in clarifying this process. If the scenario organizer was to announce the point at which events occurred, these could be made specific in the transcripts, and used in the TPRC model. Also, as discussed in Section 10.6, the quality of information sent from the scenario organization team is not always the same quality that is received. For example, sometimes the scenario organization team intend a fuzzy radio message to be sent to the emergency management team - for example, to represent a noisy environment or serious injuries. However, sometimes the message would be distorted unintentionally. The current transcripts only record one side of the phone conversations. Therefore, the quality of information in a phone call may be lost as the message is passed on to the rest of the team, like in a game of "Chinese Whispers". Noting any differences in the quality of the information that was sent and received may affect the judgment of the quality of the emergency management. For example, an emergency management team member may answer the phone and, after a long conversation, will deliver critical information to the rest of the team. Using the current methodology, it is not known whether the critical information was given at the beginning of the call or as an afterthought. From the video recording of the scenario organization team room, this information can be established. If it was at the beginning, the emergency management team member should have realized this and forwarded it to the team immediately, rather than continuing the conversation. If it was at the end, it could be for two reasons. Either the emergency management team should have predicted the important content of the phone-call and should have asked for it earlier; or the information was an unexpected progression of the incident. In the latter case, this was often used as a deliberate delay and was thrown in by the scenario organization team as an extra "test". Therefore, getting the view of things from the scenario organization room would be an important contribution to the research.

Ideally, it would be possible to identify any weaknesses in the emergency management process at any point in time. Therefore, it would be necessary to focus on each member of the emergency management team and stop the scenario at various points and interview individual team members. This may be useful in cognitive research, but would be disruptive to the emergency management process. Therefore, the use of head-mounted cameras might be useful, as has been suggested for studying naturalistic decision making (Omodei et al 1997). This would allow the assessment of each person's actions at the end of the emergency. The views from the camera should help to jog the memory of the individuals and this could help to identify weaknesses in the individual as well as general problems in emergency management. Overall, the scientific nature of the scenario organization is the important issue for any research.

As stated in Section 10.5, the fact that there was one main assessor involved in the assessment process was problematic. Any human may make an error, and the assessor is not exempt from this. Therefore, there should be no main assessor - just a number of assessors with equal contribution to the assessment process. Each should have some form of official endorsement - perhaps also in the form of a competency assessment. Determining the standards for assessors would be difficult. The definition of emergency management competency in terms of the subjective opinions has not been defined within this project. Therefore, it is required to objectively define competency then ensure that all assessors are able to identify particular characteristics (both desirable and undesirable) under test.

This assessment could be carried out by preparing videos of simulations of candidates of varying levels of competency. The assessor should be able to identify good and poor decisions; decisions that are too early, early, timely, late and too late; lapses in communication, unexpected responses etc. If their assessment is consistent with the previously-defined criteria, then he can be deemed a "competent assessor".

Also, as stated in Section 10.5, the assessor was sometimes biased by the fact that he knew the nature of the incident, which was likely to affect his judgment of the emergency manager's performance. In future, to make this a more realistic assessment, this should be a "blind" test. The assessor should be given only the information that the emergency manager is given and then they can watch the emergency unfolding from the same perspective. The assessor should be encouraged to record in real time any discrepancies between the responses that were made and the responses he would expect to be made. This would ensure that only the assessor's knowledge of emergency management would come into play - not his prior knowledge of the incident.

Ordinarily, in scientific study, the scenarios should be repeatable at a high level of accuracy. Unfortunately, as they involve an interaction between teams, this would be impossible. For example, if the scenario organisation team were given a script of messages to communicate to the emergency management team, it would not be long before the emergency management team would ask a question that was outside of the scope of the script. Therefore, the scenario should be repeatable in terms of the major events and the timings. The research could then be broadened to compare the differences between "incompetent" and "competent" candidates in one specific scenario. This would help to define "competency" in objective terms. It could also be used to assess the difference between a candidate at the beginning and end of training - to learn the true value of training or to identify whether emergency management is innate in the person or can be learnt. This would suggest whether the efforts should go into selection or training when choosing an emergency manager. This could also be used to compare different training techniques, for example, to find if cognitive or physical training result in the best performance. Changing the physical arrangements of the emergency management room and noting the impact of this can be used to assist in planning and designing. Finally, each scenario can be used with people in different roles or using different numbers of people, to see if these aspects change the level of performance.

Once the scenario arrangement technique has been formalised, there are few limits to the scope of this research. This process can be used with different teams of differing competency, different scenarios, different installations and different industries. For this research, this could identify whether performance parameters and TPRC results are affected by such factors. It also would ensure that there is less variation in the inputted data - for example, it would be possible to identify exactly how long it takes for information to get from the scenario organisation team to the whole of the emergency management team.

SECTION 12.3: DATA COLLECTION

12.3.1 DATA COLLECTION FROM SIMULATIONS

As discussed in Section 10.6, another problematic feature of this research is the intensive effort that must be applied if behavioural data are to be extracted from simulations. The criticisms of this data collection methodology focus mainly on the time that is required to produce a transcript. Due to the length of time taken by the process, it was not possible to have an independent verifier repeat the process to identify any errors. Further to this, Section 12.2 suggested a wider use of video cameras in the process. These included a video camera in the scenario organization room as well as head-mounted cameras on each of the emergency management team. These would both increase the workload involved in transcription. However, these problems could be rectified by the use of an automated system.

There is software available that changes the spoken word into the typed word. This is generally used to speed up the typing process. However, if it could be used to change the conversations in the scenario into typed text, this would not only speed up the process, but would be an objective method of producing a transcript. Ideally, this would be carried out during the scenario itself, rather than lowering the acoustic quality of the information by using the video. However, this would not provide the timing information. However, the field of Exploratory Sequential Data Analysis (ESDA) may be able to assist in this process. MacSHAPA (Sanderson 1997) was developed to enter video data including time codes into a computer for analysis. Although, this is not yet able to automatically extract the speech, identify the speaker and to record the timings at which this started and finished, there is the possibility that the technique may be capable of this in future. If the transcription (including timings) could be carried out automatically, this would greatly improve the efficiency of the total TPRC methodology. There is also the possibility that data could also be produced in a way where they can be fed automatically into the TPRC model and/or produce or add to the Performance Parameter distributions. For example, the user could highlight the data in terms of type (for example, scenario organization team informational call). The software could calculate the time taken by the task, and then the data point could be forwarded into a database for the relevant parameter. The user could highlight the relevant data in the same way and input this information into the TPRC model. For example, the user could specify a context-based start point, a point at which the resources have run out, the delay and the task time. The user could use the transcript or external information to specify the variability surrounding the values, or adapt them at his discretion. Other suggestions are shown in Section 13.4.

12.3.2 DATA COLLECTION FROM OTHER MODELS AND THEORETICAL INFORMATION

The interdependence between the physical events in an emergency and the Task Performance Resource Constraint model was a critical factor in the analysis. Initially, the external data were simplified. However, to obtain reliable results from the TPRC model, it was necessary to obtain reliable information on the objective aspects of an emergency.

Therefore, this required research into survivability, human tolerance, fire escalation and other physical parameters.

As discussed in Section 10.6.2, the main problems with using other models and theoretical data were the amount of data available or the complexity in producing it in a useful form. Therefore, the main focus of future work should be to obtain clear data from a wide variety of sources. Dhillon (1990) and Taylor-Adams (1994) have noted some resources that are helpful in this task. Some research is clearly focused on emergency intervention; some may not seem to make any life or death differences. For example, exercise physiology studies the speed of human activities. This may include studies of people of different age and fitness moving over different distances. This may not appear to have much impact in an emergency. However, if you apply these values in a TPRC model of a rescue, the information becomes valuable. This can also find a more positive use of information that was disregarded due to its outdated methods. For example, the work of Taylor (Pheasant 1987) involved time and motion studies that were used to push humans to the limits of their potential. Now these data can be applied for a more positive and beneficial purpose - to establish the upper limits of a pressured performance. This should also consider the data for teamwork. How much quicker can a fire be put out using 4 fire fighters rather 3? How effective is rescue when the more complex tasks are assigned to an expert medical professional rather than one of his team? Many of these data are collected but are not reproduced in a form where they are available for public use.

Therefore, it should be noted that data collection is not a simple task. Some data can only be obtained by starting from first principles - that is, trying to estimate the timings and probabilities from observation of the tasks and events themselves. For example, timing how long it would take to apply a compression bandage may require observation of people carrying out this task. Some data can be established from literature but they are very widespread. For example, assessing the likely survival time from particular trauma injuries involves assessing both deaths and survivals by type of injury, then looking at the times at which intervention was attempted, the type of intervention and any complications. This would probably involve the examination of medical records, which would require understanding of the terminology. In a similar way, the research on fire escalation could only really be interpreted by someone with expertise in this area. In conclusion, providing the accurate data for use in the model often requires specialist knowledge in the area of concern and considerable effort to locate and collate - if indeed, the relevant information is available! Therefore, future work should concentrate in producing these data so that they can be applied in the TPRC model by those who do not have great depth of knowledge in all of the relevant fields.

SECTION 12.4: THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

The Task Performance Resource Constraint model is a key feature of this research. Despite the criticisms described in Chapter 10, it has fulfilled three out of the four objectives of the research, as follows:

1. To develop a method of obtaining objective data from emergency scenarios on management performance

2. To develop a methodology to use these data to assess the probability of success in emergency management tasks.

3. To demonstrate how these methods can be used to evaluate the impact of changes in emergency management skill and design on risk values.

The TPRC model has shown that it is capable of using simulated data to assess the probability of success over time for emergency management tasks. It is also capable of using prototype or design information to test the probability of success in novel situations.

The results have shown good face validity with respect to real-life emergencies and in comparison with other models of HRQ - possibly because these examine "human error" as opposed to the system-focused attitude of human unreliability as "human failure". With care, the results could be applied in other QRA techniques, such as the event tree and fault tree approaches. Added together, these factors place the model in a unique position. This model facilitates the idea that risk is a "fluid" concept, reflecting situation escalation as well as human intervention. It also emphasises the importance of emergency intervention - something that human factors approaches tend to avoid or evaluate in a simplistic way by attempting to prevent the original initiating events rather than considering the escalation control. Within this approach, it demonstrates how the different types of intervention affect the probability of success as well the impact of numerical changes in the parameters.

Overall, some future changes in the TPRC methodology have been implied in Chapter 10 by the weaknesses in the current methodology. Table 24 shows, in brief, how the problems could potentially be rectified.

Table 24: Possible Development of the TPRC Model to rectify Current Weaknesses

Problem	**Possible methods of recovery**
Multiple tasks and resources	Reprogramming the model to incorporate more complex variables: • Internal performance limits before the ultimate performance limits • Capability to incorporate non-linear variables
Interaction between task and resource	Reprogramming the model to incorporate more complex variables: • Including a means of representing degrees of interaction between parameters
Uncertainty / Variability	Incorporating these aspects as separate numbers (recording this in the outcome),

	perhaps by providing an option of terms for users who may not understand the concept (e.g. Subjective parameters like "very certain", "reasonably certain") - though it should be noted that this rectification would reduce the reliability of the model.
Conditional Probability	Providing a facility within the program to link certain tasks together with respect to "real-time" and produce an overall probability of success function for the sum of the tasks
Quality of Performance Estimation	Defining quality criteria in both the performance standard to be attained and the progress rate. For many tasks, this may not apply.
Human Error Identification / Reduction	Identify a current methodology that is consistent with the TPRC approach or develop a new one to incorporate the critical aspects.
Cognitive Aspects	Identify a current methodology for Cognitive Failure Probability (possibly through prior calculation of Cognitive Error Probability) and integrate this into the approach - or - design a new methodology based on the criteria laid down in the TPRC methodology
Tasks that worsen the situation	Either use the worsened condition as the starting point and work towards recovery - or - use the multiple tasks approach as shown at the top of this table with a negative gradient for the initial task
"Psychological" emergencies	Using real and some simulation data, performance parameters distributions could be built up and applied using large variances for uncertainty and variability until there is such a point where these could be defined in more absolute terms.
Subjectivity	Reliance on expert judgment could be reduced and possibly eliminated by: • More theoretical data and external models • Building up distributions of scenario-specific data • Increasing the distributions of generic data

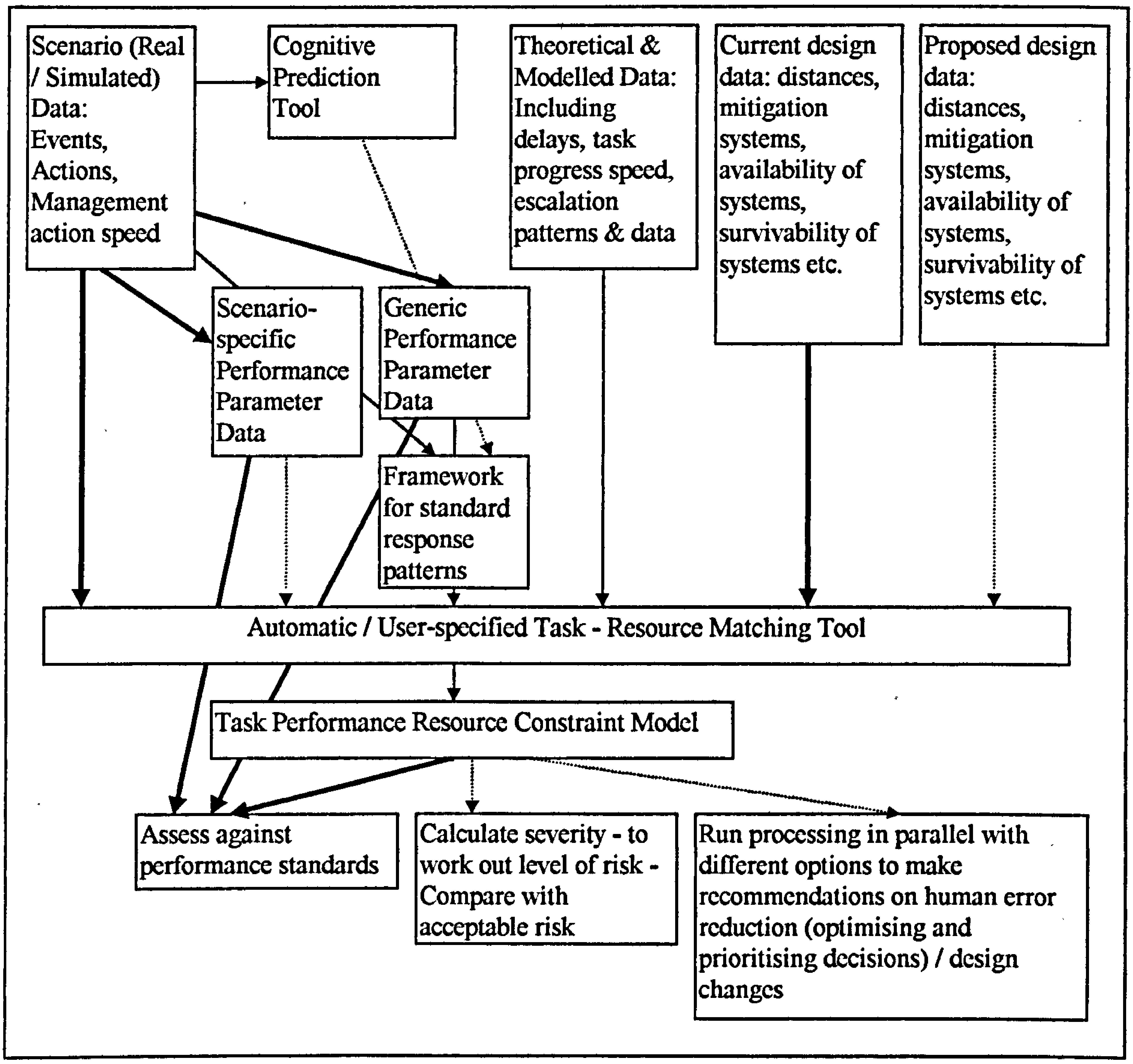
	• Formulating a framework for response patterns for delays in various situations • Automating the identification of tasks and resources that should be applied in the TPRC model.
Program Design	The program could be adapted to be more user-friendly - using a object-oriented approach, designed according to human factors principles,
Validity	This should be done through: Additional comparison of TPRC models with other risk and human reliability quantification models Use of TPRC model with more scenarios and tasks - real-life, simulated and imagined. Continually re-evaluating the validity after changes have been made to the model (such as those described in this table).

Most of these changes can be rectified with reprogramming the model, clarification of the use of variance as well as the collection of quality data. Some will be quite difficult. Beyond making the suggestions shown in Table 24, details as to how the changes that should be implemented are beyond the scope of this project. Clarification of the variance and collection of quality data could be improved with the use of the recommended scenario arrangements and data collection method, as shown in Sections 12.2 and 12.3. Therefore, the next few sections will focus on the incorporation of external data, validation of the TPRC model and the development of Performance Standards.

12.4.1 THE INCORPORATION OF EXTERNAL DATA

Currently, the TPRC model requires the user to identify the correct data to be inputted into the model. Often these are based on the scenario information. However, some data are re-used frequently and it would be recommended if they could be added into the model. For example, human movement speed, helicopter speed. These data could be recorded in an external database for use by the model. As the TPRC also has the potential to be used as a design tool, the performance parameters could be used in the same way using a framework of the actions that were likely in each type of task. Therefore, if the program is to be used to assess scenario data, the management timings and relevant design information can be inputted into the program. This could then be compared with management timings estimated from the performance parameter database. However, if the program is used to assess a new design, the relevant design information can be inputted and assessed using performance parameter data. Figure 71 shows an example of how this could work.

Figure 71: Suggested Expansions to the TPRC Model Program



In Figure 71, it can be seen that the Task Performance Resource Constraint Model can be used in two different ways as shown by the bold and dotted lines. The theoretical data and the possible automatic task/resource matching tool are used for both purposes. The theoretical data may include examples of particular task speeds or delays, for example, time to scramble helicopters. It may also be developed to integrated complex models - for example the hypothermia model developed by Tikuisis et al (1995, 1996, 1997, 1998), injuries caused by fire (Purser 1988, 1989) or fire escalation models (Peacock et al 1996, 1998, Bukowski 1997, Lie 1989, Chamberlain 1996).

Given this, the bold lines represent the use of the TPRC to assess emergency management from simulations. In this, the design is known and the actual timings taken to make decisions can be observed. These can also be compared with data produced through estimation of the responses made by a "possible" emergency manager - as defined by the cognitive predictions and the performance parameters. The scenario-specific performance parameters (once built into distributions of values) could represent known events - and, using a framework of standard response patterns, the generic performance parameters could be built for novel events.

The dotted lines represent the use of the TPRC as a design tool. This helps to identify what impact the design would have on an emergency situation. This time, the design data can be hypothetical ideas sketched out on paper - for example, a map of an installation. As there are few data on the management of such an incident, the information must be assembled from performance parameters - using the smaller distributions of scenario-specific data or the larger distributions of generic data built up using a specified framework for the standard response pattern both using the cognitive prediction tool where required. This can give an estimate of the performance of the average emergency manager (or even a very poor one), which can be used in the TPRC model. This can then be compared with the effects of other designs, to identify the one that results in the lowest risk in an emergency situation. That is, the design that best facilitates the success of emergency management is the most acceptable design. It should be noted that the scenario data need not be from simulations but can also be from real incidents - possibly recording these as a separate set of real scenario-specific and generic performance parameters (with greater reliability than the simulated set but less likelihood of building up large distributions). Real data can be used with changes in emergency management speed and design changes to identify which would have had the greatest impact on the outcome.

To reduce the reliance on expert judgment; in the future, it is possible that this system could be developed with more "intelligent" features incorporating a task/resource matching tool and a cognitive framework. For example, rather than the scenario defining the decisions that could be made for management, a tool somewhat similar to a decision support system could produce suggestions then assess their impact on the outcome using the TPRC model. Another intelligent system could identify the tasks and resources that best "match" each other to give meaningful results. This could also potentially include a severity assessment to indicate the levels of risk produced by each event or compare the obtained results against a set performance standard, as will be discussed in Section 12.4.3. Given that the risk could be calculated, the system could work on decisions in parallel, simultaneously comparing decisions that could be made in response to a given event. Ideally, this could prioritise the decisions or work out which combinations of decisions would be best in which order to maximise the outcome. Similarly, this could be used to work out the best combination of design features - or the combination of human and design choices. Overall, this would produce a useful tool for emergency planning, designing and possibly as real-time decision support in an emergency itself.
Although this is expected to result in a large program, this could ideally be used on a stand-alone PC for use by designers, emergency managers, assessors and safety personnel. However, these suggestions probably represent the distant future in the development of the TPRC model and for now, it is necessary to return to fundamentals - in particular, the model's validity.

12.4.2 VALIDATION OF THE TPRC MODEL

During this project, there was no obvious method available to compare with the TPRC model, due to its unusual use of probability of success functions relating to time. This creates problems for validation. Currently, although the results indicate good validity, to gain full scientific endorsement, there should be external validation through the use and support of alternative methods. As the model is based on mathematical principles, some scientific support can be guaranteed. However, in its "raw state", the model is unable to produce results, therefore the quality of the outputted results rely on the quality of the inputted data. Consequently, at this point, the user introduces some subjectivity.

Ideally, the model should be validated using real emergency data. For example, the recorded delays, physical measurements, escalation points and times at which tasks were completed in the Piper Alpha disaster could be applied in the model. As stated in Section 3.3.2, the emergency manager was criticised due to his lack of control over the situation as well as because his decisions were poor, late and often not communicated to the relevant people (Cullen 1990). In general, the absence of decisions is modelled in the TPRC using a null task progress rate. However, some of the platform personnel may have carried out tasks without being given orders - indicating that some emergency intervention was attempted. Section 8.3.4 gave an example of how the TPRC model could be used to model the probability of success of helicopters arriving at the platform before certain escalation (ruptures of risers) takes place. Using the conclusions by Cullen (1990) that the ruptures could have been delayed by 1 to 3 hours by cooling, the TPRC results suggest that if this emergency action had been carried out, the helicopters would easily have reached the platform before escalation occurred. Although this may seem logical based on the information known about emergencies and their intervention, there is no model that connects the two issues to produce a probability of success function with respect to time. Therefore, the model has shown its capabilities in analysing both real incidents and simulations.

The data produced by the model could also be compared against the data obtained from other risk assessment / human reliability assessment techniques. Again, this is problematic as this model produces a time-dependent probability of success function whereas most other techniques produce point values. However, identifying that the point values lie <u>within</u> the probability of success values would be an important discovery and would indicate the relationship between the methods. Within this research, the TPRC results of the crane driver scenario were compared with HAZAN and HEART - as these methods gave quantification values for reliability/risk and incorporated relevant emergency management parameters, such as time pressure and/or recognised the fact that some activities were non-routine or under emergency circumstances. However, this comparison, identified the critical differences between the probability of error and probability of failure – whilst methods such as HEART are capable of producing values for the probability of error – it is not clear how this impacts on the probability of failure as required in a Quantitative Risk Assessment. Therefore, the methods used to validate should be chosen carefully – to ensure consistency between the types of results.

In general, the TPRC model has shown its ability to analyse both simulation and real-life emergency data. It has been compared with a few methods of HRQ but the results are inconclusive - mainly due to the focus on physical outcome-based assessment of task success in comparison to the mainly psychological study of errors. Due to its consistency with what is known about real-life emergencies, it is likely that the TPRC model has, at least, a high degree of face validity. However, it has not yet been proved in terms of predictive validity. This issue of validation is something that needs to be further studied.

12.4.3 THE DEVELOPMENT OF PERFORMANCE STANDARDS

There is the possibility that TPRC model can be involved in the development of Performance Standards. Normally, Performance Standards provide numerical benchmarks of performance - for example, a firewall that survives less than 1 hour is unacceptable.

Similarly, "acceptable" values of maximum probability of success can be defined in the same way that acceptable levels of risk are identified. For example, using the probability of success curve, it may be decided that only a maximum probability of success above 0.9 would indicate an acceptable task (one that can be carried out successfully in a real-life situation). Therefore, returning to the example of the crane driver's escape - none of the tasks would be deemed to have been successful. This implies that to reduce risk to an acceptable level involves better emergency management than the scenario example - or a better design. In Figure 43, it can be seen that reducing the delay to 0 allows the crane driver to escape over the deck with a maximum probability of success of 0.99. Therefore this would be deemed an acceptable solution. However, guaranteeing such a small delay would be difficult. This could be carried out by including this in the emergency procedures - for example, "If a crane driver drops a methanol tank and it is seen to leak, he must move to the muster point immediately" (if probability of ignition is known to be high). Similarly, an increase in time resources also increases the probability of success to an acceptable level (0.997). Time resources are usually increased by alternative intervention (e.g. fire-fighting by deluge) or by design changes. This would imply that the improvement in time resources is necessary to give an acceptable result. Therefore, if this analysis had been carried out on a new design, it would imply that the design is acceptable.

In general, if acceptable levels of probability of success can be established, it is possible to use them as criteria. Designers should use the standards to ensure an acceptable design. Assessors should ensure that emergency managers are trained to produce acceptable results. Safety managers should ensure that procedures are written according to the criteria. This could also produce valuable input into the definition of competency for emergency management training and assessment. Overall, the results of this research have enormous potential to be included in the "Performance Standards" criteria that are now encouraged in the offshore industry by legislation.

SECTION 12.5: FUTURE QUESTIONNAIRE DESIGN

Although it was not a key feature of the research, the questionnaire study (as shown in Appendix 9) did provide some valid conclusions for the research. Its scope was limited by the nature of the scenario arrangements. Therefore, using simulations that are specifically designed for research purposes should facilitate the use of more detailed questionnaires.

As well as the factors that were recorded in this study, some of the factors that should be investigated include:

- Personality factors linked to good emergency management practice - leadership, stress control, delegation skills etc.
- The Emergency Manager's predicted outcome of actions
- Cognitive aspects - what lead the decision-maker to choose that decision at that time. Questions might include - Did you make the decision yourself? What exact circumstances triggered it?, Were there other considerations in making this decision? What change in circumstances would have lead you to make a different decision? Was this decision made based on written procedures? What was the worst thing that you predict could happen in response to this decision?
- Situation awareness - overall awareness of events, tasks and details of the emergency. These should be open-ended rather than fixed response - to capture the clarity and extent of the details. Questions may include - What happened at the beginning of the exercise? How did this happen?, What happened next?, What did you do and what happened when you had done this?
- Weighting of decisions - How difficult was it to make this decision? Did this decision require a large amount of thinking? Which decisions were deemed to have had the most impact on the emergency and why?

Ideally, some of the questions could also be posed while the decisions are still in the mind of the decision-maker. This could be done by interrupting the scenario to ask questions or possibly using some sort of hand-held monitor, where the team could provide a brief indication of their thoughts at that point in time. However, as suggested in Section 12.2, these methods are not recommended as they may lead to detriments in performance due to the interruption. Therefore, the use of "head-mounted cameras" as suggested in Section 12.3.1 could be used. The recordings could be shown at the end of the simulation to prompt responses.

These recommendations should help to identify what factors are really linked with good emergency management. As stated many times during the report, emergency management decisions are rated in terms of their outcome. However, unlike the TPRC model, an assessor can identify what actions should be attempted - whether or not they fail - therefore considering cognitive errors as discussed in Section 12.4. Therefore, the questionnaire can help to identify what makes a good emergency manager and what makes a person particularly skilled at identifying actions that may make a positive impact on an emergency. Also, this could assess which features of the situation or of the person lead him to make a poor decision. The results of the questionnaires (as shown in

Appendix 9) gave a small but positive (0.08) correlation between the number of bad decisions made in a scenario and the level of competency awarded by the assessor. This suggests that bad decisions do not adversely affect the competency assessment at this time.

Therefore, the main conclusion that can be drawn from these data is that assessment must be based on attributes that may not be as closely linked to good emergency management as it was first thought. These include leadership skills, delegation skills, control of stress in self and others etc. These are generally thought to be important, as they are believed to promote "good and timely" decision-making and ensuring that the decisions are implemented. However, without the effectiveness of the decision-making process itself, the attributes are useless.

The communication and action factors can be assessed objectively through observation, as has been used in this project. However, the cognitive processes that go into the decision-making require further investigation. This research would greatly contribute to the understanding of decision-making under pressure, perhaps by giving weight to the current theories of cognition, such as naturalistic decision-making.

SECTION 12.6: FUTURE COLLECTION OF PERFORMANCE PARAMETERS

Originally the performance parameters were only introduced into the research to support the Task Performance Resource Constraint Model. These data could be collected to provide "average" responses of a person, which could be used in TPRC analysis of novel (non-simulated) situations. These novel situations could also include the use of designs - so that the probability of success could be estimated in a task on an installation that was not even built! The distributions of data could also be used to show the maximum and minimum values for each task - therefore providing the fastest and slowest delays for use in TPRC analysis. Given the amount of data that were collected, this facilitated the collection of onshore and offshore distributions, pre-incident (normal conditions) and post-incident (emergency conditions) as well as distributions with respect to the competency level that was awarded by the assessor. Currently, it is not known how representative these data are - of all onshore and offshore emergency management teams on various types of installation. In the future, when more data are available, it would be useful to perform statistical analysis on the distributions to identify whether there are differences between these groups. These may assist in identifying training issues (for example, if one team is slower than average at using a radio, they may need to build confidence in this area), competency standards (if it is discovered that a highly competent team take noticeably longer than a team with notable shortfalls to carry out particular tasks, this could be used as a benchmark), and the effect of the emergency situation on performance (assisting with research into stress in emergencies, and for indicating possible design changes that could be made to compensate for certain delays).

Given that the performance parameters were used successfully in the TPRC model, there was also further potential for their use. They could be used independently of other models - as Performance Standards in their own right to be applied in emergency planning or design. For example, using the distributions shown in Appendix 11, it is possible to establish the fastest, slowest and average times for particular tasks. These can be used as a benchmark on which emergency management candidates (and their teams) can be objectively assessed. Whereas the competency assessments are more subjective and based on complex scenario-specific information, this type of assessment could establish whether a team was noticeably slower in particular tasks - therefore providing feedback on the performance.

These can also be used for designers and emergency planners. Without using the TPRC model, they can make assumptions of how long it takes to carry out the relevant management tasks, then how long it takes to carry out the physical tasks, therefore implying how long systems should withstand fires or extreme conditions. At the design or re-design stages, this could ensure that the average human response (including delays) would promote an "acceptable" outcome in an emergency. Similarly, for emergency planners, delays in action can be incorporated into the plan, therefore ensuring that the plans are realistic and result in a positive outcome.

In general, the main focus of future work in the area of performance parameters should be to widen the collection of data and to collect data on cognitive tasks. This work should also draw on the theoretical information (as described in Section 12.4.1) - for example, results from time and motion studies. The theoretical data could also be represented in terms of distributions. For example, distributions of all the possible distances of offshore platforms from land, distributions of the times taken in shutdown or blowdown. Therefore, rather than using specific point values, distributions can be used to represent the total range of values. In future, this could be built up to be a dynamic version of human and system data. For example, Pheasant (1986, 1987, 1991) provided an enormous contribution to the field of human factors by recording the important measurements of the human body in terms of population distribution. Taylor (1964) recorded the time taken by humans in particular tasks. However, these were normally used to maximise performance rather than simply to record a distribution of slowest to fastest performance timings. This approach is not recommended by ergonomics as it forces people to work at their optimal level at all times - potentially leading to accidents and injury. Using performance parameters, this study has started looking at the time taken by communications and control room operations in an emergency situation. Previously, the times taken by such tasks were not recorded in decompositional (generic) and whole (specific) terms. It was not known how long it would take to give a message by radio, or to give information to the rest of the group. Therefore, this information could potentially be very useful not only for this research but for work outside of it.

Because delay has such a critical influence on outcome in emergency management tasks, it is also possible that performance parameter distributions can be used like generic error probabilities. Instead of considering the generic probability of failure, the times taken for each component of the task could be added to produce an overall distribution of delay times - which could then be used in the TPRC model to produce the probability of success function. Therefore, it is no longer necessary to calculate the human error probabilities for emergency management situations (which is a difficult task and is often subjective), now that the times taken (which are easier to obtain and are objective) can be used.

The cognitive aspect is more problematic. However, as shown in Section 12.5, questionnaires have attempted to probe what criteria are used to identify a good emergency management decision. These criteria could then be linked to the observed time taken in making the decision - therefore producing a performance parameter for decision-making (and linked to the cognitive prediction tool shown in Figure 71). These could be categorised in terms of complexity - such as the skill, rule, knowledge type categorisation used in HCR (Hannaman & Worledge 1988). Therefore, the main recommendation for this part of the research is to obtain data from scientifically designed simulations and real emergencies. These should be from different teams (of different levels of competency if this has been defined), from different installations, different companies and difference areas of work.

Overall, these performance parameters fulfil the fourth and final objective of the research as follows:
To use the above methodology and data to define performance parameters that can be applied to generic emergency situations.

SECTION 12.7: CONTRIBUTION OF RESEARCH WITH RESPECT TO PREVIOUS KNOWLEDGE

As shown in the Chapter 2, there are many areas of study that can be linked to this research. Consequently, this research has contributed some knowledge for each field.

Despite our knowledge that human behaviour is a contributory factor to accidents as well as to preventing them (van der Schaaf 1999) and the obvious importance of aiming to prevent further disasters such as those that have occurred in the past, there has been very little research into the contribution of emergency management to reducing risk. Traditionally, Human Reliability Quantification techniques generally associate most emergency management tasks with a high probability of error - or, by extrapolation, as a low probability of success. However, this is not always the case. Many major incidents have been managed with some degree of success, where success can be defined in terms of survivors, escalation that has been controlled or assets that have been saved. This is probably due to the difficulties in equating "error" with "failure" - whereby errors may not necessarily result in poor outcomes and failure is not necessarily due to error (as discussed in Section 12.4). Given that emergency management can be measured objectively in these terms, it seems reasonable to design a technique that can measure the impact of emergency management on risk in the same way. Although the TPRC model was not demonstrated to be completely objective (as discussed in Chapter 10); with further emphasis in the development of performance parameters, it has the potential to be this in the future. Due to it being based on mathematical equations of physical phenomena as opposed to experience of human error and performance in other situations, the TPRC model clearly has stronger internal validity that most other models of human reliability. Its validity and reliability rely mostly on the data that are supplied – which can be improved through further research.

Although it only represents the quantification aspect of a Human Reliability Assessment technique, the TPRC model shows a number of advantages to previous models. Firstly, it relies mainly on objective outcome-based information, therefore is not as reliant on "expert judgment". It examines the "total" task- of incorporating the time taken by cognitive and physical actions - and its impact on the outcome. Therefore, it looks as human reliability as a total "system" issue - rather than error at specific points in the process. It can represent most tasks and resources incorporating important issues from the specific context. They can be from real-life, simulated or imagined incidents - past or future - depending on the requirements of the user. It incorporates a level of variance into the inputted values, rather than being restricted by point values. It produces a distribution of probabilities relating to a time-base chosen by the user. Therefore, as expected, in comparison to other models of HRA (HAZAN & HEART), the TPRC model is better at representing the impact of the contextual situation on success through its dynamic use of time – therefore producing more appropriate results for use in a wider context. As yet, no other HRQ technique can claim to have all of these attributes. Therefore, this could be a massive step forward in fully integrating HRQ into the PSA/QRA process.

The concept of time required and time available as used in the TPRC model is also consistent with the concept of stress. An imbalance between perceived capability and perceived demand is said to lead to stress (Sharit & Malon 1991, Cox & MacKay 1976). In the TPRC model, if the perceived imbalance results from "demand being greater than capability", probability of failure is increased. Stress has an influence on human error. Therefore, these two concepts are inherently linked. Failure may be due to a narrow margin of success caused by the physical timings of the task and the resource consumption rate. However, the physical timings also may lead to the perception of the imbalance between the two timings, leading to stress, which may result in human error, leading to failure. Therefore, the failure occurs through either the actual problems inherent in the situation or through the psychological reaction to them. This may suggest that those with a very high perception of risk would not make good emergency managers - as they would expect the tasks to fail and therefore would not try them. This could be useful as a screening technique for potential emergency managers.

Given this, the TPRC model may also be used to quantify the objective contribution of a situation to stress. If the probability of success is high but the stress associated with the task is also high, this may indicate that this person would not be well equipped to deal with risky situations. Consequently, to optimise the probability of success, the stress should really reflect the optimal level of performance - which according to Yerkes & Dodson (1908) would be a "middle" level of stress. For example, low stress may indicate slow reactions to the situation, whereas high stress may result in poor decision-making and a high probability of error.

The research in human error may also help to explain the contribution of simulation training to emergency management skill. Many of the physical emergency management tasks are not used on a day-to-day basis. For example, tannoys, deluge activation and use of hand-held radios. Using the SRK theory (Rasmussen & Jensen

1974), the simulations help these physical skills be transferred from rule-based to skill-based actions. This allows the team to focus more on cognitive demands of the task. For example, looking at the data distributions shown in Appendices 10 and 11, this may explain the delays between radio calls being longer for the onshore team than the offshore team - as they are less familiar with using hand-held radios. Also, training provides an emergency manager with "psychological resources" - the experience of dealing with particular situations - which perhaps increases the probability that these will be recognized as "typical", as in the Recognition Primed Decision Model (Klein 1989), and leading to less likelihood of cognitive error. In relation to the literature discussed in Chapters 2 and 3, this reinforces the concept that simulations should be as realistic as possible (eg. the dedicated simulations as used in the offshore industry) to identify any problems in skill-based tasks in parallel with the more complex problem-solving tasks.

The TPRC model may also be useful in the development of decision-support systems for use in an emergency. For example, an emergency manager may be able to estimate the escalation of the fire and the estimated time of the helicopter and then make a decision to wait or to evacuate by lifeboat. However, the emergency manager has many important decisions to make; therefore assistance with the calculations (incorporating all the variability) would be useful. The TPRC model may indicate that the helicopter is unlikely to arrive on time. This would guide the emergency manager towards planning a boat evacuation rather than letting the situation force him to do this at the last minute therefore increasing the risk.

The TPRC model could also be useful in design. For example, it could help identify which mitigation system is the most effective. For example, is it more useful to get a fire team on to the site (involving an initial delay but stronger impact on the fire) or activating a deluge (involving no initial delay but having a lesser impact on the fire). This also could have implications for the emergency procedures, by determining what the priority actions should be. Good design, like training, may also affect the probability of success through psychological influences. For example, if an emergency manager is confident in the reliability or effectiveness of a system, he is less likely to delay in initiating this system. The same issue applies for resources such as procedures. Therefore, this research has bridged the gap between design and emergency management.

The common-sense objective approach of the TPRC to assess the impact of emergency management on risk does not confirm or contradict the current theories of decision-making, leadership or the various styles of emergency management. Currently, the contribution of decision-making is not supplied by the model itself - but by its user. As for emergency management style, any actions that are taken that change the physical state of the emergency can be modelled. The means by which these actions are promoted is currently to the discretion of the emergency manager. It is possible that these styles could be compared in objective terms using the same scenario. However, as this was not carried out within this research project, no conclusions can be drawn as yet.

With regard to emergency action, one of the recommendations that was brought forth in the Safety Case (1992) Recommendations in response to the Piper Alpha disaster was the introduction of "competency assessments". This required training and assessment of the OIMs and their teams in physical tasks (lifeboat & muster drills etc.) and emergency management. This created problems for the decision-making aspects as it was difficult to define objective criteria for a complex cognitive task. Therefore, OPITO (1998) proposed a number of requirements, on which the assessors could base their judgments of competency (shown in Appendix 1).

Other research attempted to identify what the ideal characteristics of an emergency manager were. These were generally found to include leadership qualities, delegation skills and dealing with stress in oneself and others.

However, these findings may have drawn the attention away from the important issues. The main focus of emergency management should be on managing the emergency. This is a physical set of events, which changes over time. A fire is not put out if the emergency manager is a great leader. A suffering casualty does not recover if the emergency manager is good at delegating tasks. The leaking valve is not isolated if the emergency management team are all excellent at the skill of managing stress. The only attributes that make a difference in an emergency are those that have an impact on the physical events. Nevertheless, as stated earlier, the competency assessments in this project were found to be based on other aspects as well as the quality, timeliness and communications and responses to the decisions. Currently, it appears that the focus of competency assessment is placed on "behaviour that is believed to correlate with successful emergency response implementation" rather than the successful implementation itself. This makes it very difficult to produce industry-wide criteria for emergency management performance.

Therefore, OPITO should be encouraged to develop techniques that ensure reliable assessment of emergency management. This may include competency assessment of the assessors or use of objective assessment techniques. As stated in the literature review, offshore accident statistics have not improved as much as was hoped since the "step change in safety" was introduced in 1997 (Gibb 1999b). It should be noted that the competency of offshore emergency managers could never be guaranteed by using simulations and subjective techniques, if at all! The TPRC model could be a useful tool in this issue – to objectively demonstrate to the emergency managers the extent of the risk they produced or averted – and over a number of scenarios, the degree of improvement they made. However, it should be emphasized that although the TPRC model represents an objective assessment of the impact of emergency management on risk, this is no substitute for the competency assessment. The competency assessment should examine not only whether the decisions are successful, but whether the emergency manager attempted all the possible interventions. However, The TPRC model has successfully contributed to bridge the gap between the areas of human reliability, emergency management and quantitative risk assessment in an objective and probabilistic technique.

Apart from this, there are implications for other fields outside of the research area. The TPRC relies on modelling from many areas of study. Exercise physiology, Biomechanics and Anthropometry provide some information in the area of human physical performance, but this is very sporadic. The estimated escalation of injuries is a controversial area of research but could be collected from various case studies. However, due to the specific descriptions used in these reports, it is recommended that this should be carried out by someone with specific medical knowledge. The technical information on independent systems (for example, helicopters, standby boats) is generally very good. However, obtaining the performance and reliability information for dependent systems (linked processing plant equipment) is usually difficult due to their complexity. In terms of a petrochemical emergency escalation, the information usually required is concerned with fires or gas-leaks. Although there is a great deal of research in this area, it is rarely tailored to produce the data required for input into the model. Therefore, further research in all of these areas would contribute to the successful use of the TPRC model.

SECTION 12.8: CONCLUSIONS

12.8.1: BRIEF OVERVIEW OF ACHIEVEMENT OF OBJECTIVES

This section will describe the objectives, the extent to which they were met and why.

Objective 1. To develop a method of obtaining objective data on management performance from emergency scenarios

A method of data-collection was developed to be flexible enough to cater for changing circumstances in scenario organisation and design. Data were collected from emergency management scenarios using video-recording and formulated as transcripts including the relevant timing information. However, due to the organisation of the scenarios being outside of the control of the author, certain data could not be collected – such as the information being transmitted by the scenario organisation team. Also, the data were subject to interpretation where the recording and/or the original information were not clear – therefore some subjectivity was introduced into the process. Despite this, in the main, Objective 1 was deemed to have been met successfully in that adequate data were available for the achievement of Objective 2.

Objective 2. To develop a methodology to use these data to assess the probability of success in emergency management tasks.

A method was developed to address this objective that incorporated the use of a TPRC model as follows. The scenario-transcripts were interpreted in terms of their description of the physical events and emergency management team actions that impacted on the outcome of the emergency. These data were inputted into the TPRC model – purpose-adapted for this process - but additional data were required to support the process collected from literature-based sources. As this objective was primarily mathematical in its basis, the output from the model of probability of success functions with respect to time deemed that this objective was successfully achieved to completion. The main difficulty in this process occurred in the post-hoc collection of additional data from literature sources. If, as recommended previously, scenario design develops into a more scientific process, these data should be collected at the scenario-design stage and therefore reduce the reliance on post-hoc research.

Objective 3. To demonstrate how these methods can be used to evaluate the impact of changes in emergency management skill and design on risk values.

Given that Objective 2 was successfully achieved, it was then required to provide substance to its results by demonstrating that it could appropriately represent the impact of change on risk – by showing that differences in emergency management skill and design would influence the probability of success in emergency management tasks in the expected way. This demonstration was carried out by identifying the attributes that were observed as making a difference in real emergencies, interpreting their impact on the parameter values in the model and using them in the method. This was carried out for a number of different scenarios and tasks, including real tasks from the Piper Alpha disaster. The resulting change in the probability of success functions demonstrated success in this objective. However, the degree of success could only be established by the interpretation of these results and their applicability for use in risk assessment. When used in conjunction with event trees and fault trees, and in comparison with other methods, namely HAZAN and HEART, it was notable that the TPRC model catered neither for the impact of cognitive aspects on task success – nor the conditional probability of previous events. In a theoretical sense, this provided valuable insight into the divide between the definitions of unreliability used by the Human Reliability and Engineering communities – that of the differences between "human error" and "failure". For this goal, the TPRC model's results for "emergency management task success" may go some way to drawing together this divide, but whilst it does not incorporate the critical aspect of decision-making, it does not wholly fulfil the requirements of Risk Assessment. This aspect was beyond the scope of this research and, as recommended previously, should be a key objective of future research in this area.

Objective 4. To use the above methodology and data to define performance parameters that can be applied to evaluate generic emergency situations.

To be able to use the model for testing such changes as those occurring with designs, it is desirable to be able to carry out this without relying on scenario data – therefore aiming for a foreseeable future where the TPRC model can be carried out at the design stage of an installation to test the survivability of emergencies and the feasibility of emergency plans and procedures before any construction has taken place. For this reason, it was decided to re-use the scenario-transcripts – re-interpret the timings, categorise the timings in terms of specific events and actions as well as decomposing them into component parts identified as generic categories – these were called performance parameters. For the generic performance parameters, these produced distributions of timings. Using the structures of events observed as a pattern (situational awareness, decision, communication, action, response), these were then reapplied in the model to represent the impact of the fastest, average and slowest examples of each type of action/communication on the probability of success function. These produced results that could not only indicate where the observed scenario performance lay within a range of "possible" performances, but also allowed imagined scenarios and designs to be tested with realistic timings for human performance. All of the available scenarios within the research were decomposed to their full extent to produce these distributions. However, as consistent with the scope of this objective, it is notable that these performance parameters may not apply to other industries, installations, emergency management teams or emergency situations. Therefore, further data collection in other domains is required to establish a more representative set of data for future analysis.

This concludes the overview of the achievement of objectives.

12.8.2: BRIEF OVERVIEW OF CONTRIBUTION TO RESEARCH

Therefore, the research has contributed to knowledge in the following ways:

- Providing insight into the nature of risk as well as the factors that influence it in an emergency - through the production of probability of success functions.
- Providing a generic and flexible method of assessing human reliability in emergency management tasks - that has the potential to be totally objective in the future.
- Identifying that human unreliability may be assessed in terms of psychological (error) and system (failure) factors - and these are not necessarily linked.
- Using simulation data to validate the method and obtain a probability of success curve for the observed tasks.
- Using real-life data to show how this method can represent and analyse incidents and make recommendations for future changes
- Proving that this method can be used at the design stage of an installation and for novel situations.
- Providing performance parameter data including responses that can be used as a benchmark for emergency management performance, in the TPRC model or as a planning, design or assessment tool.

Chapter 13

REFERENCES

Adamson, Janusz. (1999) *Tutor - Assessment of Threat Management.* DERA Publication, Sevenoaks, Kent.

Adelman, Leonard. Tolcot. Martin A. & Bresnick, Terry A. (1993). "Examining the effect of information order on expert judgment". Organisational Behaviour and Human Decision Processes. Vol. 56, No.3, 348-369.

Andrews, Huw (ed.) (1999). *Croner's Health and Safety in Practice: Risk Assessment.* Croner Publications Ltd. London.

Armstrong, I.J. Haston, W.S. & Maclean, J.R. (1998). *Telepresence for Medical Decision Support Offshore.* http://www.rgu.ac.uk/subj/rgit/research/ofshore.htm (29th July 1999)

Arnold, John. Robertson, Ivan T. & Cooper, Cary L. (1991) *Work Psychology: Understanding human behaviour in the workplace.* Pitman Publishing, London

Asmolov, V.G. (1997) "Development of the methodology and approaches to validate safety and accident management". Nuclear Engineering and Design, Vol.173, 229-237.

Baldwin, Richard. (1994). "Training for the management of major emergencies". Disaster Prevention and Management, Vol.3, No.1, 16-23.

Baron, Robert A. & Byrne, Donn. (1991). *Social Psychology: Understanding Human Interaction.* Allyn & Bacon, Boston. 6th edition.

Barrell, A. (1992). Control of major hazards offshore - implementing Lord Cullen's recommendations. In: *Symposium on Major hazards onshore and offshore*, 20-22 Oct 1992, UMIST, Manchester.

Bartlett, S. Richardson, G.M. Krewski, D. Rai, S.N. & Fyfe, M. (1996). "Characterizing Uncertainty in risk assessment - conclusions drawn from a workshop". Human and Ecological Risk Assessment, Vol.2, No.1, 221-231.

Bea, R., Holdsworth, R. & Smith, C. (1996). Introduction to human and organizational factors in the safety of offshore platforms. In: *1996 International workshop on human factors in offshore operations*, December 1996, University of California, Berkeley.

Bellamy, Linda J. (1994). "The influence of human factors science on safety in the offshore industry". Journal of Loss Prevention in the Process Industries, Vol. 7, No. 4, 370-375.

Bellamy, Linda J. & Brabazon, Philip G. (1993). Problems of understanding human behaviour in emergencies. In: *Conference on Response to Incidents Offshore*. 8-9 June 1993, Aberdeen. 1-19.

Bellamy Linda J & Geyer, Tim A.W. (1991). Incorporating human factors into formal safety assessment: the offshore safety case. In: *3rd International Conference on Management and Engineering of Fire Safety and Loss Prevention*, Aberdeen, Scotland, 18-20 Feb 1991. Ch. 25, 55-63.

Bellini, James. (1986). *High Tech Holocaust*. David & Charles, Newton Abbot.

Bello, G.C. & Colombari, V. (1980). "The human factors in risk analyses of process plants: the control room operator model 'TESEO'". Reliability Engineering, Vol. 1, 3-14.

Bergman, David. (1999). The safety debate: Corporate Killing. The Safety and Health Practitioner. March 1999. 18-22.

Beroggi, Giampiero E.G. Waisal, Laurie. & Wallace, William A. (1995). "Employing virtual reality to support decision making in emergency management". Safety Science, Vol. 20, No. 1, 79-88.

BHP. (1994). Private Correspondence.

Blackman, Harold S & Byers, James C. (1995). Development of a behaviourally based human reliability analysis method. In: *39th Annual Meeting of the Human Factors and Ergonomics Society*. 9-13 Oct 1995, San Diego, CA. Ch.273, 1006-1010.

Bley, Dennis. Kaplan, Stan. & Johnson, David. (1992). "The strengths and limitations of PSA: where we stand". Reliability Engineering and System Safety, Vol. 38, No. 1, 3-26.

Boating Basics (1999). *Accidents: Hypothermia*. At: http://boatsafe.com/nauticalknowhow/boating.8_8.htm (3rd January 1999).

Boef, W. J. C. (1992a). "Launch and impact of free-fall lifeboats: part 1, Impact theory". Ocean Engineering, Vol. 19, No. 2,119-138.

Boef, W. J. C. (1992b). "Launch and impact of free-fall lifeboats: part 2, Implementation and applications". Ocean Engineering, Vol. 19, No. 2, 139-159.

Bolsover, Andy J. Skramstad, Erik. & Lyon, Angus M. (1998) Uncertainty in QRA. In: *7th Annual Conference on Offshore Installations: Hazard Management*. 1st December, London, UK.

Booth, Simon. (1990). "Interactive simulation and crisis management training". Contemporary Crises, Vol. 14, 381-394.

Bradley, Edgar A. (1995)."Determination of human error patterns: the use of published results of official enquiries into system failures". Quality and Reliability Engineering International, Vol.11, No.6, 411-427.

Brand, J. (1988). "Sea Survival". Safety Practitioner, September 1988, 32-33.

Brandie, E.F. (1995). Offshore operations - an emergency management process map. In: *IMECHE Conference on Emergency Planning and Management.* 21-22 Nov 1995, London, England. Ch.10, No.6, 41-47.

Breznitz, Shlomo & Ben-Zur, Hasida. (1997) Enhancing effective decision making by information management techniques. In: Flin, Rhona, Salas, Eduardo, Strub, Michael & Martin, Lynne (1997) *Decision making under stress: emerging themes and applications.* Ashgate, Aldershot.

Brown, Colin. (1997) Six Disasters; 368 people dead; no successful prosecutions. Now the Government acts. *The Independent newspaper.* 2nd October 1997.

Bukowski, Richard, W. (1997). Fire hazard analysis. In: Cote, A.E. et al (1997) *Fire Protection Handbook.* National Fire Protection Association, Quincy, MA. 18th Edition, Section. 11, Ch. 7, 70-77.

Burke, Eugene. (1997). Psychological research and development in the London fire brigade. In: Flin, Rhona. Salas, Eduardo. Strub, Michael. & Martin, Lynne (1997). *Decision making under stress: Emerging themes and applications.* Ashgate, Aldershot.

Burmaster, David E. (1996). "Benefits and costs of using probabilistic techniques in human health risk assessments - with an emphasis on site-specific risk assessment". Human and Ecological Risk Assessment, Vol.2, No.1, 35-43.

Butler, David J. (1992). "An experimental investigation into the effects of uncertainty on rational behaviour in two-person symmetric games". Journal of Behavioural Decision Making, Vol. 5(4),283-301.

Carrington, Clark D. (1996). "Logical probability and risk assessment". Human and Ecological Risk Assessment, Vol. 2, No. 1, 62-78.

Carrol, George. & Kidd, Stewart. (1991). Emergency training inside industry. In: *3rd International Conference on Management and Engineering of Fire Safety and Loss Prevention.* 18-20 Feb 1991, Aberdeen. 145-156.

Carter, A.D.S. (1986). *Mechanical Reliability.* Macmillan Press, London.

Cassidy, K. (1988). "Emergency planning for major hazards". The Safety Practitioner, June 1988. 15-17.

Catton, Ivan & Lim, Hakkyu (1994). "The impact of phenomenological uncertainties on an accident management strategy". Reliability Engineering and System Safety, Vol.45, No.1-2,175-194.

Chamberlain, Geoff A. (1996). "The hazards posed by large-scale pool fires in offshore platforms". Process Safety and Environmental Protection, 74, B2, p.81-87.

Chamberlain, Geoff A. (1998). Advances in Understanding Offshore Fire Hazards: An Extended Abstract. In: 7th *Annual Conference on Offshore Installations: Fire and Explosion Engineering.* 2nd December 1998. Church House Conference Centre, London. UK.

Christen, P. Bohneblust, H. & Seitz, S. (1994). "A methodology for assessing catastrophic damage to the population and environment - A quantitative multiattribute approach for risk analysis based on fuzzy set theory". Process Safety Progress, Vol. 13, No. 4, .234-238.

Clemmensen, Torkil (1995). Observation in maritime emergency management. In: 6th *IFAC/IFIP/IFORS/IEA Symposium on analysis, design and evaluation of man-machine systems.* 27-29 Jun 1995,MIT, Cambridge, MA. Ch 117,655-660.

Coastguard Agency, The. (1997). *The Coastguard Agency: Press Release 51-97.* http://www.coastguard.gov.uk/pandp/1997/51-97.htm (7th August 1998).

Coastguard, HM. (1996). *Statistics 96.* http://www.coastguard.gov.uk/hmcg/stat96.htm (21st January 1998).

Cohen, Marvin S. Freeman, Jared T. & Wolf, Steve. (1996). "Metarecognition in time-stressed decision making: recognizing, critiquing and correcting". Human Factors, Vol. 38, No. 2, 206-219.

Cojazzi, Giacomo. (1996). "The DYLAM approach for the dynamic reliability analysis of systems". Reliability Engineering and System Safety, Vol. 52, 279-296.

Cox, R.A. & Miles, A. (1991). Treatment of escalation mechanisms in the quantitative risk assessment of offshore platforms. In: 3rd *International Conference on Management and Engineering of Fire Safety and Loss Prevention.* 18-20 Feb 1991, Aberdeen, Scotland. 15-26.

Cox, Sue. & Flin, Rhona. (1998a). "Editorial: Safety culture". Work & Stress, Vol. 12, No. 3, 187-188.

Cox, Sue. & Flin, Rhona. (1998b). "Safety culture: philosopher's stone or man of straw?". Work & Stress, Vol. 12, No. 3, 189-201.

Cox, Tom. (1993). *Stress*. MacMillan Press, London.

Cox, T. & Mackay, C.J. (1976). "A psychological mode of occupational stress". A paper presented to Medical Research Council meeting *Mental Health in Industry*. November, London.

Crawley, F.K. & Grant, M.M. (1997). "Concept risk assessment of offshore hydrocarbon production installations". Transactions of IChemE, Vol. 75, Part B., August 1997, 157-163.

Cullen, The Hon Lord. (1990). *The Public Inquiry into the Piper Alpha Disaster*, HMSO, London.

Daniel, Jeremy & Westwood, John. (1997) Standby ships: the true cost. Offshore Engineer, May 1997,45.

Danielsson, Mats. and Ohlsson, Kjell. (1997) Models of decision making in emergency management. In: Harris, Don (ed) (1997) Engineering Psychology and Cognitive Ergonomics, Vol.2. Job Design and Product Design, Ashgate, Aldershot.

David, Glyn. (1996). Lessons from offshore aviation - towards an integrated human performance system. In: Flin, Rhona. & Slaven, Georgina (1996a) *Managing the offshore installation workforce.* Penwell Books, Tulsa, Oklahoma.

Davoudian, Keyvan, Wu, Jya-syin & Apostolakis, George. (1994a). "Incorporating organizational factors into risk assessment through the analysis of work processes". Reliability Engineering and System Safety, Vol. 45, 85-105.

Davoudian, Keyvan, Wu, Jya-syin & Apostolakis, George. (1994b). "The work process model (WPAM)". Reliability Engineering and System Safety, Vol. 45, 107-205.

Department of Health. (1996). *The Patient's Charter.* Crown Copyright. Cited on http://www.doh.gov.uk/pcharter/patient4.htm (1st March 1999) and http://www.surreyweb.org.uk/wsha.health5.html (1st March 1999).

Devooght, Jacques. & Smidts, Carol. (1996). "Probabilistic dynamics as a tool for dynamic PSA". Reliability Engineering and System Safety, Vol. 52, 185-196.

Dhillon, Balbir S. (1990). "Human error data banks". Microelectronics and Reliability, Vol.30, No. 5, 963-971.

Dhillon, Balbir S. & Rayapati, Subramanyam. (1988). "Human performance reliability modelling". Microelectronics and Reliability, Vol. 28, No. 4, 573-580.

Doheny, J.G. & Fraser, J.L. (1996). "MOBEDIC - a decision modelling tool for emergency situations". Expert systems with applications, Vol. 10, No. 1, 17-27.

Dougherty, Ed M. (1993), "Context and human reliability analysis". Reliability Engineering and System Safety, Vol.41, No.1,25-47.

Dougherty, Ed M. (1997)."Is human failure a stochastic process?" Reliability Engineering and System Safety, Vol.55, No.3, 209-215.

Dougherty, Ed M. & Collins, E.P. (1996). "Assessing the reliability of skilled performance". Reliability Engineering and System Safety, Vol. 51, No. 1, 35-42.

Dowell, J. (1995). "Coordination in emergency operations and the tabletop training exercise". Travail Humain, Vol. 58, No.1, 85-102.

Dowell, John. Pidgeon, Nick & Long, John. (1995) *ColTrain: the Collaborative Training Project.* http://www.soi.city.ac.uk/homes/jdowell/ColTrain/html#staff (3rd Oct 1997). Main author can be contacted at Centre for HCI Design, City University, London.

Dumire, Russell. & Peitzman, Andrew B. (1999) *Field Management and Priorities in Trauma Patient Resuscitation.* http://www.emsmagazine.com/articles/emsarts/priorities.html (1st Mar 1999)

Ellison, P.G. Monson, P.R. & Thomas, W.A. (1992). Severe accident containment risk assessments: severe accident management & training. In: *9th International Simulators Conference.* 6-9 Apr 1992, Orlando, FL. Vol. 4, Ch.63, No.4, 323-326.

Embrey, David E. (1986) SHERPA: A systematic human error reduction and prediction approach. In: International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxville Tennessee.

Embrey, David E. & Reason, James T. (1986) The application of cognitive models to the evaluation and prediction of human reliability. In: *Advances in Human Factors in Nuclear Power Systems,* 21-24 Apr 1986, Knoxville, Tennessee. 292-301.

Endsley, Mica R. (1994). Situation Awareness in dynamic human decision making: Theory. In R.D.Gilson, D.J.Garland & J.M.Koonce (Eds.) *Situation Awareness in Complex Systems.* 27-58. Embry-Riddle Aeronautical University Press, Daytona Beach, Florida.

Faith, Nicholas. (1999) *Blaze. The Forensics of Fire.* MacMillan Publishers Ltd. London.

Falker, J.M. & Nickerson, W. (1996). "A new direction for safety policy: The Offshore Oil Industry and Safety Regulation of Technology. Technology in Society, Vol. 18, No. 4, 503-510.

Fennell, Desmond (1988) *Investigation into the King's Cross Underground Fire.* Department of Transport, HMSO, London.

Fielder, F.E. (1978). Contingency Model and the Leadership Process. In: L. Berkowitz (Ed.). *Advances in experimental social psychology* (Vol. 11). Academic Press, New York.

Finucane, M (1994). "The Adoption of Performance Standards in Offshore Fire and Explosion Hazard Management". Fire Safety Journal, Vol. 23, No. 2, 171-184.

Fleming, Mark. Flin, Rhona. Mearns, Kathryn & Gordon, Rachael. (1998). "Offshore workers' perceptions of risk". Risk Analysis, Vol. 18, No. 1, 103-110.

Flin, Rhona. (1998) Safety condition monitoring: Lessons from Man-Made Disasters. Journal of Contingencies and Crisis Management, Vol. 6, No. 2, June 1998, 88-92.

Flin, Rhona. Mearns, Kathryn. Gordon, Rachael. & Fleming, Mark. (1996). "Risk perception by offshore workers on UK oil and gas platforms". Safety Science, Vol. 22, No. 1-3, 131-145.

Flin, Rhona. & Slaven, Georgina. (1995). "Identifying the right stuff: Selecting and training on-scene emergency commanders". Journal of Contingencies and Crisis Management, Vol. 3, No. 2, June 1995, 113-123.

Flin, Rhona. & Slaven, Georgina. (1996a). *Managing the offshore installation workforce.* Penwell Books, Tulsa, Oklahoma.

Flin, Rhona. & Slaven, Georgina. (1996b). "Personality and emergency command ability". Disaster Prevention and Management, Vol. 5, No. 1, 40-46.

Flin, Rhona. Slavin, Georgina & Stewart, Keith. (1996). "Emergency decision making in the offshore oil and gas industry". Human Factors, Vol. 38, No. 2, 262-277.

Flin, Rhona. Slaven, Georgina & Whyte, Fiona. (1996). Selection for hazardous occupations: offshore oil installations. In: Smith, Mike. & Sutherland, Valerie. (eds.) (1996) *International Review of Professional Issues in Selection and Assessment,* Vol. 2. John Wiley, Chichester.

Førland, Arild (1992). Simulation of evacuation, escape and rescue. In: *Symposium on Major Hazards Onshore and Offshore,* 20-22 Oct 1992, UMIST, Manchester. 679-687.

Forster, Mel. (1996). *Training for stressful environments: Implications for the Royal Navy.* British Crown Copyright/DRA, HMSO. 240-245. Author can be contacted at Psychology Department, Centre for Human Sciences, DRA, Portsmouth.

Fraser, Ramsay & Wilkie, Iain. (1998). Recent practical examples of structural response to blast loads. In: *7th International Conference on Offshore Installations: Fire and Explosion Engineering.* 2nd December 1998, London, UK.

Free, F.W. (1987). The Use of Helicopters for the Emergency Evacuation from Offshore Installations. Unpublished report for the Department of Energy.

Füredi, Frank. (1997) *The dangers of safety.* http://www.informinc.co.uk/LM/LM92/LM92_Safety.html (4th Nov 1997).

Furuta, Kazuo. & Kondo, Shunsuke. (1992). "Group reliability analysis". Reliability Engineering and System Safety, Vol. 35, 159-167.

Gertman, D.L. Haney, L.N. & Sui , N.O. (1996). "Representing context, cognition and crew performance in a shutdown risk assessment". Reliability Engineering and System Safety, Vol. 39, No. 1, 25-34.

Gibb, Bob. (1999a). Safety offshore found wanting. The Safety and Health Practitioner, September 1999, 9.

Gibb, Bob. (1999b). Safety Step Change debated at Offshore Europe. The Safety and Health Practitioner, October 1999, 6-7.

Gibb, Bob. (2000). Devotional rescue: Safety in the North Sea. The Safety and Health Practitioner, October 2000, 22-24.

Granlund, Rego. (1999) *Web-based micro-world simulation for emergency management training.* In: International Conference on Web-based modelling and simulation 1999. http://www.ida.liu.se/~reggr. (7th Aug 1999). Author can be contacted at Dept of Computer and Information Science, Linköping University, Sweden.
Graziano, Anthony M. & Raulin, Michael L. (1989) *Research Methods - A process of inquiry.* Harper & Row, New York.

Gudmestad, O. (1996) The role of human and organizational factors in the construction, fabrication and installation of offshore production facilities. In: *1996 International workshop on human factors in offshore operations.* December 1996, University of California, Berkeley. Working Group B. 1-47.

Hales, K. (1995). "Insurance - Piper Alpha "et al". Energy Exploration and Exploitation, Vol. 13, No. 2-3, 253-260.

Hannaman, G.W. & Worledge, D.H. (1988). *Some Development in Human Reliability Analysis Approaches and Tools. In: Accident Sequence Modelling: Human Actions, System Response, Intelligent Decision Support. (eds: Apostolakis, G.E. Kafka, P. & Mancini, G.)* Elsevier Applied Science, London.

Harrald, J.R. Mazzuchi, T.A. Spahn, J. Van Dorp R. Merrick, J, Shrestha, S. & Grabowski, Martha. (1998). "Using system simulation to model the impact of human error in a maritime system". Safety Science, Vol. 30, 235-247.

Health and Safety Executive. (1992). Occupational Exposure Limits: Criteria Document Summaries. EH64 / 92. HSE Books, London.

Health and Safety Executive. (1993). A guide to the offshore installations (safety case) regulations (1992). Guidance on Regulations, HSE Books, London.

Health and Safety Executive. (1996a). Health and Safety Regulations. (HSC 13). HSE Books, London. http://www.open.gov.uk/hse/regulat.htm

Health and Safety Executive. (1996b). Proposal for Regulations implementing the Directive on the Control of major accident hazards involving dangerous substances, Consultative Document, CD 128, HSE Books, London.

Health and Safety Executive. (1997a). Offshore hydrocarbon releases statistics 1997 - OTO 97 950, HSE Books, London.

Health and Safety Executive. (1997b). Offshore accident and incident statistics report 1997 - OTO 97 951. HSE Books, London

Health and Safety Executive. (1998a). Carbon monoxide: health hazards and precautionary measures. EH43 / 98. HSE Books, London.

Health and Safety Executive. (1998b). Occupational Exposure Limits. EH40 / 98, HSE Books, London.

Health and Safety Executive. (1998c). "Design Performance Indicators Project aimed at risk reduction". Offshore research focus July 1998, 2. HSE Books, London.

Health and Safety Executive. (1998d). *Safety Statistics Bulletin 1997/98*. HMSO, London.

Health and Safety Executive (1998e). *The Offshore Safety Division (OSD).* http://www.open.gov.uk/hse/osd.htm (8th July 1998).

Health and Safety Executive. (1999). *Safety Statistics Bulletin 1998/99*. HMSO, London.

Heyes, A.G. (1995) "PRA in the nuclear sector, quantifying human error and human malice". Energy Policy, Vol.23, No.12, 1027-1034.

Hockey, G. Robert J. (1997) "Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework". Biological Psychology, Vol.45, No.1-3, 73-93.

Hollnagel, Erik. (1993). *Human Reliability Analysis: Context and Control.* Harcourt Brace & Co. London.

Hollnagel, Erik (1996)."Reliability analysis and operator modelling". Reliability Engineering and System Safety, Vol.52, No.3, 327-337.

Hollnagel, Erik (1997). "Reply to "A practitioner's view on the state of HRA methodology"". Reliability Engineering and System Safety. Vol. 55, 261-262.

Hollywell, Paul D. (1996). "Incorporating human dependent failures in risk assessments to improve estimates of actual risk". Safety Science, Vol.22, No.1-3, 177-194.

Holt, Allan St.John. & Andrews, Huw. (1993) *Principles of Health and Safety at Work.* IOSH Publications, Wigston.

Hope, Jenny. (1999). Miracle of the Ice Girl. In: *Daily Mail.* October 8th 1999. p.31.

Howell, David C. (1987). *Statistical Methods for Psychology.* 2nd Edition, PWS-Kent Publishing, Boston.

Hsueh, Kae-Sheng & Mosleh, Ali. (1996). "The development and application of the accident dynamic simulator for dynamic probabilistic risk assessment of nuclear power plants". Reliability Engineering and System Safety, Vol. 52, 297-314.

Idzikowski, Chris & Baddeley, Alan D. (1983) Fear and Dangerous environments. In: Hockey, G.R.J. (1983) *Stress and fatigue in human performance.* John Wiley & Sons, London. Ch. 5, 123-144.

Institute of Petroleum. (1998) *Offshore Petroleum Industry Training Organisation.* http://www.petroleum.co.uk/opito.htm (9th October 1998).

Johannesen, Leila. (1997) *Going behind the label "Human Error".* http://www.dtic.dla.mil/iac/cseriac/gv394err.html (8th Oct 1997). Author can be contacted at: Cognitive Systems Engineering Laboratory, Department of Industrial and Systems Engineering, Ohio State University, Columbus.

Johnson, C.W. & Telford, A.J. (1996). "Extending the application of formal methods to analyse human error and system failure during accident investigations". Software Engineering Journal, Vol.1, No.6, 355-365.

Jones, A.V. (1995). Emergency planning: a regulator's perspective. IMechE Report C507/002/95.

Jones, Simon. Kirchsteiger, Christian. & Bjerke, Willy. (1999). "The importance of near miss reporting to further improve safety performance". Journal of Loss Prevention in the Process Industries, Vol. 12, 59-67.

Journal of the American Medical Association (1992). *Guidelines for Cardiopulmonary Resuscitation and Emergency Care.* At: http://hypothermia.org/jama.htm (16th Feb 1999).

Kaemp, George L. & Militello, Laura G. (1992). "The problems of decision-making in emergencies". Fire International, Vol. 135, 38-39.

Kaemp, George L. Klein, Gary. Thorsden, Marvin. and Wolf, Steve. (1996). "Decision making in complex naval command and control environments". Human Factors, Vol. 38, No. 2, 220-231.

Kahneman, D. & Tversky, A. (1972). "Subjective probability: a judgment of representativeness". Cognitive Psychology, 3, 430-454.

Kelly, G.N., Ehrhardt, J. & Shershakov, V.M. (1996) Decision support for off-site emergency preparedness in Europe. Radiation Protection Dosimetry, Vol.64, No.1-2, 129-141.

Khan, Faisal I. & Abbasi, S.A. (1997). "OptHAZOP - .An effective and optimum approach for HAZOP study". Journal of Loss Prevention in the Process Industries, Vol.10, 3, 191-204.

Khan Faisal I. & Abbasi, S.A. (1998). "Techniques and methodologies for risk analysis in chemical process industries". Journal of Loss Prevention in the Process Industries, Vol. 11, 261-277.

Khan, Faisal I. & Abbasi, S.A. (1999) MAXCRED - a new software package for rapid risk assessment in chemical process industries. Environmental Modelling & Software, Vol. 14, 11-25.

Kim, Byungjoon. & Bishu, Ram R. (1996). "On assessing operator response time in Human Reliability Assessment (HRA) using probabilistic fuzzy regression model". Reliability Engineering and System Safety, Vol.52, No.1, 27-34.

Kirchsteiger, Christian. (1997). "Impact of accident precursors on risk estimates from accident databases". Journal of Loss Prevention in the Process Industries, Vol.10, No.3, 159-167.

Kirwan, Barry. (1992a). "Human error identification in human reliability assessment. Part 1: Overview of approaches". Applied Ergonomics, Vol.23, No.5., 299-318.

Kirwan, Barry (1992b). "Human Reliability Assessment". in: Wilson, John R. & Corlett, E. Nigel. (1992). *Evaluation of Human Work: A Practical Ergonomics Methodology.* Taylor & Francis, London.

Kirwan, Barry. (1994). *A Guide to Practical Human Reliability Assessment.* Taylor & Francis Ltd. London

Kirwan, Barry. (1996a). Evolving Human Factors in Offshore Operations. In: *1996 International workshop on human factors in offshore operations.* December 1996. University of California, Berkeley.

Kirwan, Barry. (1996b). Human Reliability Assessment in the UK Nuclear power and reprocessing industries. In: Stanton, N. (Ed). *Human Factors in Nuclear Safety.* Taylor & Francis, London. 277-311.

Kirwan, Barry. (1997). "The development of a nuclear chemical plant human reliability management approach: HRMS and JHEDI", Reliability Engineering and System Safety, Vol.56, No.2, 107-133.

Kirwan, Barry. (1998a). "Human error identification techniques for risk assessment of high risk systems - Part 1: Review and Evaluation of Techniques". Applied Ergonomics,Vol.29, No.3, 157-177.

Kirwan, Barry. (1998b). "Human error identification techniques for risk assessment of high risk systems - Part 2: Towards a framework approach". Applied Ergonomics, Vol. 29, No. 5, 299-318.

Kirwan, Barry. (1999). Some developments in Human Reliability Assessment. In: Karwowski, W. & Marras, S. (eds.). *The Occupational Ergonomics Handbook.* CRC Press, London. 643-666.

Kirwan, Barry. (2000). Private correspondence. Feb 17th 2000.

Kletz, Trevor A. (1974). *HAZOP and HAZAN - Notes on the Identification and Assessment of Hazards.* Institute of Chemical Engineers, Rugby.

Kletz, Trevor A. (1988) *Learning from accidents in industry.* Butterworth & Co. Tiptree.

Kletz, Trevor A. (1996). "Inherently safer design: the growth of an idea". Process Safety Progress, Vol.15., No.1., 5-8..

Kletz, Trevor A. (1999). *HAZOP and HAZAN.* IChemE, Rugby. 4th Edition.

Kontogiannis, Tom. (1996). "Stress and operator decision making in coping with emergencies". International Journal of Human Computer Studies, Vol.45, No.1, 75-104.

Kosyachenko, S.A. Kuznetsov, N.A. Kul'ba, V.V. & Shelkov, A.B. (1998). "Emergency management, models, methods and automation". Automation and Remote Control, Vol. 59, No. 6, 765-806.

Kowalski, Kathleen Madland. (1995) "A human component to consider in your emergency management plans: the critical incident stress factor". Safety Science, Vol.20, No.1,115-123.

Kværner Oil & Gas Ltd. (1996) *QRA of Judy - Joanne Development.* Private Correspondence.

Kværner Oil & Gas Ltd. (1997) *QRA of Jade field development.* Private Correspondence.

Lagadec, Patrick. (1993). *Preventing chaos in a crisis.* McGraw-Hill, London.

Lancaster, John (1996). *Engineering catastrophes: Causes and effects of major accidents.* Abington Publishing, London. 1st edition.

Lane, J.R., Renwick, R.D. & Al-Hassan, T. (1994). "The HSE offshore fire and explosion research programme". Journal of Loss Prevention in the Process Industries, Vol.7, No.4, 376-381.

Larken, E.S.J. (1995). Practical Emergency Management. IMechE Report C507/010/95.

Leach, John. (1994). *Survival Psychology.* MacMillan, Basingstoke.

Lee, Kang W. Higgins, James J. & Tillman, Frank A. (1988) "Stochastic modeling of human performance reliability". IEEE Transactions on Reliability, Vol. 37, No. 5, 501-504.

Lees, F.P. (1994). "Major Accident Inquiries - Lawyers or Engineers?" Process Safety and Environmental Protection, Vol.72, B1, 10-14.

Lerner, Ken. (1991). "Government Negligence Liability Exposure in Disaster Management". Urban Lawyer, Vol.23, No.3., 333-353.

Liang, Gin-Shuh & Wang, Mao-Jiun. (1993). "Evaluating human reliability using fuzzy relations". Microelectronics and Reliability, Vol.33, No.1, 63-80.

Lie, T. T. (1989). Fire temperature - time relations. In: Dinenno, Philip J. Beyler, Craig L. & Custer, Richard L. (eds) (1995) *The SFPE Handbook of Fire Protection Engineering (HFPE-95)* National Fire Protection Association, Quincy, MA. (2nd edition). Section. 3, Ch. 5.

Lin, Dyi-Yih M. & Su, Yuan-Liang. (1998). "The effect of time pressure on expert system based training for emergency management". Behaviour and Information Technology, Vol. 17, No. 4, 195-202.

Lipshitz, R. (1993) Converging themes in the study of decision making in realistic settings. Klein, G. A. Orasanu, J. Calderwood, R. & Zsambok, C.E. (Eds.) (1993) *Decision making in action: Models and Methods.* Ablex, Norwood, New Jersey.

Lloyd, D.J. & Hunter, P.C. (1991). The assessment and control of offshore safety: prescriptive vs objective requirements. In: *1991 Symposium of the Safety and Reliability Society*, 18-19 Sep 1991, Sutton Coldfield, England. Ch.20, 1-11.

Loa, Wei-Whua. (1997). *Quantitative Prediction of Human Reliability using a Task Requirement - Resource Constraint Model.* Unpublished PhD thesis, Cranfield University.

Loa, Wei-Whua & Strutt, John E. (1995) Development of Human Reliability Prediction Methods Part 1: A survey of Human Reliability Assessment Techniques. In: *1st Symposium of Chinese Institute of Engineers in UK*, 1-2 April 1995, Cambridge, UK.

Loa, Wei-Whua. Strutt, John E. & Allsopp, Keith (1996). The Development of a Model for Predicting Human Reliability in System Operations. In: *5th International Conference on Human Aspects of Advanced Manufacturing: Agility and Hybrid Automation*, 7-10 Aug 1996, Maui, Hawaii.

London Ambulance Service. (1999). *Current Performance.* at: http://www.lond-amb.sthames.nhs.uk/http.dir/service/performance/current/perf_now.html (1st March 1999).

Lucas, Deborah (1992). "Understanding the human factor in disasters". Interdisciplinary Science Reviews, Vol.17, No.2., 185-190.

Lyons, Melinda N. Strutt, John E., Allsopp, Keith. Larken, E.S.J., Heels, Robin. (1998). "Development of a Methodology to Assess the Impact of Design Performance Parameters on Offshore Emergency Management". In: *7th Annual Conference on Offshore Installations: Hazard Management.* 1st December, London, UK. ERA 98-0957.

Malone, Tom. (1996). Reduction of human error through the application of human and organizational factors in design and engineering. In: *1996 International workshop on human factors in offshore operations*, December 1996, University of California, Berkeley. Working Group A.

Mansfield, D.P. (1992). Proposed offshore safety cases - a comparison with onshore CIMAH safety cases. In: *Symposium on Major Hazards Onshore and Offshore*, 20-22 Oct 1992, UMIST, Manchester, England, Vol.130, Ch.45, No.130, 39-48.

Marseguerra, M. & Zio, E. (1996). "Monte Carlo approach to PSA for dynamic process systems". Reliability Engineering and System Safety, Vol. 52, 227-241.

Matlin, Margaret, M. (1989). *Cognition.* Holt, Rinehart & Winston Inc. Fort Worth.

McIntyre, R.M. & Salas, E. (1995) Measuring and managing for team performance: emerging principles from complex environments. In R.Guzzo & E.Salas (Eds.) *Team*

Effectiveness and Decision Making in Organisations. Jossey Bass, San Francisco. 149-203.

McWhirter, Norris. (1999). *The Guinness Book of Records.* Guinness, London.

Mearns K.J. & Fenn C.E. (1993). Diet, health and the offshore worker - a pilot study, Offshore Technology Report, OTO 93 399, Robert Gordon University, Aberdeen, HSE Books, London.

Mearns, Kathryn. & Flin, Rhona. (1995). "Risk perception and attitudes to safety by personnel in the offshore oil and gas industry: a review". Journal of Loss Prevention in the Process Industries, Vol.8. No.5. 299-305.

Mearns, Kathryn. Flin, Rhona. Gordon, Rachael. & Fleming, Mark. (1998). "Measuring safety climate on offshore installations". Work & Stress. Vol. 12, No. 3, 238-254.

Meister, David. (1995). "Cognitive behaviour of nuclear reactor operators". International Journal of Industrial Ergonomics, Vol.16, No.2, 109-122.

Miller, Gerry. (1996). Further development of standards, specifications, and guidelines related to human and organizational factors (HOF) to reduce human error in offshore facilities operations. In: *1996 International workshop on human factors in offshore operations.* December 1996, University of California, Berkeley.

Miller, K. (1994) An offshore gas field safety strategy and quantitative risk assessment model. Journal of Loss Prevention in the Process Industries, Vol. 7, No.4, 331-336.

Mills, F. & Coleshaw, SRK. (1998). *Evacuation of Casualties using Freefall TEMPSC.* http://www.rgu.ac.uk/subj/rgit/research/cashand.htm (29th July 1999).

Mitroff, Ian I. (1988) Crisis management: cutting through the confusion. Sloan Management Review, Vol.29, No.2, 15-20.

Montiel, Helena. Vilchez, Juan A. Arnaldos, Josep & Casal, Joaquim (1996). "Historical analysis of accidents in the transportation of natural gas". Journal of Hazardous Materials, Vol. 51, 77-92.

Moore, Dwayne R.J. & Elliot, Barbara J. (1996). "Should uncertainty be quantified in human and ecological risk assessments used for decision making?". Human and Ecological Risk Assessment, Vol. 2, No. 1, 11-24.

Morris, Mark. Miles, Alan. & Cooper. John. (1994). "Quantification of escalation effects in offshore quantitative risk assessment". Journal of Loss Prevention in the Process Industries, Vol.7, No.4, 337-344.

Muir, Helen C. (1997). Stress and stress management. In: *Introduction to Human Factors in Aviation.* One week short course, 17-21 Feb 1997, Cranfield University.

Muir, Helen C. (1996). “Research into the factors influencing survival in aircraft accidents”. Aeronautical Journal, May 1996, 177-181.

Muir, Helen C. Bottomley, David M. & Marrison, Claire. (1996). “Effects of motivation and cabin configuration on emergency aircraft evacuation behaviour and rates of egress”. The International Journal of Aviation Psychology, Vol. 6, No. 1, 57-77.

Murphy. Kevin R. & Davidshofer, Charles O. (1991) *Psychological Testing. Principles and Applications*. Prentice Hall Publishing, London, 2nd edition.

Neal, David M. & Phillips, Brenda D. (1995). “Effective emergency management: reconsidering the bureaucratic approach.” Disasters, Vol.19, No.4, 327-337.

Nelson, Harold E. & MacLennan, Hamish (1988) Emergency movement. In: Dinenno, Philip J. Beyler, Craig L. & Custer, Richard L. (eds) (1995) *The SFPE Handbook of Fire Protection Engineering (HFPE-95)*. National Fire Protection Association, Quincy, MA. (2nd edition). Part. 2, Ch. 6, 106-115.

NIOSH (National Institute for Occupational Safety and Health). (1994). *NIOSH Pocket Guide to Chemical Hazards*. NIOSH, Diane Publishing, Cincinnati, OH.

Odell, P.R. (1995) Britain’s North Sea Oil and gas production: A critical review. In: *British Institute of Energy Economics Conference*. 11-12 Dec 1995. University of Warwick.

O’Donnell, Kevin. & Smallman, Hugh. (1993). The role of QRA offshore. In: *4th International Conference on Offshore Loss Prevention*. 3-5 Mar 1993, Aberdeen. 3-19.

Offshore Petroleum Industry Training Organisation (OPITO)(1992). *Standards of competence for managers of offshore installations*. Montrose.

Offshore Petroleum Industry Training Organisation (OPITO)(1998). Offshore Petroleum Industry Training Organisation. Montrose. at: http://www.petroleum.co.uk/opito.html (9th October 1998).

Omodei, M. Wearing, A. & McLennan, J. (1997). Head Mounted Video Recording: a methodology for studying naturalistic decision making. In: Flin, Rhona. Salas, Eduardo. Strub, Michael. & Martin, Lynne (1997). *Decision making under stress: Emerging themes and applications*. Ashgate, Aldershot.

Orasanu, Judith. (1995) Situation Awareness: Its Role in Flight Crew Decision Making. In: 8th International Symposium on Aviation Psychology. In: *8th International Symposium on Aviation Psychology*. 1995, Ohio State University, Columbus, OH. http://olias.arc.nasa.gov/publications/OSU_Orasanu/AvPs-SA.txt.html (8th Oct 1997).

Orasanu, Judith. (1997). Stress and naturalistic decision making: strengthening the weak links. In: Flin, Rhona, Salas, Eduardo, Strub, Michael & Martin, Lynne (1997) *Decision making under stress: emerging themes and applications.* Ashgate, Aldershot.

Orasanu, J. & Connolly, T. (1993). The reinvention of decision making. In: Klein, G.A. Orasanu, J. Calderwood, R. & Zsambok, C.E. (Eds.) (1993) *Decision making in action: Models and Methods.* Ablex, Norwood, New Jersey.

Orasanu, Judith & Salas, Eduardo. (1993). Team decision making in complex environments. In: Klein, G. A. Orasanu, J. Calderwood, R. & Zsambok, C.E. (Eds.) (1993) *Decision making in action: Models and Methods.* Ablex, Norwood, New Jersey.

Pape, R.P.(1992). The role of QRA in offshore safety cases. In: *Symposium on Major Hazards Onshore and Offshore*, 20-22 Oct 1992, UMIST, Manchester, England. 593-605.

Paris, Carol R.; Salas, Eduardo & Cannon-Bowers, Janis A. (2000). "Teamwork in multi-person systems: a review and analysis". Ergonomics, Vol. 43, No. 8, 1052-1075.

Park, Kyung S. & Jung, Kwang T. (1996). "Considering performance shaping factors in situation-specific human error probabilities". International Journal of Industrial Ergonomics, Vol.18, No.4., 325-331.

Parkes, K.R. (1992). Human factors, shift work and alertness in the offshore oil industry. Offshore Technology Report OTH 92 389. HMSO, London.

Paté-cornell, M. Elisabeth. (1993). " Learning from the Piper Alpha accident: a postmortem analysis of technical and organizational factors", Risk Analysis, Vol.13, No.2, 215-232.

Paté-cornell M. Elisabeth. (1995). "Managing fire risk onboard offshore platforms: Lessons from Piper Alpha and Probabilistic Assessment of Risk Reduction measures". Fire Technology, Vol.31, No.2., 99-119.

Paté-cornell M. Elisabeth. & Murphy, Dean M. (1996). "Human and management factors in probabilistic risk analysis: the SAM approach and observations from recent applications". Reliability Engineering and System Safety, Vol.53, No.2, 115-126.

Paterson, Tony (1993) *Offshore fire safety.* Penwell Books, Tulsa, Oklahoma.

Pauls, Jake. (1988). Movement of people. In: Dinenno, Philip J. Beyler, Craig L. & Custer, Richard L. (eds) (1995) *The SFPE Handbook of Fire Protection Engineering (HFPE-95).* National Fire Protection Association, Quincy, MA. (2nd edition). Part. 1, Ch. 15, 246-268.

Peacock, Richard D., Reneke, Paul A, Forney, C. Lynn & Kostreva, Michael M. (1998). "Issues in the evaluation of complex fire models". Fire Safety Journal, Vol. 30, 103-136.

Peacock, Richard D., Reneke, Paul A. & Jones, Walter W. (1996). Evaluation of complex fire models. In: *13th Meeting of the UJNR Panel on Fire Research and Safety*, 13-20 Mar 1996, Department of Commerce, National Institute of Standards and Technology, Gaithersburg, MD. Vol. 2, 81-89.

Perrow, Charles. (1984). *Normal Accidents: Living with High Risk Technologies*. Basic Books, USA.

Petty, Mikel D. Slepow, Mary P. & Horsley, Michele. (1996). "PLOWSHARES: an emergency management training simulation". Simulation, Vol.66, No.6, 357-373.

Pheasant, Stephen T. (1986) *Bodyspace - Anthropometry, Ergonomics and Design*. Taylor and Francis, London.

Pheasant, Stephen T. (1987). *Ergonomics: Standards and Guidelines for Designers*. PP 7317, British Standards Institution, London.

Pheasant, Stephen T. (1991). *Ergonomics, Work and Health*. MacMillan, London.

Pitblado, Robin. (1994). "Quality and offshore quantitative risk assessment" Journal of Loss Prevention in the Process Industries, Vol.7, No.4, 360-369.

Power, M. & McCarty, L.S. (1996). "Probabilistic Risk Assessment: Betting on its future". Human and Ecological Risk Assessment, Vol. 2, No. 1, 30-34.

Presidential Commission (1986). *Report on the Space Shuttle Challenger Accident*. Government Printing Agency, Washington DC.

Purser, David A. (1988) Toxicity assessment in combustion products. In: Dinenno, Philip J. Beyler, Craig L. & Custer, Richard L. (eds) (1995) *The SFPE Handbook of Fire Protection Engineering (HFPE-95)*. National Fire Protection Association, Quincy, MA. (2nd edition). Part. 1, Ch. 14, 200-245.

Purser, David A. (1989). "Modelling toxic and physical hazard in fires". In: Fire Safety Science - Proceedings of the 2nd International Symposium. 391-400.

Quarantelli, E.L. (1988). "Disaster crisis management: a summary of research findings". Journal of Management Studies, Vol.25, No.4, 373-385.

Quin, S & Widera, G.E.O. (1996). "Uncertainty analysis in quantitative risk assessment". Journal of Pressure Vessel Technology - Transactions on the ASME 1996, Vol.188, No.1, 121-124.

Ramabrahmam, Boppana, Sreenivasulu, B. & Millikarjunan, M. (1996). "Model on-site emergency plan - case study - toxic gas release from an ammonia storage terminal". Journal of Loss Prevention in the Process Industries, Vol.9, No.4, 259-265.

Ramsay, Cameron G., Bolsover, Andrew J., Jones, Richard H. & Medland, William G. (1994). "Quantitative risk assessment applied to offshore process installations. Challenges after the Piper Alpha disaster". Journal of Loss Prevention in the Process Industries, Vol.7, No.4, 317-330.

Rasmussen, J. & Jensen, A. (1974). "Mental Procedures in real-life tasks: A case study of electronic troubleshooting". Ergonomics, 17, 293-307.

Rasmussen, J. Pedersen, O.M. Carnino, A. Griffon, M. Mancini, C. & Gagnolet, P. (1981). *Classification system for reporting events involving human malfunctions.* Report Riso-M-2240, DK-4000, Roskilde, Riso National Laboratories, Denmark.

Read, Richard, G. (1995). The BP group approach to crisis management. *In: 1995 Symposium on Management of Safety (MANOSAF 95)*, 22 Feb 1995, Soc. Chem. Ind, London. Ch.6, 1-5.

Reason, James. (1990) *Human Error.* Cambridge University Press, Cambridge.

Redmill, Felix,Chudleigh, Morris & Catmur, James (1999). *System Safety: HAZOP and software HAZOP.* Wiley, Chichester.
Reed, John H. Rogers, George O. & Sorensen, John H. (1991). Establishing functional requirements for emergency management information systems. In: *Multiconference on Simulation in Emergency Management and Engineering and Simulation in Health Care.* 23-25 Jan 1991, Anaheim, CA. Ch.35, 168-175.

Reer, Bernhard (1994). "A probabilistic method for analysing the reliability effect of time and organizational factors". European Journal of Operational Research, Vol.75, No.3, 521-539.

Reilly, T. Secher, N. Snell, P. & Williams, C. (Eds.) (1990). *Physiology of Sports.* E & FN Spon. London.

Reinertsen, Rune. (1995). "Risk measures in practical use: risk reduction has its price, but is it known?". Reliability Engineering and System Safety, Vol.49, No.1, 47-50.

Richardson, Bill. (1994). "Crisis management and management strategy - time to "loop the loop"". Disaster Prevention and Management. Vol. 3, No. 3, 59-80.

Richardson, Bill (1995) *Socio-technical disasters: profile and prevalence.* Disaster Prevention and Management.
http://www.mcb.co.uk/services.articles/liblink/punarti/dom.richards.htm (12th Mar 1998)
Author can be contacted as Sheffield Business School, Sheffield, UK.

Richardson, G. Mark. (1996). "Deterministic versus probabilistic risk assessment: strengths and weaknesses in a regulatory context". Human and Ecological Risk Assessment, Vol. 2, No. 1, 44-54.

Robertson, J.L.M. Smart, D. & Al-hassan, T. (1996) "Offshore North Sea pipeline and riser loss of containment study (PARLOC) - Applications and Limitations in the Assessment of Operating Risks". Journal of Offshore Mechanics and Arctic Engineering - Transactions of the ASME 1996, Vol.118, No.2, 115-120.

Rogers, Martin. (1998). The Case for an Extended Life Temporary Refuge. In: 7th *Annual Conference on Offshore Installations: Hazard Management.* 1st December 1998, London, UK.

Rolfe, John M. & Taylor, A. Frank. (1989). "The training and management of personnel who will respond to aircraft disasters". Disaster Management, Vol.1, No.3, 36-41.

Rosenthal, Uriel & Pijnenburg, Bert. (1990). "Simulation-oriented scenarios - an alternative approach to crisis decision making and emergency management". Contemporary Crises, Vol.14, No.4, 277-283.

Roth, Emilie M. & Mumaw, Randall J. (1992). Enhancing the training of cognitive skills for improved human reliability: lessons learned from the cognitive environment simulation project. In: 5th *Conference on Human Factors and Power Plants*, 7-11 Jun 1992, Monterey, CA. Ch.104, 496-498.

Rundmo, Torbjørn. (1996). "Changes in risk perception among North Sea offshore personnel in the period 1990-1994". Safety Science, Vol.21, No.3, 205-221.

Rundmo, Torbjørn. & Sjöberg, Lennat. (1998). "Risk perception by offshore oil personnel during bad weather conditions". Risk Analysis. Vol. 18, No. 1.

Samuels, S.W. (1997). "Ethical and metaethical criteria for an emerging technology: risk assessment". Occupational Medicine, Vol.47, No.4, 241-246.

Samurçay, R. & Rogalski, J. (1993). "Cooperative work and decision making in emergency management". Travail Humain, Vol.56, No.1, 53-77.

Sanderson, Penelope (1997). MacSHAPA... software for observational data analysis. University of Illinois. At: http://www.csse.swin.edu.au/macshapa/index.html (14th July 1999)

Schaaf, Tjerk van der. (1999). "Humans kill 80% of all known errors - dead!". The Safety and Health Practitioner. April 1999, 6.

Schwarz, Catherine (ed.) (1991) *Chambers Concise Dictionary.* W & R Chambers Ltd, Edinburgh.

Sea-Marshall homepage. (1999). At: http://www.seamarshall.demon.co.uk/frmain.htm (1st October 1999).

Selby, C.A & Burgan, B.A. (eds.) (1998) *Blast and fire engineering for topside structures - Phase 2: Final summary report.* The Steel Construction Industry, Ascot, Berkshire.

Shafir, Eldar. (1994). "Uncertainty and the difficulty of thinking through disjunctions". Cognition, Vol. 50, No.1-3, 403-430.

Sharit, Joseph. & Malon. David M. (1991). "Incorporating the effects of time estimation into human reliability analysis for high risk situations". IEEE Transactions on Reliability, 1991, Vol.40, No.2, 247-254.

Shaw, Stephen J. (1992). "Use of risk assessment as an offshore design tool". Journal of Loss Prevention in the Process Industries. Vol.5, No.1, 10-17.

Shen, S-H., Smidts, C & Mosleh, A. (1997). "Methodology for collection and analysis of human error data based on a cognitive model: IDA". Nuclear Engineering and Design, Vol.172, No.1-2, 157-186.

Shrivastava, Paul. Mitroff, Ian I. Miller, Danny. & Migliani, Anil. (1988). "Understanding industrial crises". Journal of Management Studies, Vol. 25, No. 4, 285-299.

Siegel, Gilbert B. (1985). "Human resource development for emergency management". Public Administration Review, 52, 135-145.

Simard, A. (1997). *Global Emergency Management.* http://www.ispo.cec.be/g7/projects/theme7.html (3rd October 1997)

Skinner, David. Driscoll, Peter. & Earlam, Richard. (1996) *ABC of Major Trauma.* BMJ Publishing, London.

Skriver, Jan & Flin, Rhona. (1997). Emergency decision making on offshore installations. In: Harris, Don. (ed) (1997) *Engineering Psychology and Cognitive Ergonomics, Vol. 2, Job Design and Product Design,* Ashgate, Aldershot.

Slovic, P. Fischhoff, B. & Lichtenstein, S. (1977). "Behavioural decision theory". Annual Review of Psychology, 28, 1-39.

Smith, Denis. (1990). "Beyond contingency planning: toward a model of crisis management". Industrial Crisis Quarterly, Vol. 4, 263-275.

Smith, Denis. (1994). "Managing Behemoth. Crisis preparedness in the prison service". Prison Service Journal. 91, 37-45.

Smith, Denis. (1995). On a wing and a prayer? The human component of failure in complex systems. Unpublished report. Author can be contacted at the Liverpool Business School at Liverpool John Moores University.

Smith, E.J. (1995). "Risk management in the North Sea offshore industry: History, status and challenges". Acta Astronautica, Vol.37, 513-523.

Smith, Mike. (1996). Selection in high risk and stressful occupations. In: Smith, Mike & Sutherland, Valerie (eds.) (1996) *International Review of Professional Issues in Selection and Assessment*, Vol. 2. John Wiley & Sons, Chichester. Ch. 6, 60-80.

State of Alaska (1996). *Cold Injuries and Cold Water Near Drowning Guidelines.* (Rev 01/96). at: http://www.sarbc.org/hypo2.html (1st March 1999).

Stewart, Keith. (1994). Command team performance in simulated offshore emergencies. In: *3rd European Seminar in Human Factors in Offshore Safety.* 27-28 Sep 1994, Aberdeen, Scotland.

Stewart, M.G. (1992) "Modelling human error rates for human reliability analysis of a structural design task". Reliability Engineering and System Safety, Vol.36, No.2, 171-180.

Stewart, Stanley. (1992) *Emergency. Crisis on the Flight Deck.* Airlife Publishing Ltd, Shrewsbury.

Streger, Matthew R. (1998) *Prehospital Triage.*
http://www.emsmagazine.com/articles.emsarts/triage.html (1st Mar 1999)
Author can be contacted at Greenville County (SC) EMS.

Strutt, John E. (1994). Reliability, Risk analysis and Safety cases. Subsea Engineering Level 2. A 3 day intensive course. 1-3 Nov 1994. IBC Technical Services Ltd.

Strutt, John E. (1995). Limit State Concept. Internal Lecture Notes, CISR, Department of Marine Technology, Cranfield University, Beds, UK.

Strutt, John E. (1999). Development of key design safety performance indicators. Internal Report.

Strutt, John E. (2000). Private Correspondence. CISR, Department of Marine Technology, Cranfield University, Beds, UK.

Strutt, John E. & Lakey, John R.A. (1995). Education, training and research in emergency planning and management. IMechE Report C507/009/95.

Strutt, John E. Loa, Wei-Whua. & Allsopp, Keith. (1996). Progress toward the development of a model for predicting human reliability. In: 12th Advances in Reliability Technology Symposium (ARTS), 16-17 Apr 1996, Manchester, UK.

Strutt, John. E. Lyons, Melinda N., Allsopp, Keith., Larken, E.S.J., Værnes, Ragnar. (1997). "Development of Models and Data for Quantification of Human Reliability on Emergency Management". In: *Conference on Risk Assessment of Offshore Installations.* 18th November, London UK. ERA 97-0993.

Strutt, John E. Sharp, John. Busby, Jerry, Dealey, Peter. Tourle, Neil, Yates, Graeme. Miles, Robert. (1998). Development of design performance indicators for improved safety offshore. In: *7th Annual Conference on Offshore Installations: Hazard Management.* 1st December 1998, London, UK.

St. John Ambulance Association and Brigade, St.Andrew's Ambulance Association; The British Red Cross Society. (1997). *First Aid Manual.* Dorling Kindersley, London.

Subramaniam, Chandran (1996) Adding a surveillance subsystem to the emergency management decision support (EMDS) system. In: *12th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology/5th Symposium on Education.* 28 Jan - 2 Feb 1996, Atlanta, GA, Ch.136, 207-212.

Sullivan, James D. (1989). On the future of computer simulation in emergency management. In: *SCS Western Multiconference on Simulation in Emergency Management and Technology.* 4-6 Jan 1989, San Diego, CA. Ch.24, 120-121.

Sutherland, Valerie & Cooper, Cary L. (1996). "Stress in the offshore oil and gas exploration and production industries: an organizational approach to stress control". Stress Medicine, Vol. 12, 27-34.

Swain, A.D. & Guttman, H.E. (1983) A handbook of Human Reliability Analysis with emphasis on nuclear power plant applications. NUREG/CR-1278, Nuclear Regulatory Commission-Washington DC.

Taylor, Frederick W. (1964). *Scientific Management - Comprising Shop Management, The principles of Scientific Management and Testimony before the Special House Committee.* Harper & Row, London.

Taylor, P. (1989). *The Hillsborough Stadium Disaster Interim Report.* HMSO, London.

Taylor-Adams Sally E. (1994). Development of human error taxonomy for use with a human error database. In: *Ergonomics Society 1994 Annual Conference - Contemporary Ergonomics 1994: Ergonomics for all.* 19-22 Apr 1994, University of Warwick, Coventry. Ch.84, 329-334.

Tikuisis, P. (1995). *Predicting survival time for cold exposure.* Report Number: DCIEM-95-02 CA_ACR. Author can be contact at: Defence and Civil Inst of Environmental Medicine, Downsview, Ontario, Canada.

Tikuisis, P. (1998). *Shivering capacity and prediction of survival time*. Report Number: DCIEM-98-TM-45 CA_ACR. Author can be contact at: Defence and Civil Inst of Environmental Medicine, Downsview, Ontario, Canada.

Tikuisis, P. Belyavin, A.J. Buxton, A.C. Coleshaw, S.R.K. Higgenbottam, C. et al (1997). *Prediction of Body Cooling*. Report Number: DCIEM-97-TM-47 CA_ACR. Authors can be contact at: Defence and Civil Inst of Environmental Medicine, Downsview, Ontario, Canada.

Tikuisis, P. & Keefe, A.A. (1996). *Prediction of Sea Survival Time*. Report Number: DCIEM-96-R-12 CA_ACR. Authors can be contact at: Defence and Civil Inst of Environmental Medicine, Downsview, Ontario, Canada.

Trbojevic, V.M., Bellamy, L.J., Brabazon, P.G., Gudmestad, T. & Rettedal, W.K. (1994). "Methodology for the analysis of risks during the construction and installation phases of an offshore platform". Journal of Loss Prevention in the Process Industries, Vol.7, No.4, 350-359.

Trbojevic, V.M., Bellamy, L.J., Gudmestad, T., Rettedal, W.K. & Aarum, T. (1997). Risk Assessment in the Design Process. In: *6th International Conference on Risk Assessment of Offshore Installations*. 18th November 1997, London, UK.

Tweedale, H.M. (1992). "Balancing quantitative and non-quantitative risk assessment". Process Safety and Environmental Protection, Vol.70, No.B2, 70-74.

Ujita, Hiroshi. Kawano, Ryutaro. Yoshimura, Sandanori. (1995). "An approach for evaluating expert performance in emergency situations". Reliability Engineering and System Safety, Vol.47, No.3, 163-173.

UKOOA (1986) Medical aspects of fitness for offshore work - a guide for the examining physicians. UKOOA Ltd. London, Oct 1986.

UKOOA (1995a) Management of emergency response for offshore installations. UKOOA Ltd. London, April 1995.

UKOOA (1995b) Guidelines for fire and explosion management, UKOOA Ltd. London, May 1995

UKOOA (1997a) Management of competence and training in emergency management response. UKOOA Ltd. London, January 1997.

UKOOA (1997b) Guidelines for the management of offshore helideck operations, UKOOA Ltd. London, August 1997.

UKOOA (1997c) A step change in safety. UKOOA Ltd, London. September 1997

UKOOA (1998a) *Employment summary.* http://www.ukooa.co.uk/inform/employment.html (20th July 1998)

UKOOA (1998b) *Historical perspective.* http://www.ukooa.co.uk/inform.factfig.html (12th August 1998)

UKOOA (1998c) *Piper Alpha Media Briefing.* http://www.ukooa.co.uk/news/releases/19980626.htm (20th July 1998)

U.S. Army. *Material Safety Data Sheets.* http://www.apgea.army.mil/safety/msds/ (14th July 1998)

Vinnem, J.E. (1989). Offshore platform safety - control of jet fires by deluge systems. In: *2nd International Conference on Fire Engineering and Loss Prevention in Offshore, Petrochemical and other Hazardous Applications.* Jun 1989, Brighton, England, Ch.22, 261-270.

Vivalda, Claudia & Carpignano, Andrea. (1997). An integrated risk based approach to design and operate offshore installations. In: *6th International Conference on Risk Assessment of Offshore Installations.* 18th November 1997, London, UK.

Vroom. V.H. & Yetton, P.W. (1973). *Leadership and Decision Making.* University of Pittsburgh Press, Pittsburgh.

Watson, Milton H. (1995). *Disasters at Sea. Every ocean-going passenger ship catastrophe since 1900.* Patrick Stephens Ltd. Sparkford, Somerset. 2nd edition.

Weick, Karl E. (1988). "Enacted sensemaking in crisis situations". Journal of Management Studies, Vol. 25, No. 4, 305-317.

Weightman, Gavin. (1996) *Rescue. The History of Britain's Emergency Services.* Boxtree Ltd. London.

Wells, Celia. (1998). *Corporate Manslaughter: A cultural and legal form.* http://www.-camlaw.rutgers.edu/crimlawforum/col6num1/wells.html

Wenk, Edward. (1996). Safety, corporate culture and corporate character. In: *1996 International workshop on human factors in offshore operations.* December 1996, University of California, Berkeley.

Whalley, S.P. (1988). Minimising the cause of human error. In: *10th Advances in Reliability Technology Symposium.* Libberton, G.P. (ed), Elsevier, London.

Whittingham, Barry. (1991). The assessment of safety management systems for effective loss prevention. In: *3rd International Conference on Management and Engineering of Fire Safety and Loss Prevention.* 18-20 Feb 1991, Aberdeen.

Whyte, David, Tombs, Steve & Smith, Denis. (1995). Offshore safety management in the "new era" perceptions and experiences of workers. In: 2^{nd} *Conference on Major Hazards Onshore and Offshore*. 24-26 Oct 1995, UMIST, Manchester.

Whyte, Patrick J. (1989). "Stress offshore". The Safety & Health Practitioner. August 1989, 20-21.

Williams, J.C. (1986). HEART - a proposed method for assessing and reducing human error. In: 9^{th} *Advances in Reliability Technology Symposium (ARTS)*. University of Bradford.

Wilson, C (1991) A review of the safe evacuation of personnel from offshore installations by totally enclosed motor propelled survival craft (TEMPSC). In: 3^{rd} *International Conference on Management and Engineering of Fire Safety and Loss Prevention*. 18-20 Feb 1991, Aberdeen.

Wingerden, Kees van. Hansen, Olav. Foisselon & Lemousy, Thomas. (1998) Effect of Deluge on Explosions: FLACS Simulations compared to Full Scale Experiments. In: 7^{th} *Annual Conference on Offshore Installations: Fire and Explosion Engineering*. 2^{nd} December 1998, London, UK.

Winterfeldt, D. Von. & Edwards, W. (1986). *Decision Analysis and Behavioural Research*. Cambridge University Press, Cambridge.

Woo, G. & Muirwood, Q. (1986). North Sea Seismicity. Offshore Technology Reports. OTH86-219.

Woods, David D. (1993). Process-tracing methods for the study of cognition outside of the experimental psychology laboratory. In: Klein, G. A. Orasanu, J. Calderwood, R. & Zsambok, C.E. (Eds.) (1993) *Decision making in action: Models and Methods*. Ablex, Norwood, New Jersey.

Woods, David D., Pople, Harry E. & Roth, Emilie M. (1992). "Cognitive environmental simulation: a tool for modelling intention formation for human reliability analysis". Nuclear Engineering and Design. Vol.134, No.2-3, 371-380.

Yahoo! News. (1998). "*Oil Industry learned little from Piper Alpha*". Yahoo! News. http://www.yahoo.co.uk/headlines/980702/news/899341422-8.html

Yerkes, R.M. & Dodson, J.D. (1908). "The relation of strength of stimulus to rapidity of habit formation". Journal of Comparative Neurology and Psychology, 18, 459-482.

Yoon, Wan C. Lee, Yong H. & Kim, Young S. (1996). "A model-based and computer aided approach to analysis of human errors in nuclear power plants". Reliability Engineering and System Safety, Vol. 51, 43-52.

<u>Laws</u>

Control of Major Accident Hazards Regulations (COMAH)(1999)
Control of Industrial Major Accident Hazards Regulations(CIMAH) (1984)
Diving at Work Regulations (1997)
Health and Safety at Work Act (1974)
Health and Safety (Display Screen Equipment) Regulations (1992)
Management of Health and Safety at Work Regulations (1992)
Manual Handling Operations Regulations (1992)
Minerals Working Act (1971)
Offshore Electricity and Noise Regulations (1998)
Offshore Installations and Pipeline Works (Management and Administration) Regulations (1995)
Offshore Installations and Wells (Design and Construction etc.) Regulations (1996)
Offshore Installations (Prevention of Fire and Explosion and Emergency Response) Regulations (1995)
Offshore Installation (Safety Case) Regulations (1992)
Offshore Installations (Safety Representatives and Safety Committees) Regulations (1989)
Offshore Safety Act (1992)
Personal Protective Equipment at Work Regulations (1992)
Pipelines Safety Regulations (1996)
Provision and Use of Work Equipment Regulations (1992)
Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)(1995).
Workplace (Health, Safety and Welfare) Regulations (1992)

APPENDICES

APPENDIX 1: OPITO CHECKLIST TO ASSESS EMERGENCY MANAGEMENT PERFORMANCE - (OPITO (1992) and Flin, Slaven & Stewart (1996)

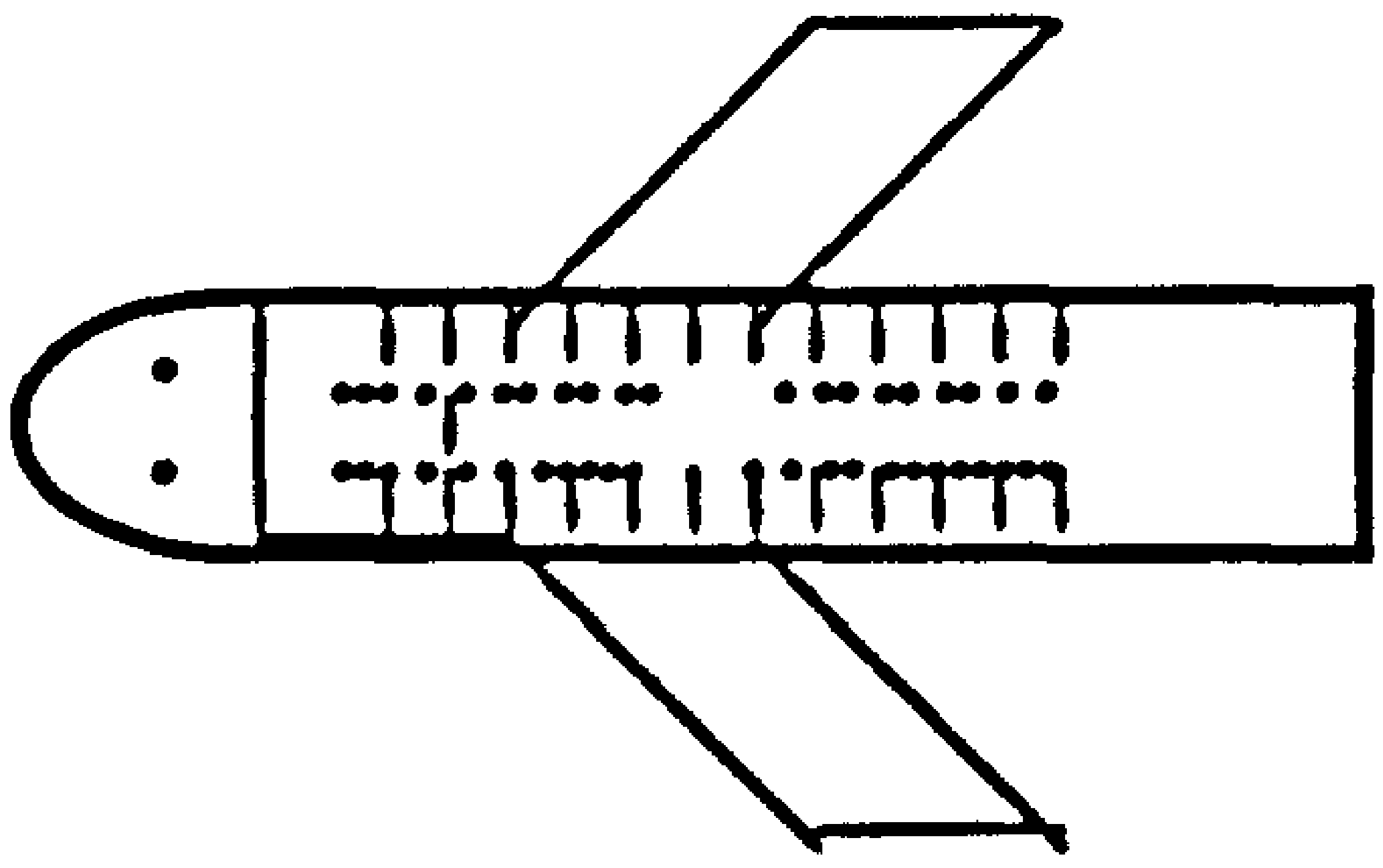
Evaluate situation and anticipate needs	**Maintain communication - Process information**	**Delegation of authority**	**Deal with stress in self and others**	**Demonstration of essential knowledge**
All relevant information obtained, evaluated and confirmed	All essential personnel and organisations immediately notified of the emergency	Appropriate tasks delegated within Command Team; tasks clear and unambiguous	Symptoms of developing excessive stress in self and colleagues are recognised quickly	Sources of help in an emergency (Coastguard, sector club, vessels, helicopter, emergency response vessels) and their facilities, methods of communication and response times
Valid interpretation made of evidence and information from all relevant sources	Installation staff updated at appropriate intervals	Appropriate responsibilities delegated off-platform; Standby Vessels and Helicopters utilised effectively; responsibilities clear and unambiguous	Appropriate action is taken to ensure the continuance of the activities	Sources of information on the properties of on site materials
Valid decisions made on the basis of information received	Essential onshore personnel and agencies updated at appropriate intervals	Satisfactory task control and monitoring channels established and maintained within Command Team	Action is taken to reduce the stress in oneself and whenever possible in colleagues	Location and operation of emergency systems (fire/gas detection, fire-fighting, comms, life saving appliances, escape systems, lifeboats)
Appropriate actions ordered in the light of information received	Appropriate communications maintained	Satisfactory control and monitoring channels established beyond command team		Layout of installation including location and functions of major pieces of equipment
Potential outcomes of the emergency reviewed against consequences / probabilities (worst, most likely, best)	Alternative communications methods established and maintained where appropriate	Command team tasks and responsibilities understood and unambiguous; Command Team effort co-ordinated effectively		Potential dangers resulting from activities in each area of the installation
Objectives clear and unambiguous	Information prioritised and processed relevantly to the demands of the situation and operational requirements; irrelevant information discarded	Overload situations monitored; duties reallocated where necessary		Safety Management Systems in operation and installation Safety Case
Resources allocated and deployed to achieve the most appropriate outcome	Information presented to facilitate effectively decision making; recording requirements met also.	External resources monitored and co-ordinated effectively as appropriate		All relevant sources of energy to prime movers
Emergency Response teams directed and co-ordinated in an effective manner				Drain, flare and vent systems
				Potential effects of crisis
				Purpose of significant control systems
				Cause and effects of significant alarms and trips
				Effects of loss of any utility and its reinstatement
				Effects of the environmental conditions on emergency response
				Potential effects of the emergency on diving operation
				Emergency Procedures
				Marine search and rescue procedures
				Causes, identification and management of stress

APPENDIX 2 : PILOT STUDY - THE INITIAL METHOD

SECTION 1: INTRODUCTION

The idea for this pilot study was based upon the computer simulations used to analyse evacuation where people are represented as dots moving towards exits similar to that shown in Figure A. Initially, this was to be a simple desktop simulation which could represent different outcomes of an emergency in response to different decisions made by an emergency manager, for example, an escalating fire in a one floor building with nine rooms and containing 5 people (including the emergency manager). It was intended that this eventually could be developed to incorporate complex environments, different sorts of incidents and varying behaviour on the part of the emergency manager and his staff. This could therefore be used to compare inexperienced and experienced, trained and untrained emergency managers.

Figure A: Example evacuation model diagram



Although representation of human behaviour in this way has been criticised as being too mechanistic (Faith 1999), it was deemed possible that the desktop simulation could be developed enough to incorporate a random element where people can behave in a number of different ways, including panicking, ignoring warnings and continuing with normal tasks, responding to warnings correctly, acting sensibly but inadvertently producing a more risky situation - all possible reactions to an emergency.

As discussed in the main report, obtaining the "big picture" of the emergency and responding with good and timely decisions is believed to be the essence of good emergency management. Therefore the desktop simulation focused on these aspects in the following way.

The "big picture" of the emergency is the description of the actual physical emergency, the cause, the escalation and the personnel involved. To represent this as a desktop simulation, it was necessary to use two boards. One board is controlled by the "scenario organiser", who is aware of the "big picture" and knows all aspects of the real emergency. This board is not revealed to the other player, the emergency manager, until the end of the simulation. This is similar to the game "Battleships" whereby people must bomb grid references and, until they get a "hit", they do not know where the ships are located. The other board is controlled by the emergency manager. Initially, they only have information as to their own location on the board, plus information on the general layout of the building and some idea of the people who are present. Information as to the escalation of the emergency and the number and location of personnel are aspects which must be obtained by the emergency manager as the simulation progresses, by travelling around the board to get information for himself or speaking to people who his "token" meets.

A "good and timely decision" is more difficult to pre-define; as in reality, it is often defined by the outcome of the decision. However, in an emergency, there are certain decisions that can be assumed as NOT good and timely, for example, to ignore the situation and to continue with normal behaviour. Therefore, it is necessary to represent the time in the simulation as well as developing a mechanism where "good" or "bad" decisions can be identified by their outcome.

To represent the time aspect of the emergency, one unit of time is taken to be one "move". The emergency manager can use his moves in a number of ways, including walking, speaking to people face-to-face, speaking to people on a tannoy or fire fighting. Also, to avoid too much complexity in the organisation of the game (although it again can be criticised as a mechanistic view of human behaviour), once the emergency manager has spoken to people, they can use "moves" in the same way but must obey his orders explicitly. As moves can be taken up by speaking, this is limited by the number of words used so it is recommended that the emergency manager is concise in his orders. However, if the meaning of the order is vague, for example "go and see if there is a fire in Room C" would result in the person doing this but then returning to his normal activity once the order has been completed. The order "go and see if there is a fire in Room C then return here" would take up more "moves" to say but would result in the intended behaviour. This allows for "errors in communication" to have an impact on the outcome of the emergency. If the emergency manager knows from the rules that his explicit orders will be obeyed and it appears that they are not, his view of the big picture will be confused and he may be forced to re-examine his communications to identify why the confusion occurred.

To test whether decisions are "good" requires more careful scientific analysis of the impact of the decision on the outcome. Ideally, this would require variations on the decisions to be tested against the outcome to identify the optimal decision in a specific scenario. In a desktop simulation situation, this requires the scenario to have pre-specified starting conditions as well as strict rules for escalation and movement of personnel. This responsibility again rests with the scenario organiser. The emergency manager token is controlled by the emergency manager, who can respond to the alarm as he pleases, which will be the first decision of the game. The other personnel tokens will continue in a pre-determined direction until ordered otherwise. In the given example, the scenario involves a fire, though a gas leak or different type of incident could also be used. The fire starts in a fixed starting position and escalates at a pre-determined rate (which need not be constant) in a pre-determined direction or direction(s). If the fire injures a person while they are carrying out their tasks, they will try to avoid it using pre-defined rules. If a fire continues to injure a person for a pre-specified number of moves, they will be initially slowed down by it and finally killed. Similarly, the fire can be fought using pre-determined rules. This strict use of rules allows numerous decisions to be tested against the same scenario and, as the outcome can be quantitatively evaluated by considering numbers of people injured or killed as well as number of "squares" of damage, the decisions can be retrospectively analysed as "good" or "bad", based on the outcome they achieve. Therefore the following desktop simulation resulted.

SECTION 2: METHOD

2.1 EQUIPMENT USED IN THE DESKTOP SIMULATION

The Rules (as given to the emergency manager - specified in 2.2)
Scenario Organiser's notes and recording table (as specified in 2.3)
Stopwatch
2 desktop boards (one showing the numbers assigned to each square - given to the emergency manager, the other also including the pattern of escalation - given to the scenario organiser and as shown overleaf)
10 two-sided name token - 2 each of "You", "John", "Paul", "George" and "Ringo". one side white, one side red.
20 safety equipment tokens
225 two-sided risk/danger tokens

2.2 THE RULES

1. You are the emergency manager of Cranfield Block. In an emergency, the safety of the people in the building is your key responsibility. The structural integrity of the building is also considered to be your responsibility.
2. Cranfield Block has nine walled rooms surrounded by corridors.
3. The people in the building will follow your explicit orders if they are able. However, some of them are not focused on the risks involved in an emergency and may not behave sensibly without such orders, and once your instructions have been completed as requested, personnel may not always continue to respond in a safe manner.
4. When a personnel piece reaches an exit (square 1 or 225), they are deemed to have left the building and therefore are safe. They may not re-enter the building but they can give radio instructions to those left inside.
5. Except for squares 1 and 225, only one person may occupy a square at one time.
6. The piece marked "you" represents your position on the board. You may place the personnel pieces on the board when you locate them, either through seeing them or through speaking to them or assuming their location: white side up represents an uninjured person, red side up represents an injured person. The "risk" pieces are to place where you estimate the danger to be. Once you are sure of the location of the danger, you can turn the "risk" pieces over, which shows the word "danger". If you make assumptions, which are later, found to be incorrect, the scenario organiser can place, remove or relocate tokens to show their real location.
7. The simulation is ended when either:
a) all personnel have left the building
b) the emergency has been stopped
c) the building has been destroyed
8. If you do not make a move every 20 seconds, a move is taken without any action by yourself. That is, the danger will escalate uncontrolled.
9. Time is represented by moves. As time is limited in an emergency, it is a critical factor. Therefore moves can be used as shown in Table A.

1 (225) **EXIT**	2 (210)	3 (195)	4 (180)	5 (165)	6 (150)	7 (135)	8 (112)	9 (85)	10 (86)	11 (87)	12 (88)	13 (89)	14 (90)	15 (91)
16 (224)	17 (209)	18 (194)	19 (179)	20 (164)	21 (149)	22 (134)	23 (111)	24 (84)	25 (61)	26 (62)	27 (63)	28 (64)	29 (65)	30 (66)
31 (223)	32 (208)	33 **(A)** (193)	34 (178)	35 (163)	36 (148)	37 (133)	38 **(B)** (110)	39 (83)	40 (60)	41 (41)	42 (42)	43 **(C)** (43)	44 (44)	45 (45)
46 (222)	47 (207)	48 (192)	49 (177)	50 (162)	51 (147)	52 (132)	53 (109)	54 (82)	55 (59)	56 (40)	57 (25)	58 (26)	59 (27)	60 (28)
61 (221)	62 (206)	63 (191)	64 (176)	65 (161)	66 (146)	67 (131)	68 (108)	69 (81)	70 (58)	71 (39)	72 (24)	73 (13)	74 (14)	75 (15)
76 (220)	77 (205)	78 (190)	79 (175)	80 (160)	81 (145)	82 (130)	83 (107)	84 (80)	85 (57)	86 (38)	87 (23)	88 (12)	89 (5)	90 (6)
91 (219)	92 (204)	93 (189)	94 (174)	95 (159)	96 (144)	97 (129)	98 (106)	99 (79)	100 (56)	101 (37)	102 (22)	103 (11)	104 (4)	105 (1)
106 (218)	107 (203)	108 **(D)** (188)	109 (173)	110 (158)	111 (143)	112 (128)	113 **(E)** (105)	114 (78)	115 (55)	116 (36)	117 (21)	118 **(F)** (10)	119 (3)	120 (2)
121 (217)	122 (202)	123 (187)	124 (172)	125 (157)	126 (142)	127 (127)	128 (104)	129 (77)	130 (54)	131 (35)	132 (20)	133 (9)	134 (8)	135 (7)
136 (216)	137 (201)	138 (186)	139 (171)	140 (156)	141 (141)	142 (126)	143 (103)	144 (76)	145 (53)	146 (34)	147 (19)	148 (18)	149 (17)	150 (16)
151 (215)	152 (200)	153 (185)	154 (170)	155 (155)	156 (140)	157 (125)	158 (102)	159 (75)	160 (52)	161 (33)	162 (32)	163 (31)	164 (30)	165 (29)
166 (214)	167 (199)	168 (184)	169 (169)	170 (154)	171 (139)	172 (124)	173 (101)	174 (74)	175 (51)	176 (50)	177 (49)	178 (48)	179 (47)	180 (46)
181 (213)	182 (198)	183 **(G)** (183)	184 (168)	185 (153)	186 (138)	187 (123)	188 **(H)** (100)	189 (73)	190 (72)	191 (71)	192 (70)	193 **(I)** (69)	194 (68)	195 (67)
196 (212)	197 (197)	198 (182)	199 (167)	200 (152)	201 (137)	202 (122)	203 (99)	204 (98)	205 (97)	206 (96)	207 (95)	208 (94)	209 (93)	210 (92)
211 (211)	212 (196)	213 (181)	214 (166)	215 (151)	216 (136)	217 (121)	218 (120)	219 (119)	220 (118)	221 (117)	222 (116)	223 (115)	224 (114)	225 **EXIT** (113)

Table A: Use of Moves in the Desktop Simulation

ACTIONS	NUMBER OF MOVES
NB. Movement can be in any direction (including diagonals) but not through office walls. No Movement can be performed by dead personnel.	
Movement of one square, if not injured (NB - movement is not restricted by carrying safety equipment)	1
Movement of one square if injured	2
ACTIVE EMERGENCY RESPONSE	
Fighting one square of danger	2
COMMUNICATION	
NB. Face to face communication requires people to be within 6 squares distance of each other. Personnel do not need to stop moving when listening to P.A. messages	
Up to 5 words spoken either face to face, via radio or P.A. in and to safe environments	1
Up to 5 words spoken either by radio or face to face in or to a dangerous environment	2
GATHERING SAFETY EQUIPMENT	
Collecting and putting on safety equipment	2
Taking off safety equipment	2
(So a change in equipment take 4 moves)	

All Emergencies escalate over time so to represent this, the number of moves from the first indication of danger (i.e. an alarm) can show the number of squares that the danger occupies, as shown in Table B.

Table B: Escalation moves in the desktop simulation

Move number (from start)	Moves before escalation when danger-fighting occurs	Squares occupied
0	+ 8	0
8	+ 7	1
15	+ 5	2
20	+ 4	3
24	+ 3	4
27	+ 3	5
30	+ 2	6
32	+ 2	7
34	+ 2	8
36	+ 2	9
38	+ 1	10
39	+ 1	11
as above + 1		as above + 1

As active danger fighting occurs, the danger can be reduced in the number of squares that it occupies. In this case, it will have one move at the same number of squares (i.e. where it does not escalate) then will continue to escalate at the respective speed for the number of squares occupied. For example, if reduced to 4 squares size, at the next move, the danger will still occupy 4 squares then will increase to 5 squares 3 moves later. If reduced to 0 squares, the danger is deemed to have been eliminated. However, in the case that the danger was about to escalate on the move at which it was fought off, the danger will STILL escalate to that square, then not escalate for the next move but continues escalating the move afterwards at the rate corresponding to that number of squares. So if it was just about to escalate to 7 squares, it escalates to 7 squares then remains at this for 2 moves before escalating to 8 squares (giving 3 moves at 7 squares in total). If the danger is escalating faster than the speed at which it is being controlled, the fighters are driven back until they can focus their attempts on the same square at once (multiplying the fighting power by the number of people fighting the fire).

Longevity of Safety Equipment

This depends on the amount of danger to which you are exposed.

Whether or not they are wearing safety equipment, unless explicitly ordered to travel into or through the danger area, personnel will try and avoid the danger, though attempts may not occur until the danger occupies the space next to the one on which they stand.

If not wearing safety equipment (or if this is now redundant), you are injured if danger fills 3 squares next to or including the square on which you stand. This does not affect your ability to move away, though at the injured rate of movement.

If not wearing safety equipment (or if this is now redundant), and standing in a corridor, if the danger fills 9 squares of danger next to or including the square on which you stand, you are killed.

If not wearing safety equipment (or if this is now redundant), and standing in a room, if the danger fills 5 squares of danger next to or including the square on which you stand, AND blocking the exit, you are killed.

Table C: Duration of Equipment use

NB Safety equipment incorporates both active danger fighting as well as protective clothing for the user

Equipment	Duration
Danger fighting - must be standing next to the square which you are fighting which must be a "safe" square - i.e. no danger currently occupies that square.	Can eliminate 3 squares of danger
Safety equipment	Can move through 6 squares of danger without injury - after this injury is sustained as though no safety equipment was used.

Table D: Equipment and Exit location

Equipment / Exit	Location
4 sets of safety gear (breathing apparatus, protective clothing, danger-fighting equipment etc)	58, 184
6 sets of safety gear (as above)	114
P.A.	113
Radio transmission and receiver stations	1, 43, 113, 183, 225
Exits from the building	1, 225
Doorways to each room	49 (A), 53(B), 57(C), 107 (D), 98(E), 119(F), 169(G), 173(H), 177(I)

Initially there are 5 people in the building including yourself.

2.2 PROCEDURE

2.2.1 Scenario Organiser's Notes and Recording Table

These are the instructions as to the initial positions of the people - they are stationary until ordered otherwise - or forced to move by the fire. This also shows the escalation pattern of the fire as shown earlier. Where the spiralling pattern would imply that the fire goes outside the building - the danger spreads to the next square on the grid where the pattern would predict, thus making spreading arch-patterns around the source of the fire.

Table E: Personnel and Danger starting positions

Personnel / Equipment	**Location**
You	188
John	117
Paul	57
George	155
Ringo	91
Fire	105 (followed by 120, 119, 104, 89, 90, 135, 134 etc. using a spiralling pattern)

2.2.2 Desktop simulation procedure to be used by the scenario organiser

The emergency manager was presented with a board (as shown earlier in Appendix 2) and his location was revealed to him by the placement of his "token" on position 188. He is also given a number of tokens, including "people token", "equipment tokens" and "token pieces" which may be placed on the board when he locates them, or once he has enough information to make assumptions about how a person or the incident is acting, he can place the tokens on the board to represent his assumptions. This board is therefore the physical representation of his idea of the big picture.

Out of sight from the emergency manager, the scenario organiser is given a board, which is identical to that of the emergency manager and prepared as according to their instructions. Once both the emergency manager and scenario organiser have prepared their boards, the scenario organiser says "You are just having your coffee break when you hear a loud bang appearing to be from the North East. This is Move 1 - What do you choose to do?". If the emergency manager does not choose to make a move within 20 seconds, the scenario organiser will say "This is Move 2- what do you choose to do?". This procedure will continue if the emergency manager does not make a move, every 20 seconds, this will continue.

2.2.3 The scenario organiser's recording table

The scenario organiser must record the action of the player and the results on a grid and notes down the specific content of any communication made. A example of the grid is shown in Table F.
The symbols are as follows:
M.113 - Move to square 113
M - Move
F 119 (fire fight square 119)
FS - Put on (or remove) fire safety gear
TR - Talk on radio
T(PA) - Talk on PA
T - Talk face to face
L - Listen

Table F: Recording Grid from Desktop Simulation

Moves	EM	John	Paul	George	Ringo	Fire cov	Fire dam	Num at exit	Num injured	Num dead
1	M					0	0			
2	M					0	0			
3	T		L			0	0			
4	T		L			0	0			
5	T		L			0	0			
6	M		M			0	0			
7	M		M			0	0			
8	M		M			1	1			
9	M		FS			1	1			
10	M		FS			1	1			
11	M. 113		M			1	1			
12	T(PA)	L	M.155	L	L	1	1			
13	T(PA)	L	M	L	L	1	1			
14	T(PA)	L	M	L	L	1	1			
15	T(PA)	L	M	L	L	2	2			
16		M.43	M.144	M.76	M.118	2	2			
17	L	TR	M	M.61	M	2	2			
18	TR	L	M	M.46	M.135	2	2			
19	L	TR	M	M.31	M.150	2	2			
20		M.58	M	M.16	M.165	3	3			
21		FS	M.149	M.1	M.180	3	3	1		
22	L	FS	M.135	TR	M.195	3	3			
23	TR	M.57	FF119	L	M.210	3	3			

SECTION 3: RESULTS OF DESKTOP SIMULATION

This methodology was used initially by trying out theoretical views of possible methods of coping with the emergency to assess its face validity. If the outcome of strategies used in the desktop simulation were comparable with those used in a real emergency, it is conceivable that this could be developed into a valid technique of quantifying the impact of emergency management decision-making.

Using the recording of moves on the scenario organiser's grid, it was possible to quantify the success of a strategy in terms of the percentage of building damaged and the percentage of people evacuated with respect to time. As shown in Table F, there are 3 units of damage at time point 23 and 1 person evacuated. 3 units damaged out of a total of 225 gives a percentage of 1.33. 1 person out of a total of 5 in the building gives a percentage of 20. Therefore at time point 23, there is 1.33 percent damage and 20 percent people evacuated.

A successful outcome would be to evacuate all the people but given this, credit is given for strategies with the least damage to the building. A strategy where the building is saved but the people are injured is considered a poor strategy.

Therefore five strategies were included:
1. People-focused, whereby the emergency manager focused mainly on the safety of the personnel in the building, aiming to evacuation all of them safely but showing no extra concern for the structural integrity of the building.
2. Building-focused, whereby the emergency manager focused mainly on maintaining the structural integrity of the building. This involved getting all the people involved to focus on controlling and putting out the fire then evacuating the building.
3. Kamikaze, whereby the emergency manager aimed to put out the fire himself and only asked for support from people who he met along the way.
4. Denial, whereby the emergency manager makes no effort to do anything until injured himself, then will attempt to escape from the building and will urge anyone he meets to do the same.
5. Selfish, whereby the emergency manager leaves the building as soon as the alarm is given but makes no effort to encourage anyone else to do the same.

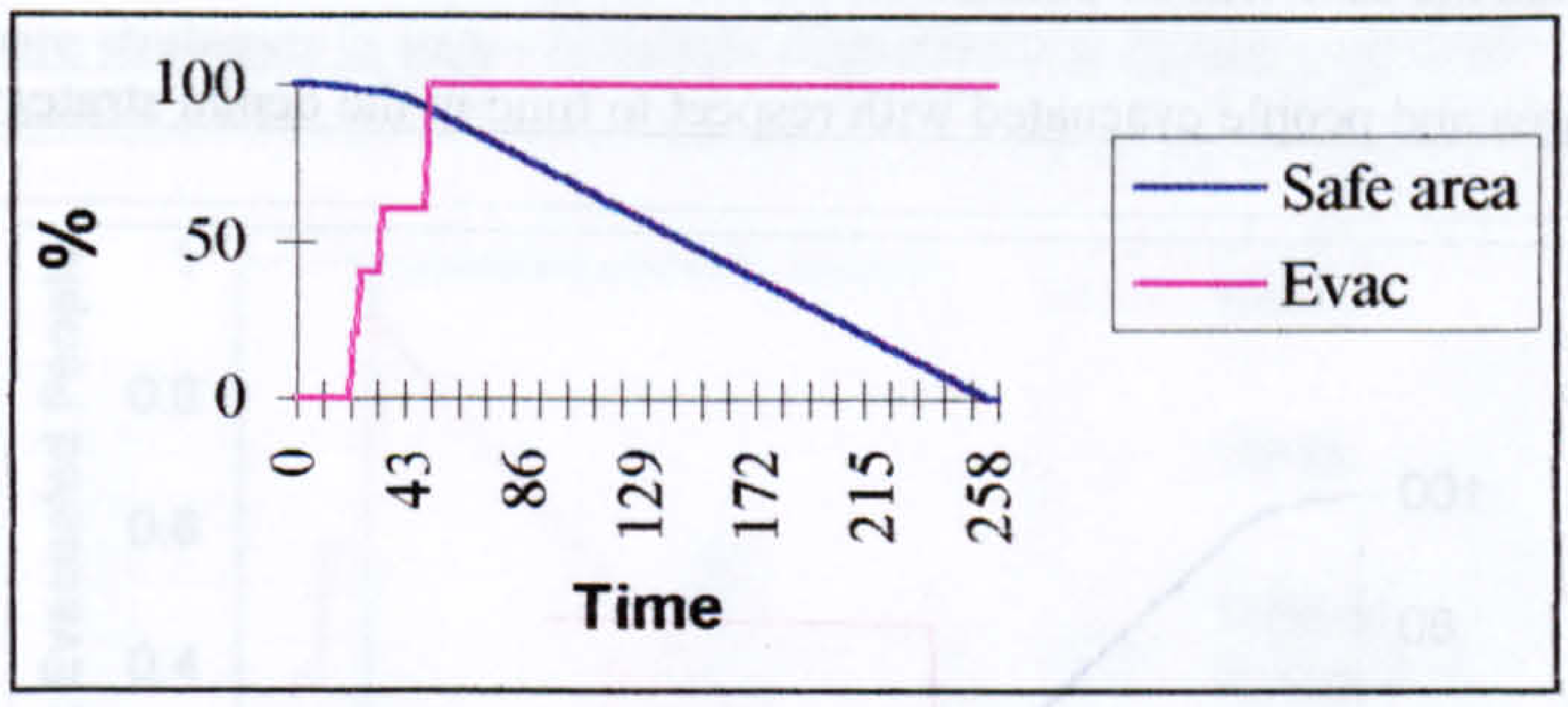
Obviously, a decision is assessed on the basis of its outcome and we would assume that if someone is focused on getting people out of a building safely that this is what would happen. However, in real emergencies, the best of intentions do not always result in the best of results. In this game, this is also true - if one focuses only on evacuating people and does not consider the controlling the escalating incident, there is a chance that someone will be trapped by the fire. Consequently, if one sends people in to fight the fire, they are also being put at risk of injury. And so, as in a real emergency, weighing up the options in the given situation is necessary.

In the strategies listed above, the people-focused and building-focused strategies are generally considered as good approaches to follow. However, if they are initiated too late, it may be impossible to end up with a good outcome as the fire has escalated to a degree where much of the building is damaged and people may be trapped. So, as in a real emergency, even a good strategy must be timely to result in a good outcome. The Kamikaze strategy involves the active fire fighting and rescuing of personnel by the emergency manager. Here, he does not fulfil his role of coordinator and in a real emergency; this would normally be considered a poor strategy. However, the worst strategies are the Denial and Selfish strategy. In Denial, the emergency manager treats the situation as normal and so allows all the other personnel to continue work as normal, putting themselves as risk. In the Selfish strategy, the emergency manager saves himself and leaves the other personnel to suffer.

3.1 RESULTS OF PERCENTAGE SAFE AREA AND PERCENTAGE PERSONNEL EVACUATED WITH RESPECT TO TIME

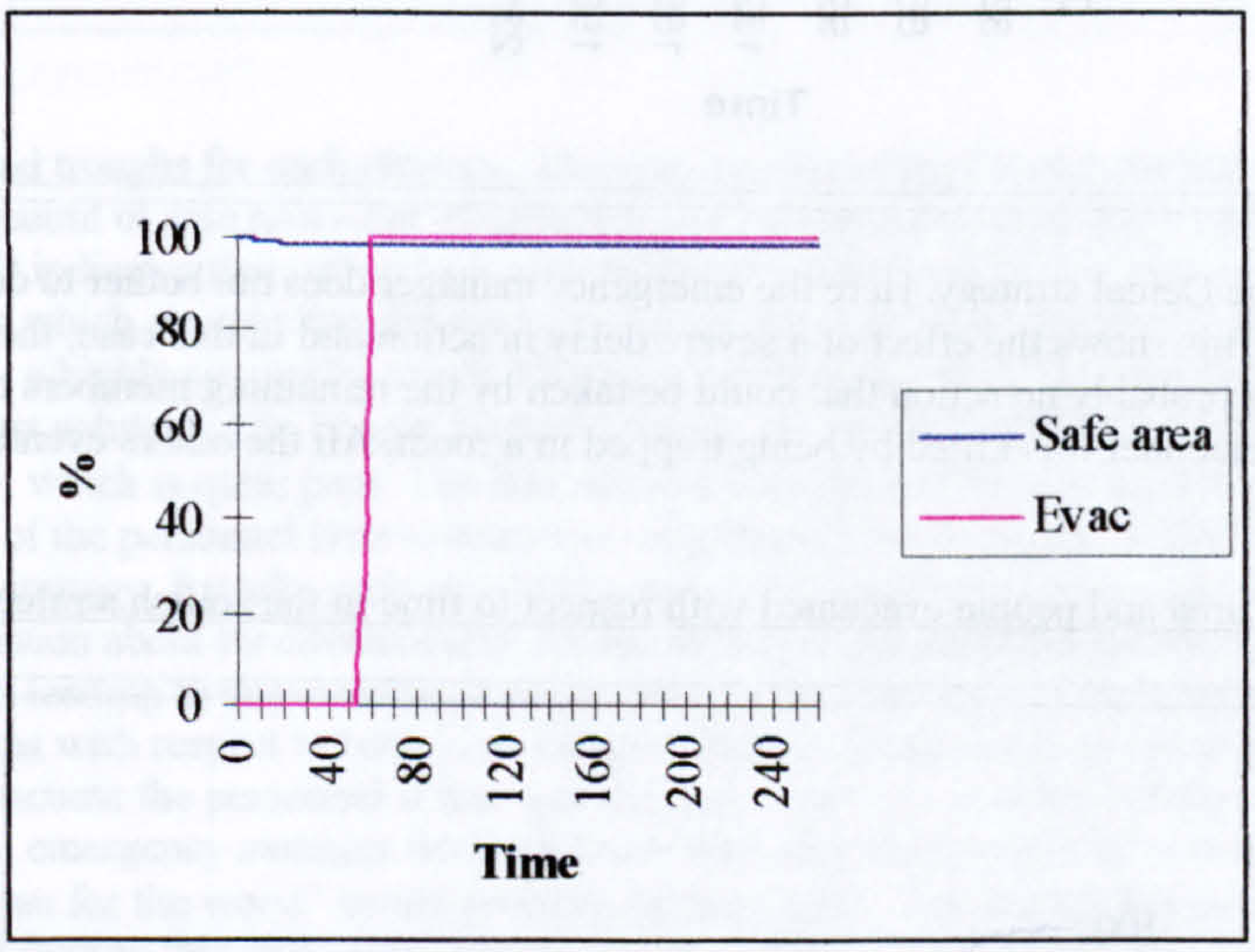
From the moves taken up in these strategies as shown on the scenario organiser's recording grid, we can establish % safe area and % people evacuated in relation to the number of moves taken (time). The following pages show graphs of the impact of strategy on % safe area in the building and % people evacuated with respect to time.

Figure B: Percentage safe area and people evacuated with respect to time in the people-focused strategy



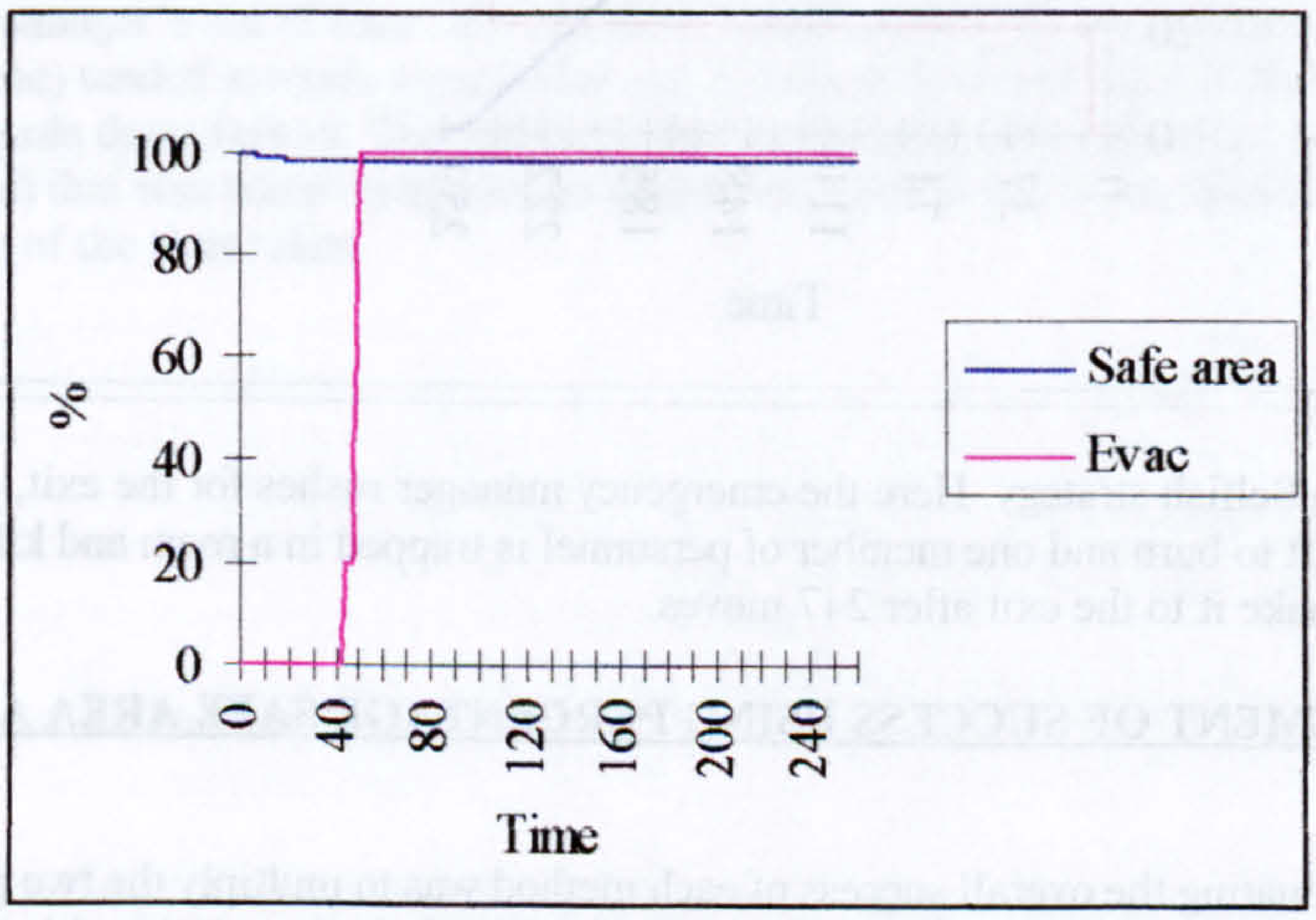
The first graph shows the people-focused strategy, whereby the priority is to get all the people out, including if this requires rescuing some of them. There is a 100% success rate in people evacuated, which is completed in 50 moves. However, due to lack of consideration of the state of the building, once the person has been rescued, the building is left to burn so is totally destroyed.

Figure C: Percentage safe area and people evacuated with respect to time in the building-focused strategy



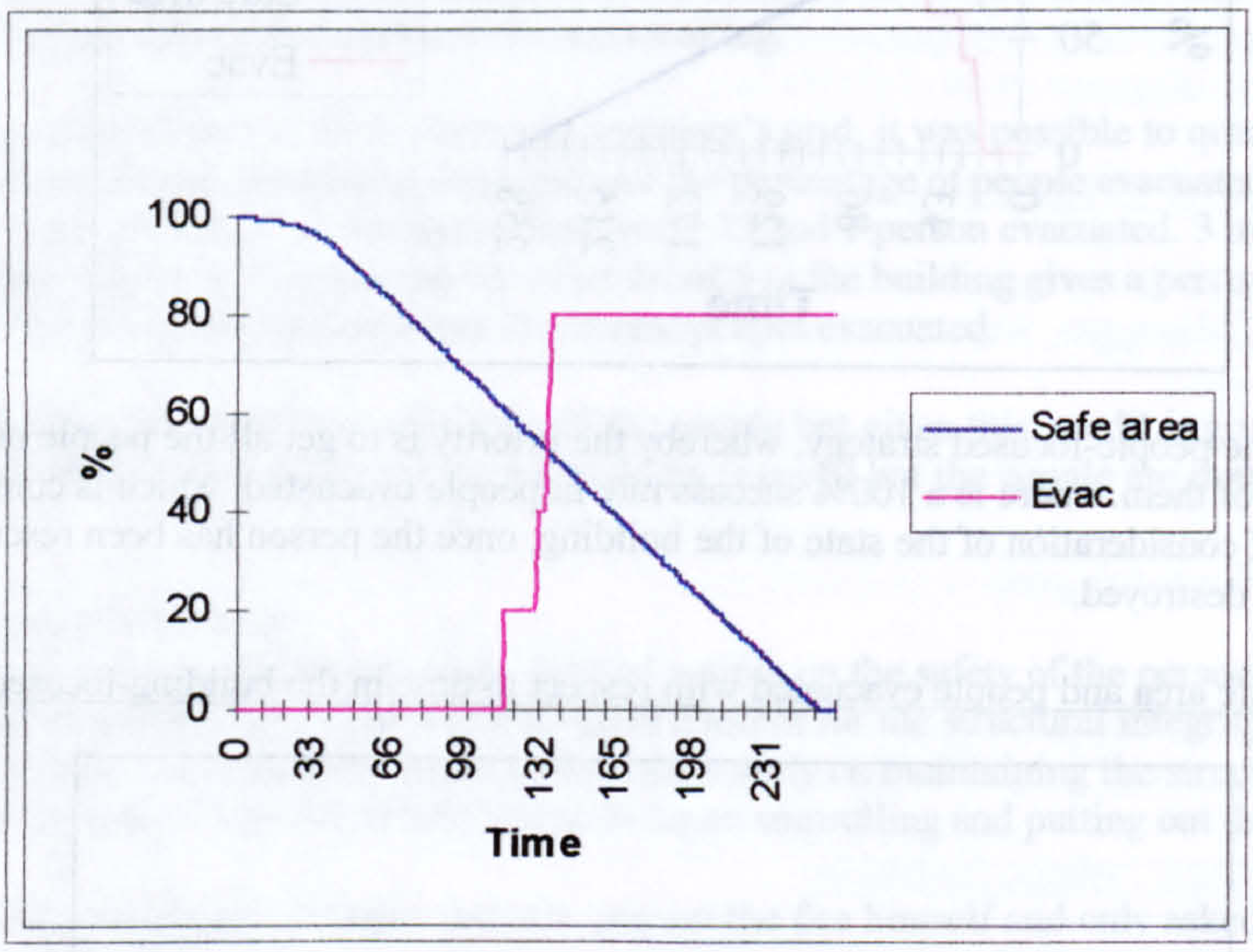
The second graph shows the building-focused strategy. Here, the rescue of people is important but more the critical focus is on reducing the effect of damage to the building. In this, there is only minimal damage to the building (1.78%) and all the people are evacuated safely in 60 moves, which clearly results in a very good strategy.

Figure D: Percentage safe area and people evacuated with respect to time in the Kamikaze strategy



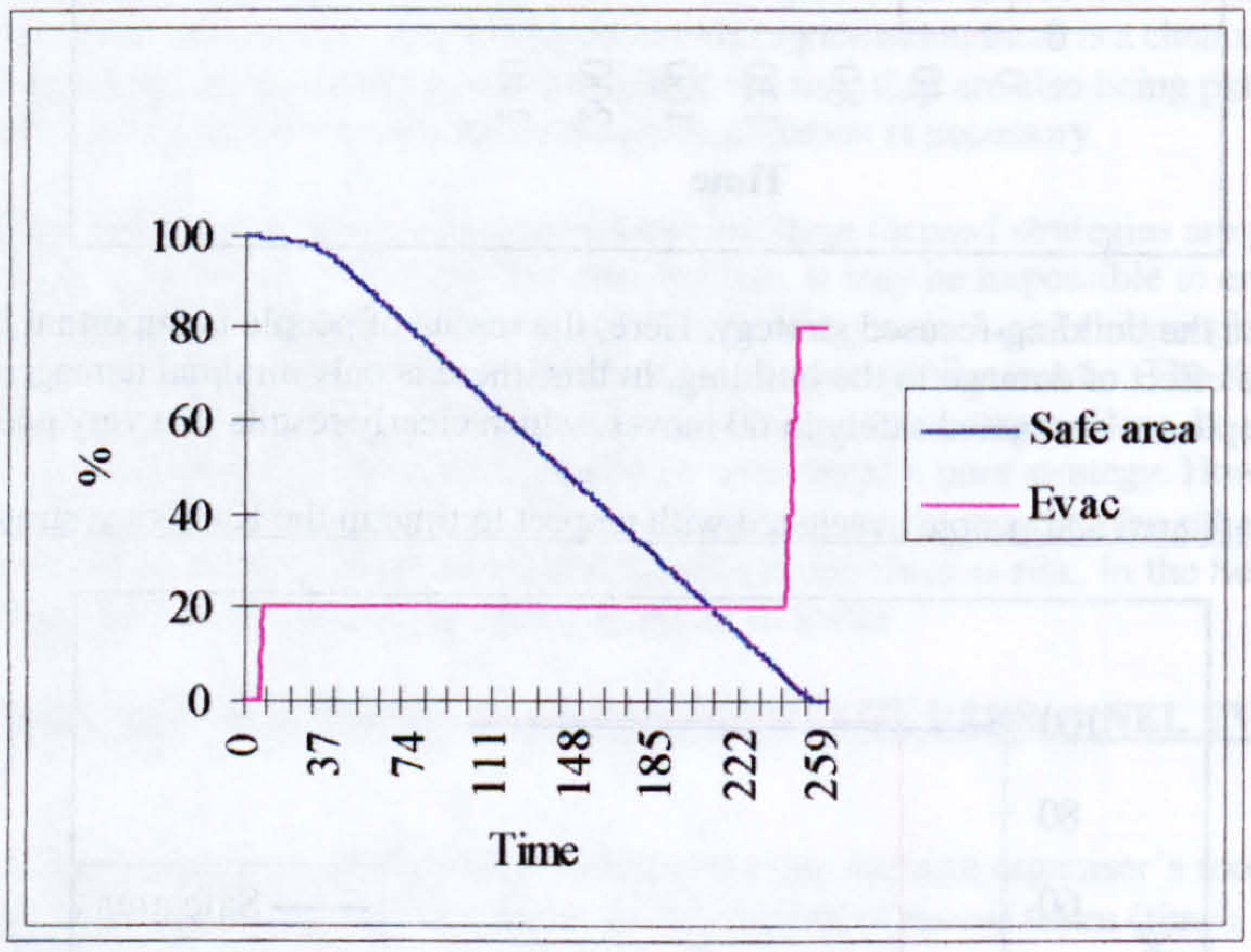
The third graph shows the Kamikaze strategy where the emergency manager chooses to rescue the people and fight the fire himself. This actually resulted in a very good result with approximately 1.78% damage to the building (the same as the building-focused strategy) and all personnel evacuated safely after 51 moves. This is therefore the best strategy out of the top three - which is not normally representative of the outcome of a real emergency. However, the possible reasons why this was the case will be pointed out in the discussion.

Figure E: Percentage safe area and people evacuated with respect to time in the denial strategy



The fourth graph shows the Denial strategy. Here the emergency manager does not bother to do anything until the fire is directly affecting him. This shows the effect of a severe delay in action and in this case, the fire has escalated to such a degree that there is probably no action that could be taken by the remaining members of personnel that could stop it. One member of personnel was killed by being trapped in a room. All the others eventually get to an exit, this taking 137 moves.

Figure F: Percentage safe area and people evacuated with respect to time in the selfish strategy



The fifth graph shows the Selfish strategy. Here the emergency manager rushes for the exit, arriving there after 8 moves. The building is left to burn and one member of personnel is trapped in a room and killed. The other members of personnel manage to make it to the exit after 247 moves.

3.2 OVERALL ASSESSMENT OF SUCCESS USING PERCENTAGE SAFE AREA AND PERSONNEL EVACUATED

One way of evaluating the overall success of each method was to multiply the two percentage values (taken as decimals) - people evacuated x safe area. Although saving the people is the priority, this still may indicate the optimal strategies. A strategy where the people are evacuated slowly or not at all and the building is destroyed over time would clearly be a poor outcome.

Figure G represents the product of the two percentage values with respect to time for all 5 strategies.

<u>Figure G: Graph to compare strategies in terms of people evacuated x safe area over time</u>

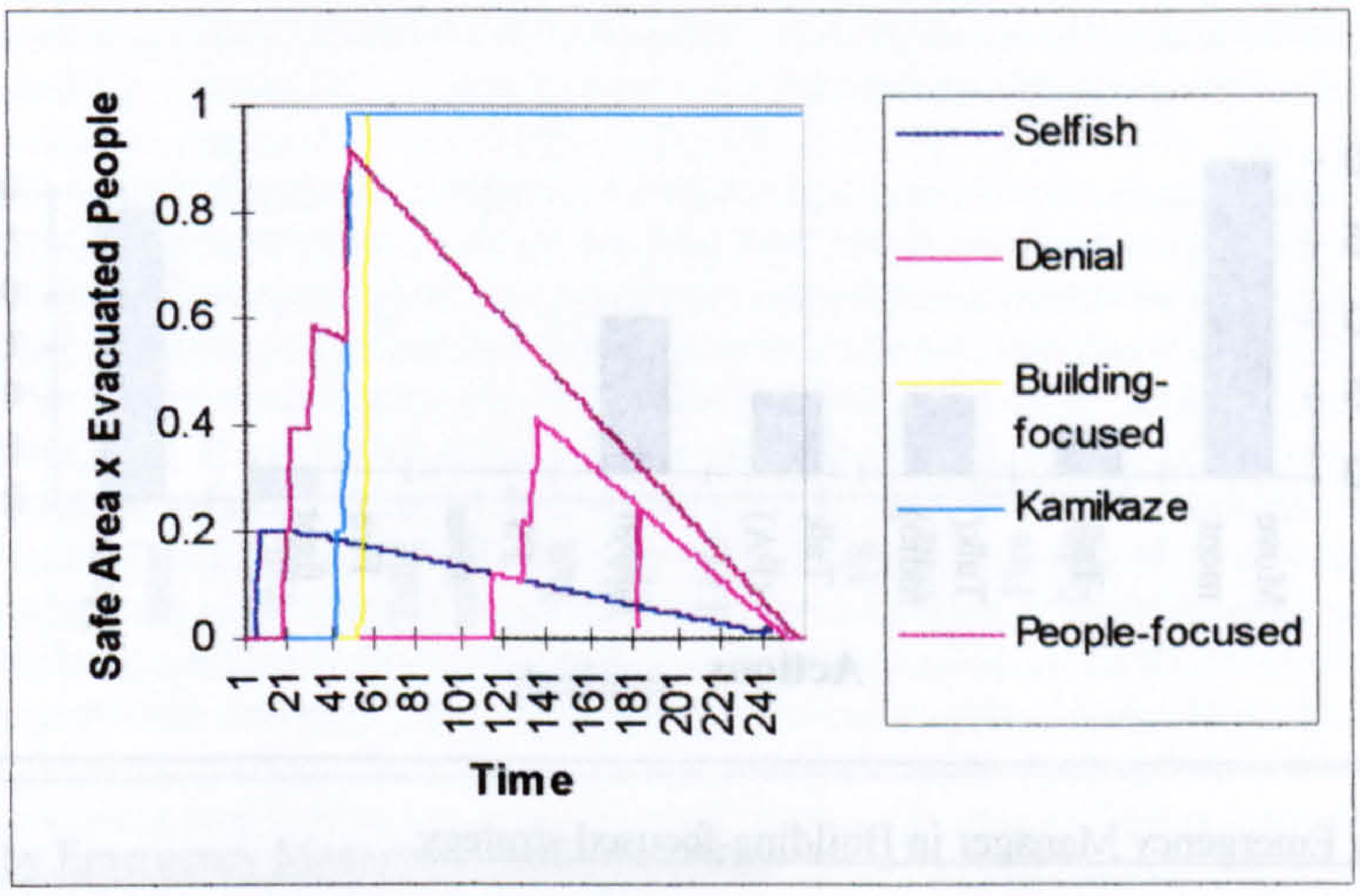


Figure G shows peaks and troughs for each strategy. The peaks indicate that there are a high number of people evacuated and a large amount of safe area - the troughs indicate low numbers of people evacuated and small amounts of safe area. A value of 0 indicates that either no people have been evacuated or that there is no safe area available. From this, we can assess which strategy has the most successful outcome. Both the Kamikaze and Building-focused strategy peak at 0.9822 - a highly successful result. However, because the Kamikaze strategy peaks earlier - this indicates that it is the best solution. The People-focused strategy is also very effective - peaking at 0.92. The denial strategy peaks at 0.4125, which is quite poor. The late response means that the safe area has decreased - effectively increasing the risk. One of the personnel fails to evacuate - reinforcing this view. The selfish strategy can generally be considered as the worst strategy. It peaks early at 0.1991 - and being the first to result in a successful evacuation may lead to the wrong impression about its effectiveness. As the safe area gradually decreases, the other personnel are forced to evacuate, again leading to one member being trapped in the building. Overall, the product of % personnel evacuated and % safe area with respect to time is an effective means of assessing the strategies. In this simulation, it was relatively easy to evacuate the personnel if this was the only focus - to save the building as well is a particular challenge. Of course, the emergency manager does not know how easy the evacuation will be. However, the maxim "hope for the best and plan for the worst" would probably be advisable. If an emergency manager had first attempted to control the fire then if finding this impossible resorted to evacuating the personnel, this would have resulted in our two most effective strategies. This type of interaction graph with respect to time may be a key factor in designing a method of quantifying the impact of emergency management decisions on risk.

3.3 USE OF TIME RESOURCES BY THE EMERGENCY MANAGER

Given that time was a limited resource, it was thought that it would be useful to compare the strategies in terms of the emergency manager's use of time. If it could be identified that the more successful strategies (as determined by the outcome) tended towards a particular use of time, this would suggest that the management role should be orientated towards these factors. Therefore, another assessment was carried out to examine the percentage of time (number of moves) that was taken up by the emergency manager in doing certain activities. The following bar charts show a breakdown of the time taken.

Figure H: Use of time by Emergency Manager in People-focused strategy

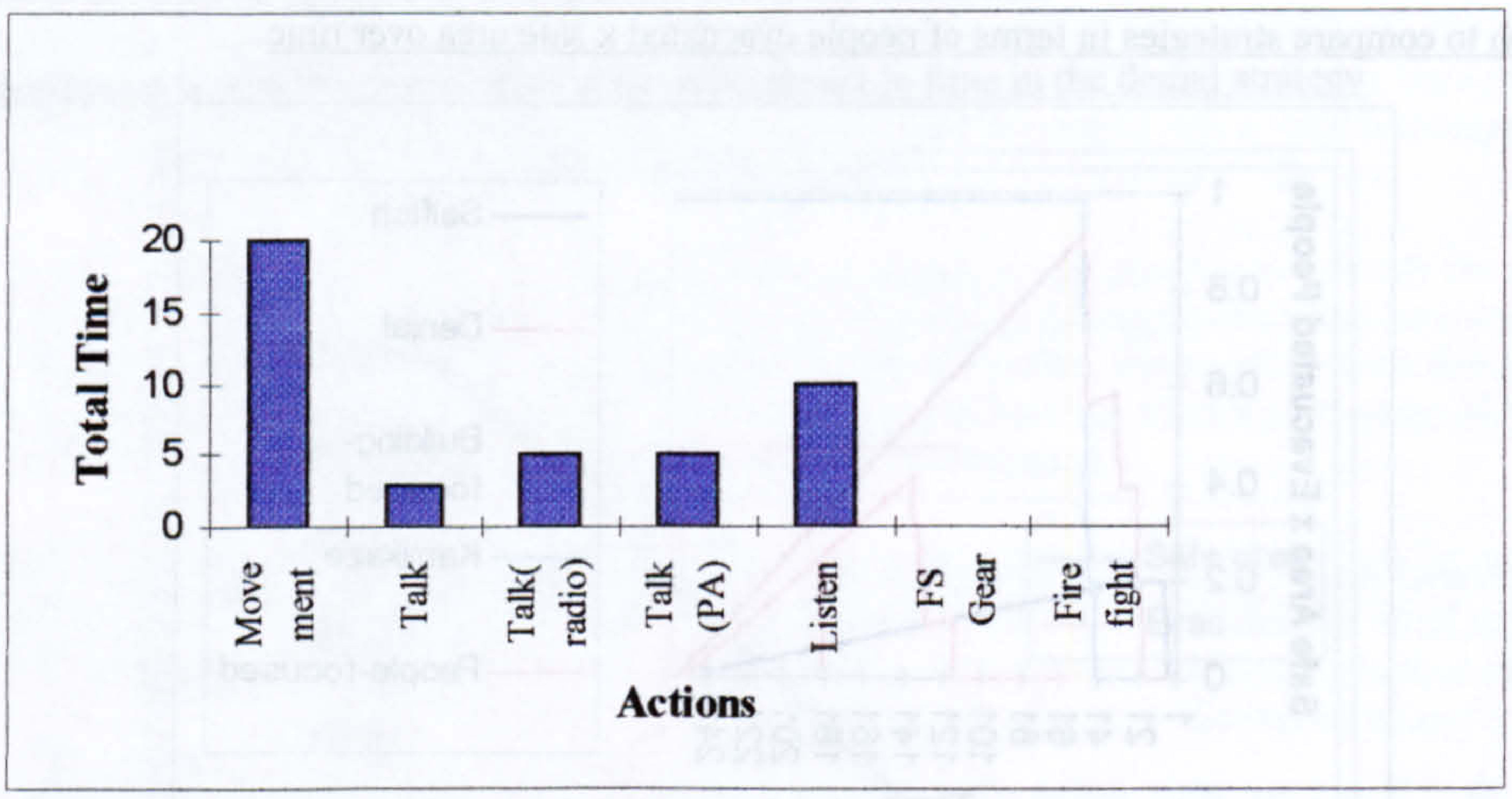


Figure I: Use of time by Emergency Manager in Building-focused strategy

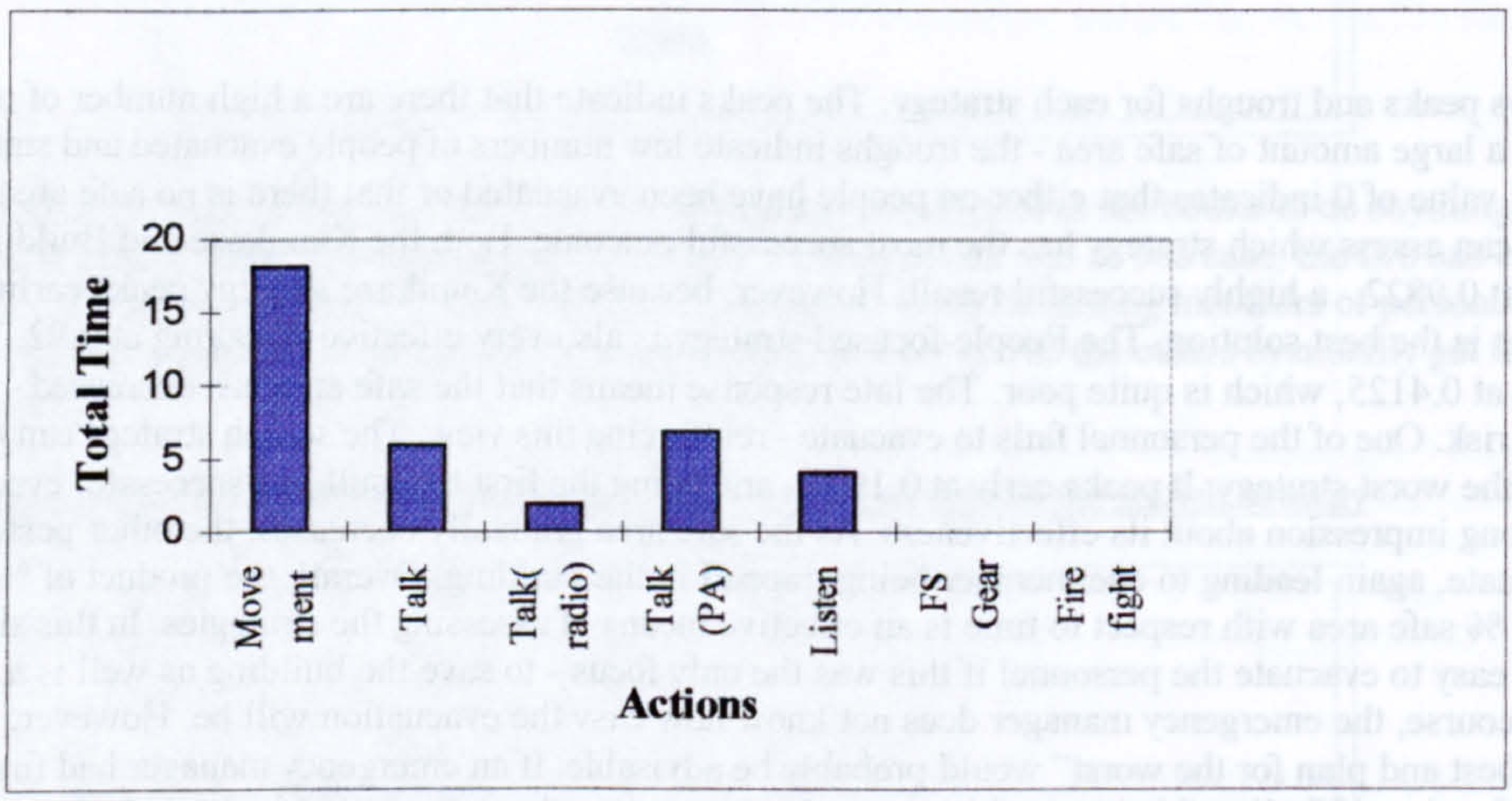


Figure J: Use of time by Emergency Manager in Kamikaze Strategy

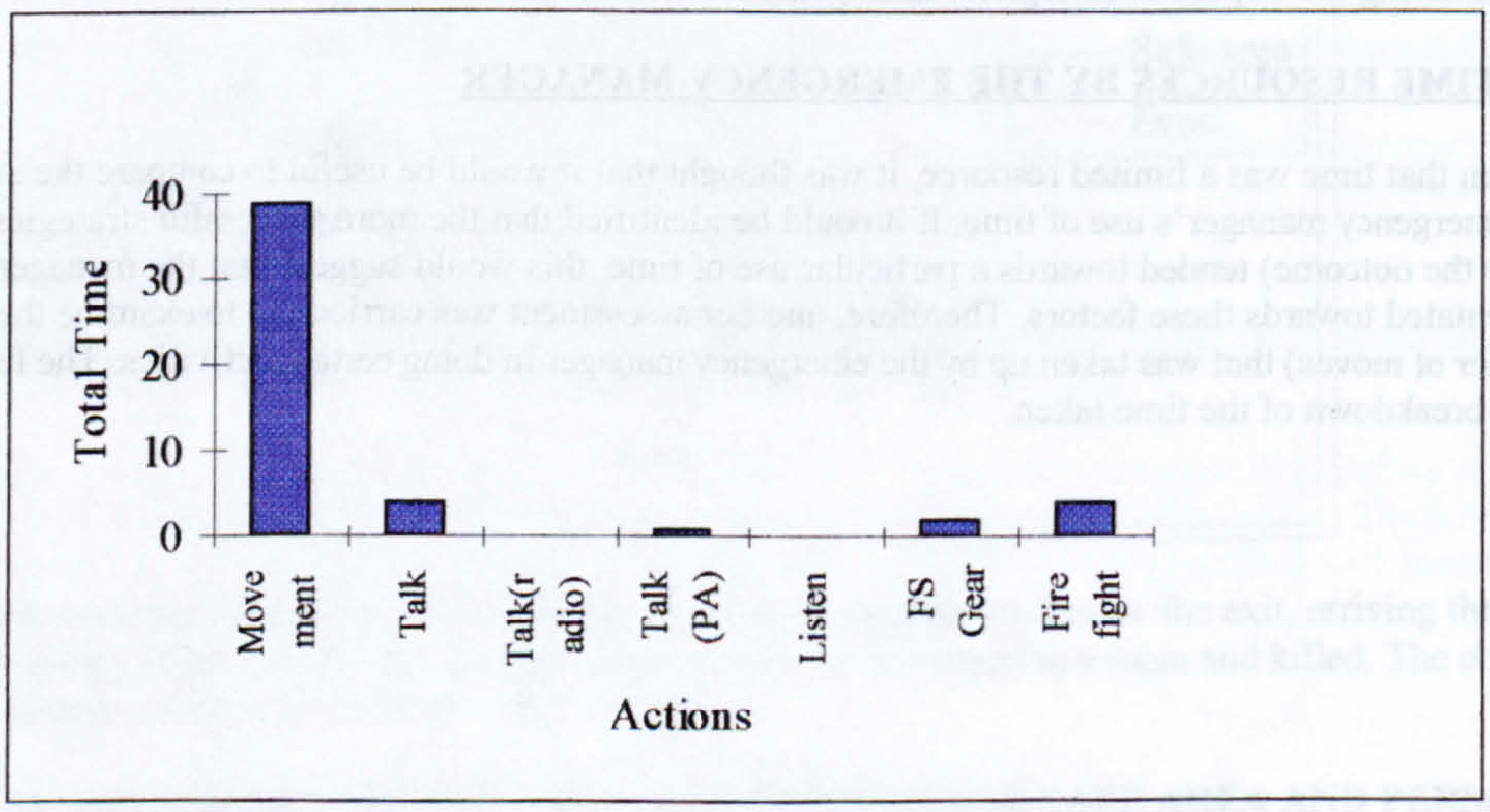


Figure K: Use of time by Emergency Manager in denial strategy

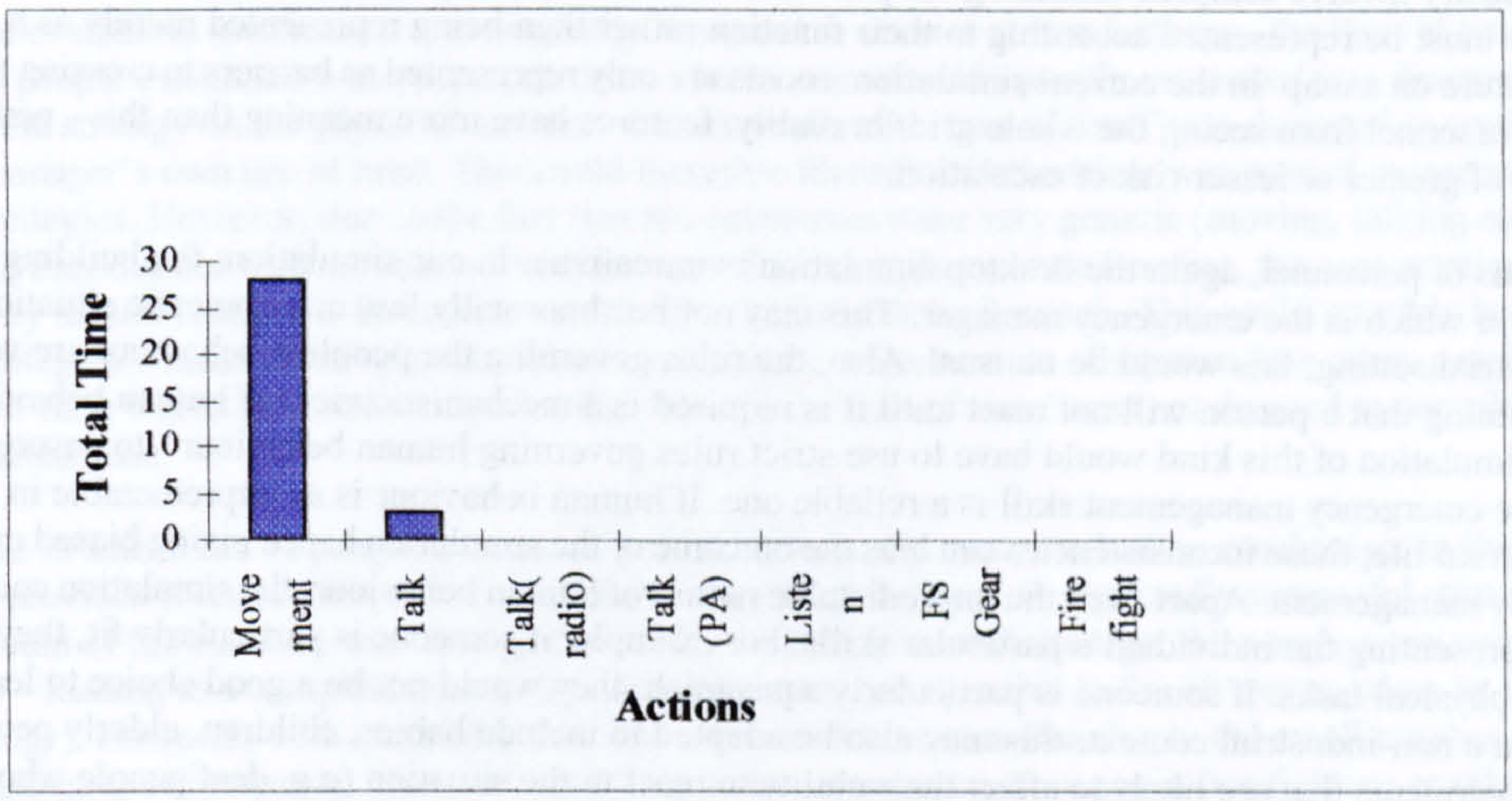
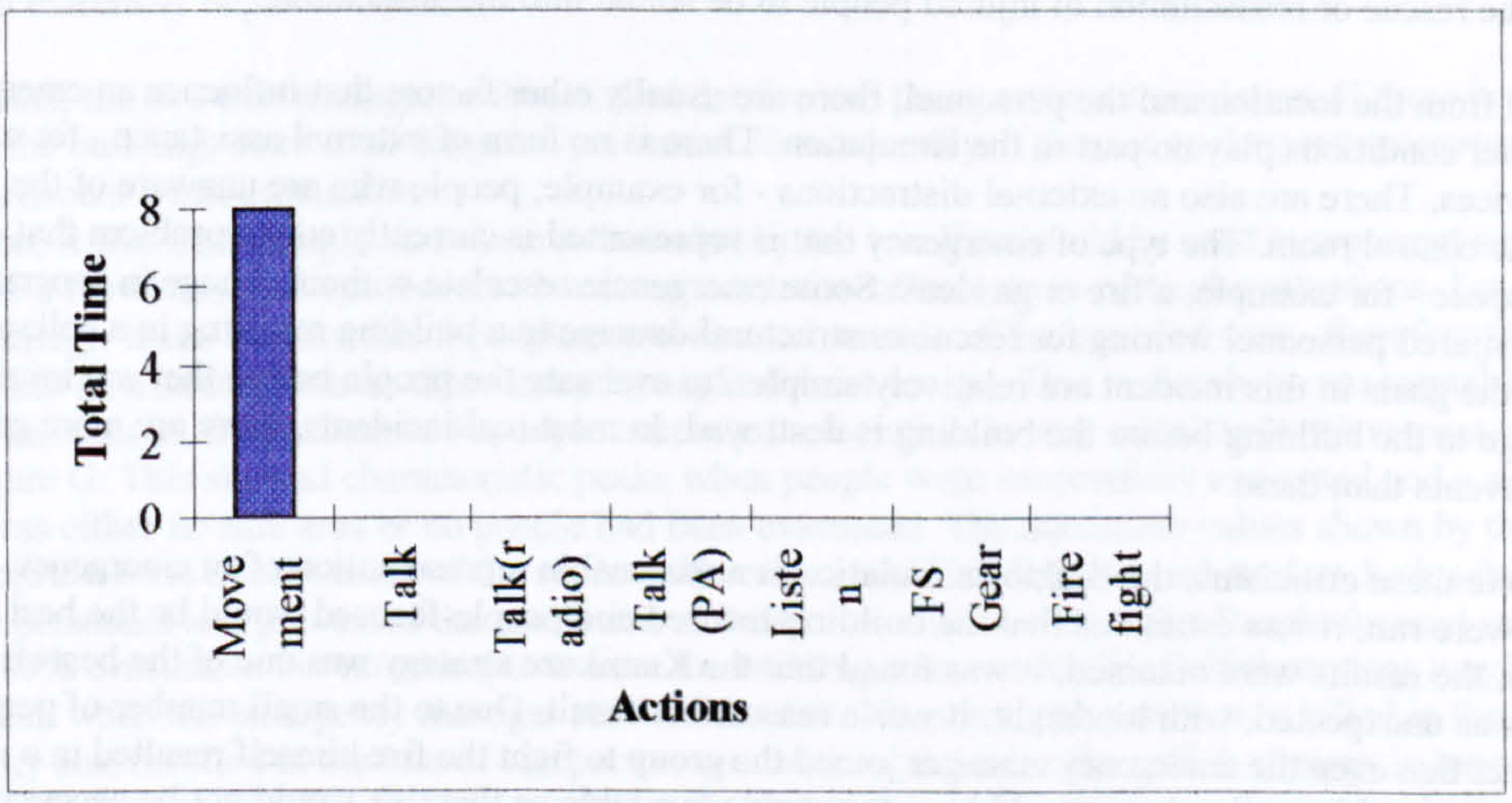


Figure L: Use of time by Emergency Manager in selfish strategy



These bar charts show some indication of how the better strategies used the resources available. It is notable that all three of the better strategies use some communication, in particular the P.A system, whereas the other strategies use little or no communication. However, these bar charts only represent how the time was taken in terms of activity type and does not make any judgement on the content of the activity type, for example, running away from or into the fire, ordering people specifically what to do or being vague about instructions. In future use of the game, it is likely that there should be categorisation of the content of the activities to identify any weaknesses in strategy, decision-making or use of communication.

SECTION 4: DISCUSSION OF THE DESKTOP SIMULATION

Although simple, the method may provide a useful way of representing the impact of decisions and attitude on the outcome of an emergency. For each strategy, it has produced a quantitative output of % damage of the building and % people safely evacuated, which are key factors in a real emergency. However, it is not possible to base strong conclusions on such small amounts of data and theoretically designed strategies. Therefore this discussion will comment on the implications of the results, criticisms of the method and recommendation for future work.

To evaluate the methodology in more detail, it should really be considered as two separate sections:-

1. the desktop simulation itself - which should be a realistic representation of an emergency; and
2. the evaluation mechanism, which having proved itself in providing a valid assessment of the emergency management in the simulation could potentially be used to evaluate real emergency management.

4.1 DISCUSSION OF THE DESKTOP SIMULATION

In general, the desktop simulation is currently too simple to represent a real emergency situation. The grid is two-dimensional and represents a basic structure of a building. However, the implications of stairs, doorways, narrow corridors, ladders and elevators would be difficult to represent. Also, most of the emergencies that require modelling in industry involve complex technological processes. For example, a petrochemical or nuclear installation has features that must be represented according to their function rather than being represented merely as a geographical feature on a map. In the current simulation, rooms are only represented as barriers to crossing the grid or preventing the personnel from seeing the whole grid. In reality, features have more meaning than this - perhaps indicating areas of greater or lesser risk of escalation.

In terms of personnel, again the desktop simulation is unrealistic. In our simulation, the building has 5 personnel - one of which is the emergency manager. This may not be abnormally low in a domestic situation but in a hazardous industrial setting, this would be unusual. Also, the rules governing the people's behaviour are very simplistic. Assuming that a person will not react until it is required is a mechanistic view of human behaviour. However, any simulation of this kind would have to use strict rules governing human behaviour - to ensure that the evaluation of the emergency management skill is a reliable one. If human behaviour is as unpredictable in the simulation as in real life, these inconsistencies can bias the outcome of the simulation hence giving biased evaluations of the emergency management. Apart from the unpredictable nature of human behaviour, the simulation could also be improved by representing the individual's particular skills. For example, if someone is particularly fit, they would be best chosen for physical tasks. If someone is particularly squeamish, they would not be a good choice to lead the medical team. In a non-industrial context, this may also be adapted to include babies, children, elderly people or people with impairments that are likely to affect their ability to react to the situation (e.g. deaf people who cannot hear alarms or public announcements). In addition, the simulation does not reflect the implications of being rescued. For example, there is no stage between injured and death - a stage of incapacitation would be more appropriate. This would enable the rescue or resuscitation of injured people to be added into the simulation.

Apart from the location and the personnel, there are usually other factors that influence an emergency. For example, weather conditions play no part in the simulation. There is no form of external assistance - for example, emergency services. There are also no external distractions - for example, people who are unaware of the incident phoning into the control room. The type of emergency that is represented is currently only a problem that spreads over time and space - for example, a fire or gas leak. Some emergencies escalate without change in geographical size - for example, injured personnel waiting for rescue or structural damage to a building resulting in a collapse. Consequently, the goals in this incident are relatively simple - to evacuate the people before they are injured and to limit the damage to the building before the building is destroyed. In most real incidents, there are more goals and more limiting events than these.

Despite these criticisms, the desktop simulation is a reasonable representation of an emergency. Before the five strategies were run, it was estimated that the building-focused and people-focused would be the best strategies. However, when the results were obtained, it was found that the Kamikaze strategy was one of the best strategies. Although this was unexpected, with hindsight, it was a reasonable result. Due to the small number of people in the building, the fact that even the emergency manager joined the group to fight the fire himself resulted in a much faster control of the incident. Normally, there would be more people available so that this would not be necessary. However, in this situation, it produced a favourable result. If the rules or the planned escalation were different to the current simulation, this outcome may have been different.

The running of the simulation is also problematic. It is designed so that the pressure is on the emergency manager to make quick decisions - almost to the degree where one decision is made straight after the previous one. However, due to the complexity of organisational tasks, the scenario organiser is trying to note the moves used by the emergency manager in various tasks, the pattern and escalation (or mitigation) of the fire, the longevity of any safety equipment, any injuries being sustained and any movements being carried out by other personnel. For this reason, it is often more likely that the scenario organiser is put under pressure by the emergency manager - who has already planned his next move before the scenario organiser has completed his changes. The implications of these problems will be discussed in Section 4.3.

In general, the desktop methodology provides a useful tool for running through emergency management exercises or assessing the impact of emergency management decisions on the outcome of the emergency. However, on its own, it provides no more than a cognitive exercise in emergency problem solving. It is the evaluation mechanism that provides us with a potential means of evaluating emergency management decisions in terms of quantitative reliable measures based on the outcome of the emergency.

4.2 DISCUSSION OF THE EVALUATION MECHANISM

The evaluation mechanism was originally designed to consist of two features - the "use of time" and the % safe area / % people evacuated with respect to time. The % safe area / % people evacuated was designed to examine the effect of the strategy on the physical outcome. Consequently, the "use of time" was designed to analyse the emergency manager's own use of time. This could therefore identify whether time was wasted on particular tasks for the poorer strategies. However, due to the fact that the categories were very generic (moving, talking on the radio, listening etc), they did not take the context into account. For example, as stated earlier, the conversation could be about how they should rescue the casualties or about last night's football match. This could possibly be rectified by making the categories much more specific. However, to create a mechanism of representing every possible context-specific use of time would be problematic. For this reason, the "use of time" was not deemed to contribute to the evaluation mechanism.

Therefore, the % safe area / % people evacuated was taken to be the main evaluation mechanism in this study. As stated in the previous section, this proved the Kamikaze strategy to be an unexpectedly successful strategy. Although the same amount of the building was damaged as in the Building-focused strategy, the people were evacuated much more quickly - leading to a complete evacuation after 51 moves (comparable to the 60 moves taken by the Building-focused strategy). However, with hindsight, this was a reasonable assumption due to the small number of people present to manage the emergency. The additional help of the emergency manager in fire fighting enabled the team to be organised more efficiently to evacuated soon after the fire had been put out. If the rules had been adapted so that it was easier to sustain incapacitating injuries - or if the fire had escalated in unexpected patterns, this may have resulted in an extremely negative outcome.

Despite this fact, the two best strategies extinguished the fire and thus prevented escalation. If there is no further escalation in the building, there is no danger to personnel. Consequently, if there is no danger to personnel, there is no reason to implement a fast evacuation.

For this reason, it was first thought that the area bounded by the two lines could be used to represent success (shown in Figures B-F). However, this was found to be unrepresentative of success in particular situations. For example, in the selfish strategy, it can be seen that 3 people are evacuated outside of the bounded area - therefore the area would be comparable with a strategy where these extra 3 people did not escape. This is clearly an unacceptable measure of success. For this reason, the product of % people evacuated x % safe area was calculated with respect to time, as shown in Figure G. This showed characteristic peaks when people were successfully evacuated and a zero value when there was either no safe area or no people had been evacuated. The maximum values shown by the peaks adequately represent the effectiveness of the success. Kamikaze and Building-focused strategy both achieved a 100% rescue of the personnel and prevented the escalation of the fire at an early stage. The People-focused strategy managed a 100% evacuation but no attempts to save the building were made. The Selfish strategy may have resulted in an early peak when the emergency manager reached the exit. However, one person was killed in the process. The Denial strategy also resulted in the loss of one person - so is really as bad as the selfish strategy in terms of outcome. However, this strategy results in a higher peak due to the fact that once the emergency manager admits there is a problem, he ensures that all personnel are informed - so that if they are able to evacuate, they do. The selfish strategy leaves the other personnel in the building until they are faced with the fire - increasing the risk that they will be injured. In conclusion, this indicates that the product of the two variables is the most promising method to be developed into an objective quantitative measure of the impact of emergency management on risk for the following reasons:

- The values are based on measurable quantities (such as number of people evacuated and safe / damaged area)
- The variables are based on physical outcome rather than abstract qualities (such as personality attributes) therefore the assessment of the decision is based on outcome not on subjective interpretation. This is a reasonably objective measure as it is based on fixed pre-specified rules.
- The effects of different decisions or attitudes are reflected in the outcome. This type of simulation can be repeated with different decisions - for comparison. Therefore, it provides an objective means of benchmarking emergency management decisions and identifying the optimal strategies.
- The results suggest that the assessment mechanism has reasonable fact validity given the scenario under examination.

4.3 IMPLICATIONS FOR FUTURE WORK

It is clear that both the desktop simulation and evaluation mechanism require some improvement. The evaluation mechanism cannot be tested fully without a number of desktop simulations that must differ in terms of complexity, scenario and environment. These improvements would help to identify any weaknesses in the evaluation mechanism. However, as stated earlier, the desktop simulation was somewhat problematic for the scenario organiser to run. The complexity of the scenario organiser's tasks would make it difficult to improve the desktop simulation while keeping it in its current state. For example, even adding a small number of people to the board would cause organisational problems. Given this, any improvements to the desktop simulation would first need to consider the role of the scenario organiser. Obviously, the optimal solution is to automate. Depending on the degree of automation required, the scenario organiser could use a computer to record the emergency manager's responses and to plot the progress of the incident or the whole simulation could be automated to a degree where a scenario organiser is no longer required.

Some degree of automation would greatly improve this desktop simulation. However, it is necessary to establish whether the large amount of effort applied to such a project would be worth the eventual outcome. Such a project must be useful not only to a research project such as this - but must have a broader scope. Currently, the desktop simulation enables an emergency manager to apply his decisions to a given situation and then to obtain a quantitative indication of his success. As this process can be repeated ad infinitum, the emergency manager can identify which of his actions are most effective and any errors of judgement that were made. This can facilitate the direct comparison of novice and expert emergency managers over identical scenarios. This may then enable some degree of cognitive insight into how an emergency manager deals with a real situation - perhaps through meta-cognition - whereby the emergency manager can discuss why each decision was made. Also, by use of different scenarios, it could be tested whether skills learnt in one type of scenario are transferable to other scenarios - for example, are the skills situation-specific (and perhaps environment-specific) or are they general "emergency management skills" - for example, would someone who is excellent in offshore emergency management still respond effectively when they are faced with a road accident? In this case, the desktop simulation could be used to test and train emergency managers in the cognitive aspects of the task.

Emergency management is usually taught and assessed using a dedicated simulation. This requires the whole emergency management team to be available for the simulation so another team must be manning the real emergency control room. There must be another group of people available to play the roles of the scenario organisation team. These are usually people who know the emergency management team, the installation and the problems that may occur in managing the prescribed emergency scenarios. They are guided by a scenario organiser who is usually an external consultant with specific expertise in running emergency scenarios. The scenario assessors often include internal senior managers and external consultants with expertise in training and assessment. The process requires at least 2 rooms, large amounts of equipment - sometimes technical panels identical to those used in the real control room. Also, the whole training and assessment process often takes a number of days. To summarise this, emergency management training and assessment is a costly process - and if the given emergency management candidate is simply unable to organise his thoughts, communicate or make decisions; it would have been a very expensive mistake. With a computer simulation (which as mentioned in Chapter 3 is currently not available to train general emergency management skills in the offshore industry), it could be quickly identified whether a potential candidate has the cognitive skills to either competently manage an emergency - or if he has the potential to learn it. This would also be beneficial to the candidate as they could identify their own skills and weaknesses before experiencing a dedicated simulation. If they can gain confidence in developing their cognitive decision making skills in a PC-based simulation, there is less risk of a humiliating and demoralising failure when they are faced with a dedicated simulation - or even a real incident. Consequently, if when they were given continued practise, candidates were still not able to cope with managing PC-based emergencies, they would be unlikely to put themselves forward for an emergency management role. This study does not in any way endorse the idea that PC-based applications could replace the dedicated or "real" simulations. However, they could provide an inexpensive means of educating the candidates in the cognitive side of emergency management.

Apart from this, the software could also be used to record the candidates' responses as "reasonable responses". For example, one candidate may have decided to evacuate the building by door 1, whereas another candidate in the same situation may have decided to get all the people on to the roof. Both of these decisions were thought to be reasonable responses by the people who made them. However, when a building or an installation is in the design phase, the designer must try and estimate these reasonable responses - to ensure that his design will facilitate a safe outcome to an emergency. Through the use of this software, it is possible to set up an emergency simulation based around the design. This can then be used to obtain reasonable responses - and possibly to identify risks that had not previously been identified. Taking this process one step further, a database of "reasonable emergency responses" can be collected - therefore ensuring that designers may not need to use real emergency managers - but instead can apply the range of possible responses to the programmed incident. In both cases, this facilitates the identification of risks at the design stage - both being cost-effective and promoting inherently safer design.

Given that automation is the key recommendation, it must be decided what form it should take. The main factors to consider are:

- 1.The Level of Automation - the degree of intervention of the Scenario Organiser
- 2. The Level of Detail Required
- 3. The Breadth of Scope Required
- 4. The Format of the Presentation

Therefore, it is necessary to elaborate on each of these factors.

1. The system may just be used to take account of the use of moves and to remind the scenario organiser of the progress of the incident; it may be a networked system involving terminals for use by the emergency manager and scenario organiser, or may be completely stand-alone, with the progress of the emergency to be defined by the software. The choice of these factors depends partly on its intended purpose as well as the expected investment into the project compared with the benefits that it could bring. If it is expected that a large number of people would require training, re-training and preliminary assessment, the stand-alone version is probably the best. If however, the system is to be a simple tool designed to assist a scenario organiser, it is preferable that it is designed to record and analyse the progress of moves. The networked version has the advantage that the emergency manager and scenario organiser need not be in the same place. Such tests could be run via the Internet giving a quick and easy indication of performance. Also, the software could potentially be expanded to include whole emergency management teams, each using a networked terminal. This could identify weak links in the team or overall problems in communication.

However, the choice is also affected by the required level of complexity and scope of the simulations. The uncertain nature of an emergency situation provides problems for stand-alone software. It is possible to incorporate uncertainties through use of random response generation or artificial intelligence. However, during a dedicated simulation, an emergency management assessor may request that the incident escalates in a particular way in response to particular actions. Such post-hoc decisions would be difficult to incorporate if the system is completely autonomous. Software does not have such an agenda unless it is pre-specified before the scenario begins. Also, if software was to use random responses, it could result in unfair or unrealistic biases towards either favourable or unfavourable conditions. The purpose of the research was to produce a reliable methodology to assess emergency management skill. If the software itself is producing and responding to uncertainties, it would be difficult to guarantee its reliability as a repeatable test.

Therefore, this suggests that the scenario organiser should remain as part of the desktop simulation - either through a network attachment to the console of the emergency manager - or by using the current desktop simulation with the assistance of software to record and analyse the moves taken. This decision is based on the chosen complexity of the simulation - the greater the complexity, the greater the workload on the scenario organiser. Therefore, for life-like simulations, the networked version is the final recommendation. This allows any post-hoc changes to be recorded plus any interpretations. For example, a scenario organiser can deliberately misinterpret a vague communication and respond by acting incorrectly, whereas to program a stand-alone computer to react in a "human" way to complex communications is currently impossible. The scenario organiser can also add distractions - for example, by providing wordy explanations of the status report to waste the time of the emergency manager. Obviously any post-hoc changes or deliberate deviations such as these must be recorded. Essentially, they provide randomness to the methodology, affecting its reliability. However, as long as they are formally recorded, this ensures that they are repeatable and that biased simulations are not compared directly to unbiased ones in terms of the performance assessment. As this element can be incorporated specifically into the methodology, it should not affect its reliability.

Ideally, the desktop simulation should also produce the "success/time" and "use of time" graphs rather than just providing the data. By this addition, the implications of the decisions made can be observed soon after the scenario has been completed. This early feedback would be beneficial as a training aid to the candidates and would again facilitate the work of the scenario organiser / assessor.

2. The level of detail that must be chosen for the computer again depends on its purpose and the importance of correctness. If the software is to be used as an initial test in cognitive skill, the level of detail can be reasonably low. If the software is designed to test an emergency manager's specific knowledge about his environment, the level of detail must be very high.
In general, as software has developed, the level of detail has improved. Originally, it was only possible to represent people by use of a spot on the screen. Today's software allows us to identify individual people by their physical characteristics or voices, and they often have defined skills and personalities. To be extremely realistic, the behaviour of the people should be realistic. The roles and skills of people must also be considered (e.g. medical skills, fire-fighting skills) as well as physical and psychological weaknesses (e.g. physical strength, fitness or disabilities, fear of water, heights). The effect of injuries on people should be based on known medical information. Similarly, the escalation of an incident should be based around real or simulated escalation (perhaps obtained from other sources of software) rather than a simple set of rules as in the current desktop simulation. The environment should be represented as a Three-dimensional "virtual reality" building, accurate to a degree where the survival times of the firewalls are based on realistic information. The risks should be based on the known physical characteristics of the environment. Similarly, the performance of the safety equipment may be based on real information on longevity, probability of failure and its impact on the risks involved. To summarise, the amount of detail required to make a realistic scenario would be enormous and therefore would probably be limited by the capabilities of the hardware. Therefore, the level of detail should be prioritised and designed according to the purpose of the software.

3. The breadth of scope relates to the scope of the software's use. If this is to be a research tool - for example, to identify whether emergency management skills are scenario or environment-specific or are transferable to other

situations - it is necessary to provide a large number of scenarios and environments. For example, scenarios in one environment may include acts of terrorism, natural disasters, contagious diseases, leaks of hazardous substances and vehicle impacts. The different environments may include domestic settings, air traffic control towers, factories and nuclear power plants. If the software is aimed at a particular client group, for example, the offshore oil and gas industry, it should provide different types of software to fit all possible installation types. These may be mobile drilling rigs, large production platforms, service vessels etc. If the client requires a high level of detail for a specific installation, it is likely that the software would need to be purpose-designed for the client. This would still require a large number of scenarios but only one specific environment.

4. The format of the presentation really refers to the format displayed to the emergency management candidate. The scenario organiser must have a multi-purpose screen - to enable him to view the emergency manager's opinion of the simulation, the real state of the simulation and other features, for example, progress of moves, number of people injured and the quantitative results. Therefore, the choice of visual formats for the emergency manager is between the following options:

- the plan view of the grid
- the virtual-reality approach
- the multi-purpose approach

The current desktop simulation uses the plan view of the grid, similar to many board games. This approach is also often used in emergency management simulations to work out the progress of people and the location of particular hazards.
The virtual reality approach represent the view that is seen from the emergency manager's eyes in the actual situation - which may include reading procedures, looking at a plan view of the grid, observing people and hazards.
The multi-purpose approach includes a number of screens - each referring to a different aspect. For example, there may be a plan view, a virtual reality view, and views showing information about the installation, the personnel, or even the candidate's progress in managing the emergency.
The format of presentation should also take into account the communication aspects. In general, the simulation would have more ecological validity if it was representative of communication in a real emergency. In general, most emergency communication is audible - because it is faster to say something than to write it down. Therefore, if audible communication was incorporated into the simulation, this would allow some of the related problems to occur - fuzzy signals, overlapping messages, forgetting what has just been said and any specific features of the person's voice - for example, problems with unusual accents. However, some aspects of emergency management may include written communications or use of technology (e.g. activating switches). In this case, it should be represented in as close a manner to the real actions as possible.

SECTION 6: CONCLUSION

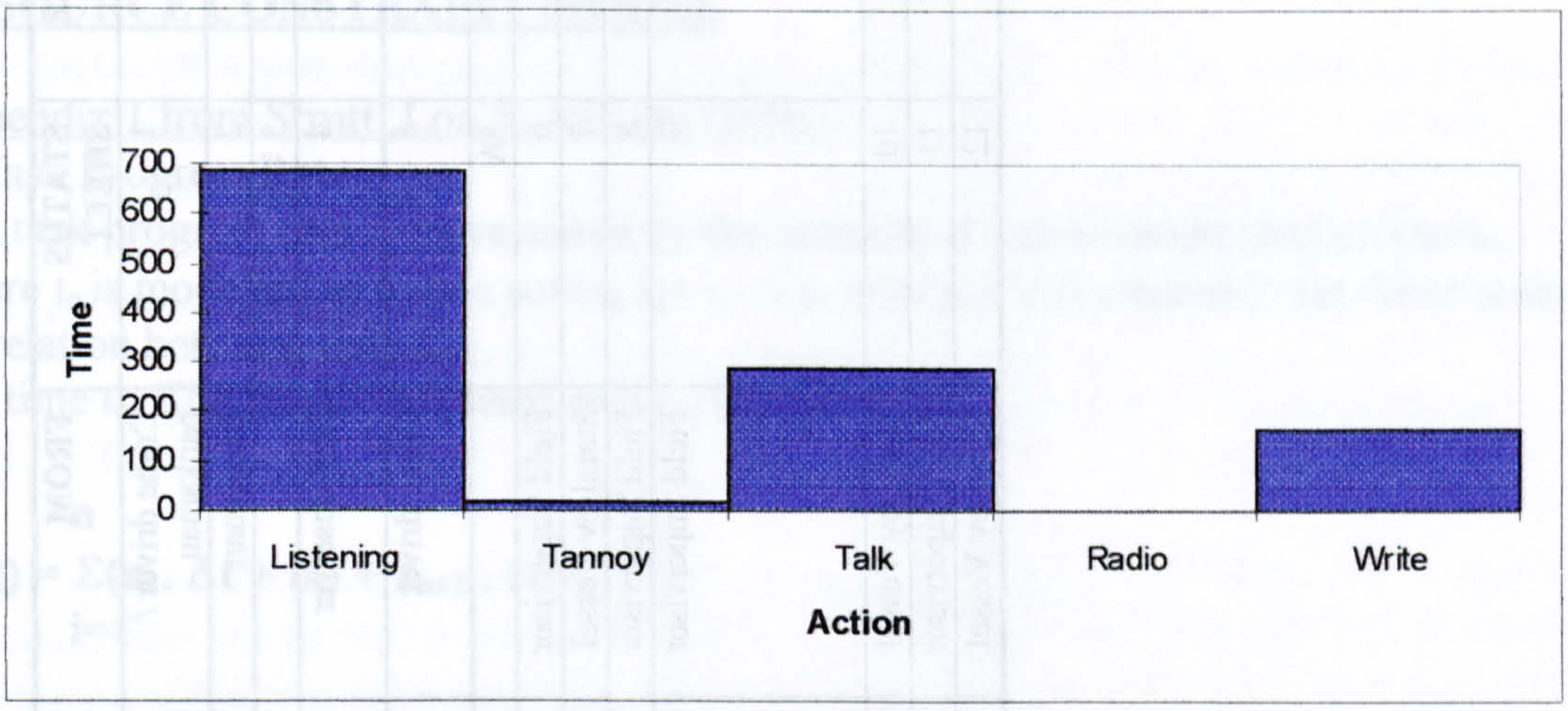
Overall, the methodology shows the potential to be improved into a valid test of emergency management decision-making. The desktop simulation aspect is somewhat lacking, due to the low level of detail used. It therefore requires much improvement to be a practical method of obtaining data to test the evaluation mechanism. In general, the key recommendation from this study is to automate. However, the evaluation mechanism already has some face validity and therefore has great potential for being used with real emergency data

However, these current results suggest that using the simulation and evaluation mechanism together requires much improvement before this is a practical alternative to the current methods of assessing emergency exercises. Although use of a desktop simulation can never provide the realism of a full exercise or a real emergency, it could assist in the evaluation of thought-processes, which may give a valid indication of the candidate's ability in managing a real emergency. Emergency exercises are often expensive - requiring large numbers of people and expensive equipment. If a simple desktop simulation such as this can provide an adequate preliminary test or training for emergency managers, it would certainly be beneficial.

However, shortly after this methodology had been completed to this stage, it became clear that there would be some access to dedicated simulations run for the offshore industry. Obviously, the data from such exercises are extremely valuable when developing a method to assess the contribution of emergency management to risk reduction.

Therefore, due to the availability of these data and the need for considerable improvements for the desktop simulation to progress, the recommendations were not implemented within this project. However, many of the ideas that emerged during this pilot study were useful in developing an evaluation mechanism for the dedicated simulations. For example, the Performance versus Time concept is comparable to the TPRC analysis. The "Use of Time" analysis was carried out for the first offshore scenario - the helicopter crash as shown in Figure M.

Figure M: Use of Time in Dedicated Simulation of Helicopter Crash



Like in the desktop simulation, this was not a particularly effective assessment technique. It does not represent the content of the conversations or actions. Also, the category marked as "listening" may be over-estimated, as it is not clear whether someone is listening to the action, reading boards or is concentrating on their own thoughts. In general, most of the communication made was internal to the group - whereas the radio transmissions and tannoys were minimal. This demonstrates that the "leader" function was providing an overview of the situation, whereas the other members of the team were responsible for the external communications. This is generally considered to be a good strategy for emergency management. In this particular scenario, the tannoy was unavailable due to a Level 4 shutdown (power cut) and so this may not be a true reflection of the use of tannoy in emergencies in general.

However, on its own, this graph shows little information on the ideal strategy for emergency management and therefore the "use of time" analysis is inadequate to represent quality in emergency management performance.

APPENDIX 3: EXAMPLE OF A DEDICATED SIMULATION BRIEF - METHANOL TOTE TANK SCENARIO

TIME	STATUS SHEET	FROM	TO	INFORMATION
0.00	1	Crane driver / banksman	CRO	Just to warn you, they may have a problem down on the laydown area. The load swung in the wind and one of the methanol tanks got a bad knock. I can't see any damage from here.
0.02	2	Banksman	CRO	We've got trouble at the tote tanks, there is methanol everywhere!!! We'll get some hoses rigged straight away.
0.04	3		CRO	Indications of fire at the Methanol laydown area. Level 3 shutdown.
When sent	4	First observer	CRO	There is a methanol fire around the tote tanks. I can see a terrific heat haze and paint is blistering off the tanks.
0.06	5	Crane driver	CRO	Get me some help up here. I'm stuck in the cab!! I daren't open the door, the heat is intense. Get them to play some hoses on the ladder!
	5A		CRO	Indications of fire on Mezzanine deck, North side.
0.09	6	Field Supervisor	Crane Driver	Don't worry Joe, We'll get some water up there for you.
0.10	7	Stand-by Vessel	CRO	Someone has jumped into the sea!! We're launching the FRC and we're moving round to the North side.
0.10	8	Field Supervisor	CRO	Joe Bloggs has bailed out of the crane. He's in the water, North side. We are rigging hoses for containment.
0.13	9	Field Supervisor	CRO	Both foam monitors are going now, but the wind is making it very difficult to laydown a decent blanket. We're pulling up extra foam branches, but I'm concerned about the amount of foam we have. I think we should wait until everything is rigged and we can hit with enough foam to kill it quickly. If we use to little there is a risk that we will not completely kill it and then run out of foam. I think we should concentrate on containment until everything is ready.
0.15	10	Stand-by Vessel	Radio Operator	The FRC has recovered the man overboard. They are bringing him back now. I have no details of his condition.
0.17	11	Field Supervisor	CRO	We have as many hoses ready now as we can supply with foam. We need to kill the deluge before we start.
0.20	12	Stand-by Vessel	Radio Operator	The man is now on board the Stand-by Vessel. I'm afraid there is nothing we can do for him.

APPENDIX 4: FORMULAE USED IN THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL

Appendix 1 from Strutt, Loa & Allsopp (1996)

1. Task Progress Rate

The task progress rate is represented by the amount of work completed by time t_n, where t_n is modelled as a time series, $t_n = n.\ \Delta t_n$ in which it is assumed that there is no correlation between time t_{n+1} and time t_n. The work completed at time t is given by:-

$$W(t) = \sum_{i=1}^{n}(a_i . \Delta t + b_i) + a_{n+1} . (t - t_n)$$

$$\text{where } t_n - \sum_{i=1}^{n} \Delta t_i$$

and $t_n \geq t \geq t_{n+1}$ (sic – see below)

(whilst $t_n \geq t \geq t_{n+1}$ is the formula quoted in Strutt et al (1996), it is intended to read $t_n \leq t \leq t_{n+1}$ representing the fact that t is any number between t_n and t_{n+1})

The assumption is that work progresses by a series of random jump b_i at random interval Δt with random rate of learning a_i in between. Where the task is problem solving, work progress is understood to mean knowledge accumulation i.e. a learning process and a, b and Δt model the learning rate, b_o is task start point of the initial level of knowledge learned from past experience. For each time interval (i), the values of a, b, Δt are chosen from the Weibull distribution at random with scale parameter η and shape parameter β. These values are given by:

$$\Delta t = \eta_1 . (-\ln(R_1))^{1/\beta_1}$$

$$a = \eta_2 . (-\ln(R_2))^{1/\beta_2}$$

$$b = \eta_3 . (-\ln(R_3))^{1/\beta_3}$$

where R_i is a random number between 0 and 1.

2. Resource Consumption Process

The resources used in task performance accumulates in time with the same time steps as those for task progresses. The resource consumption rate is also made dependent on η_2 and β_2. This provides where appropriate a connection between the consumption rate and of resources is given by:

$$R(t) = \sum_{i=1}^{n} (Cr_i . \Delta t) + Cr_{n+1} . (t - t_n)$$

where

$$\mathbf{Cr_i = X.(1+2.R_4.dc.\ \eta_2 /a_i)}$$

The parameter C is considered as the steady (basic(rate of resource usage. Cr_i is the actual resource consumption rate at a particular time interval (i). The parameter dc is a fractional rate increase scale factor for extra resource usage. This fractional increase in the rate of resource usage is dependent on the work progress rate through the parameter a. This dependency is assumed to be inversely proportional to a, hence the factor η_2 /a. This strict proportionality is moderated through a further random factor R_4. R_1 -R_4 are successive random numbers equally likely to be between 0 and 1.

3. Prediction of Human Reliability

The total amount of work (the work requirement) to complete a task or the information needed to solve a problem is modelled as a Weibull distribution with a scale factor η_W and shape factor β_W. The cumulative distribution of work completed (or useful information gathered) will be

$$\mathbf{F_W = 1 - exp\ [\ (W / \eta_W)^{\beta_W}\ ]}$$

The probability of success is represented by

$$\mathbf{P_S(W,t) = \int f_L(t).F_W\ .\ dt}$$

Where $f_L(t)$ is the pdf of work completed (amount learned) between t and (t+dt). The resources available to complete the task is also given by a Weibull distribution with a scale factor η_R and shape factor β_R. The cumulative distribution of resources consumed will be

$$\mathbf{F_R = 1 - exp\ \{(R/\eta_R)^{\beta_R}\ \}}$$

The probability of failure due to resource restriction is then represented by

$$\mathbf{P_f(R,t) = \int f_c(t).F_R\ .\ dt}$$

Where $f_c(t)$ is the pdf of the resources consumed between t and (t+dt). In this case, the probability of success is represented as

$$\mathbf{P_S(R,t) = 1 - P_f(R,t)}$$

At a given time T, there exists a bivariate distribution f(W,R;t). The human reliability in completing the task is regarded as the product of the probability of success task in problem solving, and the expression is given by:-

$$\mathbf{R(t) = \iint f(W,R;t).F_W.(1-F_R).dW.dR}$$

The Weibull Equation (cited in Loa 1997 Appendix B)

Using a process that starts at t=0, the failure cumulative distribution function of the Weibull distribution is:

$F(t) = 1 - \exp\{ - [t/\eta]^{\beta} \}$ [The Reliability function $R(t) = 1 - F(t)$]

$(1 - F(t))^{-1} = [t/\eta]^{\beta}$

$\ln \ln (1- F(t))^{-1} = \beta \ln t - \beta \ln \eta$

where η is the scale parameter and β is the shape parameter

IF we let $x = \ln(t)$
and $y = \ln[-\ln(R(t))]$ this can be represented by a straight line of the form $y = m x + c$.
If this case $m = \beta$ and $c = -\beta \ln(\eta)$. Therefore $\eta = \exp(-c/\beta)$

For a given data set, the value of β and η can be calculated using the following steps.

Let n be the total number of data points.
Rearrange the list of data points, t, into increasing order in Column 1.
In Column 2, number the data points from 1 to n - giving each of the original data points a "position" in the list, i.
In Column 3, work out the probability, p, associated with this position, creating a new column of values using the equation $i/(1+n)$.
In Column 4, take logs of Column 1 to give $\ln(t)$
In Column 5, use the values in column 3 to calculate $\ln(-\ln(1-p))$.
Plot Column 4 against Column 5 using a scatter graph.
If the graph approximately follows a straight line, the data can be modelled using a Weibull distribution.
In this case, the slope of the line gives β and the intercept gives $-\beta \ln(\eta)$.

To calculate the mean and variance of the Weibull distribution, we can use the following equations.

$\mu = E[t] = \int_0^{\infty} t \,.\, f(t).\, dt$

The result of this integration is:

$\mu = \eta.\Gamma(1 + {}^1/_{\beta})$

Where Γ is the Gamma function

$\Gamma(x) = \int_0^{\infty} t^{x-1}.e^{-t}.dt$

with the stipulation that x>0.

The variance of a Weibull distribution is:

$\sigma^2 = \int_0^\infty t^2 . f(t). dt - \mu^2$

Thus

$\sigma^2 = \eta^2. [\Gamma (1 + {}^1/_\beta) - \Gamma^2 (1 + {}^1/_\beta)]$

APPENDIX 5: PROGRAM LISTING

```
program         Meldam;

uses    wincrt;

var     i,imax,no,noran           :integer;
        Dsmean,DSCOV,Fulmean,FulCOV,iTmean,iTCOV,
        delt,DSsc,DSsh,t,D,dt,a,b,c,dc,Fulsc,Fulsh,F,dF,Pd,iTsc,iTsh          :real;
        Dam,Ful         :extended;
        p,pW   : array[1..6] of real;
        tt        : array[1..100] of real;
        PLS,WeiP       :array[1..100] of extended;
        indat,outdat,outdat2   :text;

procedure Weiparam(mean:real;COV:real;var scale:real;var shape:real);

FUNCTION gammln(xx: real) : real;
CONST
        stp = 2.50662827465;
VAR
        x,tmp,ser:        double;
BEGIN
        x := xx-1.0;
        tmp := x+5.5;
        tmp := (x+0.5)*ln(tmp)-tmp;
        ser := 1.0+76.18009173/(x+1.0)-86.50532033/(x+2.0)+24.01409822/(x+3.0)
-1.231739516/(x+4.0)+0.120858003e-2/(x+5.0)-0.53638e-5/(x=6.0);
        gammln := tmp+ln(stp*ser)
END;

FUNCTION fx(x:real):real;

begin
        fx := ln(1+ sqr(COV)) + 2*gammln(1 + 1/x) - gammln ( 1 + 2/x)
end;

FUNCTION zbrent(x1,x2,tol: real) : real;
LABEL 99;
CONST
        itmax = 100;
        eps = 3.0e-8;
VAR
        a,b,c,d,e: real;
        min1,min2,min: real;
        fa,fb,fc,p,q,r: real;
        s,toll,xm: real;
        iter: integer;
```

```
BEGIN
a := x1;
b := x2;
fa := fx(a);
fb := fx(b);
IF fb*fa > 0.0 THEN BEGIN
        writeln('pause in routine ZBRENT');
        writeln('root must be bracketed');
        readln
END;
fc := fb;
FOR iter := 1 TO itmax DO BEGIN
        IF fb*fc > 0.0 THEN BEGIN
                c := a;
                fc := fa;
                d := b-a;
                e := d
        END;
        IF abs(fc) < abs(fb) THEN BEGIN
                a := b;
                b := c;
                c := a;
                fa := fb;
                fb := fc;
                fc := fa
        END;
        toll := 2.0*eps*abs(b)+0.5*tol;
        xm := 0.5*(c-b);
        IF (abs(xm) <= toll) AND (abs(fa) > abs(fb)) THEN BEGIN
                s := fb/fa;
                IF a = c THEN BEGIN
                        p := 2.0*xm*s;
                        q := 1.0-s
                END
                ELSE BEGIN
                        q := fa/fc;
                        r := fb/fc;
                        p := s*(2.0*xm*q*(q-r) - (b-a) * (r-1.0));
                        q := (q-1.0)*(r-1.0)*(s-1.0)
                END;
                IF p > 0.0 THEN q := -q;
                p := abs(p);
                min1 := 3.0*xm*q-abs(toll*q);
                min2 := abs(e*q);
                IF min1 < min2 THEN min := min1 ELSE min := min2;
                IF 2.0*p < min THEN BEGIN
                        e := d;
                        d := p/q
```

```
                END
                ELSE BEGIN
                        d := xm;
                        e := d
                END
        END
        ELSE BEGIN
                d := xm;
                e := d
        END;
        a := b;
        fa := fb;
        IF abs(d) > toll THEN b := b+d
        ELSE BEGIN
                IF xm >= 0 THEN b := b+abs(toll)
                ELSE b := b-abs(toll)
        END;
        fb := fx(b)
    END;
    writeln('pause in routine ZBRENT');
    writeln('maximum number of iterations exceeded');
    readln;
    zbrent := b;
99:
END;

begin
    shape := zbrent(0.5/COV,1.5/COV,0.001);
    scale := mean*exp(-gammln(1 + 1/shape))
end;

begin
    assign(indat,'a:\inMel.dat');{Input file}
    reset(indat);
    assign(outdate,'a:\oumelA.dat');
    rewrite(outdat);
    assign(outdat2,'a:\outmelB.dat');
    rewrite(outdat2);
    readln(indat,imax);
    writeln(outdat,imax,',');
    writeln(outdat2,imax,',');
    readln(indat,delt);
    writeln(outdat,delt,',');
    writeln(outdat2,delt,',');
    readln(indat,noran);
    writeln(outdat,noran,',');
    writeln(outdat2,noran,',');
    writeln(outdat);
```

```
writeln(outdat2);
read(indat,iTmean);
readln(indat,iTCOV);
Weiparam(iTmean,iTCOV,iTsc,Ish);
writeln(outdat,iTmean,’,’,iTCOV,’,’,iTsc,’,’,iTsh,’,’);
writeln(outdat2,iTmean,’,’,iTCOV,’,’,iTsc,’,’,iTsh,’,’);
for i := 1 to 3 do
begin
        read(indat,p[2*i - 1]);
        readln(indat,p[2*i]);
        Weiparam(p[2*i - 1],p[2*i],pW[2*i - 1],pW[2*i]);
        writeln(outdat,p[2*i - 1],’,’,p[2*i],’,’,pW[2*i - 1],’,’,pW[2*i],’,’);
        writeln(outdat2,p[2*i - 1],’,’,p[2*i],’,’,pW[2*i - 1],’,’,pW[2*i],’,’);
end;
read(indat,DSmean);
readln(indat,DSCOV);
Weiparam(DSmean,DSCOV,DSsc,DSsh);
writeln(outdat,Dsmean,’,’,DSCOV,’,’,DSsc,’,’,DSsh,’,’);
writeln(outdat2,Dsmean,’,’,DSCOV,’,’,DSsc,’,’,DSsh,’,’);
read(indat,c);
readln(indat,dc);
write(outdat,c,’,’);
writeln(outdat,dc,’,’);
write(outdat2,c,’,’);
writeln(outdat2,dc,’,’);
read(indat,Fulmean);
readln(indat,FulCOV);
Weiparam(Fulmean,FulCOV,Fulsc,Fulsh);
writeln(outdat,Fulmean,’,’,FulCOV,’,’,Fulsc,’,’,Fulsh,’,’);
writeln(outdat2,Fulmean,’,’,FulCOV,’,’,Fulsc,’,’,Fulsh,’,’);
writeln(outdat);
writeln(outdat2);
close(indat);
for i := 1 to imax do
tt[i] := i*delt;
Randomize; {Alternative random generation }
{Randseed := 2}
writeln (‘Meldam running’);
for no := 1 to noran do
begin
        t := iTsc*exp(ln(-ln(Random))/iTsh);
        D := 0;
        F := c*t;
        a := 0;
        b := 0;
        for i := 1 to imax do
        begin
                if (tt[i] < t) and (D = 0) then
```

```
        begin
            Ful := c*tt[i];
            Ful := exp(ln(Ful/Fulsc)*Fulsh);
            if Ful > 1.0e4 then
            Ful := 0
            else
            Ful := exp(-Ful);
            Dam := 1.0
        end
        else
        begin
            while t < tt[i] do
            begin
                dt := pW[1]*exp(ln(-ln(Random))/pW[2]);
                a := pW[3]*exp(ln(-ln(Random))/pW[4]);
                b := pW[5]*exp(ln(-ln(Random))/pW[6]);
                dF := c*(1 + 2*dc*a*random/pW[3]);
                D := D + a*dt + b;
                F := F + dF*dt;
                t := t + dt
            end;
            Dam := D - a*(t - tt[i]) - b;
            if Dam = 0 then
            Dam := 0
            else
            Dam := exp(ln(Dam/DSsc)*DSsh);
            if Dam > 1.0e4 then
            Dam := 0
            else
            Dam := exp(-Dam);
            Ful := F = dF* (t - tt[i]);
            Ful := exp(ln(ful/Fulsc)*Fulsh);
            if Ful > 1.0e4 then
            Ful := 0
            else
            Ful := exp(-Ful)
        end;
        if no = 1 then
        PLS[i] := (1 - Dam)*Ful
        else
        PLS[i] := ((no - 1)*PLS[i] + (1 - Dam)*Ful)/no
    end
end;
for i := 1 to imax do
begin
    if PLS[i] < 1.0e-7 then
    begin
        if PLS[i] < 2.0e-13 then
```

```
                    WeiP[i] := -30
                    else
                    WeiP[i] := ln(PLS[i])
          end
          else
          WeiP[i] := ln(-ln(1 - PLS[i]));
          if PLS[i] < 1.0e-30 then
          PLS[i] := 0.00;
          writeln(outdat,ln(tt[i]):12,',',WeiP[i]:12,',');
          writeln(outdat2,tt[i]:12,',',PLS[i]:12,',')
     end;
     close(outdat);
     donewincrt
end.
```

APPENDIX 6: TRANSCRIPT

TRANSCRIPT OF METHANOL TOTE TANK SCENARIO

Time	Event
0:00:00	ASSUME INCIDENT OCCURRED
0:00:01	CD: Control room, Deck
0:00:03	call ends (CD)
0:00:05	CRO: Control, call back
0:00:06	call ends (CR0)
0:00:07	CD: Yeah, just to warn you, we've had a bit of a knock, moving these tote tanks around, the wind took the load and there was an edge-on, an edge-on knock, pretty hard, I'm just going to have a look now.
0:00:18	call ends (CD)
0:00:18	PS: Okay, stop all hot work, please CRO on the tannoy
0:00:21	Announcement ends (PS)
0:00:22	CRO (tannoy): Attention all personnel, attention all personnel, all hot work is to cease immediately, all hot work is to cease immediately, all hot work permits to be returned to the control, return all hot work permits to the control room, thankyou.
0:00:34	tannoy ends (CRO)
0:00:34	PS: I'm removing all u.v. ask the OIM to come to the control room
0:00:36	CD: Control room, Deck
0:00:37	Phone rings
0:00:37	call ends (CD)
0:00:38	Announcement ends (PS)
0:00:39	CRO (tannoy) : OIM report to the control room, OIM report to the control room
0:00:40	u.v. detectors removed
0:00:43	tannoy ends (CRO)
0:00:45	ASSUME CD FINDS METHANOL HAS LEAKED
0:00:45	CD: Control room Deck
0:00:46	call ends (CD)
0:00:47	Phone stops (PS answered)
0:00:47	PS (on phone): R control
0:00:48	CRO: Go ahead Deck
0:00:49	Announcement ends (PS) - Phone call ends
0:00:49	call ends (CRO)
0:00:49	RO: That was him on the phone
0:00:50	Announcement ends (RO)
0:00:50	OIM and FS arrive
0:00:50	CD: Yeah, we've got a problem down here, there's methanol everywhere, we're going to start getting some hoses rigged out but wait there.
0:00:56	OIM: What's the status?
0:00:57	Announcement ends (OIM)
0:00:58	call ends (CD)
0:00:58	PS: Crane is lifting tote tanks, methanol, on the laydown area, top deck, and they've dropped it, and now there's methanol everywhere, the crane driver's investigating, we've stopped all hot work, we've taken the u.v. detectors off the board and I think probably it might be a good idea if you want to muster people
0:01:12	Announcement ends (PS)
0:01:12	OIM: Yeah, do it
0:01:13	CRO: Muster?
0:01:14	Announcement ends (OIM)
0:01:14	Announcement ends (CRO)
0:01:15	PS: Yes please
0:01:16	Announcement ends (PS)
0:01:16	FS: Do you want me down there?
0:01:17	Announcement ends (FS)
0:01:18	OIM: First, get some people and try and get some foam, see what it's like across there
0:01:21	Announcement ends (OIM)

0:01:21	FS: OK, I'll go over there on the workshop roof
0:01:22	PS: Is there deluge on there ?
0:01:23	Announcement ends (PS)
0:01:23	Announcement ends (FS)
0:01:23	OIM: Yeah
0:01:23	FS: And see if I can get in that way.
0:01:24	Announcement ends (OIM)
0:01:24	Announcement ends (FS)
0:01:24	OIM: Yeah, that's probably closest but mind you, the wind's this direction so you may be want to come through there so you can swing it through here.
0:01:32	Announcement ends (OIM)
0:01:33	FS: I'll do both
0:01:34	Announcement ends (FS)
0:01:34	OIM: OK, take 4 people with you
0:01:36	Announcement ends (OIM)
0:01:36	ASSUME FIRE IGNITED
0:01:37	ALARMS GO OFF (indicating fire)
0:01:41	ALARMS RESET (PS)
0:01:42	OIM: Has the muster started?
0:01:43	Announcement ends (OIM)
0:01:43	PS: We've got a fire detected on the Mezz deck and the Weather deck on Johnson OIM, we've gone into a level 3, I've put the Weather deck deluge off and Johnson and the...
0:01:52	Announcement ends (PS)
0:01:52	OIM: Put all the deluges on please
0:01:53	Announcement ends (OIM)
0:02:09	FS: Right, OIM, I've put them on the board there right, I'm taking them out now 2 mechies and 2 proddies.
0:02:10	Level 3 activated and deluge activated
0:02:17	Announcement ends (FS)
0:02:20	ASSUME FS LEAVES
0:02:22	PS: All deluge on, OIM, apart from accommodation and GCD
0:02:24	CRO (tannoy) Attention all personnel, attention all personnel, all personnel report to their muster stations, all personnel report to their muster stations, all hand-held radios to Channel 15, all hand held radios to Channel 15.
0:02:26	Announcement ends (PS)
0:02:32	P arrives
0:02:35	G arrives
0:02:37	Tannoy ends (CRO)
0:02:37	ASSUME MUSTER STARTED
0:02:40	RO arrives
0:02:41	PS: We've had a tote tank dumped on the top laydown area on the Weather deck, there's methanol everywhere, we've set the deluges off on every deck apart from gas compression, accommodation and helideck, we're in a level 3 shutdown situation
0:02:55	Announcement ends (PS)
0:02:58	D arrives
0:03:01	CD: Control room come in
0:03:02	call ends (CD)
0:03:02	PS: Shut down, 12:48 tote tank on the top laydown area of the weather deck
0:03:04	CRO: Control room call back
0:03:05	call ends (CRO)
0:03:06	CD: Can you get them to play some water up there, I can't get out of the cab, as soon as I open the door, it's scalding
0:03:07	Announcement ends (PS)
0:03:11	call ends (CD)
0:03:12	CRO: The crane driver's actually trapped in the crane, he can't get out of the cab
0:03:14	Announcement ends (CRO)
0:03:14	PS: Get on to the fire team
0:03:15	Announcement ends (PS)

0:03:16	OIM: That's all we can do
0:03:17	Announcement ends (OIM)
0:03:17	CRO: Crane driver, just stay where you are for the moment, we'll get people to you as soon as we can.
0:03:20	call ends (CRO)
0:03:21	PS: 12:48
0:03:22	Announcement ends (PS)
0:03:22	FS: Control room, this is the field supervisor, we're on our way up to get some deluge water on to that crane, so just hold on.
0:03:30	call ends (FS)
0:03:31	CD: OK, I'll bring the crane around and put the tail out to sea with the back towards where the fire is, it's bloody roasting out here already.
0:03:40	call ends (CD)
0:03:42	PS: 12:47, P, amend that time
0:03:44	Announcement ends (PS)
0:03:46	P: What's that, muster?
0:03:47	Announcement ends (P)
0:03:47	PS: No, the levels
0:03:48	Announcement ends (PS)
0:03:55	OIM: 12:48
0:03:56	Announcement ends (OIM)
0:03:58	RO: 12:45
0:04:00	Announcement ends (RO)
0:04:03	OIM: Time out
0:04:04	Announcement ends (OIM)
0:04:04	CRO: Time out everyone
0:04:06	call ends (CRO)
0:04:06	OIM: Right, the situation, we've got methanol spilt on the weather deck, we've confirmed fires on the Mezz deck and Johnson Weather deck, I've sent the field supervisor to investigate with a team of 4 and to rescue the crane driver from the cab, carry on.
0:04:15	ASSUME FIRE TEAM ARRIVE ON SITE
0:04:18	FS: Yeah, crane driver, crane driver, this is the field supervisor
0:04:21	call ends (FS)
0:04:23	CD: Go
0:04:24	call ends (CD)
0:04:24	FS: Yeah, can you stop swinging the crane, you're dragging the container on the deck, stop swinging the crane
0:04:26	Announcement ends (OIM)
0:04:30	call ends (FS)
0:04:34	G: Is the POB complete?
0:04:38	Announcement ends (G)
0:04:43	CRO: Well, there's one missing, obviously
0:04:45	Announcement ends (CRO)
0:04:45	ASSUME FOAM CANNON ACTIVATED
0:04:45	ASSUME CD JUMPS
0:04:45	P: Is the POB complete?
0:04:47	Announcement ends (P)
0:04:47	FS: Team leader, fire team leader, control
0:04:50	call ends (FS)
0:04:50	CRO: Control, go ahead
0:04:51	call ends (CRO)
0:04:52	FS: We have now got the foam cannon, the one situated underneath the crane rest, we have got that directed on to the methanol laydown area, we will try and get access on top of the workshop.
0:05:00	ASSUME POB COMPLETE
0:05:00	ASSUME SB LAUNCHED
0:05:04	SB: ... is on its way into the water now and we will be around the side
0:05:07	call ends (FS)
0:05:08	CRO: Copy that
0:05:09	call ends (CRO)

0:05:13	RO: We have a man overboard apparently, on the North side of the platform
0:05:15	call ends (SB)
0:05:17	Announcement ends (RO)
0:05:17	P: Is that the crane driver?
0:05:18	Announcement ends (P)
0:05:18	RO: One man overboard, North side of the platform
0:05:20	Announcement ends (RO)
0:05:20	?: Right
0:05:21	call ends (?)
0:05:22	OIM: Have they got that?
0:05:23	Announcement ends (OIM)
0:05:23	RO: 332 is in the water going round
0:05:24	Announcement ends (RO)
0:05:25	Phone rings
0:05:27	RO: Must be the crane driver, all other personnel are accounted for
0:05:30	Announcement ends (RO)
0:05:39	Phone is answered (PS)
0:05:40	PS: Hello (on phone)
0:05:41	Announcement ends (on phone) (PS)
0:05:43	PS: Yes (on phone)
0:05:44	Announcement ends (on phone) (PS)
0:05:45	PS: OK, thankyou (on phone)
0:05:46	Announcement ends (on phone) (PS) - assume helicopters ordered
0:05:47	Phone call ends (PS)
0:05:47	PS: On the line OIM
0:05:48	Announcement ends (PS)
0:05:48	OIM: Where's the POB?
0:05:49	Announcement ends (OIM)
0:05:49	PS: POB - one missing, the crane driver
0:05:51	Announcement ends (PS)
0:05:52	OIM: Obviously can't be, I've got one man over the side
0:05:54	Announcement ends (OIM)
0:05:55	P: Unless, it's the crane driver
0:05:56	Announcement ends (P)
0:05:56	OIM: Somebody has to tell us
0:05:58	Announcement ends (OIM)
0:05:58	PS: Can you get on to the fire team leader
0:05:59	Announcement ends (PS)
0:05:59	CRO: Fire team leader, fire team leader, call back
0:06:01	call ends (CRO)
0:06:05	FS: Yeah, can you wait one minute
0:06:07	call ends (FS)
0:06:14	P: Has the SB picked up that man overboard?
0:06:17	Announcement ends (P)
0:06:17	RO: I'm not aware of any pick up yet
0:06:19	Announcement ends (RO)
0:06:19	P: Can you get in contact with him?
0:06:20	Announcement ends (P)
0:06:20	RO: Yeah
0:06:21	Announcement ends (RO)
0:06:26	CRO: Fire team leader, call back
0:06:27	call ends (CRO)
0:06:27	SB: Call back
0:06:29	call ends (SB)
0:06:28	D: Yeah, I don't know what you want to do with this methanol store, we've got 4...
0:06:33	Announcement ends (D)
0:06:34	P: What time is blowdown complete?
0:06:35	METHANOL DUMP STARTED

0:06:35	SB: Yeah, we're coming into the platform ready to pick him up
0:06:36	Announcement ends (P)
0:06:40	call ends (SB)
0:06:40	PS: Methanol dumped 12:52
0:06:42	Announcement ends (PS)
0:06:43	SB: Yeah, we've got him in sight and we're going to get him out of the water
0:06:48	call ends (SB)
0:06:50	ASSUME FS FINDS CD IS NOT IN THE CRANE AND THAT IT IS HOT ON THE WORKSHOP ROOF
0:06:51	OIM: Call the field supervisor and find out if the crane driver is there or its somebody else
0:06:55	Announcement ends (OIM)
0:06:55	CRO: Field supervisor call back
0:06:56	call ends (CRO)
0:06:56	RO: They've got the MOB in sight now
0:06:58	Announcement ends (RO)
0:06:59	FS: Field supervisor control
0:07:00	ASSUME CD IS PICKED UP
0:07:01	call ends (FS)
0:07:02	CRO: Can you confirm that the crane driver is still in the crane or is he the man who has gone overboard
0:07:06	call ends (CRO)
0:07:07	FS: It looks to me as if he's done a runner, it might be him who's gone overboard. I'll just give you an update whilst we're on the radio, I cannot get on top of the workshop roof, it's very hot, the foam is on, the one below the crane pedestal, that is on the methanol laydown area, I recommend we get across to gas compression deck and get some portable foam monitors across on to the methanol area, use the wind to direct it across.
0:07:27	Phone rings
0:07:30	Phone is answered
0:07:39	call ends (FS)
0:07:40	PS: Tell him "do that" yeah
0:07:41	Announcement ends (PS)
0:07:41	CRO: Copy that, do that
0:07:42	call ends (CRO)
0:07:46	FS: Team leader, control, can you get 4 people to carry portable foam drums and meet me on gas compression Mezz deck, gas compression Mezz deck.
0:08:00	call ends (FS)
0:08:00	P: How many people does he want?
0:08:01	Announcement ends (P)
0:08:01	PS: 4
0:08:02	Announcement ends (PS)
0:08:03	CRO: despatching 4 people to you now, FS
0:08:05	call ends (CRO)
0:08:05	4 PEOPLE DESPATCHED TO GCD
0:08:07	G: 4 despatched, P
0:08:08	Announcement ends (G)
0:08:09	P: 4, despatched
0:08:10	Announcement ends (P)
0:08:10	G: 4, despatched
0:08:11	Announcement ends (G)
0:08:14	P: Location GCD, Mezz deck
0:08:17	Announcement ends (P)
0:08:21	OIM: Time out 20 seconds
0:08:23	Announcement ends (OIM)
0:08:27	CRO: Time out in 10 seconds, FS
0:08:28	call ends (CRO)
0:08:32	P: Any update on the helicopter
0:08:34	Announcement ends (P)
0:08:39	RO: Ready in 20
0:08:40	Announcement ends (RO)

0:08:41	P: Ready in 20
0:08:42	Announcement ends (P)
0:08:44	OIM: Time out, right, as I see it, the rescue of the crane driver has become a job for the standby boat and the FRC - that's their job, our job is actually to contain the fire, try and out it out, complete to level 3 shutdown, that's my scenario for the moment, carry on
0:09:00	ASSUME PEOPLE ARRIVE ON GCD, START SETTING UP FOAM
0:09:03	FS: Team leader, control
0:09:05	call ends (FS)
0:09:09	Announcement ends (OIM)
0:09:09	PS: End of time out
0:09:11	call ends (PS)
0:09:10	CRO: Come in fire team leader
0:09:11	call ends (CRO)
0:09:14	CRO: Fire team leader, go ahead
0:09:15	call ends (CRO)
0:09:16	FS: We're not setting up the portable foam, setting up the portable foam now on GCD weather deck in proximity to B compressor, we're also going to set another foam unit to direct on to the helifuel storage area.
0:09:40	call ends (FS)
0:09:41	CRO: Copy that
0:09:42	call ends (CRO)
0:09:42	OIM: Don't they have the deluges already on that anyway?
0:09:46	Announcement ends (OIM)
0:09:48	CRO: Just for your info, fire team leader, the deluge is already on that area anyway, but continue if you feel it's necessary
0:09:55	call ends (CRO)
0:09:56	FS: Yeah, there's an immense amount of heat up here and there's a lot of heat so we'll put as much water on as possible
0:09:57	?...
0:10:01	call ends (FS)
0:10:02	CRO: Copy that
0:10:02	PS: We did, not on accom or GCD
0:10:03	call ends (CRO)
0:10:06	Announcement ends (PS)
0:10:08	call ends (?)
0:10:11	OIM: I think you can put on the helideck and GCD as well, other than that area and we've got helicopters coming in - GCD has people in that area
0:10:24	Announcement ends (OIM)
0:10:24	PS: Yeah
0:10:25	Announcement ends (PS)
0:10:28	OIM: How are the levels?
0:10:29	Announcement ends (OIM)
0:10:32	PS: Blowdown is 13:03, 10 minute away and we're still holding 40 bar
0:10:35	ASSUME METHANOL DUMPED
0:10:41	Announcement ends (PS)
0:10:41	OIM: OK
0:10:42	Announcement ends (OIM)
0:10:42	P: How's the methanol situation PS?
0:10:44	Announcement ends (P)
0:10:44	PS: That's now dumped
0:10:45	Announcement ends (PS)
0:10:45	P: Dumped
0:10:46	Announcement ends (P)
0:10:46	PS: The tank is empty
0:10:47	Announcement ends (PS)
0:11:00	P: RO, has the SB picked up yet?
0:11:02	Announcement ends (P)
0:11:02	RO: Yeah, they've got him, he's not back to the main vessel yet

0:11:05	Announcement ends (RO)
0:11:05	P: How is he?
0:11:06	Announcement ends (P)
0:11:06	RO: He's in a bad way
0:11:07	Announcement ends (RO)
0:11:07	P: What?
0:11:08	Announcement ends (P)
0:11:09	RO: He's in a bad way but they're doing what they can
0:11:12	Announcement ends (RO)
0:11:13	P: Do a time out because all the challenges are out
0:11:17	Announcement ends (P)
0:11:19	P: There's only one missing
0:11:20	Announcement ends (P)
0:11:26	P: Can you ask the fire team leader if he's got his 4 men?
0:11:29	Announcement ends (P)
0:11:29	PS: Yes, he has, they're at B turbine area, B compressor
0:11:34	Announcement ends (PS)
0:11:36	CRO: If I contact anyone, ask for foam…
0:11:41	Announcement ends (CRO)
0:11:42	P: Need a doctor mobilised now
0:11:44	Announcement ends (P)
0:11:49	P: Mobilise a doctor from Humberside
0:11:51	Announcement ends (P)
0:11:51	RO: Suggest a paramedic on board on the helicopter
0:11:54	Announcement ends (RO)
0:11:57	PS: Have we got a Sea King?
0:11:59	Announcement ends (PS)
0:11:59	P: Don't know yet
0:12:00	Announcement ends (P)
0:12:02	P: The first Sea King comes in at 13:20, I'm just asking for, I'm just asking to see if they've got any medical assistance
0:12:07	PS: G, has the standby boat recovered the man overboard
0:12:08	Announcement ends (P)
0:12:10	Announcement ends (PS)
0:12:10	G: Yeah, the little one has not the main boat yet
0:12:15	Announcement ends (G)
0:12:15	PS: OK
0:12:16	Announcement ends (PS)
0:12:17	PS: How many totes of methanol were on that top laydown, G, can you remember?
0:12:20	Announcement ends (PS)
0:12:29	OIM (tannoy): Attention all personnel, attention all personnel, update on the situation, we've had a methanol spill on the Weather deck, on the methanol laydown area, we've confirmed fires on the Weather deck and the Mezz deck. We're fighting this at the moment, no cause for alarm, we have helicopters on the way to us, I'll keep you updated as it progresses, Thankyou
0:12:54	Announcement ends (OIM)
0:12:59	OIM: Time out 20 seconds
0:13:00	Announcement ends (OIM)
0:13:00	ASSUME MAN OVERBOARD IS IN THE STANDBY BOAT
0:13:02	CRO: Time out in 20 seconds
0:13:04	Call ends (CRO)
0:13:04	SB: Got back on now
0:13:06	call ends (SB)
0:13:06	?: Got a medic on
0:13:07	call ends (?)
0:13:09	?: 2 8
0:13:11	call ends (?)
0:13:12	?: Mobilised
0:13:14	call ends (?)

0:13:16	OIM: Time out, right standby boat has picked up the man although he's not back to the main boat, our biggest concern at the moment is to contain this fire, we've already dumped the methanol from the main tanks, complete the level 3 shutdown, which should be in about 8 minutes time. That's the situation as it is, carry on
0:13:20	Phone rings
0:13:25	Phone is answered
0:13:38	Announcement ends (OIM)
0:13:40	ASSUME PS IDENTIFIES NUMBER OF TANKS ON THE DECK
0:13:42	P: Have you got on to 2 8, R.O
0:13:43	Announcement ends (P)
0:13:43	PS: I've just checked the records OIM and there's 5 full methanol tanks up there and 7 empty
0:13:47	Announcement ends (PS)
0:13:49	P (start phone call) : ... and I would like you to mobilise a helicopter from Humberside airport a.s.a.p to us. We need a paramedic in the helicopter, thankyou
0:13:50	OIM: Get on to the field supervisor
0:13:52	Announcement ends (OIM)
0:13:58	Announcement ends (P) (on phone)
0:14:00	ASSUME DIESEL FIRE STARTS
0:14:00	ASSUME PARAMEDIC ORDERED
0:14:06	FS: Fire team leader control
0:14:08	call ends (FS)
0:14:08	CRO: Go ahead team leader
0:14:09	call ends (CRO)
0:14:10	FS: Yeah, it just looks like the heat has caused the diesel tank or fuel tank or something to rupture in the crane, cause we've got a small fire in the crane now
0:14:22	call ends (FS)
0:14:23	CRO: Actually in the crane itself, in the crane cabin
0:14:26	call ends (CRO)
0:14:27	FS: In the crane cab, I don't think it's anything of immediate concern though
0:14:31	call ends (FS)
0:14:32	CRO: Copy that
0:14:33	call ends (CRO)
0:14:34	CRO: Fire in the crane cabin
0:14:35	Announcement ends (CRO)
0:14:59	D: Pressure? about 10 bar
0:15:02	Announcement ends (D)
0:15:03	Phone call ends (PS)
0:15:03	PS: Yeah
0:15:04	CRO: The man overboard, they still haven't got an ID on him
0:15:05	Announcement ends (PS)
0:15:06	Announcement ends (CRO)
0:15:07	G: Rescue 2 8, 13:32
0:15:10	Announcement ends (G)
0:15:10	P: Rescue 2 8, 13:32
0:15:13	Announcement ends (P)
0:15:20	ASSUME FOAM MONITOR IS NOW OUT OF FOAM
0:15:25	FS: Fire team leader control
0:15:27	call ends (FS)
0:15:27	CRO: Go ahead
0:15:28	call ends (CRO)
0:15:29	FS: Yeah, it looks like the foam monitor I've got going from below the crane pedestal has run out of foam, I'm going to make my way up there, right, and sort that out, but I'm going to leave these other two monitors with 2 personnel on GCD Weather deck to look after the foam on the fixed monitors that they've got up there.
0:15:53	call ends (FS)
0:15:54	CRO: Copy that
0:15:55	call ends (CRO)
0:16:07	PS: Field supervisor, field supervisor, this is control

0:16:10	call ends (PS)
0:16:11	FS: Yeah, field supervisor
0:16:12	call ends (FS)
0:16:13	PS: Yeah, just for clarity, confirm please that it is the foam monitor under the crane boom rest and not the pedestal that you are proceeding towards that's the boom rest over
0:16:22	Call ends (PS)
0:16:23	FS: Yes, that's the boom rest below the helideck, the boom rest below the helideck
0:16:28	call ends (FS)
0:16:29	PS: Thankyou
0:16:30	call ends (PS)
0:16:55	OIM: Can you get an update from the field supervisor exactly how the fire and that
0:16:57	CRO: Field supervisor, call back
0:16:58	Announcement ends (OIM)
0:16:59	call ends (CRO)
0:17:01	FS: Yeah field supervisor
0:17:03	call ends (FS)
0:17:03	CRO: What's your situation please?
0:17:05	call ends (CRO)
0:17:07	FS: Yeah, can you hold please?
0:17:08	call ends (FS)
0:17:09	CRO: Copy
0:17:10	call ends (CRO)
0:17:11	PS: Small fires now
0:17:12	Announcement ends (PS)
0:17:16	G: There's one on the Mezz deck
0:17:18	Announcement ends (G)
0:17:22	PS: Not necessarily a fire
0:17:24	P: 5 minutes to blowdown complete
0:17:25	Announcement ends (PS)
0:17:26	Announcement ends (P)
0:17:28	P: How many people have we got left?
0:17:29	Announcement ends (P)
0:17:48	FS: Yeah, team leader control
0:17:49	call ends (FS)
0:17:50	CRO: Go ahead
0:17:51	call ends (CRO)
0:17:52	FS: Yeah, just a concern I've got here, I'm running out of foam, can you get me the status on what we've got left over
0:17:56	Phone rings
0:18:00	call ends (FS)
0:18:01	Phone stops
0:18:01	CRO: Standby
0:18:02	call ends (CRO)
0:18:02	P: Does he want more foam where he is
0:18:04	Announcement ends (P)
0:18:04	CRO: Do you require more foam up to where you are at the moment
0:18:07	call ends (CRO)
0:18:09	FS: Yeah, the lads on the GCD Weather Deck, they will need some more foam shortly and I'm going to try and set something else up on the CP Weather deck because it would appear that we've got a few more tanks popped, there's certainly a lot of heat up here and a lot, so there's a big fire up there.
0:18:27	call ends (FS)
0:18:27	P: Has he got anything going from the helideck?
0:18:29	Announcement ends (P)
0:18:30	OIM: One under the helideck
0:18:32	Announcement ends (OIM)
0:18:32	P: Has he got the helideck because they're powerful
0:18:34	Announcement ends (P)
0:18:38	CRO: Field supervisor, field supervisor, call back

0:18:40	call ends (CRO)
0:18:40	D: He wasn't going to because of the wind
0:18:41	Announcement ends (D)
0:18:43	FS: Field supervisor
0:18:44	D: It wouldn't with that wind
0:18:45	Announcement ends (D)
0:18:45	call ends (FS)
0:18:45	CRO: Have you set off any of the foam monitors from the helideck
0:18:48	call ends (CRO)
0:18:51	FS: Yeah, the wind's such that it's not really going to make it's quite windy up there, it's not going to make that on the methanol area.
0:18:57	G: There's spare foam on side of - there is some there outside the lab, there's 10 spare drums
0:19:00	call ends (FS)
0:19:08	Announcement ends (G)
0:19:11	G: There's also some on the South side
0:19:15	Announcement ends (G)
0:19:15	FS: Did you get that message, control?
0:19:18	call ends (FS)
0:19:18	CRO: Yeah, we got that message
0:19:19	call ends (CRO)
0:19:20	OIM: Time out in 20
0:19:21	Announcement ends (OIM)
0:19:21	CRO: Time out in 20 seconds
0:19:23	call ends (CRO)
0:19:23	P: Despatch 3 guys to get over and get some foam to them, despatch 3 men to take some foam over to them
0:19:29	PS: P, last reported fire was in the crane pedestal but there's obviously something major happening here, but this foam G is talking about is there.
0:19:32	Announcement ends (P)
0:19:38	Announcement ends (PS)
0:19:38	P: Yes
0:19:39	Announcement ends (P)
0:19:39	PS: So we could possibly get some
0:19:40	Announcement ends (PS)
0:19:40	OIM: Time out, right, no change to my status, just an update, we're still continuing to fight and contain the fire, level 3 shutdown should be in about 3 minutes with blowing down, any update, any status from yourselves.
0:19:50	ASSUME 3 PEOPLE ARE DESPATCHED TO GET FOAM
0:20:00	Announcement ends (OIM)
0:20:00	P: We're on the foam, we've just despatched 3 men to take some foam over to FS, secondary plan coming up is that we can actually despatch men up from the safe staircase going round where the back of the lab is and round to it right, so we'll despatch another 3 men now to do it and pull all the foam over to the safe area.
0:20:25	Announcement ends (P)
0:20:25	PS: So that's 6 men you're despatching in total
0:20:27	Announcement ends (PS)
0:20:27	P: We've despatched 3
0:20:28	Announcement ends (P)
0:20:28	OIM: Carry on
0:20:29	Announcement ends (OIM)
0:20:29	P: We'll do it now, next 3
0:20:31	Announcement ends (P)
0:20:32	PS: 2 teams of 3
0:20:33	Announcement ends (PS)
0:20:34	P: 2 teams of 3
0:20:35	Announcement ends (P)
0:20:36	CRO: Field supervisor call back
0:20:37	call ends (CRO)

0:20:39	FS: Yeah, field supervisor, control
0:20:40	ASSUME THAT 3 PEOPLE ARE DESPATCHED TO GET FOAM
0:20:41	call ends (FS)
0:20:42	CRO: We've despatched 2 teams of 3 men in each top get foam and take it over to your men…
0:20:48	call ends (CRO)
0:20:51	FS: Yes, okay, the best route for GCD is obviously up by the cellar deck, uh, up by the Mezz deck for the CP Weather deck, you can come past the control room on to them stairs.
0:21:03	call ends (FS)
0:21:04	CRO: Copy that
0:21:05	call ends (CRO)
0:21:06	OIM (tannoy): Attention all personnel, attention all personnel, update, we have recovered the missing man, he is on the standby boat now, we are still fighting, containing the fire on the Weather deck, the field supervisor has 2 fire teams up there, although he has not put it out, he seems to have it under control, I'll come back to you later on with some further information thankyou.
0:21:33	Announcement ends (OIM - tannoy)
0:21:35	END OF SCENARIO

APPENDIX 7: DEFINITIONS OF GENERIC PERFORMANCE PARAMETERS

Type of measurement	Description
Scenario organisation team's calls - non-informational	Radio call from the scenario organisation team, either to the emergency management team or to another member of the scenario organisation team (for the emergency management team to overhear). A non-informational call is one that does not give any other information about the emergency or one's actions - other than confirmation of a radio call, attempting to call another person or the completion of a radio call. Eg. "Fred, do you copy", "Joe, come in", "Copied that message, Paul".
Scenario organisation team's informational calls	As above, this is a radio call from the scenario organisation team. However in this case, the call provides additional information, either about one's actions, the situation or a question for other information. It therefore consists of any calls which do not fit into the above category. Care must be taken to ensure that where information is being passed that it is recorded as such. For example, if "copy that" is in response to "will you go and check out the B condenser?" - this provides the information that the person involved will carry out this action so is an informational call. If "copy that" is in response to "I am going to check out the B condenser", it is merely a confirmation that the message has been confirmed and will therefore be considered as non-informational.
Emergency management team's calls - non-informational	This is a call from the emergency management team to the scenario organisation team. The criteria for non-informational calls is as described in the scenario organisational team's non-informational calls.
Emergency management team's calls - informational	This is a call from the emergency management team to the scenario organisational team. The criteria for informational calls is as described in the scenario organisational team's informational calls.
Scenario organisation team's calls	Both informational and non-informational calls grouped together
Emergency management team's calls	Both informational and non-informational calls grouped together
Non-informational calls	Both scenario organisation team's and emergency management team's calls grouped together
Informational calls	Both scenario organisation team's and emergency management team's calls grouped together
Radio calls	All radio calls
Delays between radio calls	The time taken to respond to a call - from the end of one person's call to the beginning of the responding person's call.
Total time to deliver a message	This must include a first initiating call (eg. "Charlie, come back"), and at least one informational call. They also will normally include a confirmation call that the message has been received. Repeat attempts to contact someone are not included in the time taken to deliver a message. Incomplete messages (for example, due to the stopping of the scenario) are not included at all.
Announcements	This is the time taken for one of the emergency management team to give an announcement to those present. This does not include taking on the radio, tannoy or telephone. This may be a question, confirmation of a question and may be part of an informal discussion between a few members of the team or a formal announcement to the whole group. As there is not normally the structure of radio calls where calling and confirmation are necessary, there is no categorisation of informational and non-informational announcements.
Delays between Announcements	This is the time taken for one member of the emergency management team to respond with an announcement to something said by another member of the team. This may be the time between "Charlie, are you listening?" and "yes". It could also be the time between "Which way is the wind blowing?" and "Ummmm, South East".
Times between telling to standby and calling back to give information	This could be from either direction (SO to EMT or EMT to SO). This gives an indication of how long it takes to respond to an unexpected request for particular information. The time is taken from the end of the call stating "standby" to the beginning of the message that delivers the requested information. Note that this is not the actual informational call giving the requested information but is normally the non-informational call for the relevant respondent.
Totally unintelligible calls	This is self-explanatory in that it records the time taken in calls (almost always

	those from the scenario organisation team) that can not be interpreted at all. This may be accidental due to poor reception, or deliberate, when trying to pretend the caller is talking through hazardous conditions or with serious injuries. This may also be affected in that it is somewhat subjective - it is interpreted from the video recording during the production of the transcript and may have been more intelligible during that actual scenario. They are represented in the transcript as ????
Partially unintelligible calls	These are similar to the category above except that some of the message can be deciphered. For example, "Must be regen… propane…in circulation…"
Time left between failed attempts to call in/out	This somewhat represents the patience of the caller but nevertheless provides an additional delay in the management of an incident. If there is no response to an initiating call, eg. "Charlie, come back", the is the amount of time from the end of this call to when the caller start to try the call again.
Delays to answer phone	This is the time from when the phone starts ringing to when it is answered by the emergency management team.
Time at which the phone stopped ringing	This is when the phone was not answered by the emergency management team and is left to ring. It represents the patience of the scenario organisation team - and at what point vital information may be lost due to missing the phone call. This may indicate some disorganisation in the group but also is known to occur during "time-outs".
Phone call length	This is length of time taken by the emergency management team from answering the phone to putting the phone down. It also includes out-going phone-calls to the scenario organisation team but as the point at which the phone was answered by them cannot be observed, this was taken as the mid-point between the end of dialing and the first words spoken by the member of the emergency management team. This assumes that on answering the phone, the scenario organisation team member will be the first to speak. Again, we cannot assume at what point the scenario organisation team member ends the call, so this is based exclusively on the point at which the emergency management team member ends the call.
Information passed from EM to SO	Time from information being known in the Emergency Management team to be passed to the relevant external bodies (Scenario organisation team)
Information passed from SO to EM	Time from information being known in the Scenario Organisation team to be passed on tot he Emergency Management team.
Time to initiate following orders (control panel work)	This is the time taken from the completion of an order to carry out control panel work (usually given by a senior member of the emergency management team) to the initiation of the work. Eg. "Activate the deluge, Charlie" to the point at which the relevant button is pressed.
Incident - control panel responds	This is the time from when we know the incident occurs to the point at which the control panel (alarms etc.) respond.
Control panel response - operator response	In this case, the control panel exhibits a particular "behaviour" requiring the operator to respond. For example, alarm goes off - operator resets alarm.
Time to initiate following orders (moving / calling others outside)	Similar to the orders given for control panel work, these orders involve either movement (usually outside of the control room) or for communication. For example, "Get over to the B generator" - visible leaving of the control room or reply "We're now heading over to the B generator". Alternatively, "call Charlie and let him know what's going on?" - "Charlie, we've got a problem…"
Delays from being given information externally to drawing the attention of the group to it	This may involve the time between an phone-call providing vital information is complete and the completion of passing this information on to the rest of the emergency management team. This again represents a delay whereby certain members of the team are acting without crucial information that is available internally.
Time out announced - Time out started	It is normal that the chief emergency manager initiates the time out, as will be described in more detail in the next section. This is done by announcing that a time out will occur within a particular number of seconds (usually 10 or 20). This is designed to give the emergency management team chance to finish their radio messages, phone calls or to organise themselves ready for a break in the action. Occasionally, the emergency manager leaves much longer than the 10/20 seconds specified, either due to unforeseen circumstances or because he was not adequately organised to carry out the time out. Occasionally, the emergency manager does not give the 10/20 seconds warning that he offered and so the team are not completely ready for the time-out when it starts. This could lead to radio

	or phone calls continuing during the time-out, providing a distraction, as well as removing a member of the emergency management team from the discussion. Therefore, these data record the time between the end of the announcement that announces that a time out will occur shortly and the initiation of the announcement starting the time out. Eg. "Time out in 20 seconds" - "Time out now gentlemen"
Time out length	Time-outs are a point in the exercise where actual management tasks stop (eg. radio and phone calls) and the emergency management team group together to listen to the chief emergency manager. This is designed to be brief but all-inclusive. This will establish the key tasks (all known as focus points) and a collation of any new and important information that is not known by the whole management group. Although, this process requires that any urgent radio calls or telephone calls are ignored (hence producing delays in response to them), it is believed that the group knowledge and focus achieved by the time out will enable the team to work more effectively once emergency management is resumed. Therefore this records the duration of time outs. This not only indicates how long it takes for a group to be brought up to date on information and "re-focused" but also indicates the length of time for which the emergency management team are unavailable to answer phones or radio calls and hence are delaying in the actual initiation of tasks.
Delays between time-outs	This indicates the duration of time between time-outs. This therefore indicates times at which the team are focused on particular issues, until a new time-out brings new issues. Too frequent time-outs result in little progress being made before the teams are given new tasks and another interruption from the actual management. Too infrequent time-outs mean that emergency management team members may be unaware of critical factors known by other team members that could potentially affecting their tasks. That is, the team could "lose the big picture". This variable records the time between the end of one time out and the beginning of the next one.
Incident - first time out starts	This indicates the time taken for the Emergency management team, and particular the Chief Emergency manager, to be sufficiently aware of the situation to make a plan of action. The time is recorded from the initiating event (eg. explosion, crash, leak) to the moment when the time out is started.
CCR (Central Control Room) aware of incident - First time out starts	Given that it may take some time for the Emergency management team to become aware of the initiating event, this may be more indicative of their organisational skills than the time from the incident to the first time-out. Timings are recorded from the point at which the CCR are aware of the presence of an incident (even though they may not be aware of its cause or content) to the beginning of the time out.
Em arrives - first time out starts	This is the time from when the EM (OIM) arrives to the point at which the first time out is started.
Incident - start first informational tannoy	This is the time taken from the incident to the initiation of the first informational tannoy. An informational tannoy is defined as one that does not only call a muster or relevant personnel to act - but provides some details of the incident or the management actions that are being carried out.
OIM arrives - start first informational tannoy	As it is normal that the chief emergency manager (OIM) makes the informational tannoys, these values indicate the time taken for the OIM to assimilate the information to such a degree that he feels confident enough to present it to the rest of the installation personnel.
Incident - Start first tannoy	This is the time taken from the incident to the initiation of the first tannoy. This is usually carried out by the control room personnel as opposed to the OIM (who may or may not be present). It usually consists of a call to muster stations and rarely gives about the nature of the incident. It occasionally refers to particular personnel, for example, calling technicians to check out a possible leak.
Tannoy length	This is the duration of a tannoy.
Time between tannoys	This is the time between one tannoy and the next one. It therefore indicates the length of time that the installation personnel may be left without updated information.
Incident - start of first call out from CCR	This indicates the time from the incident to the first active response by the EMT. This response may be a radio call, a phone-call or an order to initiate control panels.

Incident - start of first call into CCR from incident site	This indicates the time from the incident to the first active response by the SO - this may initiate the contact which provides the EMT with information on the incident or may be requesting their action.
Incident - start of first informational call into CR from incident site	This is the first informational call into the CCR from the incident site.
Incident - EM arrives	This is the time between the incident and the arrival of the Emergency Manager - this may be not applicable if the emergency manager is already present at the beginning of the incident.
Incident - call EM	This is the time between the incident and the initiation of the call for the emergency manager to attend the control room (if applicable). This may indicate a delay for the control room staff to recognise the seriousness of an event and that they will require additional assistance.
Call EM - EM arrives	This is the time from the end of the call made to bring the EM to the control room to the point at which the EM arrives.
EM arrives - EM's first response	This indicates the time for the emergency manager to assert his influence on the situation. For example, from arriving to saying "what's going on?". This is not applicable if the emergency manager is present at the start of the incident.
Incident - EM's first response	This indicates the time from the incident for the Emergency manager to get involved. He may leave the initial stages to the control room staff or may start controlling the incident straightaway.

APPENDIX 8: LISTS OF PERFORMANCE DATA

Offshore Scenario 1 - Helicopter Crash (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - Muster alarm initiated	13
Incident - Order to stop hot work given	33
Incident - Start Level 3 shutdown	13
Medical team requested - medical team sent	27, 207
Fire team requested - fire team sent	98, 24,
Fire incident suggested - deluge started	58
Incident - helicopters ordered	325
Muster point 2 at risk - Ordered to relocated to muster point 3	277
call OIM - OIM arrives	18
Incident - first medical team sent	128
Incident - first fire team sent	128
Muster ordered - muster complete	178
Fire team arrive on site - Fire team realise they need another team	36
Medical team arrive on site - medical team realise they need another team	253
2nd Medical team needed - medical team leaves	217
Fire teams meet - coordinate activities	33,
Fire team leave - fire team arrive at incident	49, 80, 140
Medical team leave - arrive at incident	273,
Helicopters ordered - helicopters arrive	Not recorded during scenario timing
Helicopters ordered - helicopters mobilised	Not recorded during scenario timing
Activate level 3 - blowdown complete	1344
Time for control panel to respond to situation (fire detected after heli crash)	1
Helicopter crashes - FS suggests that they should expect no survivors	811
Incident - escalation to level 4 shutdown	64
Incident - start deluge	91
Incident - dump methanol	801
Incident - muster point 2 out of action	851
Incident - bridge clear	1051
Incident - helicopter smoking	1151
Start deluge - bridge clear	950
Fire team arrives on site - bridge clear	874
Start deluge - helicopter smoking	1050
Fire team arrives on site - helicopter smoking	974

OFFSHORE SCENARIO 2 - METHANOL TANK (COMPLETE WITH GENERIC PERFORMANCE PARAMETERS

BEHAVIOUR	RAW TIMES (in seconds)	MEAN AND SUM	S.D.	MIN, MAX
EMERGENCY				
Total time to deliver a message (radio): must include first call in/out, possibly a response and at LEAST one informational call. One-sided or incomplete conversations due to scenario end are not included or repeat attempts to call in/out	17, 13, 39, 12, 22, 70, 60, 27, 30, 23, 15, 39, 41, 29,	31.21429 (N=14) 437	17.30353	13, 70
Scenario organisation team's informational calls	11, 8, 5, 8, 9, 6, 15, 11, 5, 5, 32, 14, 24, 5, 11, 2, 1, 2, 2, 12, 4, 24, 5, 8, 18, 9, 12,	9.925926 (N=27) 268	7.482934	1, 32
Scenario organisation team's non-	2, 1, 1, 1, 3, 1, 3, 1, 2, 2, 2, 2,	1.761905	0.70034	1, 3

informational calls	2, 2, 1, 2, 1, 1, 2, 3, 2,	(N=21) 37		
Emergency management team's informational calls	3, 4, 1, 2, 7, 3, 9, 2, 3, 3, 6,	3.909091 (N=11) 43	2.42712	1, 9
Emergency management team's non-informational calls	1, 1, 1, 2, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 3, 1, 2, 1, 1, 1, 2, 1, 2, 1, 1,	1.266667 (N=30) 38	0.52083	1, 3
Scenario organisation team's calls	2, 11, 1, 1, 8, 1, 5, 8, 9, 3, 1, 6, 3, 15, 11, 1, 2, 2, 5, 5, 2, 32, 14, 2, 24, 5, 11, 2, 1, 2, 2, 2, 12, 4, 2, 24, 1, 5, 2, 1, 1, 8, 18, 2, 9, 3, 2, 12,	6.354167 (N=48) 35	6.923563	1, 32
Emergency management team's calls	1, 1, 1, 3, 2, 1, 1, 2, 1, 1, 4, 1, 2, 1, 1, 1, 1, 7, 1, 2, 1, 3, 1, 1, 1, 3, 9, 1, 2, 2, 1, 1, 1, 3, 2, 3, 1, 2, 1, 6, 1,	1.97561 (N=41) 81	1.753394	1, 9
Non-informational radio calls	2, 1, 1, 1, 1, 1, 1, 2, 3, 1, 3, 1, 1, 1, 2, 2, 1, 2, 1, 2, 1, 2, 1, 1, 1, 1, 2, 2, 1, 1, 2, 1, 1, 3, 1, 1, 2, 2, 1, 1, 1, 1, 1, 2, 2, 3, 1, 2, 1, 2, 1,	1.470588 (N=51) 75	0.64352	1, 3
Informational radio calls	11, 8, 5, 3, 8, 9, 6, 15, 11, 5, 5, 4, 32, 1, 14, 2, 24, 7, 5, 11, 2, 1, 2, 2, 12, 3, 4, 24, 9, 5, 2, 8, 3, 18, 3, 9, 6, 12,	8.184211 (N=38) 311	6.970421	1, 32
Total Radio calls	2, 1, 11, 1, 1, 1, 8, 1, 1, 5, 3, 8, 9, 2, 3, 1, 6, 3, 1, 15, 11, 1, 1, 2, 2, 1, 2, 5, 5, 1, 2, 4, 32, 1, 14, 2, 1, 2, 1, 1, 24, 1, 7, 5, 11, 1, 2, 2, 1, 2, 2, 2, 1, 12, 3, 4, 1, 2, 1, 24, 1, 3, 1, 9, 5, 1, 2, 2, 2, 1, 1, 1, 1, 8, 1, 3, 18, 2, 2, 3, 9, 3, 1, 2, 1, 2, 6, 12, 1,	4.337079 (N=89) 386	5.640648	1, 32
Delays between dependent radio calls	2, 1, 2, 1, 2, 1, 6, 2, 1, 2, 0, 0, 1, 1, 3, 1, 1, 2, 4, 3, 5, 3, 1, 1, 6, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 2, 0, 2, 1, 1, 1, 1, 2, 3, 0, 3, 0, 2, 1, 3, 1,	1.581818 (N=55) 87	1.342895	0, 6
Times between calls telling to standby and calling back to give information	2, 40	21 (N=2) 42	26.87006	2, 40
Totally unintelligible calls	11	11 (N=1) 11	-	
Partially unintelligible calls	11, 6	8.5 (n=2) 17	3.535534	6, 11
Time left between failed attempts to call in / out	8, 3	5.5 (n=2) 11	3.535534	3, 8
Delays to answer phone	10, 14, 3, 5, 5,	7.4 (n=5) 37	4.505552	3, 14
Time at which phone stopped ringing (not answered)	-	-	-	
Phone call length	2, 8, 38,	16 (n=3) 48	19.2873	2, 38
Announcements (excluding tannoys but including time outs)	3, 4, 2, 1, 1, 14, 2, 1, 1, 1, 3, 2, 1, 1, 1, 8, 1, 2, 1, 9, 1, 8, 4, 14, 5, 2, 1, 1, 1, 2, 1, 1, 1, 2, 1, 20, 4, 2, 2, 4, 1, 2, 1, 1, 3, 1, 1, 1, 1, 1, 2, 2, 1, 2, 1, 3, 2, 1, 1, 5, 2, 2, 4, 2, 1, 1, 1, 1, 1, 1, 3, 2, 2, 1, 1, 25, 4, 4, 13, 1, 1, 9, 1, 2, 1, 1, 1, 2, 3, 1, 1, 1, 3, 4, 1, 3, 5, 5, 2, 2, 3, 2, 1, 6, 3, 5, 1, 3, 1, 22, 1, 4, 2, 9, 1, 3, 2, 2, 3, 3, 3, 1, 2, 3, 2, 1, 2, 2, 2, 2, 1, 1, 11, 4, 1, 9, 9, 1, 1, 20, 25, 2,	3.251701 (n=147) 478	4.428803	1, 25

	1, 1, 2, 1, 1,			
Delays between dependent announcements	1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 0, 0, 1, 2, 0, 2, 5, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 3, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 3, 0, 0, 0, 3, 1, 0, 4, 4, 1, 0, 6, 0, 0, 0, 0, 0, 0, 1, 1,	0.707692 (n=65) 46	1.307706	0, 6
Information known in EMT - SOT told	716, 58, 8,	260.6667 (n=3) 782	395.1219	8, 716
Information known in SOT - EMT told	18, 13, 10, 22, 30, 15, 49, 40, 22, 33	25.2 (n=10) 252	12.58571	10, 49
Time to initiate following orders (control panel work)	17	17 (n=1) 17	-	
Incident - control room response	1	1 (n=1) 1	-	
Control panel response - Operator response (eg. resetting alarms)	4	4 (n=1) 4	-	
Time to initiate following orders (calling others outside/leaving the room)	1, 70, 59, 5, 126, 7,	44.66667 (n=6) 286	49.72189	1, 126
Delays from being given information externally - Drawing the attention of the group to it	32, 15, 16, 45, 3, 149, 7, 4,	33.875 (n=8) 271	48.73379	3, 149
Time out announced - Time out started	21, 16, 19	18.66667 (n=3) 56	2.516611	16, 21
Time out length	20, 25, 22, 49	29 (n=4) 116	13.49074	20, 49
Delay between time outs	258, 247, 362	289 (n=3) 867	63.45865	247, 362
Incident - First time out starts	243	243 (n=1) 243	-	
OIM arrives - starts first time out	193	193 (n=1) 193	-	
CCR aware of incident - First time out starts	225	225 (n=1) 225	-	
Incident - Start first informational tannoy (eg. not calling for muster, just informing personnel of progress)	749	749 (n=1) 749	-	
OIM arrives - starts first informational tannoy	699	699 (n=1) 699	-	
Incident - Start first tannoy	22	22 (n=1) 22	-	
Tannoy length	12, 4, 13, 25, 27	16.2 (n=5) 81	9.628084	4, 27
Time between tannoys	5, 101, 592, 492	297.5 (n=4) 1190	287.9404	5, 592
Incident - start of first call out from CR (first ACTIVE response by EMT)	5			
Incident - start of first call into CR from incident site	1			
Incident - start of first informational call into CR from incident site	7			
Incident - EM arrives	50			
Incident - call EM	43			
EM arrives - EM's first response (question / order)	6			
Incident - EM's first response	56			
call EM - EM arrives	7			
Incident - u.v. detectors removed	40			
Incident - methanol spill discovered	45			
Incident - order to stop hot work given	34			

(tannoy)				
Incident - fire ignited	96			
Methanol spill discovered - fire ignited	51			
Fire ignited - deluge activated	34			
Fire ignited - level 3 shutdown started	34			
Incident - FS leaves to attend incident	140			
Fire ignited - FS leaves to attend incident	44			
Methanol spill discovered - FS leaves to attend incident	95			
Incident - muster started	157			
Methanol leak discovered - muster started	112			
Fire ignited - muster started	61			
Muster started - Muster complete (minus 1)	143			
Fire team leave - Fire team arrive on site	115			
Fire team arrive - foam monitor activated	30			
Fire ignited - crane driver jumps into water	189			
Crane driver jumps - standby boat reports launching rescue craft	15			
Incident - helicopters ordered	346			
Fire ignited - helicopters ordered	250			
Incident - methanol dump started	395			
Leak identified - methanol dump started	350			
Fire ignited - methanol dump started	299			
Crane driver jumps - FS finds crane driver not in crane	125			
Fire team arrive on site - FS finds crane driver not in crane	155			
Fire team activate foam monitor - FS finds crane driver not in crane	125			
Fire ignites - Fire team find the workshop roof is hot	314			
crane driver jumps - crane driver is picked up by rescue craft	135			
standby boat launch rescue craft - crane driver is picked up	120			
Fire team arrive on site - FS orders 4 more people to the GCD	225			
Fire team find the workshop roof is hot - FS orders 4 more people to GCD	70			
4 people despatched to GCD - 4 people arrive on GCD	55			
Fire team requested - fire team leave	5, 83			
Methanol spill declared - PS finds out how many tanks were there	742			
Fire ignited - diesel fire starts	744			
Workshop roof hot - diesel fire starts	430			
Standby boat inform CR of someone in the water - helicopter with paramedic ordered	525			
Foam monitor started - Foam monitor out of foam	635			
Foam monitor out of foam - 3 people	270			

despatched to replace it				
Methanol dump started - methanol dumped	240			
Man picked up by rescue craft - man on board standby boat	360			
Man on standby boat - paramedic ordered	60			

Offshore Scenario 3 - GCD Cooler (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - muster started	29
Muster started - muster complete	91
Incident - level 3 started	27
Incident - deluge started	27
Incident - EMT identify location is Mezz deck GCD	130
Incident - FS team leave	126
Muster alarm started - FS team leave	97
FS leaves - arrives on site and identifies that B inter cooler has gone	54
Incident - FS identifies that B inter-cooler has gone	180
Incident - casualty sheltering in GCD	225
Casualty sheltering in GCD - request medical team	57
Incident - deluge on CP	293
FS arrives on site - can't get across Mezz deck	120
FS arrives on site - can't get to West side	210
FS cannot get across Mezz - cannot get on west side	90
Incident - medical team mobilised	412
Casualty sheltering in GCD - medical team mobilised	187
Medical team requested - medical team mobilised	130
FS leaves - FS gets to south side Mezz	329
FS arrives on site - FS gets to south side Mezz	275
FS can't get to West side - FS gets to south side Mezz	155
FS can't get to Mezz deck - FS gets to south side Mezz	65
Incident - assume production technicians despatched	510
FS arrives - BA running out	365
FS cannot get to west side - BAs running out	155
FS cannot get across Mezz - BAs running out	245
FS gets south side Mezz - BAS running out	90
Production technicians despatched - arrives CP Mezz	60
Production technicians arrive on CP Mezz - back at CP	60
BAs running out - BA team leave	100
FS at south side - FS discovers door too smoky	190
FS at south side - FS discovers problems with handles	235
FS discovers door too smoky - FS discovers problems with handles	45
BA team 1 leave - BA team 2 arrive	75
BAs running out - BA team arrive	175
Incident - Fire subsiding	1225
BA team 1 leave incident - BA team 1 arrive in CR	160
FS discovers door too smoky - FS gain access	360
FS discovers problem with handles - FS gain access	315
2 people requested to weather deck - despatched	45
Stretcher carriers requested - despatched	66
Stretcher team despatched - arrive on site	153
Medical team mobilised - arrive	788
Medical team arrive - understand casualty's symptoms	45
Incident - Medics understand casualty's symptoms	1245
Incident - situation coming under control	1260

Activate deluge - situation coming under control	1233
Level 3 shutdown started - blowdown complete	1208
Fire team requested - despatched	29
Production team requested - sent	28
Incident - isolation of GCD suggested	452
FS gains access - FS now approach south east	195

Offshore Scenario 4 - HV Switchgear Room (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Event - PW gets to switchgear room	60
Event - PW finds smoke in switchgear room	60
Event - muster started	102
Event level 3 shutdown started	126
Muster started - finished (minus 3)	128
Incident - HV power failure	321
Incident - FS leaves	327
Incident - Despatched team to accommodation	405
FS leaves - FS arrives on site	88
Team requested - team despatched	13
Incident - smoke in LV switchgear room	474
HV power failure - smoke in LV switchgear room	213
FS arrives on site - FS at LV switchgear room	95
FS leaves - FS arrives at LV switchgear room	183
FS in LV switchgear room - finds he needs backup	30
Incident - Alarm (lab and stores)	531
HV power failure - alarm (lab and stores)	210
Smoke in LV switchgear room - alarm in lab and stores	57
Team requested - team despatched	38
Team despatched - team arrive	45
FS arrives in LV switchgear room - FS decided to pull back as vis is zero	210
BA decide to enter LV - FS decides to pull back as vis is zero	75
Smoke in LV - FS decides to pull back as vis is zero	246
FS arrives in LV - Ba out of air	630
Smoke in LV - FS arrives in LV	36
FS need back up - BA out of air	300
1 BA team enter LV - BA team out of air	195
FS decides to pull back as vis is zero - BA out of air	120
BA team 3 despatched - Meet FS	545
FS meet BA team 3 - BA teams to HV and accommodation	110
BA team despatched to accom - BA teams to HV and accommodation	460
BA teams on standby - BA teams to HV and accommodation	415
PW to switchgear room - casualty found	1080
BA team enter accommodation - casualty found	80
BA enter HV switchgear room - BA team leave	165
shutdown and blowdown start - completed	1204
BA team out of air and returning - FS requires more bottles	530
BA team enter HV and accommodation - need more bottles	310
BA leave HV - FS outside stores	145
BA enter accommodation - find 1 steward	365
Alarm (lab and stores) - FS arrives	839
BA requested - sent	45
Incident - stewards found	1425
Incident - whole side of switchgear room burning	1450
HV power failure - whole side of switchgear room burning	1129
Smoke in LV - whole side of switchgear room burning	976
Fire (lab and stores) - whole side of switchgear room burning	919

Vis zero in accommodation - whole side of switchgear room burning	736
Incident - fire escalation	1533
HV power failure - fire escalation	1212
Smoke in LV switchgear room - fire escalation	1059
Fire (lab and stores) - fire escalation	1002
Vis zero in accommodation - fire escalation	813
Whole side of switchgear room burning - fire escalation	83
Team requested - despatched	15
Team despatched - arrive	310
Fire escalation - FS gets hoses working	192
Whole side of switchgear room burning - Control room start to relocate	290
Fire escalation - Control room start to relocate	207
Vis zero in accommodation - control room start to relocate	1020
Start to relocate - complete	69
Relocated - fire reserve halon	156

Offshore Scenario 5- Dropped Object (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - start muster	13
Incident - fire alarm activated	32
Incident - shutdown started	69
Fire alarm activated - shutdown started	37
Incident - deluge started	90
Fire alarm activated - deluge started	58
Incident - FS arrives on site	150
Muster started - muster complete	177
Incident - CM finds that they are trapped on GCD	260
FS arrives on site - FS returned to CRO	169
CM finds they are trapped in GCD - CM return to GCD control room	90
CM finds injured person - Injured person says he saw someone on the bridge before it collapsed	270
Incident - jet fire and explosion on slug catcher	434
Fire alarm activated - jet fire and explosion on slug catcher	402
FS leaves - FS arrives and starts setting up hoses on ESV valves	145
FS leaves - FS finds lower bridge gone	160
Injured person reports seeing someone on bridge - Standby boat looks for body in water	70
FS starts setting up hoses - hoses tied off	105
People find they are trapped on GCD - People start launching lifeboat	640
People find injured person at GCD control room - People start launching lifeboat	550
SB look for body in water - Search completed with no success	270
FS ties off hoses - Fire diminishing	270
Deluge started - Fire diminishing	930
People start launching lifeboat - Lifeboat reports engines are not working	240
FS ties up hoses - Fire under control	440
Deluge started - fire under control	1100
Fire diminishing - fire under control	170
FS on site - FS returned to CR	67
Shutdown and blowdown started - blowdown of CP complete	1011
Blowdown of CP complete - Shut subsea barrier	545
Rigger sent to lower load - Shut subsea barrier	452
FS leaves - FS arrives on site and identifies bridge is severely damaged	54

Onshore Scenario 1 - Hot Oil Leak (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - Order level 1 shutdown	51
Incident - Muster ordered	56
Muster ordered - Muster initiated	3
Incident - Priority one and priority two calls ordered by OIM	143
CCR informed that there are casualties and a fire - Priority one and priority two calls ordered	35
Incident - OIM orders fire truck to be sent to the forward muster point (in Time Out)	293
CCR aware of casualties - OIM orders fire truck to be sent to the forward muster point (in Time out)	185
Incident - OIM orders the outfall to be off (in Time out)	293
Incident - OIM orders fixed monitors to be put on (in Time out)	293
Incident - OIM ordering that security should take all calls from the public	596
Phone call ends - OIM ordering that security should take all calls from the public	10
Complete order for level 1 - initialised	8
Foam monitors requested (during time out) - confirmed that they were being initiated	64
OIM orders Priority 1 and 2 - Assume they have been called	59
Fire brigade arrives at gate - assume diverted to incident	52
Ambulance arrives at gate - assume diverted to incident	82
2 more fire engines arrive at gate - assume diverted to incident	93
OIM orders outfall to be turned off (during time out) - Assume that it has been done	2
Report diesel and hot tanks threatened - OIM orders cooling	39
OIM orders cooling - On-scene commanders informed of order	17
Muster complete and EM team made aware that 2 are missing - OIM orders search and rescue (within time out)	212
OIM orders search and rescue - informed that casualties have already been located	4
On-scene commander requests foam monitors to be turned off - Informed that it requires manual isolation	10
Incident - Assume JF is attempting rescue	59
Assume JF is attempting rescue - First casualty rescued	608
Assume JF is attempting rescue - second casualty rescued	1623
First casualty out - Casualty in ambulance	738
Muster alarm - Muster completed (minus casualties)	287
OIM orders a fire truck (during time out) - Fire truck mobilised	214
Foam monitors on - requested off to assist in searching for casualties	302
Fire truck mobilised - Arrives on scene	145
Priority one and priority two calls sent - Fire brigade arrives at gate	697
Fire brigade diverted - Assume working on fire	? - never recorded
Priority one and two calls sent - Ambulance and police car arrive at the gate	932
Assume ambulance diverted - assume ambulance has picked up the casualty	188
Priority one and two calls sent - 2 more fire engines arrive at the gate	1203
Told foam monitor is manually deactivated - Assumed that the team have turned it off	10
Assumed foam is turned off - Request that it is turned back on again	196
Incident - Fire threatening the diesel and hot oil	980
Manual hose ordered - Confirmed it will be done	11
Assume monitors are running - Say they are beginning to make headway on the fire	810
CCR informed that there are casualties - Assume PD rescued	1530
CCR informed that there are casualties - JF at the forward muster point in shock	1498
Incident - Making headway on the fire	1688
Ambulance arrives at the gate - Assume that it has been diverted	79
Ordered police car to tour village - Assume arrived	? (not noted in scenario -

	possibly occurring outside of scenario time)
Ambulance arrived at gate - Ambulance arrived at casualties	178
Priority one and priority two calls - 2 more fire engines arrive at gate	1199
2 more fire engines at gate - Assume diverted to incident	91
Incident - Rescued PD from fire	1852
On-scene commander informed of order to cool diesel and hot tanks - Assume that this cooling has been initiated	27
Diesel and hot oil threatened - EM team informed	14
Level 1 ordered - Shutdown complete	? (not noted in scenario - possibly occurring outside of scenario time)
Level 1 initiated - Shutdown	? (not noted in scenario - possibly occurring outside of scenario time)
Level 1 initiated - Confirmed that there is no pressure	1781
Order Level 1 shutdown - Confirmed that there is no pressure	1789

Onshore Scenario 2 - Broken Leg On Regen Unit (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - EM orders level 2 shutdown	29
Incident - EM orders level 1 shutdown	233
Incident - Muster ordered by OIM	29
Incident - OIM orders priority 1 and 2 calls (fire trucks and ambulances)	233
Aware of casualties - OIM orders priority 1 and 2 calls (fire engines and ambulances)	214
EM aware of casualties - EM says fire truck required at forward muster point	452
Incident - OIM says need fire truck at forward muster point	471
Muster ordered by OIM - assume CRO ordered muster (on phone) (muster initiated)	12
Level 2 ordered - Shutdown started	12
Level 2 ordered - OIM orders level 1	204
Level 1 ordered - started	48
Incident - EM orders the outfall to be put off	Not specified if carried out
EM orders outfall to be put off - Assume outfall put off	Not specified if carried out
Incident - fixed monitors on	1354
EM orders priority 1 and 2 calls - Assume calls	53
EMT aware of people missing - EM orders search and rescue	190
Assume rescue has been initiated - Rescue complete	Not occurring in scenario time
First casualty rescued - Casualty in ambulance	Not occurring in scenario time
Gas low - Team agree to use portable gas detectors	78
Muster alarm - Assume Muster completed (minus casualties)	981
Fire engines arrive - spray system in use	662
Ambulance arrives at gate - Ambulance picks up casualty	Not in scenario time
Fire engine arrives at gate - Fire engine diverted to incident	60
Ambulance arrives at gate - Ambulance diverted to incident	60
Ambulance diverted - picks up casualty	Not in scenario time
Fire engine diverted - arrives at incident	215
Fire engine arrives at the gate - spray system set up	358
Crane starts rescue - Casualty down from column	in excess of 315
Casualty injured - assume helped by PD	115
Muster started - MF arrives at muster point	65
MF leaves Forward Muster point - Arrives at GSU	228

OIM orders fire truck to be mobilised - Fire truck mobilised	143
Fire truck mobilised - Meets MF	200
Fire truck meets MF - They arrive on site	43
Fire truck ready - Route given and initiated	32
PD helps casualty - casualty needs new air	610
Crane available - Crane arrives	600
W suggests despatch people to meet crane - Person meets crane	380
Fire engines ordered - First fire engine arrives	842
Police car ordered - Police car arrives	1693
Ambulances ordered - First ambulance arrives	842
Person meets crane - They move crane to rescue position	648
Known that there is a missing cleaner - cleaner found	201
Report casualty short of air - airline being put up	672
EMT know about casualty - EMT ask if lifting gear is required	683
EMT ask if lifting gear is required - Crane available	35
Muster initiated - Fire truck mobilised	577
Incident - Toxic alarms go off	281
Incident - Gas in S + SW	818
Incident - Gas low indication	1571
Incident - Depressurised column	2301
Gas in S + SW - Gas low indicated	754
Toxic alarms SE - Toxic alarms - S+SW	537
Shutdown - Gas low enough to use portable detectors	1831
Toxic alarm - gas low enough to use portable detectors	754
Level 1 - Gas low indication	1291
Level 1 - Column depressurised	1960

Onshore Scenario 3 - Tanker driver bangs his head (scenario-specific data only)

BEHAVIOUR	**RAW TIMES (in seconds)**
EMT aware of wind direction - SOT ordered to relocate muster point	149
ESV not closing - team ordered to work on it	125
Event - Level 1 activated	78
Event - deluge activated in refrig	78
Aware of event - level 1 activated	57
Aware of event - deluge activated	57
Event - terminal alarm (muster) started	78
Aware of event - terminal alarm (muster) started	57
Event - fixed monitors on	85
Aware of event - fixed monitors on	64
Event - outfall off	85
Aware of event - outfall off	64
Event - got foam down the drains	600
Event - got cooling on tanker	600
Security ordered to open back gate - assume its done	48
Ambulance ordered - first arrives	738
Ambulance ordered - second arrives	1183
Cooling on tanker - fire dying	555
Cooling on tanker - main fires out	850
Foam down the drains - fire dying	555
Foam down the drains - main fires out	850
ESV closed - depressurised	Not recorded in scenario time
Identify someone is missing - Missing person found	250

Muster started - identify that someone is missing	582
Muster started - Muster complete minus missing person	582
Muster started - Muster complete, including missing person	832
Event - ESV not closing	990
ESV not closing - team working on it	210
Team working on ESV - ESV closed	150
Team ordered to work on ESV - Assume team working on it	85
Event - fire	98
Fire - fireball	712
Event - fireball	810
Fire ball - fire dying	345
Event - fire dying	1155
Fire dying - main fires out	295
Event - main fires out	1450
Event - driver in ambulance	1280
Event - driver rescued	98
Driver rescued - driver in ambulance	1182
Level 1 started - complete	Not recorded in scenario time
Deluge activated - fire dying	1077
Fixed monitors activated - fire dying	1070
Deluge activated - main fires out	1372
Fixed monitors activated - main fires out	1365
Fire engines ordered - first fire engine arrives on site	431
Fire engines ordered - second fire engine arrives on site	738
First fire engine arrives on site - in working position	207
Second fire engine arrives on site - in working position	65
Ordered to relocate muster point - muster complete (minus missing person)	371

Onshore Scenario 4 - Explosion at tail gas unit (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Shutdown started - TGU flat	930
Ambulance ordered - first arrives	810
Ambulance ordered - second arrives	1109
Muster started - first person at muster	60
Muster point started moving - Muster point moved	360
Muster start - muster complete	980
Muster started - MW arrives	1290
Muster complete - MW arrives	310
Muster started - Muster point started moving	240
Start search of building - complete search	90
Event - order fire engines and ambulances	361
Event - MAC alarm	17
Event - MAC alarm 2	35
Event - smoke seen	100
Event - fire dying down	840
Event - fire out	1140
Event - TGU flat	990
Event - water curtains up	900
Event - Technician rescued	525
Event - 3 casualties found	360
Event - someone arrives at fire truck	480

Casualties found - one in shock	720
Casualties found - technician rescued	165
Casualties rescued - at muster point	195
Ambulance arrives at gate - casualties in ambulance	390
Fire engines ordered - first fire engine arrives on site	359
Fire engine at gate - fire engine at incident	120
Fire engines arrive - water curtains up	60
Fire out - start search for casualty	50
Team hear about missing person - start search	11

Onshore Scenario 5 - Brown liquid emission (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Event - shutdown activated	156
Aware of event - shutdown activated	156
Event - terminal alarm (muster) started	156
Aware of event - terminal alarm (muster) started	156
Ambulance ordered - first arrives at gate	370
Ambulance ordered - second arrives	1390
Muster start - muster complete (minus 3)	134
Muster completed (minus 3) - JW found	940
Muster completed (minus 3) - PD at lab	920
Muster completed (minus 3) - people in chemical suits	810
Event - order fire engines and ambulances	500
Fire engines ordered - fire engine arrives at gate	370
Fire engines ordered - 2nd fire engine arrives at gate	865
Priority 1 and 2 called - police car arrives	1230
Event - security can smell gas	30
Event - team aware of casualties	120
EMT aware of casualties - start muster	36
Event - muster completed (minus 3)	290
Event - order fire engines and ambulances	500
Event - outfall off	590
Event - plant depressurised	1265
Shutdown started - depressurised	1169
Event - identify leak	1560
EMT aware of F stuck in the lab - F out of the lab	760
People in chemical suits - team go into solvent regen	380
RP missing - RP found	135
Leak identified - Leak isolated	360
Leak isolated - Foam blanket on tps	150
Leak identified - foam blanket on tps	510
Event - EMT told that F stuck in the lab	640
EMT aware of casualties - Priority 1 and 2 calls started	380
Event - leak isolated	1920

Onshore Scenario 6 - leak on GSU B (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Event - shutdown activated	130
Aware of event - shutdown activated	130
Event - terminal alarm (muster) started	130
Incident - Evoke offsite plan	408
Aware of event - terminal alarm (muster) started	130
Incident - gas alarms in GSU B	102
Incident - MAC alarm 1	110
Incident - MAC alarm 2	242

Incident - railway workers can smell gas	420
Gas alarms in GSU B - rail workers can smell gas	318
Muster started - Muster complete (minus two people)	740
Level 1 started - finished	(never announced)
Incident - outfall off	408
Incident - start depressurising GSU A and B	408
Start depressurising - LP depressurised	1067
Start depressurising - HP depressurised	1327
Incident - priority one and two calls made	408
Priority one and two calls made - first fire engine arrives at the gate	162
Incident - foam monitors started	625
Gas alarm initiated - foam monitors started	523
Muster complete minus two - start search	150
Priority one and two calls made - ambulance arrives at gate	432
Fire engine arrives at gate - fire engine meets with PD	360
Muster complete minus two - U found	440
Start search - U found	290
Ambulance at the gate - sent to casualties	430
Priority one and two calls made - fire engines, ambulances and police arrive at gate	882
Fire engine arrives - sent to incident	46
Muster complete minus two - CD found	900
Start search - CD found	750
Railway workers smell gas - overcome by gas	480
Railway workers overcome by gas - found by rescuers	745
CD found - CD in ambulance	290
U found - U in ambulance	750
Railway workers found - in ambulance	205

Onshore Scenario 7 - Collapsed scaffolding (scenario-specific data only)

BEHAVIOUR	**RAW TIMES (in seconds)**
Incident - JF aware of scaffolding	20
Incident - MAC alarm on GSA	61
Incident - AE arrives at regen	80
Incident - HVAC flammable gas and toxic gas detection	140
AE arrives at regen - finds the scaffolding is on the sales gas	60
Incident - Lev 1 started	170
Incident - P1 and 2 calls made	170
Incident - depressurising started	170
Incident - muster started	189
Incident - monitors started	218
Incident - outfall off	270
Muster start - move muster point to rgc	121
Incident - turbine started shutting down	335
Incident - shutdown complete	365
Shutdown started - complete	195
Incident - stop essential services	365
Incident - water curtains started	365
Incident - hot oil spill occurs	520
Incident - toxic gas detection stops	525
Gas detected - toxic gas detection stops	385
Incident - ESV shut	525
Incident - find that tappings are broken	725
Incident - ambulances arrive	855
P! and 2 calls - ambulances arrive	685
Incident occurs - fire engines arrive	855
P1 and 2 - fire engines arrive	685

Fire engines arrive - on incident site	65
Start depressurisation - column depressurised	810
Ambulances arrive - on incident site	235
Muster started - complete minus 7	931
Incident - start moving scaffolding	1160
Muster complete minus 7 - MI and HS located	100
P1 and 2 - police arrive	1140
Muster started - 2 more people are found	1296
Muster complete minus 7 - 2 more people arrive	365
Start moving scaffolding - casualties rescued	960
P1 and 2 - more fire engines arrive	1785
Start moving scaffolding - find HS and MI	60
Start moving scaffolding - found last person	600
Muster minus 7 - found last person	640
Hot oil spill - spill dying down	1170
Incident - PD finds leak is air	1640

Onshore Scenario 8 - Spinal injury on column, icy weather (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - MI with casualty	95
Incident - Muster started	190
Incident - priority one and two calls made	211
Incident - order snorkel	211
Muster started - PD at muster point with blankets	135
Incident - AG going into shock	365
Priority one and two calls made - ambulance arrives at gate	154
Incident - crane drives into pipeline	575
Incident - fire engine crashes into gate	575
Incident - medic arrives at casualty	575
AG going into shock - condition deteriorating	445
Incident - AG's condition deteriorating	810
Incident - shutdown started	820
Incident - smell of gas	875
PD at muster point - PD wearing BAs	550
Crane on sales gas line - smell gas at plant	600
Diesel pump failed - manual activation attempted and failed	206
Incident - AG having breathing problems	1345
AG going into shock - AG having breathing problems	980
AG condition deteriorating - AG having breathing problems	535
Priority one and two calls made - 2nd ambulance at gate	1204
Priority one and two calls made - fire engine arrives at gate	1264
Incident - AG cardiac arrest	1655
AG in shock - cardiac arrest	1290
Condition deteriorating - cardiac arrest	845
Breathing problems - cardiac arrest	310
Fire engine crash - gates opened	1290
Shutdown started - completed	1065

Onshore Scenario 9 - Leak At Dewpoint A (scenario-specific data only)

BEHAVIOUR	RAW TIMES (in seconds)
Incident - flammable gas detection on dewpoint A	18
Incident - MAC alarm activated	25
Incident - Level 1 shutdown started	42

Incident - Muster started	42
Incident - initiated monitors	42
Incident - muster complete (minus missing people)	260
Incident - priority one and two calls	260
Muster complete - PD in BA	105
Muster complete - 2 on the fire truck	160
Incident - gas cloud drifting	470
Incident - monitor facing the correct direction	670
Monitor initiated - monitor facing the right direction	628
Muster completed - fire truck sent to muster point	420
Incident - MF finds a body	845
2 on fire truck - fire truck sent to muster point	260
Priority one and two calls - fire engines and ambulances arrive	690
Incident - all 3 casualties found	1040
MF finds a body - all 3 (two more) casualties found	195
Casualties found - Casualties at muster point	180
Muster started - 1 person missing	1658
Muster complete - 1 person missing	1440

APPENDIX 9: QUESTIONNAIRE STUDY

SECTION 1: OBJECTIVES OF THE QUESTIONNAIRES

Although the scenario was being adequately recorded using the video, initially the expert opinion of the performances was not. This meant that behaviour that was being observed may have exhibited a skewed view of emergency management performance and therefore the TPRC results based on these data may not be wholly representative. For example, if the candidates show excellence in emergency management including many good and timely decisions, the delays used in the TPRC model may be short. Without subjective feedback of performance, these timings may be used to represent "average" emergency management performance and thus any emergency manager may be erroneously expected to perform just as well. Consequently, the emergency manager may have made late or wrong decisions, resulting in a failure to prevent escalation and adverse consequences. This would give the impression that emergency management had very little impact on the outcome.
Therefore a questionnaire was designed to record the opinions of the assessor(s).
In general, the questionnaires included:

- Assessment of overall performance in the scenario
- Assessment of individual tasks - in terms of timeliness and content
- Comparison of the observed performance with the optimal performance - what the assessor would have preferred to see

They were structured so that they could be easily compared with the model inputs - including comments on the delays, communication, action and expected response - similar to the SADCAR concept mentioned in Section 5.3.5.3 of the main report

However, even when a group of assessors agree with each other, they may not be entirely correct. It is often considered a lot easier to watch someone else dealing with a problem than to have to deal with it yourself. Without the stress of the situation, it is possible to analyse the problem with a "clear head". The assessor is usually an expert in emergency management and has prior knowledge of the escalating situation. Therefore, based on his insight and experience, it is reasonable for him to expect a better performance than the emergency manager may give (as suggested in Section 2.3.6.2). For example, the assessor may have thought certain decisions were correct when the emergency manager believes they were not. As the emergency manager has the advantage in terms of on-site knowledge, it was decided that the questionnaires should also record the views of the emergency management candidate. The two questionnaires could then be compared with each other - to resolve any differences and identify any areas where either the assessor or emergency management candidate could be mistaken. The results could also be compared with the TPRC model - to see whether the desired performance has any impact on the emergency. However, this cannot be used as a validation mechanism for the TPRC - as any person's expert judgement may not be valid.

The questionnaires that were designed are shown at the end of this Appendix. For each objective and each important decision that was observed, a copy of page a must be filled in. These might include objectives such as "put out fire" and "save casualties" and decisions such as "start deluge", "order ambulances and fire engines" and "isolate valves". Finally, page b was used to get an overall evaluation of the competence of the candidate. Therefore, both the assessor(s) and candidate were asked about the same decisions - to facilitate comparison.

SECTION 2: QUESTIONNAIRE PROCEDURE

To ensure that the questionnaires examined the important and critical decisions, it was necessary to use an independent observer. This independent observer would watch the whole scenario and note down the critical objectives and decisions - that is, those any decision or actions that could change the flow or outcome of the emergency. These would be recorded in the appropriate spaces in the two sets of questionnaires. Finally, as soon as the exercise was complete and before there was any chance to discuss the scenario or debrief, the candidate would be taken aside and would be taken through the questionnaire. The questionnaire was designed to be filled in by the candidate. However, the independent observer would clarify questions as required - for example, if the question was not applicable or if their handwriting was illegible. However, it was stipulated that the independent observer could only read the questions - NOT the choice of answers. This was to ensure that the independent observer did not put emphasis on one of the answers, either accidentally or intentionally, leading to a biased response.

Once all the candidate's answers were recorded, the assessor(s) would be individually taken through his questionnaire in a similar way. It was ensured that the assessor did not discuss his opinion of the candidate's performance before his questionnaire was completed. This was to ensure that their opinions of the performance were not biased by other people's views. Once both questionnaires were complete, the debriefing could then take place. The results of both questionnaires are discussed in the next section.

SECTION 3: QUESTIONNAIRE RESULTS

3.1 RAW DATA FROM QUESTIONNAIRES

The questionnaires were given out to the candidates and the main assessor for 8 scenarios (4 scenarios for each candidate). This section will initially consider the overall assessments and comparison between scenarios data.

For the assessor, the overall assessment was produced in response to the question "In your opinion, what was the overall level of competence displayed by the candidate in THIS scenario ONLY?". They were then given the choice of "HIGHLY COMPETENT / COMPETENT / NOTABLE SHORTFALLS / NOT COMPETENT" and were encouraged to elaborate on why they made this choice. Following this, they were asked, "How does this compare to the previous scenarios managed by this candidate?" and were given the choice of "NOT AS GOOD AS BEFORE / SAME AS BEFORE / BETTER THAN BEFORE".
The candidate was given an appropriately worded equivalent question (at the end of this Appendix). Therefore the results of overall assessments and comparisons are shown in table α.

Table α: Results of overall assessments and comparisons
Candidate 1

	Scenario 1	Scenario 3	Scenario 5	Scenario 7
Self-assessments				
Highly competent				
Competent	■	■	■	■
Notable shortfalls				
Not competent				
Examiner's assessment				
Highly competent		■	■	■
Competent				
Notable shortfalls	■			
Not competent				

	Scenario 1	Scenario 3	Scenario 5	Scenario 7
Self-assessment	N/A			
Better than before		■		
Same as before			■	■
Not as good as before				
Examiner's assessment	N/A			
Better than before		■		■
Same as before			■	
Not as good as before				

Candidate 2

	Scenario 2	Scenario 4	Scenario 6	Scenario 8
Self-assessment				
Highly competent				
Competent	■	■	■	■
Notable shortfalls				
Not competent				
Examiner's assessment				
Highly competent				
Competent		■	■	■
Notable shortfalls	■			
Not competent				

	Scenario 2	Scenario 4	Scenario 6	Scenario 8
Self-assessment	N/A			
Better than before			■	
Same as before		■		■
Not as good as before				
Examiner's assessment	N/A			
Better than before			■	
Same as before		■		■
Not as good as before				

As shown in table α, all the questionnaires show pleasing results with regard to internal consistency (assessment of whether ratings are consistent when comparing them with previous scenario). The comparisons given as either "better than before", "same as before" and "not as good as before" do not result in contradictory ratings. The differences can all be explained as variations within categories - for example, "only just competent" and "not quite highly competent" may give assessments of "better than before" or "not as good as before" but still be "competent".

In terms of the comparison between the examiner's and candidate's opinions, Candidate 1 gives a level of "competent" for all of his scenarios, whereas the examiner gives "notable shortfalls" for Scenario 1 and "highly competent" for Scenarios 3, 5 and 7. This may indicate that the views on the level of competency are either assumed to cover a broad band of performance by the Candidate or a too narrow band of performance by the examiner. Out of these 4 scenarios, the examiner is shown to be more generous in his assessment than the candidate.

Candidate 2 also gives a level of "competent" for all his scenarios. In this case, the examiner agrees with him except for Scenario 2, which is seen to have "notable shortfalls". In this case, the overall opinion is agreement, with a slight amount of leniency on the part of the candidate or strictness on the part of the examiner.

Based on the assessments of these and one extra scenario for each candidate (not assessed with questionnaires), Candidate 1 was passed as a "competent" emergency manager. It was recommended that Candidate 2 had further training as his overall assessment stated that he exhibited "notable shortfalls". This suggests that the average performance over all the scenarios should be competent or better to be awarded overall competency. As Candidate 1 showed a level of "Highly competent" and Candidate 2 showed a level of "Competent" in their last scenarios, this suggests that it is not sufficient just to prove that the level of performance has been achieved. Therefore, the overall assessment is apparently based on even the earliest scenarios - rather than the final level of performance attained.

Therefore, it is necessary to examine the individual decisions and compare them with the overall assessments as well as comparing the views of the candidate and examiner. The actual questionnaire answers regarding the individual decisions are shown in Section 7.

Two types of comparison are relevant - firstly, the level of agreement between the examiner and candidate, then secondly, the extent to which the assessments of individual decisions agree with the awarding of overall levels of competency. To find out whether the results are statistically significant, it is necessary to obtain numerical values for at least one of the variables. This was carried out by counting the total number of decisions that were recognised as being made within the simulation (by the observer and added to by the assessor). Then for the agreement assessment, the candidate's answers would be compared with the assessor's answers. If both agree for one decision, the agreement rating is incremented by 1. When all the decisions have been compared in this way, there will be a total number of "agreed" opinions, which is converted into a fraction of the total number of decisions. For example, consider the situation where 10 decisions are identified in the scenario. The assessor believes 8 of them were "good" whereas the candidate believes that all 10 of them were "good" - the agreement will be 8 out of 10. This comparison would also be carried out for timeliness, communications and actions. These would be added together to produce an "overall agreement" number for the scenario and to produce an "overall agreement" number for the candidate for each of the 5 sections (quality, timeliness, communications, actions and overall rating). The results obtained are shown in table β.

Table β: Numerical Comparison between Examiner's and Candidate's Opinion

Scenario	**agreement on decision (%)**	**agreement on timing (%)**	**agreement on communication (%)**	**agreement on action (%)**	**overall agreement (%)**
1	12/12 (100)	10/12 (83)	11/12 (92)	10/12 (83)	43/48 (90)
3	14/14 (100)	11/14 (79)	14/14 (100)	14/14 (100)	53/56 (95)
5	14/15 (93)	13/15 (87)	14/15 (93)	14/15 (93)	55/60 (92)
7	21/22 (95)	22/22 (100)	21/22 (95)	20/22 (91)	84/88 (95)
Candidate 1	**61/63 (97)**	**56/63 (89)**	**60/63 (95)**	**58/63 (92)**	**235/252 (93)**
2	9/10 (90)	8/10 (80)	9/10 (90)	9/10 (90)	35/40 (88)
4	13/16 (81)	10/16 (63)	11/16 (69)	12/16 (75)	46/64 (72)
6	12/12 (100)	11/12 (92)	12/12 (100)	12/12 (100)	47/48 (98)
8	10/10 (100)	9/10 (90)	10/10 (100)	10/10 (100)	39/40 (98)
Candidate 2	**44/48 (92)**	**38/48 (79)**	**42/48 (88)**	**43/48 (90)**	**167/192 (87)**

One hypothesis might be that the agreement should improve as the scenarios progress and as the candidate is learning more about the level of performance required of him by the assessor. If this is not the case, then perhaps the feedback of performance is either inadequate, or is not being fully understood by the candidate.

As shown in the above table, Candidate 1 shows overall greater agreement with the Assessor than Candidate 2, showing a 93% agreement compared to 87%. However, Candidate 2 improves to a greater degree - showing a 98% agreement in his last 2 scenarios. The overall agreement is consistent with the overall level of competency awarded.

The numerical values representing performance were prepared in a similar method as for the agreement assessment. This is based on a "digital" representation of performance, where either the performance is good or is bad. If the decision is judged as a poor one then, as in the questionnaire, it is assumed that reaction to it will be poor. It must also be noted for simplicity that an "early" decision is judged to be as good as a timely decision as it shows a degree of foresight. This is something that is encouraged by the emergency management training organisations. However, "too early" is not represented in the questionnaire, as this would be considered as a poor decision. Also, to facilitate the numerical analysis, "late" is judged to be the same as "too late". Neither of these are ideal compromises. However, "too late" was only used on 1 occasion and "early" was used on 4 occasions - out of a total of 111 questions. Therefore, this is unlikely to significantly affect the analysis.

Again, the total number of decisions was used as the maximum value. However, this time, the performance number was incremented only if it was judged to be good. When all the decisions have been added in this way, there will be a total number of "good" results, which is converted into a fraction of the total number of decisions. For example, consider the same situation as described earlier - where 10 decisions are identified in the scenario. The assessor believed 8 of them were "good", therefore his value is 8/10. However, the candidate believed that all 10 of them were "good" - therefore his value is 10 out of 10. Again, this was used to produce an "overall assessment" number for each scenario and each candidate for each of the 5 sections (quality, timeliness, communications, actions and overall rating). The results obtained are shown in table χ.

Table χ: Numerical Assessment of Performance Indications

Person / Scenario	good decision (%)	good timing (%)	good communications (%)	good actions (%)	overall
Assessor / 1	12/12 (100)	11/12 (92)	11/12 (92)	10/12 (82)	44/48 (92)
Cand1 / 1	12/12 (100)	11/12 (92)	12/12 (100)	12/12 (100)	47/48 (98)
Assessor / 3	14/14 (100)	14/14 (100)	14/14 (100)	14/14 (100)	56/56 (100)
Cand1/ 3	14/14 (100)	14/14 (100)	14/14 (100)	14/14 (100)	56/56 (100)
Assessor / 5	14/15 (93)	12/15 (80)	14/15 (93)	14/15 (93)	54/60 (90)
Cand1 / 5	15/15 (100)	14/15 (93)	15/15 (100)	15/15 (100)	59/60 (98)
Assessor / 7	22/22 (100)	22/22 (100)	22/22 (100)	22/22 (100)	88/88 (100)
Cand1 / 7	21/22 (95)	22/22 (100)	21/22 (95)	20/22 (95)	84/88 (95)
Assessor / all Cand1	62/63 (98)	59/63 (94)	61/63 (97)	60/63 (95)	242/252 (96)
Cand1 / all Cand1	62/63 (98)	61/63 (97)	62/63 (98)	61/63 (97)	246/252 (98)
Assessor / 2	9/10 (90)	7/10 (70)	8/10 (80)	9/10 (90)	33/40 (83)
Cand2 / 2	10/10 (100)	9/10 (90)	9/10 (90)	10/10 (100)	38/40 (95)
Assessor / 4	12/16 (75)	11/16 (69)	12/16 (75)	12/16 (75)	47/64 (73)
Cand2 / 4	15/16 (94)	14/16 (88)	14/16 (88)	15/16 (94)	58/64 (91)
Assessor / 6	12/12 (100)	11/12 (92)	12/12 (100)	12/12 (100)	47/48 (98)
Cand2 / 6	12/12 (100)	11/12 (92)	12/12 (100)	12/12 (100)	47/48 (98)
Assessor / 8	10/10 (100)	9/10 (90)	10/10 (100)	10/10 (100)	39/40 (98)
Cand2 / 8	10/10 (100)	10/10 (100)	10/10 (100)	10/10 (100)	40/40 (100)
Assessor / all Cand2	43/48 (90)	38/48 (79)	42/48 (88)	43/48 (90)	166/192 (86)
Cand2 / all Cand2	47/48 (98)	44/48 (92)	45/48 (94)	47/48 (98)	183/192 (95)

When considering the marks awarded by the assessor, Candidate 1 obtained a best overall mark of 100% for scenarios 3 and 7. Candidate 2's best mark was 98% - for scenarios 6 and 8. These breakdowns of these results in terms of decision, timing, communication and action are also shown, as well as the overall performance marks. In this case, Candidate 1 was given an overall performance mark of 96%, whereas Candidate 2's mark was 86% - again reflecting the overall competency levels awarded.

However, it must be noted that Candidate 1 made more decisions per scenario than Candidate 2 - progressing slowly to a peak of 22 in his last scenario, compared with 16 in Candidate 1's second scenario. This may also influence the assessor's opinion. In any case, it is necessary to carry out some form of statistical analysis to identify whether the results are meaningful. Therefore, this will be described in the next section.

3.3 STATISTICAL ANALYSIS OF QUESTIONNAIRE DATA

Statistical analysis should identify whether there is a relationship between the levels of competency awarded and the examiner's opinions of the decisions. The levels can be ranked in order - from highly competent to not competent. It can also be assumed from the results that there is continuity within the levels (for example, when a candidate was judged as being "better than before" but was still considered "competent). It was therefore decided that Spearman's correlation coefficient for ranked data would be the best method. Unfortunately, there would not be enough data to clarify significance in every part of the analysis. Ideally, we would want ≥10 examiner's opinions of the scenarios, ≥10 candidates carrying out the same scenario and ≥10 scenarios (Howell 1987). Therefore, the analysis of the overall performance scores for which we have 2 values would certainly be inadequate. However, the analysis of the 8 scenarios is possible and therefore a Spearman's test is carried out on the relationship between the numerical values and the levels of competency as shown in tables α and χ.

Three analyses were carried out - the relationship between the level of competency awarded by the assessor and the assessor's opinions on decision quality, decision timing and overall decision assessment. It can be hypothesised that there should be a positive correlation between these factors - better individual decisions correlate with higher levels of competency being awarded. The analysis should identify whether the assessment is made predominantly on particular features of the decisions (e.g. timeliness) or an overall impression of the decisions. It should also identify if the assessor is consistent in his marking or if the overall assessment is based on features outside of the questionnaire. This was carried out using numerical representation of the levels of competency (where highly competent > competent > notable shortfalls > not competent) and the percentage values are shown in brackets in table χ. The results of the statistical analysis are shown in table δ.

Table δ: Spearman's Correlation Coefficient for Ranked Data carried out on Assessor's Data

Relationship tested	Spearman's coefficient r_s
Level of Competency against Decision Quality	0.34
Level of Competency against Timing	0.48
Level of Competency against Overall decision assessment	0.55

As it can be seen, in each case, the correlation is positive. This indicates that it is unlikely that someone who makes consistent poor or wrongly timed decisions will be considered as competent. Similarly, it is unlikely that someone who makes consistently good and timely decisions will be considered as having notable shortfalls. However, the correlation coefficients are not particularly strong. This may be due to the small amount of data available or due to inconsistencies within the data.

However, it was noted that there was an apparent relationship between the actual number of decisions made and the level of competency awarded. Therefore, a Spearman's calculations was carried out on these data obtaining a value of $r_s = 0.7$. This was somewhat surprising as this was independent of whether the decisions were good or bad. Therefore, the correlation between level of competency and the number of good decisions was evaluated. This resulted in a value of $r_s = 0.86$ for the 8 scenarios. This is the strongest correlation obtained between the data. It suggests that the key indicator of competency level is the number of good decisions made per scenario - ignoring the overall relationship of good to bad decisions indicated by the % score (which gave a correlation of 0.34 as shown in the table). To confirm this, a correlation between the number of bad decisions and competency was calculated. It might be expected that this would produce a negative correlation - that is, the more bad decisions that are made, the lower the level of competency. However, Spearman's rho gave a value of 0.08 for this calculation. This indicates that although the relationship was approximately random, it was positive. This suggests that bad decisions do not adversely affect the competency assessment. The possible reasons for this will be discussed in the Section 4 of this Appendix.

This questionnaire was intended to add the subjective opinions to the objective analysis carried out using the TPRC model. This could indicate whether the simulation data were a representative sample of emergency management practice and were not skewed towards excellence or incompetence. Although, there are not enough data to provide a full distribution of competency, these results suggest that this is the case.

SECTION 4: IMPLICATIONS OF THE QUESTIONNAIRE RESULTS

The questionnaires were designed to capture the subjective assessments of the simulations. This could help to identify the key features that affect the levels of competency awarded to the candidates. It could also be used to collect the subjective expert opinions of the quality of each emergency management decision. It was also deemed necessary to collect the candidate's opinions of his own decisions particularly with regard to those that were site-specific or context-based. In this case, the assessor was external to the installation and therefore would not necessarily have detailed knowledge of the installation. However, the candidate was being assessed on emergency management performance, which must relate partly to his specialist knowledge about the installation. Therefore, it was likely that the assessor would make judgments about performance based on assumptions rather than on definite information about the installation - which could be identified with feedback from the candidate.

It was only possible to use the questionnaires in the 8 onshore simulations so there are no subjective offshore data. However, from the results shown in Section 3 of this Appendix, it can be seen that these yielded some interesting results.

4.1 Discussion of Overall Ratings

The overall ratings of each scenario were analysed in three different ways. Firstly, "competency rating" was assessed against "comparison with previous scenario rating". This was designed to assess the consistency of the answers. If the competency rating was based on solid foundations and strict judgments, these should be consistent, hence providing the technique with some level of reliability.

Secondly, the competency ratings of the candidate and the assessor were compared. This was designed to assess whether they were similar - hence basing their judgments on the same information. If there were vast differences, this would suggest that their opinions were based on different criteria. Therefore, it would be important to resolve these differences before the candidate could be expected to work towards the performance that the assessor would want to see; or, before the assessor could identify the critical performance behaviour that was seen to be necessary by the candidate. Finally, it was necessary to compare the assessments of individual scenarios with the collective opinion given at the end of the course.

Initially, the questionnaire demonstrated that there was consistency in the overall ratings. For example, there were no occasions where a rating of "better than before" resulted in a lower competency rating than the previous scenario. This applied to both candidates and the assessor. This indicates that the use of a 4-choice competency assessment system is acceptable. The candidates and the assessor are able to assign a competency indicator to a performance, with consistency over time. Therefore, this suggests that either the assessors and candidates are able to memorize all of their previous responses or they are using self-defined criteria on which to base the competency assessment. Therefore, if they can remember earlier performances, they can compare them with the current performance and make a comparative judgment using their criteria.

The agreement between the candidates and the assessor is a different matter. Both candidates give a self-assessment of "competent" for all of the scenarios, whereas the assessor's results were more varied. This may have been due to a broad definition of the terms on the part of the candidates. The results suggested that Candidate 1 was more negative in his self-assessments than the assessor whereas Candidate 2 was more positive. Therefore, as all three people showed internal consistency in their marking, this may suggest that the assessor's results also showed consistency between candidates. The assessor was motivated to pass both candidates but had a responsibility to ensure that only the candidates that are capable are assessed as competent. Given this, Candidate 1 was considered "competent" and Candidate 2 was considered to have "notable shortfalls" in the overall assessment. It is assumed that this was based on an overall rating of the week's performance rather than the eventual level of performance achieved. In the last of their scenarios, Candidate 1 was rated as "highly competent" and Candidate 2 was rated as "competent". During the week's scenarios, their performance improved to these levels. Therefore, based on their final performance, it would appear that both were capable of successfully managing an emergency. However, it is possible that their overall ratings were lowered due to their earlier failures, which suggested a lack of consistency in their competency. Therefore, according to these results, it appears that the assessor must identify a consistent level of competent (And highly competent) performances to award competency to a candidate.

4.2 Discussion of Questionnaire Assessment of Individual Decisions

The assessments of individual decisions were compared in two main ways. The candidate's judgments were compared with the assessor's decisions - to assess the agreement between the opinions. The second analysis involves the comparison of performance in decisions with overall scenario performance. This could only be carried out for the assessor as the candidates gave a rating of "competent" for every scenario so no differences were shown. The answers were converted into numerical values, which facilitated the use of statistical analysis.

Feedback is generally considered one of the important parts of learning - and most particularly in emergency management training (Carrol & Kidd 1991). The agreement of performance ratings indicates that the candidate and assessor are looking for the same types of performance. Therefore, if the candidate knows he was late making a decision, or that a decision was not communicated well to the appropriate parties - this will be identified in the questionnaire. If the candidate does not know that he erred, this suggests that he does not know the performance requirements of the assessor. The assessor should rectify this by providing feedback to ensure improvements in performance. In these results, it was discovered that Candidate 1 showed a higher level of agreement with the assessor than Candidate 2. This is consistent with the final competency level assigned. It would be expected that greater agreement indicates greater understanding of the requirements of the test, therefore resulting in improved performance. However, these results showed greater improvements in agreement by Candidate 2. This may perhaps reinforce the idea that the competency assessment is based on the whole week of scenarios rather than the later ones.

The second assessment involved the overall assessment of decisions. Instead of comparing the relationship between the assessor's judgment and the candidate's judgment, this obtains numerical results based on whether the ratings were "good" or "not good". Therefore, based on our understanding of emergency management, "early" and "timely" are both considered good, whereas "too early", "late" and "too late" are not. A large percentage indicated a large number of decisions that were "good". This was carried out for quality, timeliness, communication, action and an overall rating. Again, Candidate 1 achieved the better results - both in terms of self and assessor ratings - obviously making a greater percentage of good decisions.

As suggested in Chapter 2, making "good and timely" decisions is a critical part of emergency management. Ensuring that these decisions are communicated successfully to the relevant people and that they are implemented are equally as important to ensure that the desired outcome is achieved. Chapter 2 and Appendix 1 list many attributes that are typical or recommended in an emergency manager. These included leadership, delegation, team working etc. However, these attributes are believed to make decision-making and the communication of decisions more effective and efficient. This in turn will make an impact on the emergency. Therefore, it may not be necessary to assess an emergency manager in terms of his attributes and behaviour - but to focus on his ability to make "good and timely" decisions and ensure that they are implemented.

If this is the case, it should be possible to obtain a high correlation between the results of the decision analysis and the overall competency assessment of each scenario. Therefore, it was necessary to carry out statistical analysis, in the form of a Spearman's correlation coefficient test. The main factors were decision quality (good or bad), timeliness and the overall assessment (a value that incorporated judgments of quality, timeliness, communications and actions). These three factors were each correlated against overall scenario rating (notable shortfalls, competent, highly competent). Again, these would only be carried out for the assessor's ratings as the candidates gave a rating of "competent" for every scenario. Spearman's rho indicated a positive correlation for these three relationships. This indicated that the higher the quality of decisions, the more likely it was to receive a higher competency rating. However, although the correlations were positive, they were not very high (decision quality = 0.34, timeliness = 0.48, overall = 0.55). The relationship between overall decision rating and competency indicated that there were other factors that were important.

As it appeared from the results that competency was linked to the number of decisions that were made, this correlation was calculated. It was somewhat surprising that it resulted in a rho value of 0.7. As this was notably higher than the overall assessment of the decisions, it was decided that a further calculation should be carried out - between number of good decisions and competency. This resulted in a rho value of 0.86. From these statistical assessments, it would seem that competency is based partly on the number of good decisions made per scenario. Given that the relationship between competency and bad decisions was calculated as 0.08, this reinforced the idea that the assessment was focused predominantly on good decisions. It was initially thought that weighting the decisions might help to identify how the competency assessments could come up with this result. In the current system, there is no indication of whether the decision is bad because it adversely affects the outcome of the emergency or if it is just unnecessary. However, in Scenario 4, Candidate 2 made 4 bad decisions. The assessor recommended that he should have used full blowdown as opposed to a limited blowdown. He should not have ordered 10 ambulances and 10 fire engines when he did not really know the extent of the incident. Further to this, he did not protect the surrounding areas from column depressurisation, which should have been carried out at the beginning of the incident. The other decision was to move the muster point to the tail gas unit, which was not made by the candidate but was implemented nevertheless. The numbers of ambulances and fire engines were considered to be "overkill" but would not have provided further risk. However, the blowdown and column depressurisation were decisions that could potentially affect the outcome of the emergency. This scenario was said to have been managed "competently" whereas earlier scenarios with no bad decisions were said to have "notable shortfalls". This fact, together with the results of the correlations, suggests that the assessor may be influenced more by the apparent activities of the emergency manager than the expected impact of his actions. That is, perhaps leadership qualities and delegation skills may have been emphasized as being more important than their impact on the decision-making and emergency action. Clearly, it may seem illogical that the number of poor decisions resulted in a positive correlation with competency, however this reinforces the concept that the emergency management assessment techniques and risk assessment techniques focus on different factors.

SECTION 5: CRITIQUE OF THE QUESTIONNAIRES

5.1 Questionnaire Design

As mentioned earlier, any changes to the questionnaire would have produced a disruption to the scenario procedure. As the simulations were run for the purpose of assessment rather than research, the scenario organiser indicated that they could only be short. Therefore, unfortunately there were many aspects that could not be investigated as is discussed in Section 13.5 of the main report.

The questionnaire produced some illogical results - particularly relating the assessment of individual decisions in relation to the competency level awarded to that specific scenario. This could be due to the brevity of the questionnaire rather than weaknesses in the assessment process. Aspects that were critical to assessment, such as delegation skills, team organisation and efficient communication of information, may not have been adequately represented in the questionnaire. In general, the questionnaire was relevant to the TPRC model, rather than capturing the essence of emergency management assessment. The focus was on emergency management's relation to its outcome rather than the organisational skills promoting it. Therefore, this does may help to explain why the correlation between the number of bad decisions and competency was small but positive.

5.2 Questionnaire Procedure

Like the scenario arrangements, the questionnaire procedure relied on the availability of personnel. Therefore, only the main assessor and the emergency management candidate were available to answer questionnaires. This meant that any valuable data, from the scenario organiser or emergency management team members, were lost. Also, in the total research project, there was only information recorded for 8 scenarios - representing 1 assessor and 2 emergency management candidates. With such a small number of participants, these results can hardly be representative of candidates, assessors and scenarios as a whole.

However, from the results, it can be seen that both candidates give a self-assessment of "competent" for all of the scenarios. This may have been due to a broad definition of the term. However, it may also be linked to experimenter effects - or in this case, assessor effects. Although the candidate was reassured that the answers would not influence their overall assessment, they may not have believed this and were trying to "impress" the assessor or bias him into giving them a good competency rating. It may also be due to biases or heuristics. Consider the anchoring and adjustment heuristic. This involves basing future judgments on adjustments of the first judgment. It is likely that the candidates will use "competent" as their main answer for this reason. Overall, this suggests that an independent assessor should be used - someone who is <u>not</u> the same person who trained the emergency management candidate. This would ensure that the candidate is genuinely making effort towards effective emergency management rather than focusing on behaviour that will "please" the assessor. This will also ensure that the assessor is not biased by having built up knowledge of the candidate's management style or personality.

Finally, it should be mentioned that because the questionnaire was given at the end of the scenario, some aspects will have been forgotten. For example, if the emergency manager makes a decision which is later realised to be erroneous. By the end of the scenario, the emergency manager will know this was poor and would be unlikely to say otherwise in a questionnaire. They may even forget what good reasons were evident for making the decision at the time. Therefore, giving the questionnaire at the end of the scenario produces results that are biased by the outcome. If the questions regarding each decision could be asked immediately after each decision (and before any consequences could occur), this would produce a better understanding of emergency management decision-making. The main conclusions from this research are shown in the main report in Section 12.5 and comparisons between the questionnaires and the TPRC modelling are shown in Section 11.2.2.2.

SECTION 6 : QUESTIONNAIRES

Questionnaire for Examiners in Emergency Management Training Exercise (may be answered either individually or as a group)

Examiner No (if required):...........................
Scenario Title / Number..............................
Date:......./...../......

Concerning The Objective :...

Do you think the candidate successfully managed this aspect of the emergency?

YES / NO

Was the decision to .... A good one?

YES / NO

Underline the most appropriate word describing the timing of this decision

TOO EARLY, EARLY, TIMELY, LATE, TOO LATE.

If you believe the decision was mis-timed, when would YOU have carried out this decision (relate this to the events that occurred)?

....

....

Was this decision communicated in such a way that the people who were designated to carry out the actions could respond immediately?

YES / NO

Did the people who were designated to carry out the action respond to the communication correctly and immediately?

YES / NO

If NO, why do you believe this was the case?

....

....

Why was this not a good decision? And what would YOU believe to be the correct decision (please continue overleaf if required)

....

....

....

....

....

....

....

....

....

In your opinion, what was the overall level of competence displayed by the candidate in THIS scenario ONLY?

HIGHLY COMPETENT / COMPETENT / NOTABLE SHORTFALLS / NOT COMPETENT

Please make brief comments to indicate why this level was awarded if they have not been covered in the previous sections

....

....

....

How does this compare to the previous scenarios managed by this candidate?

NOT AS GOOD AS BEFORE / SAME AS BEFORE / BETTER THAN BEFORE

....

....

Thank you VERY much for your time in answering this questionnaire

---

Questionnaire for Candidates in Emergency Management Training Exercise

Candidate No (if required):...........................
Scenario Title / Number..............................
Date:......./...../1998

Concerning The Objective :..

Do you think you successfully managed this aspect of the emergency?

YES / NO

Was the decision to .... A good one?

YES / NO

Underline the most appropriate word describing the timing of this decision

TOO EARLY, EARLY, TIMELY, LATE, TOO LATE.

If you believe the decision was mis-timed, when should you have carried out this decision (relate this to the events that occurred)?

....

....

Was this decision communicated in such a way that the people who were designated to carry out the actions could respond immediately?

YES / NO

Did the people who were designated to carry out the action respond to the communication correctly and immediately?

YES / NO

If NO, why do you believe this was the case?

....

Why was this not a good decision? And what would you now believe to be the correct decision (please continue overleaf if required)

....

....

....

....

....

....

....

....

....

In your opinion, what was the overall level of competence displayed by yourself in THIS scenario ONLY?

HIGHLY COMPETENT / COMPETENT / NOTABLE SHORTFALLS / NOT COMPETENT

Please make brief comments to indicate why this level was chosen if they have not been covered in the previous sections

....

....

How does this compare to the previous scenarios managed by yourself?

NOT AS GOOD AS BEFORE / SAME AS BEFORE / BETTER THAN BEFORE

....

....

Thank you VERY much for your time in answering this questionnaire

SECTION 7: RESULTS FROM QUESTIONNAIRES

Decision	Good/Bad	Timing	Communicated well?	Action expected?
Examiner's view Scenario 1				
Activate level 1	good	timely	yes	yes
Isolate spillage	good	timely	yes	yes
Direct assets down specific route	good	timely	yes	yes
Stop outfall	good	timely	yes	yes
Get police to reassure villagers	good	timely	yes	yes
Turn foam monitor off	good	timely	yes	yes
cool diesel tanks	good	timely	yes	yes
contain problem	good	timely	yes	yes
mobilise fire trucks	good	timely	no - no indication of severity	no - see comms
send search and rescue team	good	timely	yes	no - problems in reporting in.
call priority 1 and 2 calls	good	late	yes	yes
muster	good	timely	yes	yes
Candidate's view Scenario 1				
Activate level 1	good	timely	yes	yes
Isolate spillage	good	timely	yes	yes
Direct assets down specific route	good	timely	yes	yes
Stop outfall	good	timely	yes	yes
Get police to reassure villagers	good	timely	yes	yes
Turn foam monitor off	good	timely	yes	yes
cool diesel tanks	good	late	yes	yes
contain problem	good	timely	yes	yes
mobilise fire trucks	good	timely	yes	yes
send search and rescue team	good	timely	yes	yes
call priority 1 and 2	good	timely	yes	yes

calls				
muster	good	timely	yes	yes

Decision	Good/Bad	Timing	Communicated well?	Action expected?
Examiner's view Scenario 2				
muster	good	timely	yes	yes
activate level 1	good	timely	yes	yes
priority 1 and 2 calls	good	late	yes	yes
order crane	good	timely	yes	yes
rescue AE using crane	bad - recommend he waits for the fire brigade	N/A	N/A	N/A
get extra air for AE	good	timely	yes	yes
assess cloud with portable gas monitors	good	timely	yes	yes
make 1st PA	good	late	yes	yes
make 2nd PA	good	timely	yes	yes
activate off-site plan	good	timely	no	yes
Candidate's view Scenario 2				
muster	good	timely	yes	yes
activate level 1	good	timely	yes	yes
priority 1 and 2 calls	good	timely	yes	yes
order crane	good	timely	yes	yes
rescue AE using crane	good	timely	yes	yes
get extra air for AE	good	timely	yes	yes
assess cloud with portable gas monitors	good	timely	yes	yes
make 1st PA	good	late	yes	yes
make 2nd PA	good	timely	yes	yes
activate off-site plan	good	timely	no	yes

Decision	Good/Bad	Timing	Communicated well?	Action expected?
Examiner's view Scenario 3				
activate level 1	good	early	yes	yes
activate platform alarm	good	early	yes	yes
muster	good	timely	yes	yes
activate fixed monitors	good	timely	yes	yes
order extra assets (P1 calls)	good	timely	yes	yes
move forward muster point	good	timely	yes	yes
start 1st PA	good	timely	yes	yes
stop outfall	good	early	yes	yes
get foam down drains	good	early	yes	yes
get water curtains on tanker	good	timely	yes	yes
isolate manual valve	good	timely	yes	yes

isolate leak	good	timely	yes	yes
depressurise refrigeration unit	good	timely	yes	yes
find missing person	good	timely	yes	yes
Candidate's view Scenario 3				
activate level 1	good	timely	yes	yes
activate platform alarm	good	timely	yes	yes
muster	good	timely	yes	yes
activate fixed monitors	good	timely	yes	yes
order extra assets (P1 calls)	good	timely	yes	yes
move forward muster point	good	timely	yes	yes
start 1st PA	good	timely	yes	yes
stop outfall	good	timely	yes	yes
get foam down drains	good	timely	yes	yes
get water curtains on tanker	good	timely	yes	yes
isolate manual valve	good	timely	yes	yes
isolate leak	good	timely	yes	yes
depressurise refrigeration unit	good	timely	yes	yes
find missing person	good	timely	yes	yes

Decision	**Good/Bad**	**Timing**	**Communicated well?**	**Action expected?**
Examiner's view Scenario 4				
Level 1 Shutdown	good	timely	yes	yes
Limited blowdown	bad - full blowdown necessary			
Priority 1 calls	good	timely	yes	yes
Muster	good	timely	yes	yes
Set up forward muster point	good	timely	yes	yes
Order resources	good	timely	yes	yes
Order 10 ambulances and 10 fire engines	bad - overkill, too early to determine problem was this severe			
Depressurise tail gas unit	good	timely	yes	yes
Move forward muster point to tail gas unit	bad - not candidate's decision			
Move forward muster point to gas sweetening unit	good	timely	yes	yes
Evoke off-site plan	good	timely	yes	yes
Search and rescue missing person	good	timely	yes	yes
Divert ambulance to workshop	good	timely	yes	yes
Move main muster	good	timely	yes	yes

point to muster point 2				
Not protecting the surrounding areas from column depressurisation	bad - protection should have been put in place at the beginning	N/A	N/A	N/A
Isolate source of fire	good	late	yes	yes
Candidate's views Scenario 4				
Level 1 Shutdown	good	timely	yes	yes
Limited blowdown	good	timely	yes	yes
Priority 1 calls	good	timely	yes	yes
Muster	good	timely	yes	yes
Set up forward muster point	good	timely	yes	yes
Order resources	good	timely	yes	yes
Order 10 ambulances and 10 fire engines	good	timely	yes	yes
Depressurise tail gas unit	good	timely	yes	yes
Move forward muster point to tail gas unit	no - error on focus board	N/A	N/A	N/A
Move forward muster point to gas sweetening unit	good	timely	no - errors from focus board	yes
Evoke off-site plan	good	late	yes	yes
Search and rescue missing person	good	timely	yes	yes
Divert ambulance to workshop	good	timely	yes	yes
Move main muster point to muster point 2	good	timely	yes	yes
Not protecting the surrounding areas from column depressurisation	good	timely (N/A)	yes (N/A)	yes (N/A)
Isolate source of fire	good	timely	yes	yes

Decision	**Good/Bad**	**Timing**	**Communicated well?**	**Action expected?**
Examiner's view Scenario 5				
Activate level 1	good	timely	yes	yes
Muster	good	timely	yes	yes
Get fire engine via Colliery road	good	timely	yes	yes
Knock outfall off	good	timely	yes	yes
Mobilise fire truck to forward muster point	good	timely	yes	yes
Send BAs to the men	good	timely	yes	yes
Identify and contain leak	good	late	yes	yes
Priority 1 calls	good	timely	yes	yes
Use ambulance to	bad - unnecessary	N/A	N/A	N/A

rescue man and dog				
Direct R to make calls	good	timely	yes	yes
Search/rescue missing man	good	timely	yes	yes
Break into lab to get BAs to F	good	timely	yes	yes
Get foam to spillage TPS	good	late	yes	yes
Keep police car at the gate to divert traffic	good	timely	yes	yes
Get 1 police car to tour the village	good	timely	yes	yes
Candidate's view Scenario 5				
Activate level 1	good	timely	yes	yes
Muster	good	timely	yes	yes
Get fire engine via Colliery road	good	timely	yes	yes
Knock outfall off	good	timely	yes	yes
Mobilise fire truck to forward muster point	good	timely	yes	yes
Send BAs to the men	good	timely	yes	yes
Identify and contain leak	good	timely	yes	yes
Priority 1 calls	good	timely	yes	yes
Use ambulance to rescue man and dog	good	timely	yes	yes
Direct R to make calls	good	timely	yes	yes
Search/rescue missing man	good	timely	yes	yes
Break into lab to get BAs to F	good	timely	yes	yes
Get foam to spillage TPS	good	late	yes	yes
Keep police car at the gate to divert traffic	good	timely	yes	yes
Get 1 police car to tour the village	good	timely	yes	yes

Decision	**Good/Bad**	**Timing**	**Communicated well?**	**Action expected?**
Examiner's view Scenario 6				
Make 1st PA	good	too late	yes	yes
Isolate the rich amine separator	good	timely	yes	yes
Manual isolations	good	timely	yes	yes
Muster	good	timely	yes	yes
Level 1 shutdown	good	timely	yes	yes
Make priority 1&2 calls	good	timely	yes	yes
Put outfall off	good	timely	yes	yes
Evoke offsite plan	good	timely	yes	yes

Depressurise GSU A and B	good	timely	yes	yes
Get foam down drains and TPS	good	timely	yes	yes
Locate missing men	good	timely	yes	yes
Send ambulances to railway	good	timely	yes	yes
Candidate's view Scenario 6				
Make 1st PA	good	late	yes	yes
Isolate the rich amine separator	good	timely	yes	yes
Manual isolations	good	timely	yes	yes
Muster	good	timely	yes	yes
Level 1 shutdown	good	timely	yes	yes
Make priority 1&2 calls	good	timely	yes	yes
Put outfall off	good	timely	yes	yes
Evoke offsite plan	good	timely	yes	yes
Depressurise GSU A and B	good	timely	yes	yes
Get foam down drains and TPS	good	timely	yes	yes
Locate missing men	good	timely	yes	yes
Send ambulances to railway	good	timely	yes	yes

Decision	**Good/Bad**	**Timing**	**Communicated well?**	**Action expected?**
Examiner's view Scenario 7				
Muster	good	timely	yes	yes
Priority 1 & 2 calls	good	timely	yes	yes
Level 1 shutdown	good	timely	yes	yes
Activate platform alarms	good	timely	yes	yes
Activate fixed monitors	good	timely	yes	yes
Outfall off	good	timely	yes	yes
Move the forward muster point forward	good	timely	yes	yes
Set the water curtains up	good	timely	yes	yes
Shut the turbine down	good	timely	yes	yes
Send the fire engines through the colliery	good	timely	yes	yes
Ensure the fire engines have cutting equipment	good	timely	yes	yes
Get tarpaulins to protect casualties from hot oil	good	timely	yes	yes
Get someone to reassure casualties	good	timely	yes	yes
Get assistance in cutting to remove casualties	good	timely	yes	yes
Isolate leak	good	timely	yes	yes

Identify hissing (further leak)	good	timely	yes	yes
Get police to tour village	good	timely	yes	yes
Get nitrogen purge on sales gas manifold	good	timely	yes	yes
Mobilise crane driver	good	timely	yes	yes
Depressurise line	good	timely	yes	yes
Make 1st PA	good	timely	yes	yes
Make 2nd PA	good	timely	yes	yes
Candidate's view Scenario 7				
Muster	good	timely	yes	yes
Priority 1 & 2 calls	good	timely	yes	yes
Level 1 shutdown	good	timely	yes	yes
Activate platform alarms	good	timely	yes	yes
Activate fixed monitors	good	timely	yes	yes
Outfall off	good	timely	yes	yes
Move the forward muster point forward	good	timely	yes	yes
Set the water curtains up	good	timely	yes	yes
Shut the turbine down	No - shouldn't have happened	N/A	N/A	N/A
Send the fire engines through the colliery	good	timely	yes	yes
Ensure the fire engines have cutting equipment	good	timely	yes	yes
Get tarpaulins to protect casualties from hot oil	good	timely	yes	no
Get someone to reassure casualties	good	timely	yes	yes
Get assistance in cutting to remove casualties	good	timely	yes	yes
Isolate leak	good	timely	yes	no
Identify hissing (further leak)	good	timely	yes	yes
Get police to tour village	good	timely	yes	yes
Get nitrogen purge on sales gas manifold	good	timely	yes	yes
Mobilise crane driver	good	timely	yes	yes
Depressurise line	good	timely	yes	yes
Make 1st PA	good	timely	yes	yes
Make 2nd PA	good	timely	yes	yes

Decision	**Good/Bad**	**Timing**	**Communicated well?**	**Action expected?**
Examiner's view				

Scenario 8				
Muster	good	timely	yes	yes
Order crane to GSU B	good	timely	yes	yes
Police car to tour village	good	timely	yes	yes
Priority 1 calls	good	timely	yes	yes
Shutdown level 1	good	timely	yes	yes
Send nurse to casualty	good	timely	yes	yes
Send electrician to start fire water pumps	good	timely	yes	yes
Outfall off	good	timely	yes	yes
Not to blowdown	good	timely	yes	yes
Evoke off-site plan	good	late	yes	yes
Candidate's view Scenario 8				
Muster	good	timely	yes	yes
Order crane to GSU B	good	timely	yes	yes
Police car to tour village	good	timely	yes	yes
Priority 1 calls	good	timely	yes	yes
Shutdown level 1	good	timely	yes	yes
Send nurse to casualty	good	timely	yes	yes
Send electrician to start fire water pumps	good	timely	yes	yes
Outfall off	good	timely	yes	yes
Not to blowdown	good	timely	yes	yes
Evoke off-site plan	good	timely	yes	yes

APPENDIX 10: NUMERICAL DISTRIBUTIONS PARAMETERS

Post-Incident Offshore Data (E & C)

BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	8.970297	202	1812	6.925985	25896	80.46623	39	1
scenario organisation team's non-informational calls	1.768116	207	366	0.889173	810	3.126234	5	1
emergency management team's informational calls	5.09901	101	515	3.257315	3687	25.9999	16	1
emergency management team's non-informational calls	1.351695	236	319	0.671009	537	1.827079	6	1
scenario organisation team's calls	5.325183	409	2178	6.085129	26706	28.35758	39	1
emergency management team's calls	2.474777	337	834	2.535484	4224	6.124523	16	1
non-informational calls	1.546275	443	685	0.806929	1347	2.390968	6	1
informational calls	7.679868	303	2327	6.227462	29583	58.98037	39	1
radio calls	4.037534	746	3012	5.019285	30930	16.30168	39	1
delays between dependent radio calls (question - answer)	1.51277	509	770	1.956801	3110	2.288473	21	0
announcements	3.315096	987	3272	4.403231	29964	10.98986	43	1
delays to announcements	0.535109	413	221	1.036636	561	0.286342	7	0
Total time to deliver a message (NB. does not include repeat attempts to call)	28.625	120	3435	16.21187	129603	819.3906	115	9
Time from standby to calling back	30.42857	7	213	20.04044	8891	925.898	53	2
Totally intelligible calls	4	5	20	4.472136	160	16	11	1
Partially intelligible calls	11	26	286	8.899438	5126	121	39	1
Time left between failed attempts to call in/out	15.39394	33	508	16.81134	16864	236.9734	83	2
Delays to answer phone	8.888889	27	240	7.767453	3702	79.01235	37	2
Time at which phone stopped ringing (not answered)								
Phone call length	24.78571	14	347	16.81656	12277	614.3316	64	2
Information known in EMT-SO	100.1613	31	3105	214.0189	1685123	10032.28	1022	5
Information known in SO - EMT	33.79762	84	2839	23.92346	143455	1142.279	117	1

Time to initiate following orders (control panel work)	15.22222	9	137	14.06927	3669	231.716	38	1
Incident - control panels and instruments respond	7.5	8	60	12.67168	1574	56.25	29	0
Control panel response - operator response	33.7	10	337	37.98552	24343	1135.69	121	4
Time to initiate following orders (calling others outside/moving)	27.46341	41	1126	29.91496	66720	754.2391	126	1
Delays from being given information externally - drawing the attention of the group to it	34	57	1938	78.86109	414160	1156	467	2
Time out announced - started	28.83333	18	519	14.34553	18463	831.3611	69	11
Time out length	50.28571	21	1056	29.61443	70642	2528.653	127	20
Delay between time outs	281.75	16	4508	102.2106	1426834	79383.06	491	111
Incident - first time out starts	230.2	5	1151	57.28612	278087	52992.04	313	154
CCR aware of incident - first time out starts	226	5	1130	56.78028	268276	51076	312	153
EM arrives - first time out starts	165.2	5	826	29.72709	139990	27291.04	193	122
Incident - start first informational tannoy	258.6	5	1293	338.6138	793007	66873.96	749	15
EM arrives - starts first informational tannoy	578.5	2	1157	170.4127	698365	334662.3	699	458
Incident - starts first tannoy	20.2	5	101	8.288546	2315	408.04	34	15
Tannoy length	16.66667	27	450	9.825399	10010	277.7778	40	1
Time between tannoys	282.0435	23	6487	249.6116	3200347	79548.52	807	2
Incident - start of first call out from CR	64.8	5	324	37.6125	26654	4199.04	92	5
Incident - start of first call into CR from incident	36.6	5	183	33.12552	11087	1339.56	86	1
Incident - start of first informational call into CR from incident site	76.2	5	381	67.04625	47013	5806.44	184	7
Incident - EM arrives	65	5	325	57.07889	34157	4225	166	31
Incident - call EM	40	5	200	36.85105	13432	1600	102	13
call EM - EM arrives	25	5	125	22.32711	5119	625	64	7
EM arrives - EM's first response	18.4	5	92	21.8815	3608	338.56	56	2
Incident - EM's first response	74.6	5	373	52.43854	38825	5565.16	168	45

Post-Incident Onshore Data (L & P)

BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	6.413386	508	3258	4.277179	30170	41.13152	25	1
scenario organisation team's non-informational calls	1.428571	525	750	0.734342	1354	2.040816	6	1
emergency management team's informational calls	5.766773	313	1805	3.933736	15237	33.25567	26	1
emergency management team's non-informational calls	1.307554	556	727	0.708263	1229	1.709697	8	1
scenario organisation team's calls	3.879961	1035	4008	3.934187	31524	15.0541	25	1
emergency management team's calls	2.913694	869	2532	3.235839	16466	8.489612	26	1
non-informational calls	1.366327	1081	1477	0.723248	2583	1.866851	8	1
informational calls	6.16687	821	5063	4.159054	45407	38.03028	26	1
radio calls	3.438486	1902	6540	3.662677	47990	11.82318	26	1
delays between dependent radio calls (question - answer)	1.77745	1357	2412	1.718971	8294	3.159329	16	0
announcements	4.49322	1180	5302	6.995876	81526	20.18903	59	1
delays to announcements	0.886194	536	475	1.488936	1607	0.78534	14	0
Total time to deliver a message (NB. does not include repeat attempts to call)	24.90882	340	8469	13.65376	274151	620.4495	107	6
Time from standby to calling back	38.09677	31	1181	77.77333	226453	1451.364	436	1
Totally unintelligible calls	4.404762	42	185	4.260193	1559	19.40193	22	1
Partially intelligible calls	7.482143	112	838	3.931811	7986	55.98246	20	1
Time left between failed attempts to call in/out	10.17241	58	590	10.3976	12164	103.478	60	1
Delays to answer phone	4.550459	109	496	6.066737	6232	20.70667	46	0
Time at which phone stopped ringing (not answered)	21.5	6	129	7.687652	3069	462.25	32	14
Phone call length	24.31111	45	1094	12.38368	33344	591.0301	61	7
Information known in EMT-SO	65.92157	51	3362	72.66191	485616	4345.653	390	4
Information known in SO - EMT	37.58242	91	3420	28.31139	200670	1412.438	159	7
Time to initiate following orders	10.58824	17	180	13.25264	4716	112.1107	48	0

(control panel work)								
Incident - control panels and instruments respond								
Control panel response - operator response	0	1	0	(N/A)	0	0	0	0
Time to initiate following orders (calling others outside/moving)	25.10638	47	1180	36.42815	90668	630.3305	154	0
Delays from being given information externally - drawing the attention of the group to it	25.06061	66	1654	38.98082	140218	628.034	216	1
Time out announced - started	30.6	35	1071	13.79727	39245	936.36	70	0
Time out length	68.54286	35	2399	21.94692	180811	4698.123	132	28
Delay between time outs	458.8462	26	11930	266.101	7244278	210539.8	1443	83
Incident - first time out starts	245	9	2205	98.64203	618067	60025	404	111
CCR aware of incident - first time out starts	233.2222	9	2099	126.5166	617585	54392.6	482	96
EM arrives - first time out starts								
Incident - start first informational tannoy	620.25	8	4962	257.1474	3540554	384710.1	963	166
EM arrives - starts first informational tannoy								
Incident - starts first tannoy	527.8889	9	4751	305.9503	3256845	278666.7	963	104
Tannoy length	18.66667	15	280	4.980916	5574	348.4444	29	13
Time between tannoys	1059	6	6354	606.7217	8569442	1121481	1938	299
Incident - start of first call out from CR	10.66667	9	96	6.892024	1404	113.7778	22	3
Incident - start of first call into CR from incident	26.55556	9	239	35.82636	16615	705.1975	88	1
Incident - start of first informational call into CR from incident site	40.66667	9	366	52.99528	37352	1653.778	156	1
Incident - EM arrives								
Incident - call EM								
call EM - EM arrives								
EM arrives - EM's first response								
Incident - EM's first response	34.11111	9	307	45.46824	27011	1163.568	152	5

Pre-incident data (Onshore)

BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	4.96875	32	159	3.83098	1245	24.68848	16	1
scenario organisation team's non-informational calls	1.44	25	36	0.650641	62	2.0736	3	1
emergency management team's informational calls	7.428571	14	104	4.619595	1050	55.18367	15	2
emergency management team's non-informational calls	1.1818	22	26	0.501081	36	1.396694	3	1
scenario organisation team's calls	3.421053	57	195	3.380339	1307	11.70358	16	1
emergency management team's calls	3.61111	36	130	4.197127	1086	13.04012	15	1
non-informational calls	1.3191489	47	62	0.593676	98	1.740154	3	1
informational calls	5.7173913	46	263	4.19345	2295	32.68856	16	1
radio calls	3.494624	93	325	3.696719	2393	12.21239	16	1
delays between dependent radio calls (question - answer)	1.957746	71	139	1.477804	425	3.832771	8	0
announcements	3.190476	21	67	3.325944	435	10.179138	14	1
delays to announcements	3.307692	13	43	3.966203	331	10.94083	15	0
time to follow orders	5.5	2	11	6.363961	101	30.25	10	1
Total time to deliver a message (NB. does not include repeat attempts to call)	22.72222	18	409	6.124258	9931	516.2994	35	11

Pre-incident data (Offshore)

BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	3	1	3	(0)	9	9	3	3
scenario organisation team's non-								

informational calls								
emergency management team's informational calls								
emergency management team's non-informational calls								
scenario organisation team's calls	3	1	3	(0)	9	9	3	3
emergency management team's calls								
non-informational calls								
informational calls	3	1	3	(0)	9	9	3	3
radio calls	3	1	3	(0)	9	9	3	3
delays between dependent radio calls (question - answer)								
announcements	1	2	2	0	2	1	1	1
delays to announcements	0	1	0	(0)	0	0	0	0
time to follow orders								
Total time to deliver a message (NB. does not include repeat attempts to call)								

Post-Incident Onshore data (where rated as highly competent)

BEHAVIOUR	**MEAN**	**N**	**SUM**	**S.D**	**SUM of SQUARES**	**MEAN SQUARED**	**MAX**	**MIN**
scenario organisation team's informational calls	5.925287	174	1031	4.338315	9365	35.10903	25	1
scenario organisation team's non-informational calls	1.289308	159	205	0.543616	311	1.662316	4	1
emergency management team's informational calls	6.09434	106	646	4.90195	6460	37.14098	26	1
emergency management team's non-informational calls	1.337209	172	230	0.886685	442	1.788129	8	1
scenario organisation team's calls	3.711712	333	1236	3.914879	9676	13.7768	25	1
emergency management team's calls	3.151079	278	876	3.866759	6902	9.9293	26	1
non-informational	1.314199	331	435	0.7412	753	1.72712	8	1

calls				59				
informational calls	5.989286	280	1677	4.551957	15825	35.87154	26	1
radio calls	3.456628	611	2112	3.899895	16578	11.94828	26	1
delays between dependent radio calls (question - answer)	1.786207	435	777	1.924327	2995	3.190535	15	0
announcements	4.222386	679	2867	6.231453	38433	17.82854	50	1
delays to announcements	0.830816	331	275	1.584514	1057	0.690255	14	0
Total time to deliver a message (NB. does not include repeat attempts to call)	24.5431	116	2847	12.58114	88077	602.3639	70	7
Time from standby to calling back	34.91667	12	419	33.76512	27171	1219.174	109	1
Totally unintelligible calls	4.315789	19	82	3.972861	638	18.62604	14	1
Partially intelligible calls	7.610169	59	449	3.823777	4265	57.91468	20	2
Time left between failed attempts to call in/out	15.26667	15	229	17.76219	7913	233.0711	60	2
Delays to answer phone	3.83871	31	119	3.984108	933	14.73569	15	1
Time at which phone stopped ringing (not answered)	15	1	15	N/A	225	225	15	15
Phone call length	25.21429	28	706	13.01952	22378	635.7602	61	9
Information known in EMT-SO	84.42857	14	1182	98.06255	224806	7128.184	390	17
Information known in SO - EMT	31.775	40	1271	19.94414	55899	1009.651	120	8
Time to initiate following orders (control panel work)	11.125	8	89	12.22921	2037	123.7656	31	1
Incident - control panels and instruments respond								
Control panel response - operator response								
Time to initiate following orders (calling others outside/moving)	32.85	20	657	40.55182	52827	1079.123	154	3

Delays from being given information externally - drawing the attention of the group to it	18.70588	34	636	27.50816	36868	349.91	136	2
Time out announced - started	28.69231	13	373	15.78176	13691	823.2485	70	12
Time out length	83	13	1079	23.14447	95985	6889	132	42
Delay between time outs	367.1	10	3671	173.0597	1617171	134762.4	794	174
Incident - first time out starts	283.6667	3	851	96.57294	260053	80466.78	378	185
CCR aware of incident - first time out starts	267	3	801	94.27089	231641	71289	349	164
EM arrives - first time out starts								
Incident - start first informational tannoy	409	3	1227	230.6881	608277	167281	625	166
EM arrives - starts first informational tannoy								
Incident - starts first tannoy	304	3	912	135.1	313752	92416	436	166
Tannoy length	19.33333	6	116	6.15359	2432	373.7778	29	13
Time between tannoys	1239.667	3	3719	845.9458	6041569	1536773	1938	299
Incident - start of first call out from CR	17	3	51	5	917	289	22	12
Incident - start of first call into CR from incident	14.66667	3	44	18.71719	1346	215.1111	36	1
Incident - start of first informational call into CR from incident site	26	3	78	29.8161	3806	676	59	1
Incident - EM arrives								
Incident - call EM								
call EM - EM arrives								
EM arrives - EM's first response								
Incident - EM's first response	27.33333	3	82	12.05543	2532	747.1111	40	16

Post-Incident Onshore data (where rated as competent)

BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	6.641975	162	1076	4.126294	9888	44.11584	18	1
scenario organisation team's non-informational calls	1.5	202	303	0.761316	571	2.25	4	1
emergency management team's informational calls	5.326316	95	506	3.071634	3582	28.36964	15	1
emergency management team's non-informational calls	1.28125	192	246	0.573464	378	1.641602	4	1
scenario organisation team's calls	3.788462	364	1379	3.797459	10459	14.35244	18	1
emergency management team's calls	2.620209	287	752	2.637547	3960	6.865496	15	1
non-informational calls	1.393401	394	549	0.684289	949	1.941566	4	1
informational calls	6.155642	257	1582	3.818016	13470	37.89193	18	1
radio calls	3.273425	651	2131	3.383974	14419	10.71531	18	1
delays between dependent radio calls (question - answer)	1.601322	454	727	1.380117	2027	2.564231	12	0
announcements	4.625	264	1221	7.703605	21255	21.39063	55	1
delays to announcements	1.009346	107	108	1.456899	334	1.018779	8	0
Total time to deliver a message (NB. does not include repeat attempts to call)	23.36937	111	2594	10.31057	72314	546.1274	70	6
Time from standby to calling back	13.66667	6	82	16.45195	2474	186.7778	46	2
Totally unintelligible calls	3.454545	11	38	2.504541	194	11.93388	8	1
Partially intelligible calls	7.217391	23	166	4.562261	1656	52.09074	18	2
Time left between failed attempts to call in/out	9.5	26	247	5.756735	3175	90.25	27	4
Delays to answer phone	4.142857	35	145	3.70328	1067	17.16327	15	1
Time at which phone stopped ringing (not	24	4	96	8.485281	2520	576	32	14

answered)								
Phone call length	21.73333	15	326	11.43595	8916	472.3378	46	7
Information known in EMT-SO	57.40909	22	1263	63.73357	157809	3295.804	295	4
Information known in SO - EMT	40.625	32	1300	31.74266	84048	1650.391	159	9
Time to initiate following orders (control panel work)	5	3	15	5.196152	129	25	11	2
Incident - control panels and instruments respond								
Control panel response - operator response								
Time to initiate following orders (calling others outside/moving)	22.63636	11	249	24.29927	11541	512.405	66	0
Delays from being given information externally - drawing the attention of the group to it	31.6	20	632	47.60296	63026	998.56	216	3
Time out announced - started	29.81818	11	328	11.89805	11196	889.124	61	18
Time out length	61.18182	11	673	17.29056	44165	3743.215	83	28
Delay between time outs	551.875	8	4415	413.1214	3631213	304566	1443	83
Incident - first time out starts	264	3	792	146.932	252266	69696	404	111
CCR aware of incident - first time out starts	290	3	870	185.8413	321374	84100	482	111
EM arrives - first time out starts								
Incident - start first informational tannoy	730.3333	3	2191	222.7674	1699411	533386.8	963	519
EM arrives - starts first informational tannoy								
Incident - starts first tannoy	730.3333	3	2191	222.7674	1699411	533386.8	963	519
Tannoy length	17.2	5	86	2.588436	1506	295.84	20	14
Time between tannoys	721.5	2	1443	256.6798	1107009	520562.3	903	540

Incident - start of first call out from CR	10	3	30	7	398	100	17	3
Incident - start of first call into CR from incident	34.33333	3	103	44.60194	7515	1178.778	85	1
Incident - start of first informational call into CR from incident site	62.33333	3	187	81.79446	25037	3885.444	156	5
Incident - EM arrives	-							
Incident - call EM	-							
call EM - EM arrives	-							
EM arrives - EM's first response	-							
Incident - EM's first response	56	3	168	83.19255	23250	3136	152	5

Post-Incident Onshore data (where rated as notable shortfalls)

BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	7.574468	94	712	4.871443	7600	57.37257	25	1
scenario organisation team's non-informational calls	1.443396	106	153	0.805696	289	2.083393	6	1
emergency management team's informational calls	5.376812	69	371	3.464532	2811	28.9101	21	1
emergency management team's non-informational calls	1.246154	130	162	0.635653	254	1.552899	6	1
scenario organisation team's calls	4.325	200	865	4.565478	7889	18.70563	25	1
emergency management team's calls	2.678392	199	533	2.875723	3065	7.173783	21	1
non-informational calls	1.334746	236	315	0.722157	543	1.781546	6	1
informational calls	6.644172	163	1083	4.4551	10411	44.14502	25	1
radio calls	3.503759	399	1398	3.900697	10954	12.27633	25	1
delays between dependent radio calls (question - answer)	2.010169	295	593	1.781394	2125	4.040781	10	0
announcements	5.483871	124	680	9.888388	15756	30.07284	59	1

delays to announcements	1.25	44	55	1.432594	157	1.5625	5	0
Total time to deliver a message (NB. does not include repeat attempts to call)	24.77333	75	1858	14.66156	61936	613.718	104	9
Time from standby to calling back	56.54545	11	622	126.2952	194676	3197.388	436	4
Totally unintelligible calls	5.727273	11	63	6.018154	723	32.80165	22	1
Partially intelligible calls	7.684211	19	146	3.757254	1376	59.04709	14	1
Time left between failed attempts to call in/out	6.142857	7	43	2.115701	291	37.73469	8	2
Delays to answer phone	5.619048	21	118	11.01125	3088	31.5737	46	1
Time at which phone stopped ringing (not answered)								
Phone call length	23	1	23	N/A	529	529	23	23
Information known in EMT-SO	63.5	8	508	70.18954	66744	4032.25	182	6
Information known in SO - EMT	51.45455	11	566	42.74895	47398	2647.57	140	14
Time to initiate following orders (control panel work)	16.75	4	67	21.40677	2497	280.5625	48	0
Incident - control panels and instruments respond								
Control panel response - operator response	0	1	0	N/A	0	0	0	0
Time to initiate following orders (calling others outside/moving)	17.91667	12	215	43.57117	24735	321.0069	148	1
Delays from being given information externally - drawing the attention of the group to it	34.81818	11	383	51.94193	40315	1212.306	135	1
Time out announced - started	34.375	8	275	15.96369	11237	1181.641	49	0
Time out length	56.5	8	452	16.70757	27492	3192.25	89	35
Delay between time outs	424	6	2544	116.6242	1146662	179776	547	222

Incident - first time out starts	189	2	378	21.2132	71892	35721	204	174
CCR aware of incident - first time out starts	125.5	2	251	41.7193	33241	15750.25	155	96
EM arrives - first time out starts								
Incident - start first informational tannoy	915	1	915	N/A	837225	837225	915	915
EM arrives - starts first informational tannoy								
Incident - starts first tannoy	509.5	2	1019	573.4636	848041	259590.3	915	104
Tannoy length		3	64					
Time between tannoys	1192	1	1192					
Incident - start of first call out from CR	3.5	2	7	0.707107	25	12.25	4	3
Incident - start of first call into CR from incident	44.5	2	89	61.51829	7745	1980.25	88	1
Incident - start of first informational call into CR from incident site	49	2	98	60.81118	8500	2401	92	6
Incident - EM arrives								
Incident - call EM								
call EM - EM arrives								
EM arrives - EM's first response								
Incident - EM's first response	23.5	2	47	4.949747	1129	552.25	27	20

Post-Incident Onshore and Offshore Data (E, C, L & P)

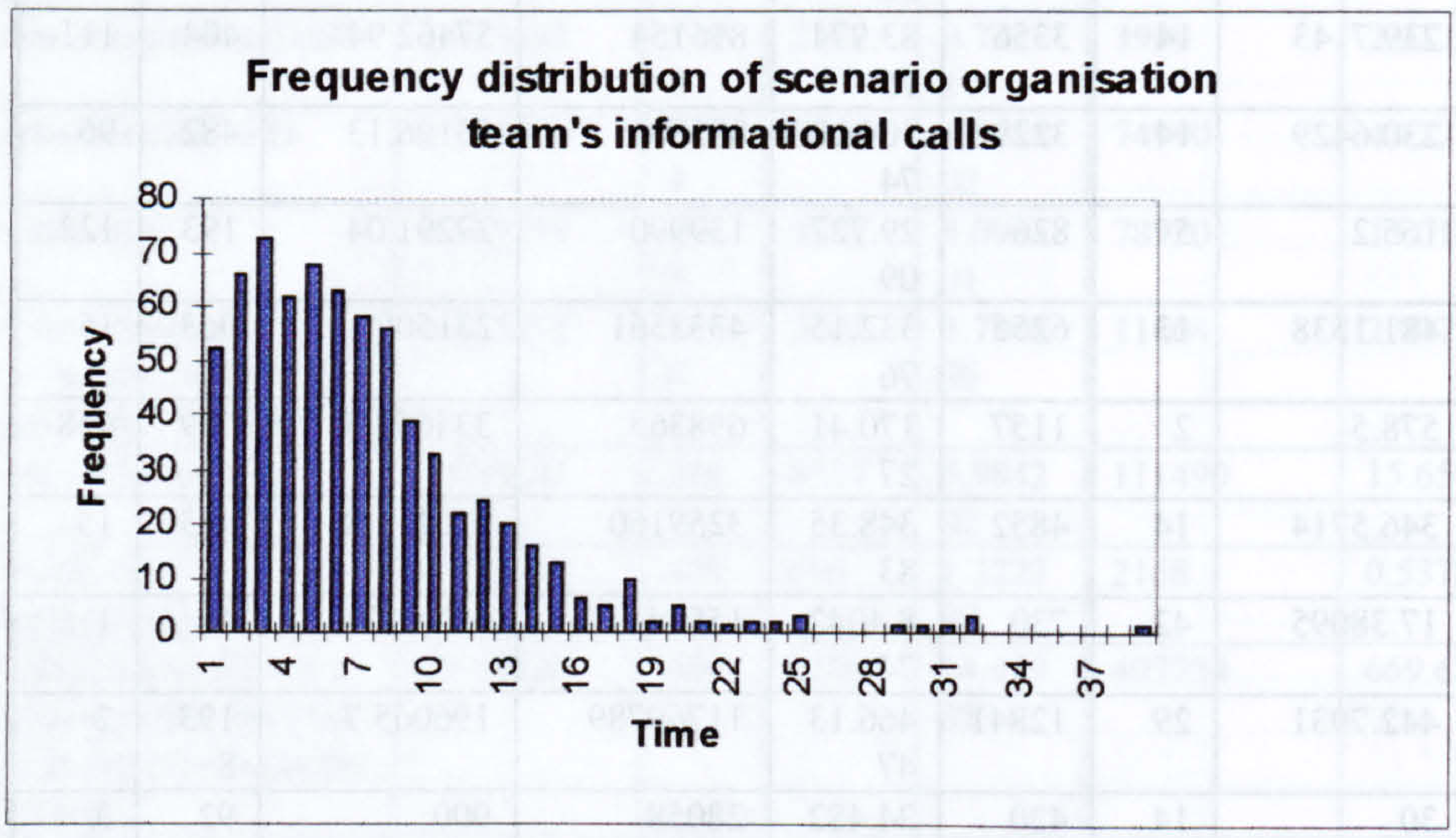
(as shown in Appendix 11)

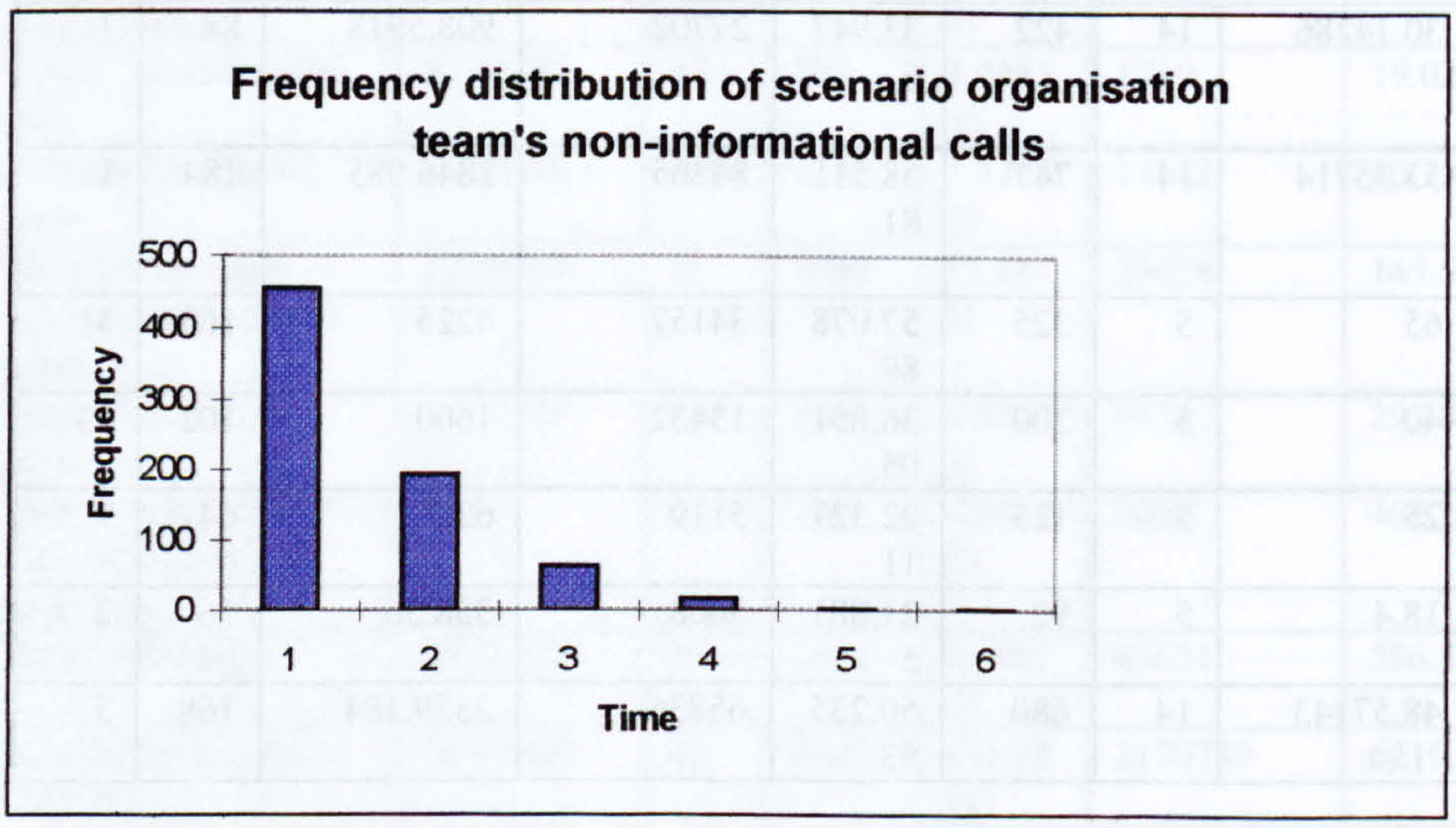
BEHAVIOUR	MEAN	N	SUM	S.D	SUM of SQUARES	MEAN SQUARED	MAX	MIN
scenario organisation team's informational calls	7.140845	710	5070	5.292824	56066	50.99167	39	1
scenario organisation team's non-informational calls	1.52459	732	1116	0.795471	2164	2.324375	6	1
emergency management team's informational calls	5.603865	414	2320	3.787015	18924	31.4033	26	1
emergency management team's non-informational calls	1.320707	792	1046	0.697241	1766	1.744267	8	1
scenario organisation	4.289875	144	6186	4.6897	58230	18.40303	39	1

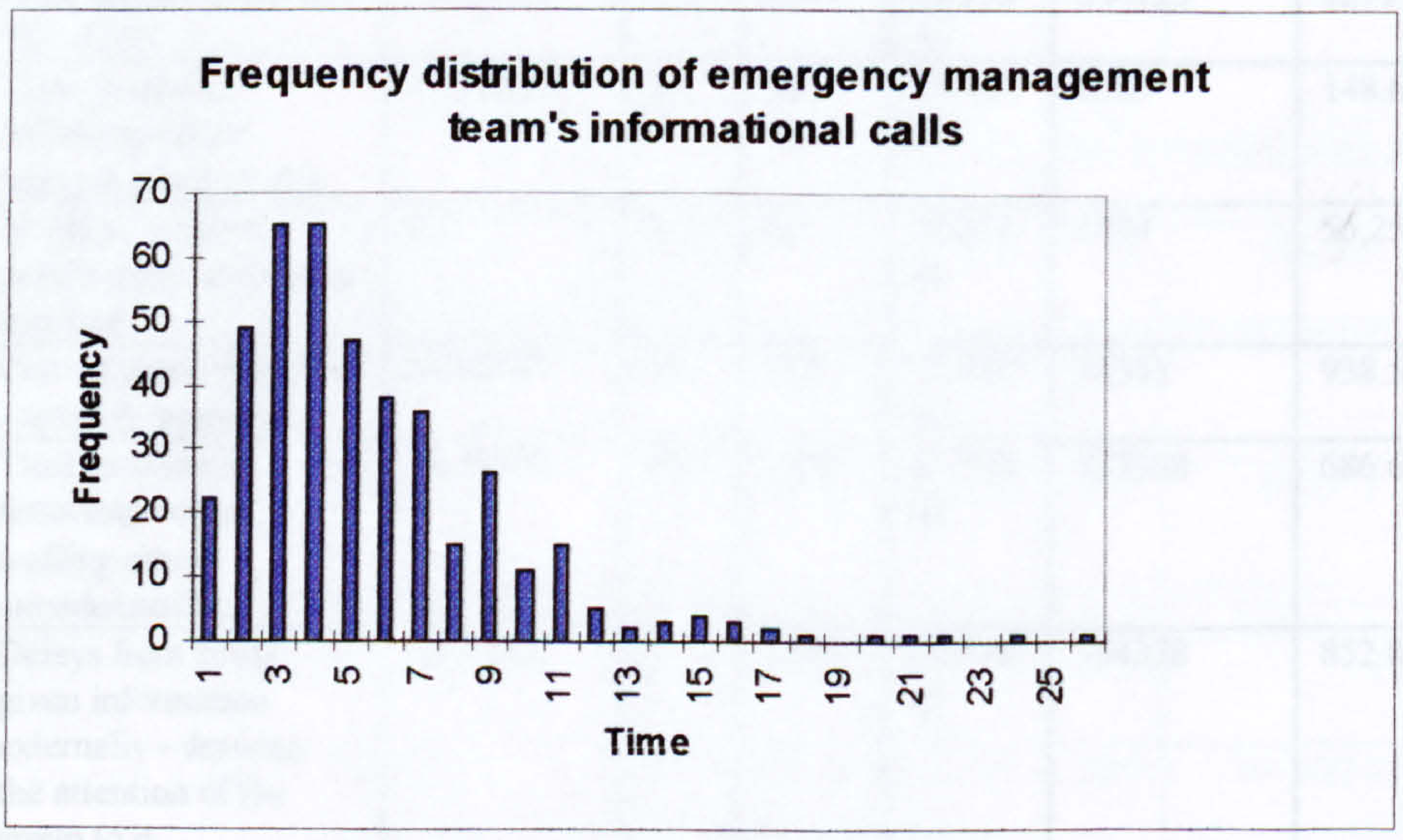
team's calls		2		38				
emergency management team's calls	2.791045	1206	3366	3.061655	20690	7.789931	26	1
non-informational calls	1.418635	1524	2162	0.752719	3930	2.012526	8	1
informational calls	6.574733	1124	7390	4.848802	74990	43.22712	39	1
radio calls	3.607251	2648	9552	4.098501	78920	13.01226	39	1
delays between dependent radio calls (question - answer)	1.705252	1866	3182	1.790336	11404	2.907884	21	0
announcements	3.956622	2167	8574	5.984202	111490	15.65486	59	1
delays to announcements	0.733404	949	696	1.322298	2168	0.537881	14	0
Total time to deliver a message (NB. does not include repeat attempts to call)	25.87826	460	11904	14.43935	403754	669.6844	115	6
Time from standby to calling back	36.68421	38	1394	70.55881	235344	1345.731	436	1
Totally unintelligible calls	4.361702	47	205	4.234565	1719	19.02445	22	1
Partially intelligible calls	8.144928	138	1124	5.374379	13112	66.33984	39	1
Time left between failed attempts to call in/out	12.06593	91	1098	13.24118	29028	145.5868	83	1
Delays to answer phone	5.411765	136	736	6.639356	9934	29.2872	46	0
Time at which phone stopped ringing (not answered)	21.5	6	129	7.687652	3069	462.25	32	14
Phone call length	24.42373	59	1441	13.40767	45621	596.5185	64	2
Information known in EMT-SO	78.86585	82	6467	143.1874	2170739	6219.823	1022	4
Information known in SO - EMT	35.76571	175	6259	26.29053	344125	1279.186	159	1
Time to initiate following orders (control panel work)	12.19231	26	317	13.44625	8385	148.6524	48	0
Incident - control panels and instruments respond	7.5	8	60	12.67168	1574	56.25	29	0
Control panel response - operator response	30.63636	11	337	37.44135	24343	938.5868	121	0
Time to initiate following orders (calling others outside/moving)	26.20455	88	2306	33.38392	157388	686.6782	154	0
Delays from being given information externally - drawing the attention of the group to it	29.20325	123	3592	60.69812	554378	852.8299	467	1
Time out announced - started	30	53	1590	13.87305	57708	900	70	0

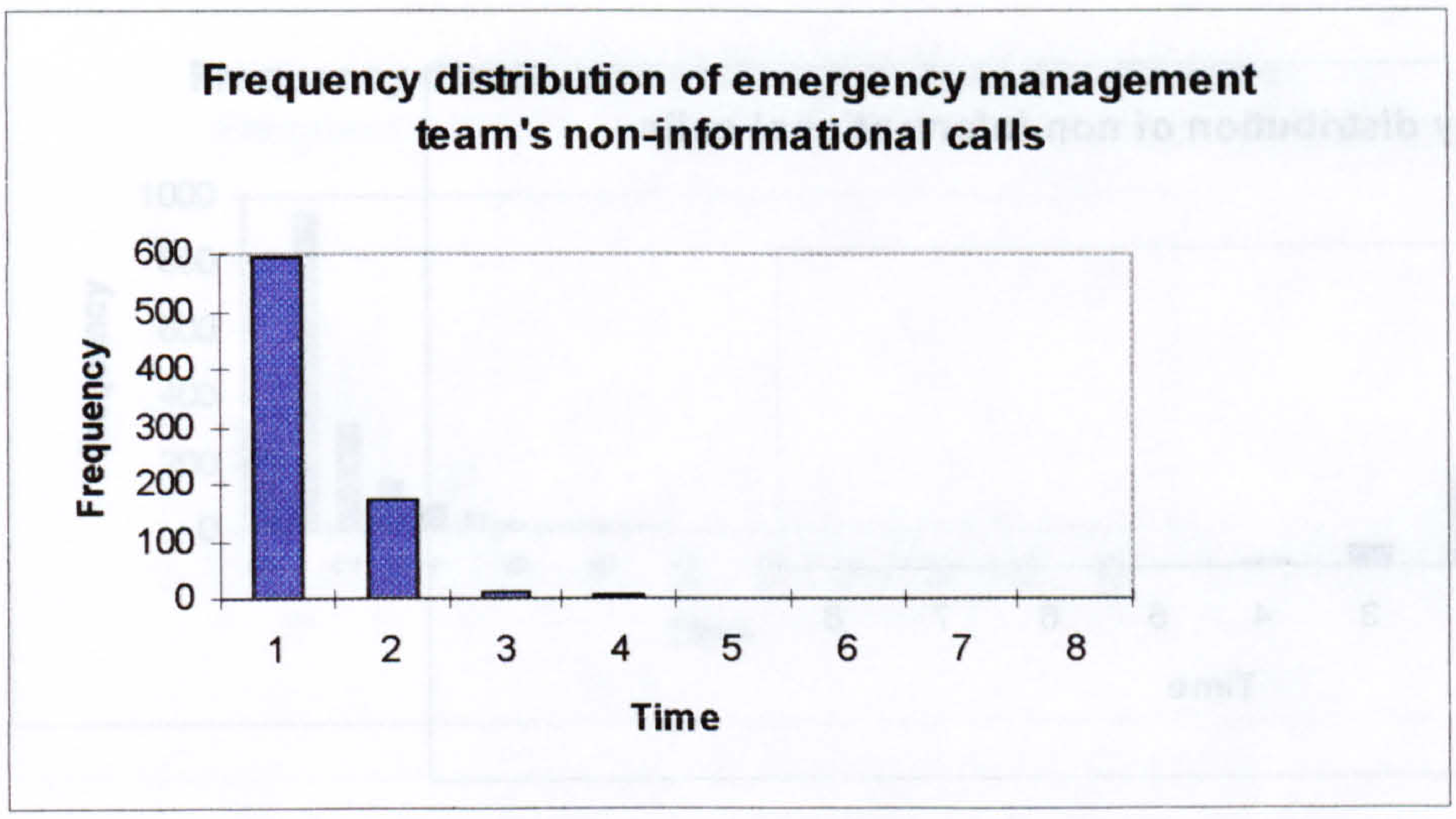
Time out length	61.69643	56	3455	26.38589	251453	3806.449	132	20
Delay between time outs	391.381	42	16438	233.6138	8671112	153179	1443	83
Incident - first time out starts	239.7143	14	3356	83.97475	896154	57462.94	404	111
CCR aware of incident - first time out starts	230.6429	14	3229	104.1874	885861	53196.13	482	96
EM arrives - first time out starts	165.2	5	826	29.72709	139990	27291.04	193	122
Incident - start first informational tannoy	481.1538	13	6255	332.1576	4333561	231509	963	15
EM arrives - starts first informational tannoy	578.5	2	1157	170.4127	698365	334662.3	699	458
Incident - starts first tannoy	346.5714	14	4852	348.3583	3259160	120111.8	963	15
Tannoy length	17.38095	42	730	8.404274	15584	302.0975	40	1
Time between tannoys	442.7931	29	12841	466.1347	11769789	196065.7	1938	2
Incident - start of first call out from CR	30	14	420	34.48299	28058	900	92	3
Incident - start of first call into CR from incident	30.14286	14	422	33.9476	27702	908.5918	88	1
Incident - start of first informational call into CR from incident site	53.35714	14	747	58.51181	84365	2846.985	184	1
Incident - EM arrives	65	5	325	57.07889	34157	4225	166	31
Incident - call EM	40	5	200	36.85105	13432	1600	102	13
call EM - EM arrives	25	5	125	22.32711	5119	625	64	7
EM arrives - EM's first response	18.4	5	92	21.8815	3608	338.56	56	2
Incident - EM's first response	48.57143	14	680	50.23593	65836	2359.184	168	5

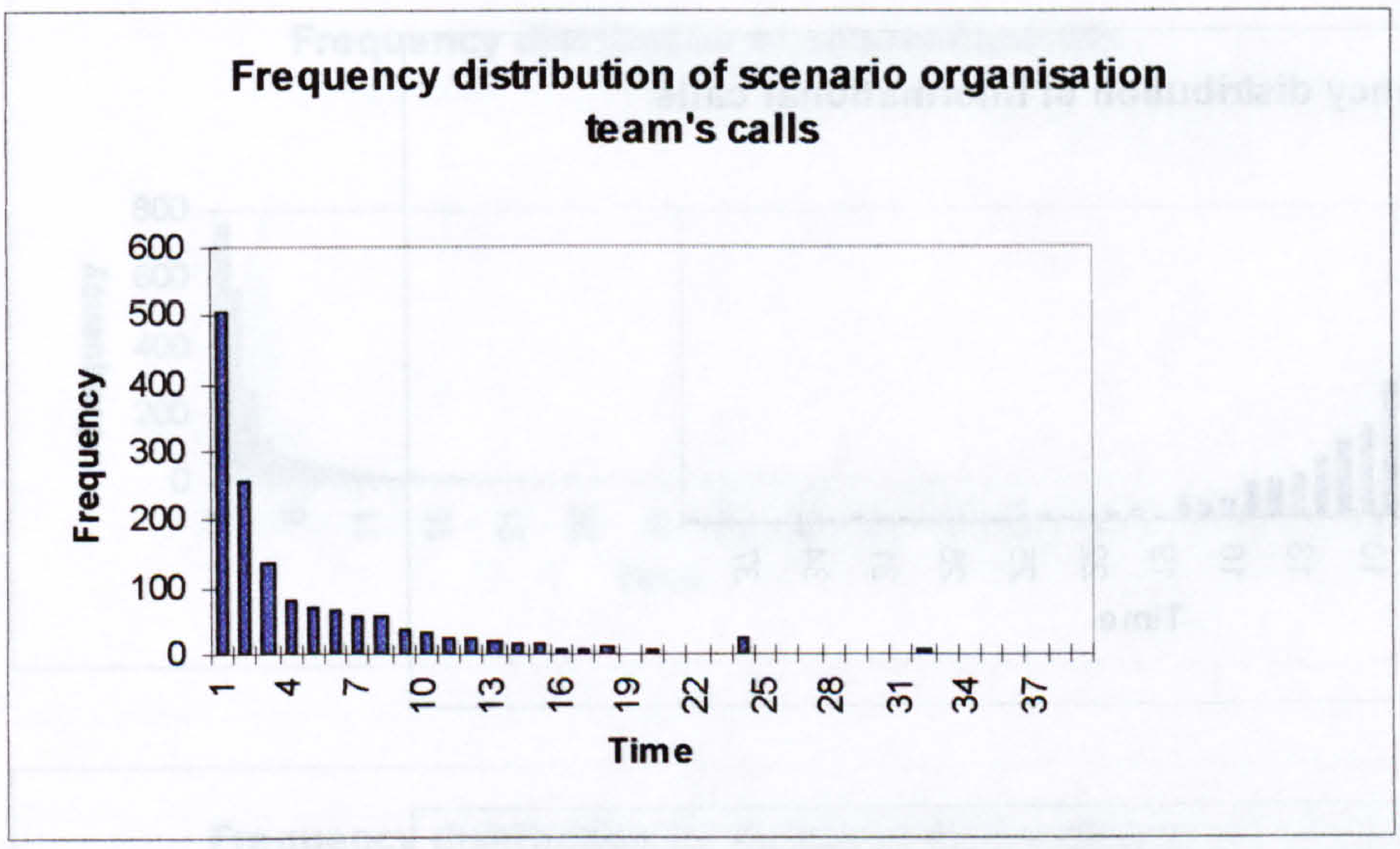
APPENDIX 11: FREQUENCY DISTRIBUTIONS OF PERFORMANCE PARAMETERS

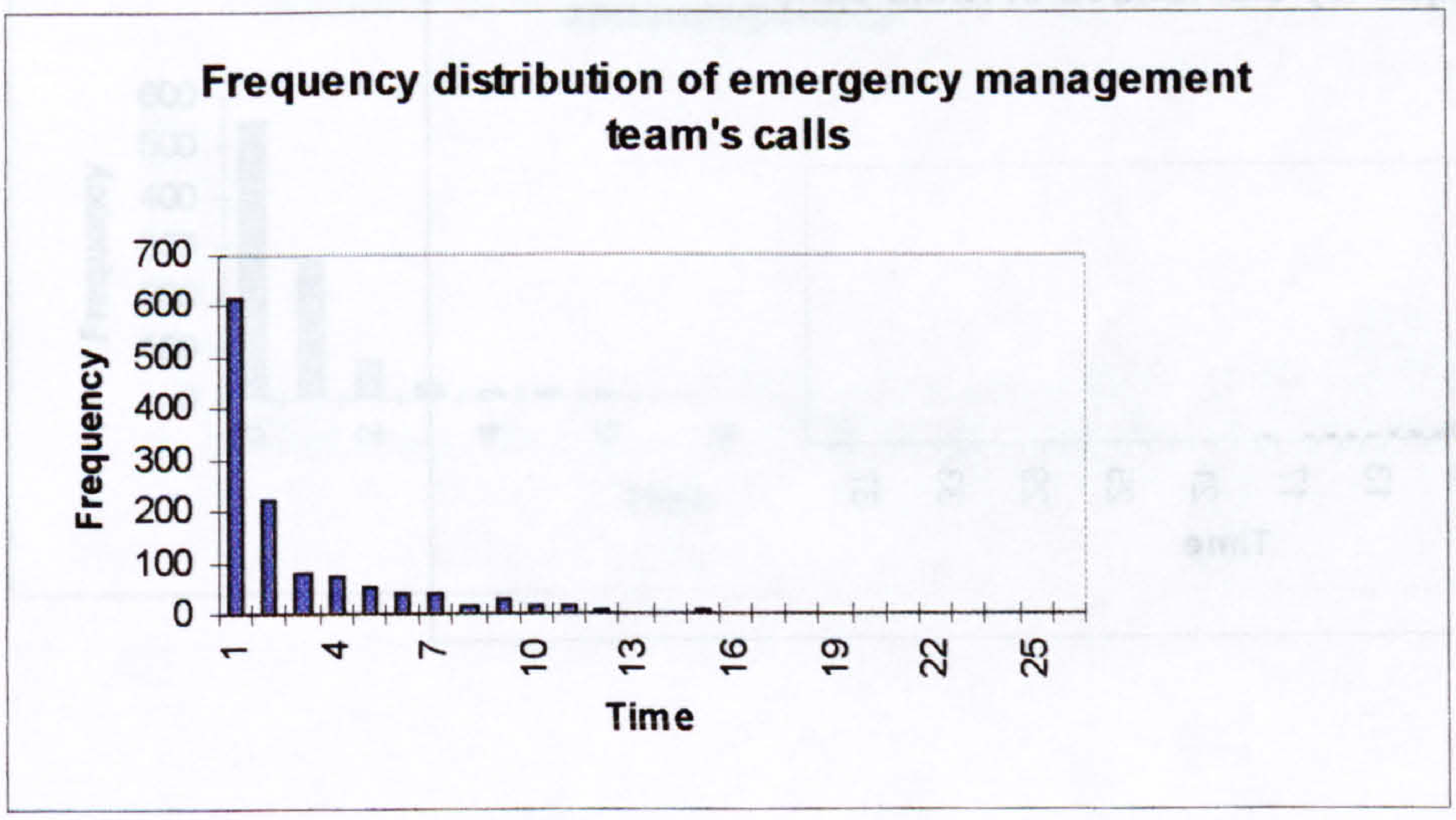


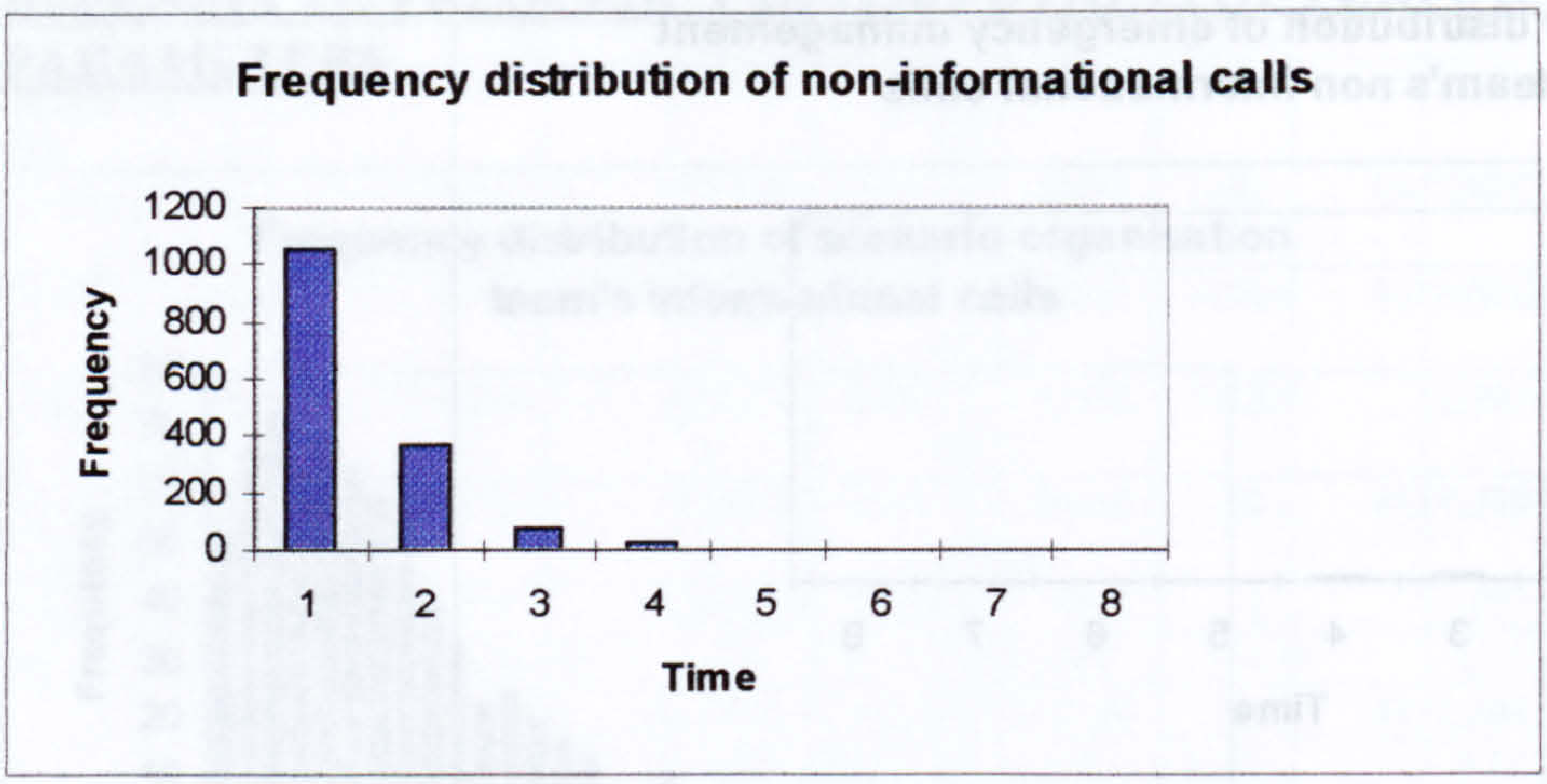


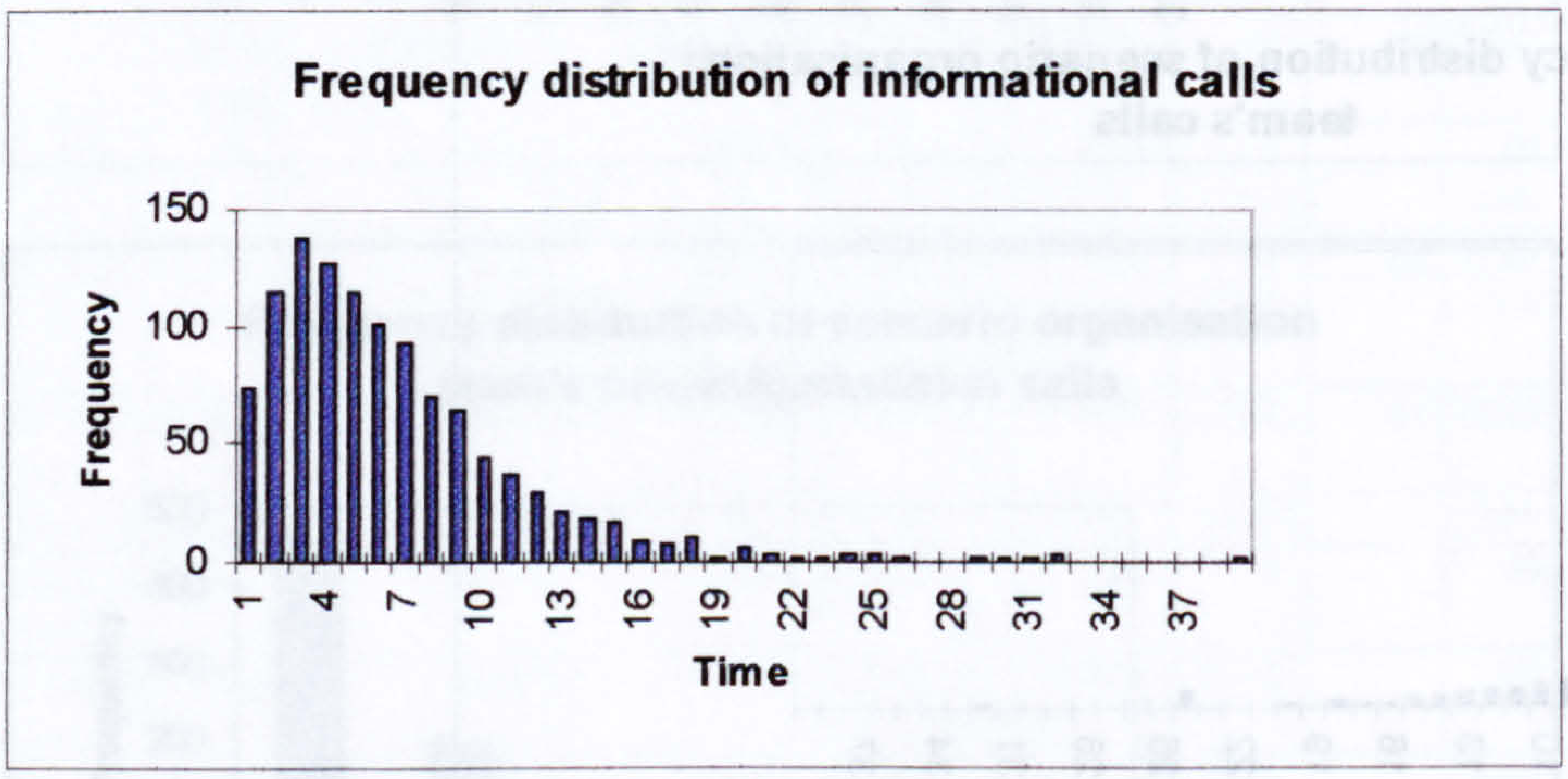


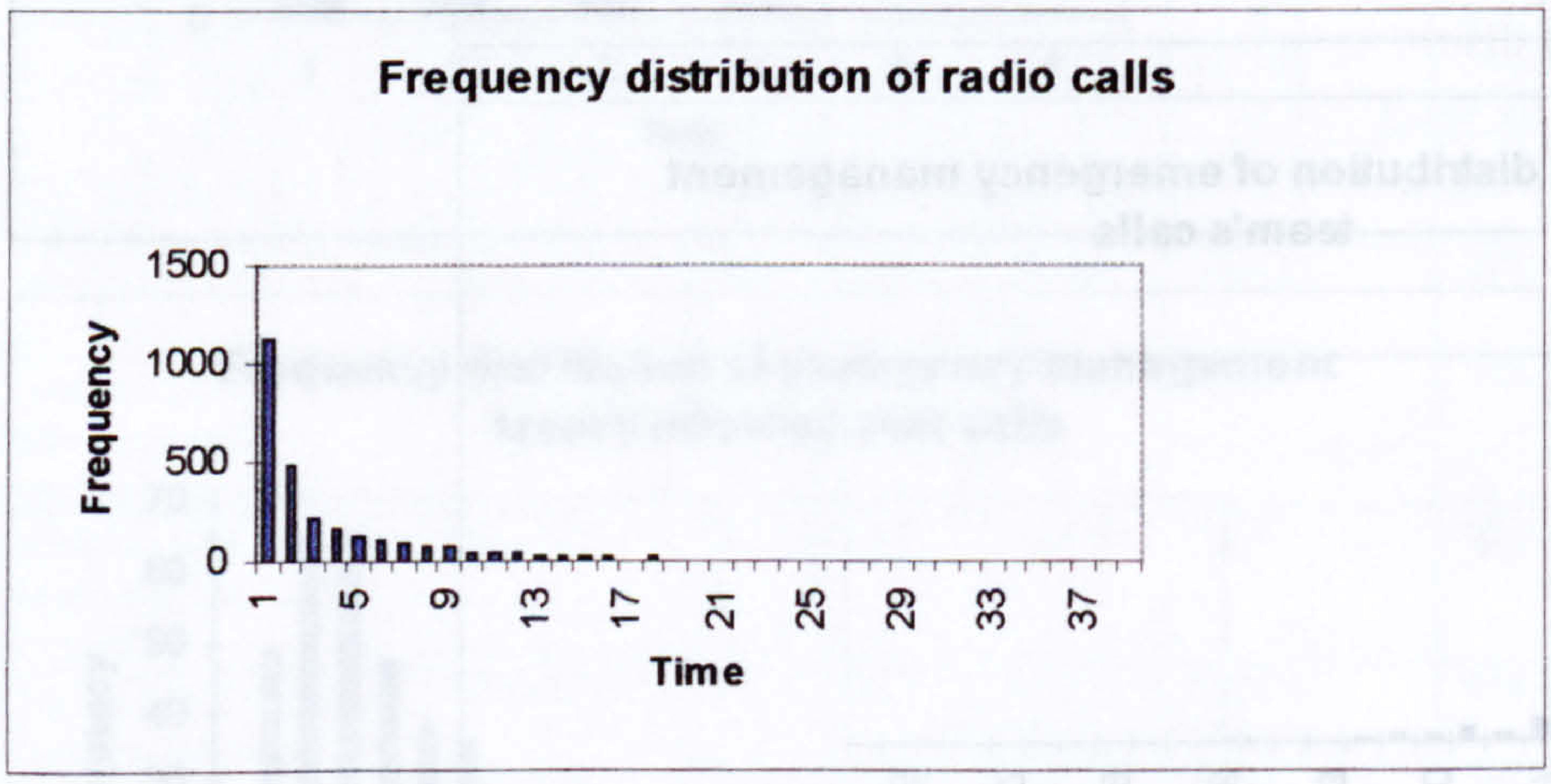

Frequency distribution of emergency management team's non-informational calls

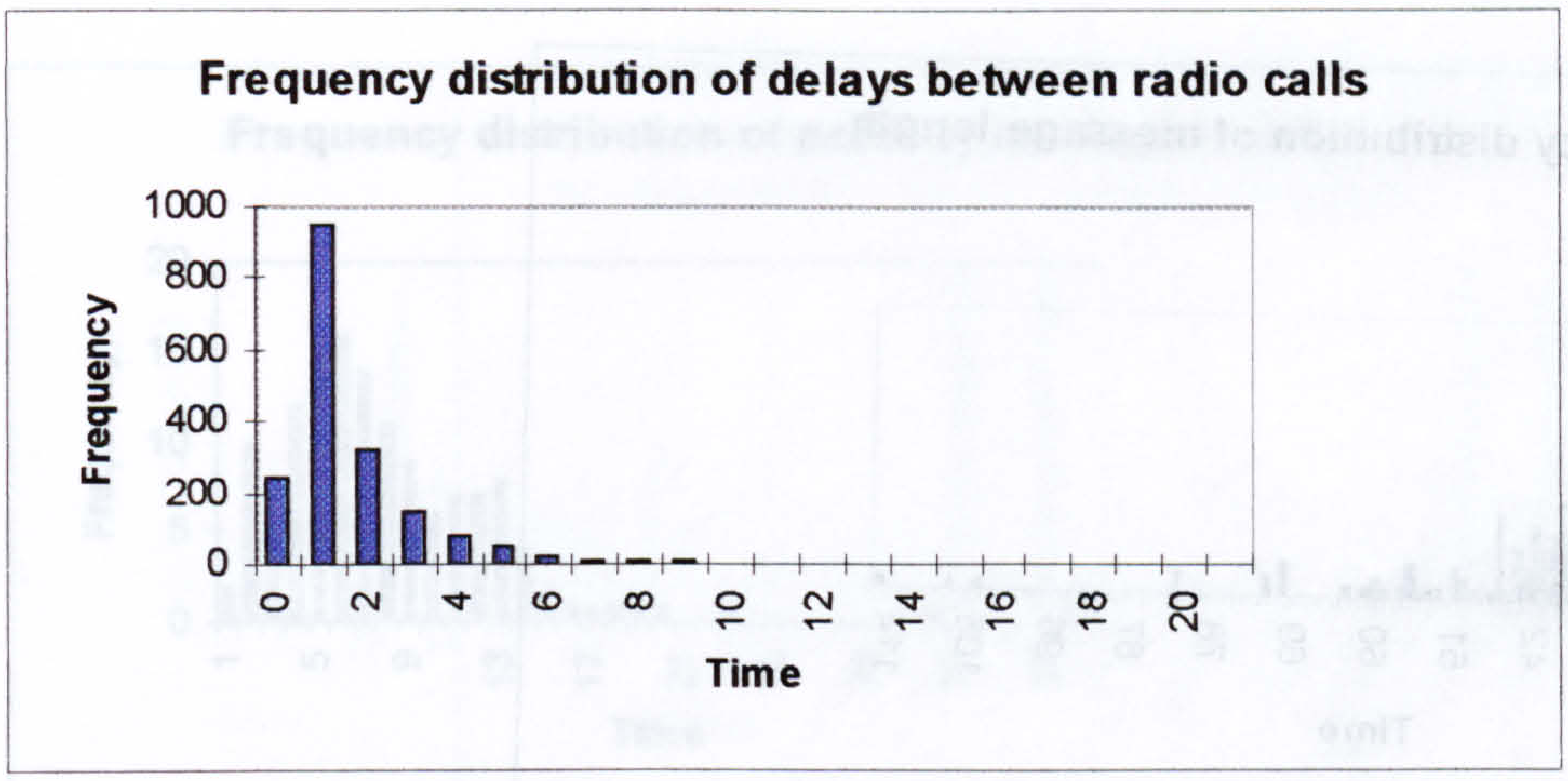

Frequency distribution of scenario organisation team's calls

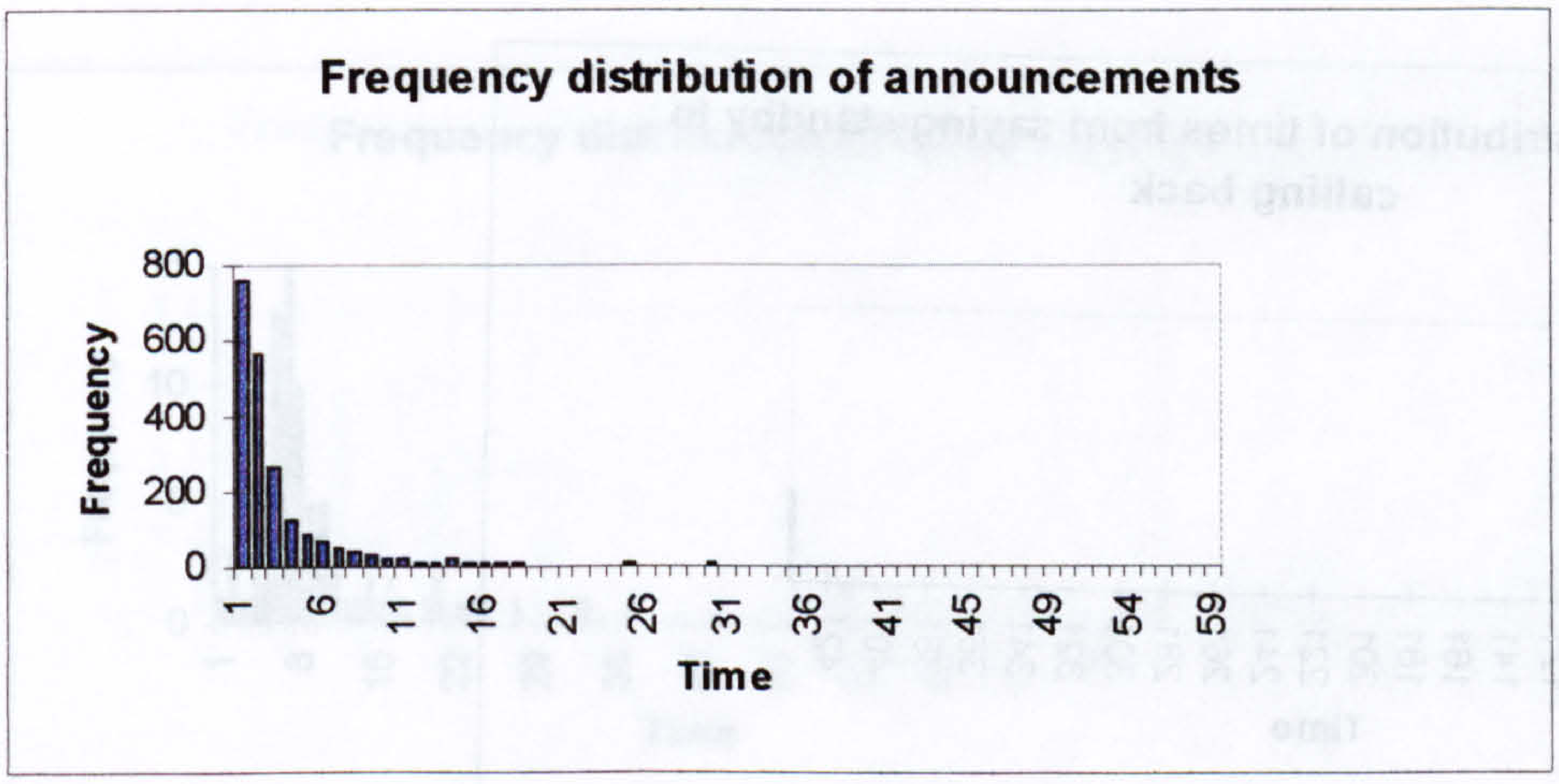

Frequency distribution of emergency management team's calls

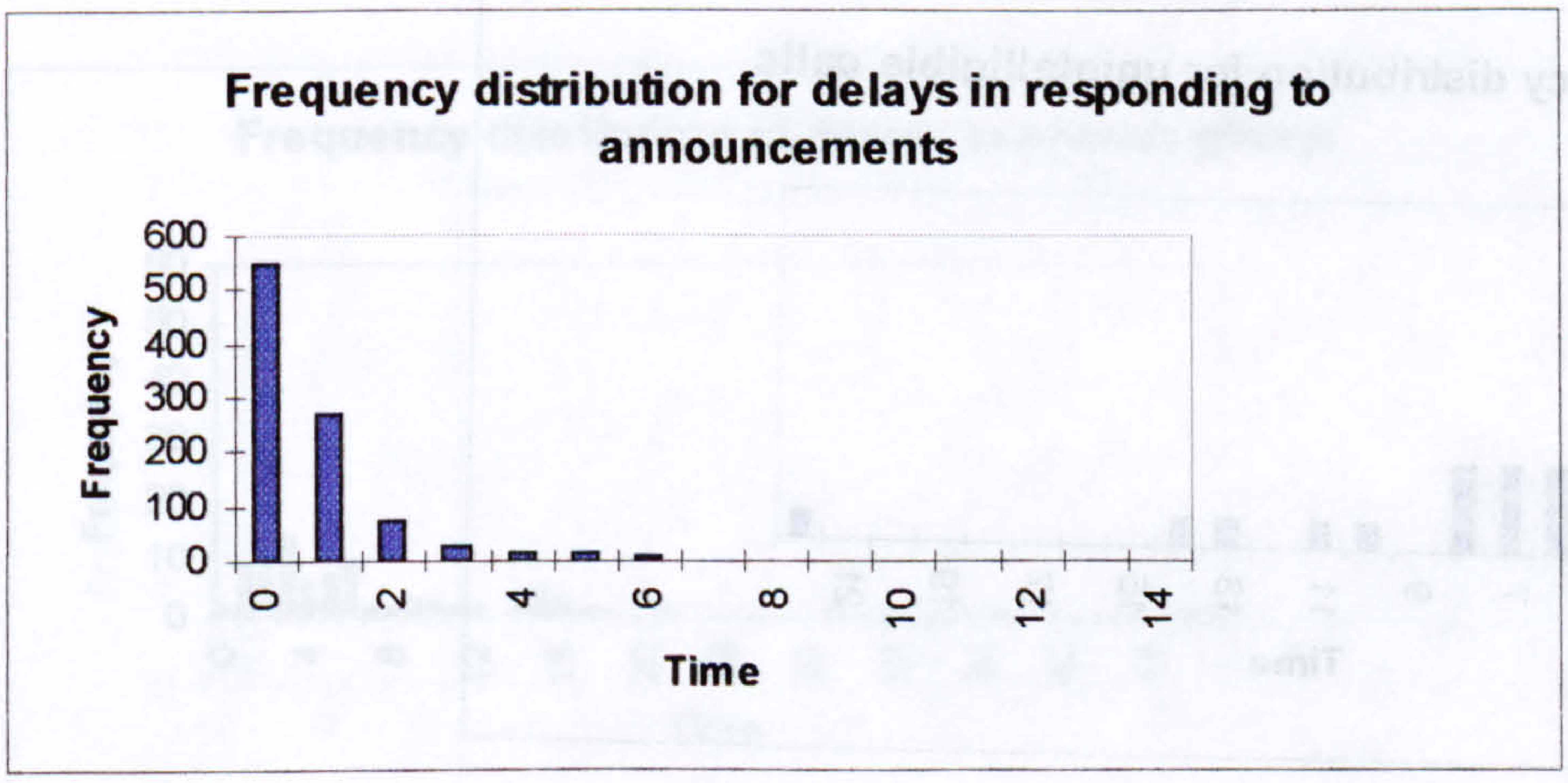

Frequency distribution of non-informational calls

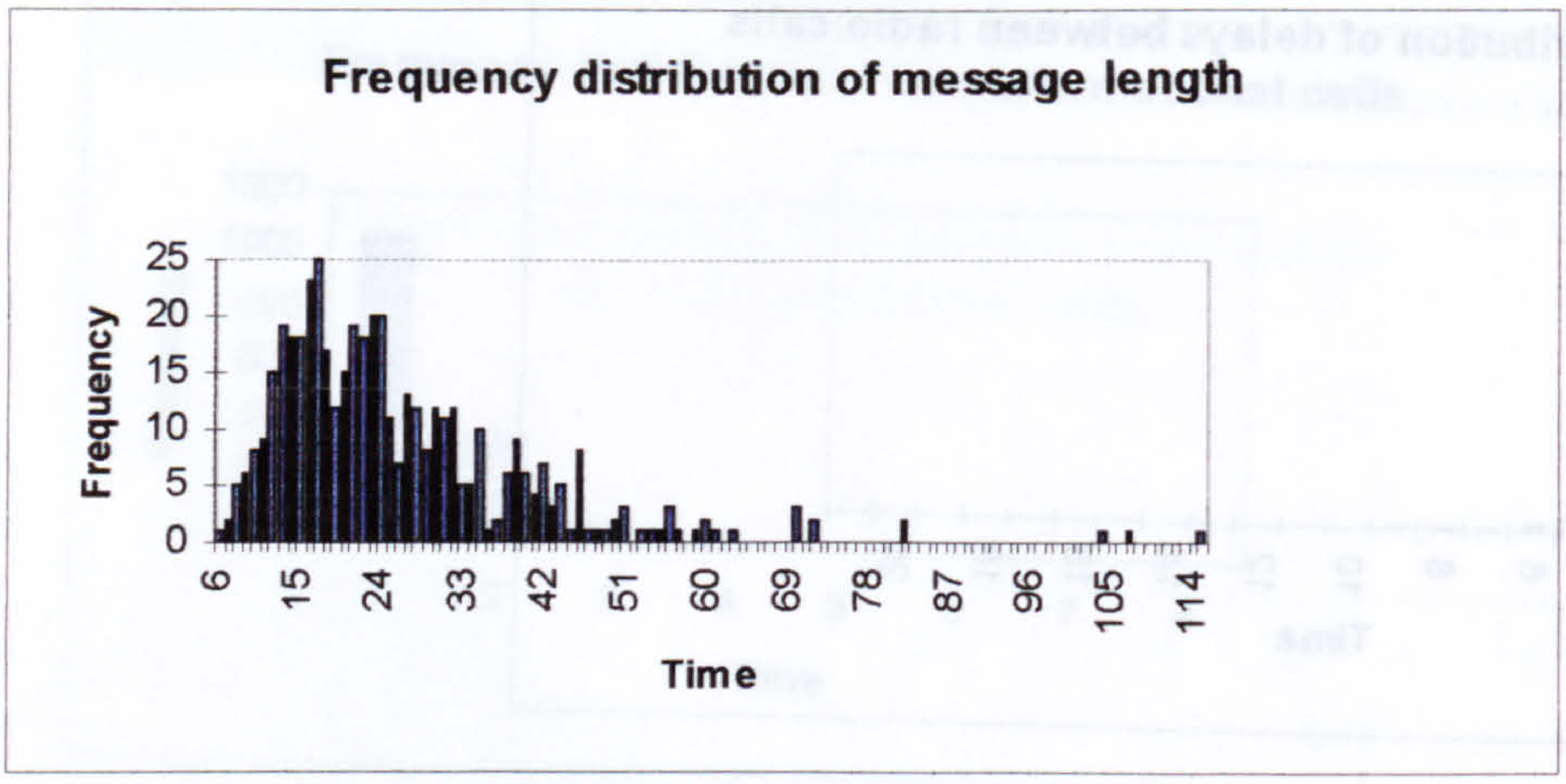

Frequency distribution of informational calls

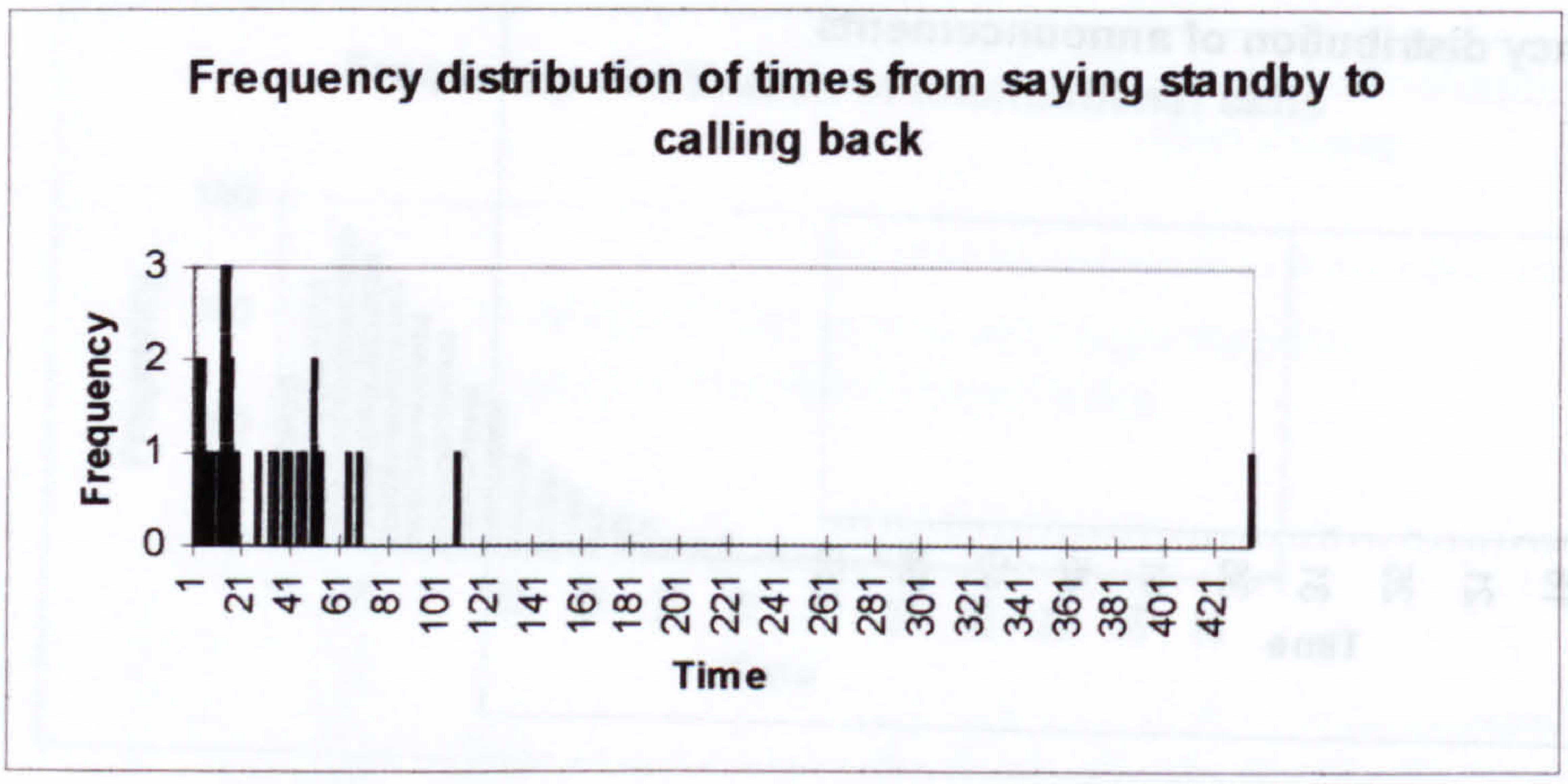

Frequency distribution of radio calls

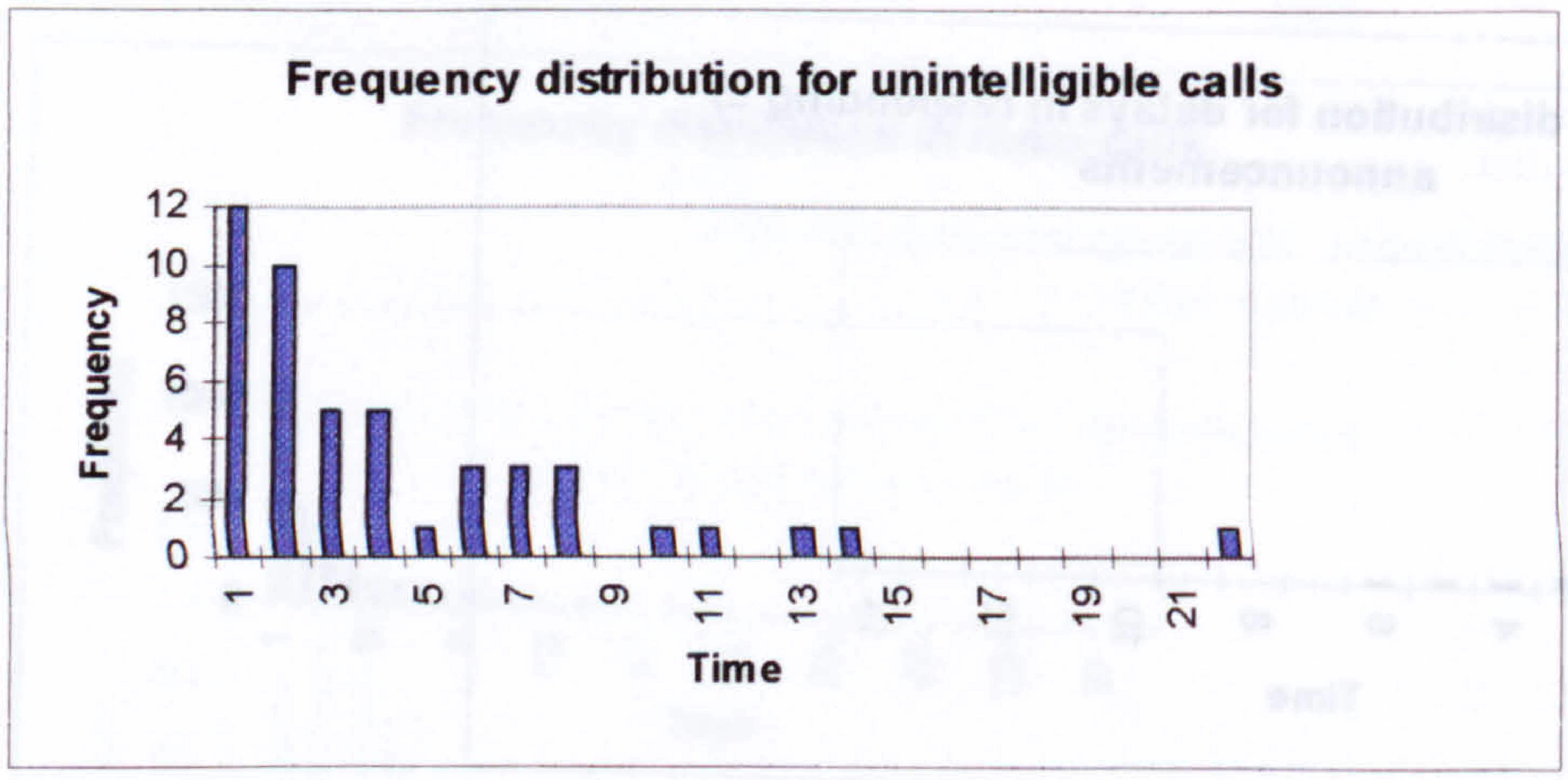

Frequency distribution of delays between radio calls

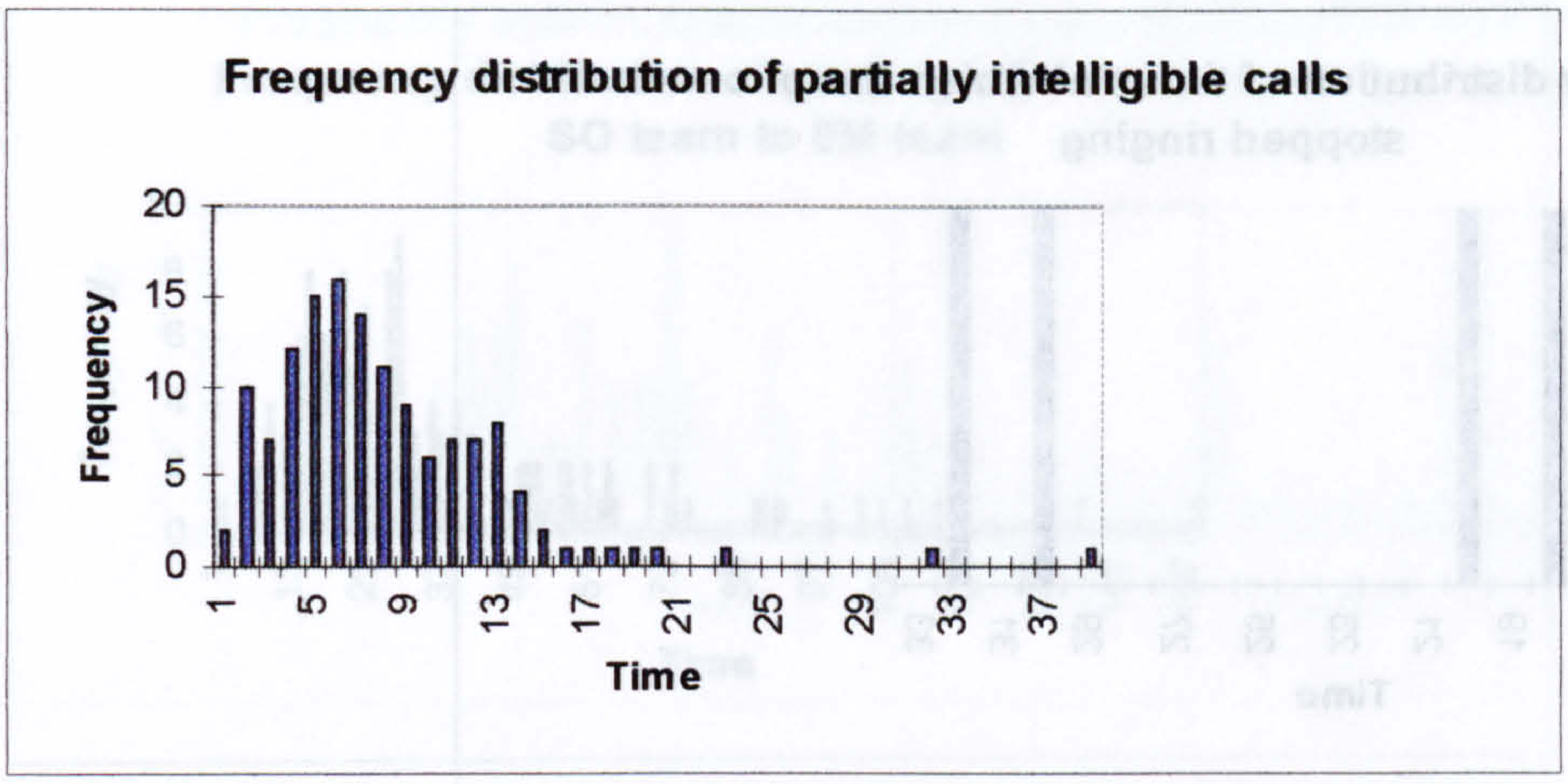

Frequency distribution of announcements

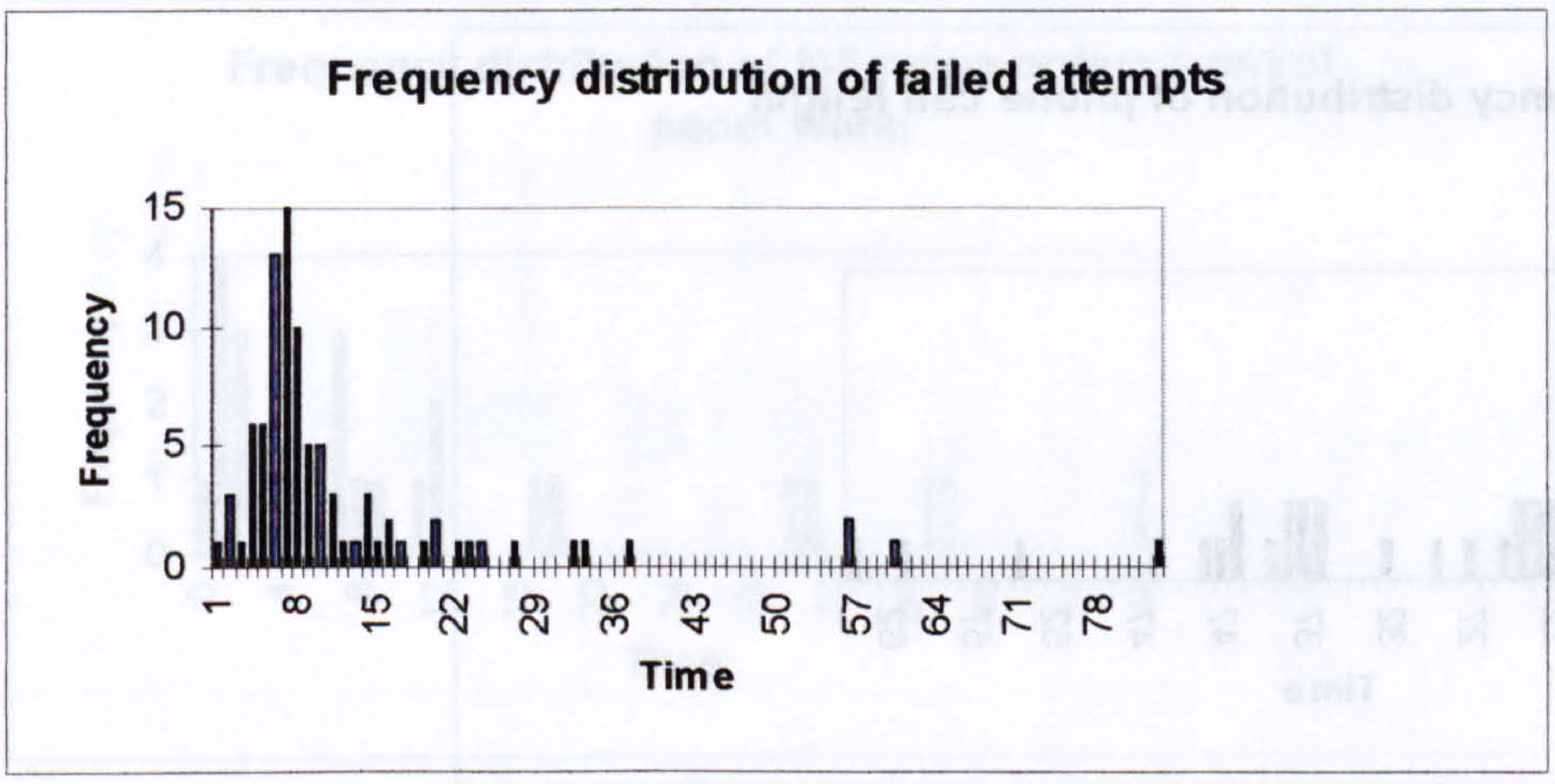

Frequency distribution for delays in responding to announcements

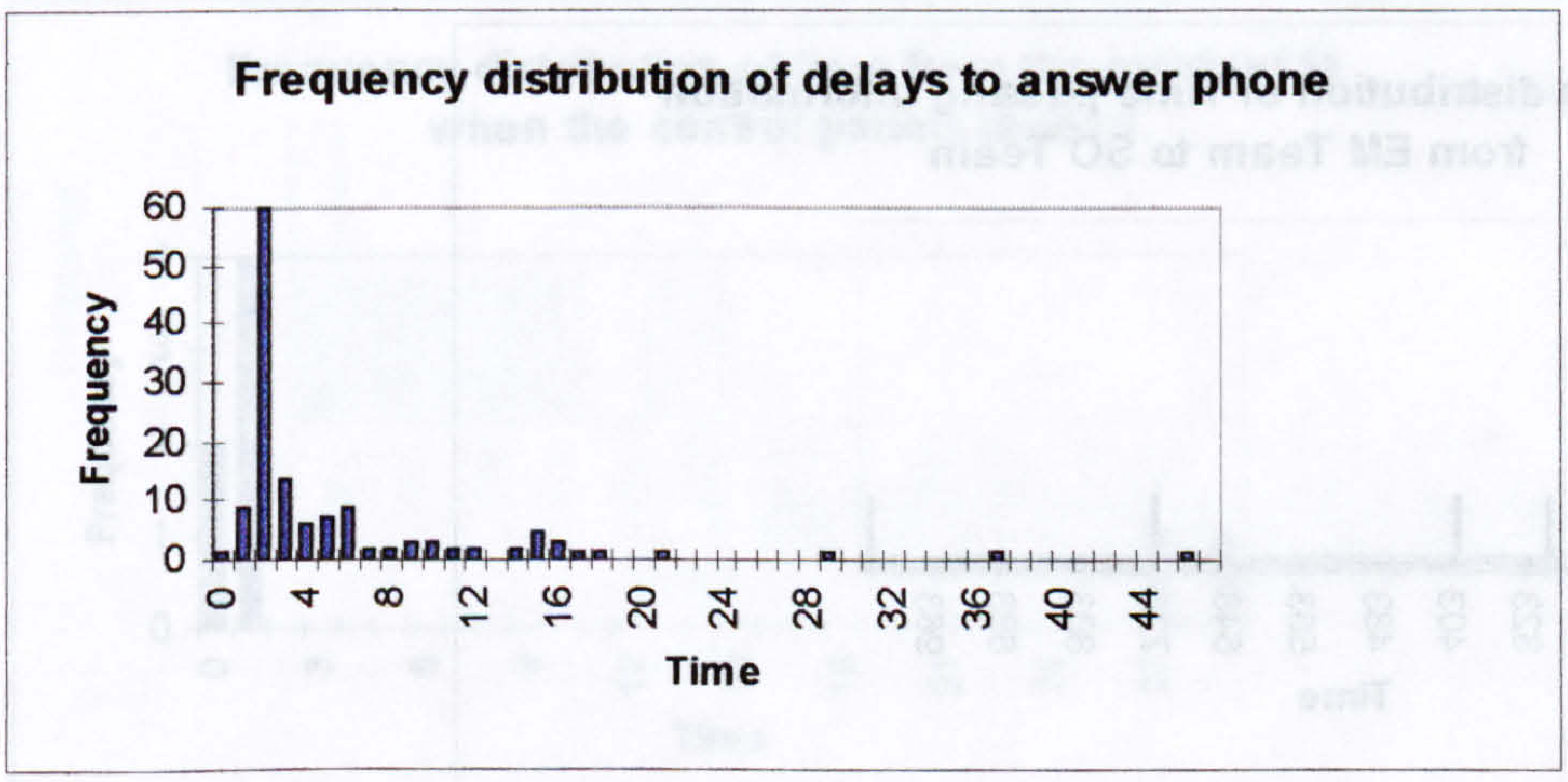

Frequency distribution of message length
Frequency
25
20
15
10
5
0
6
15
24
33
42
51
60
69
78
87
96
105
114
Time

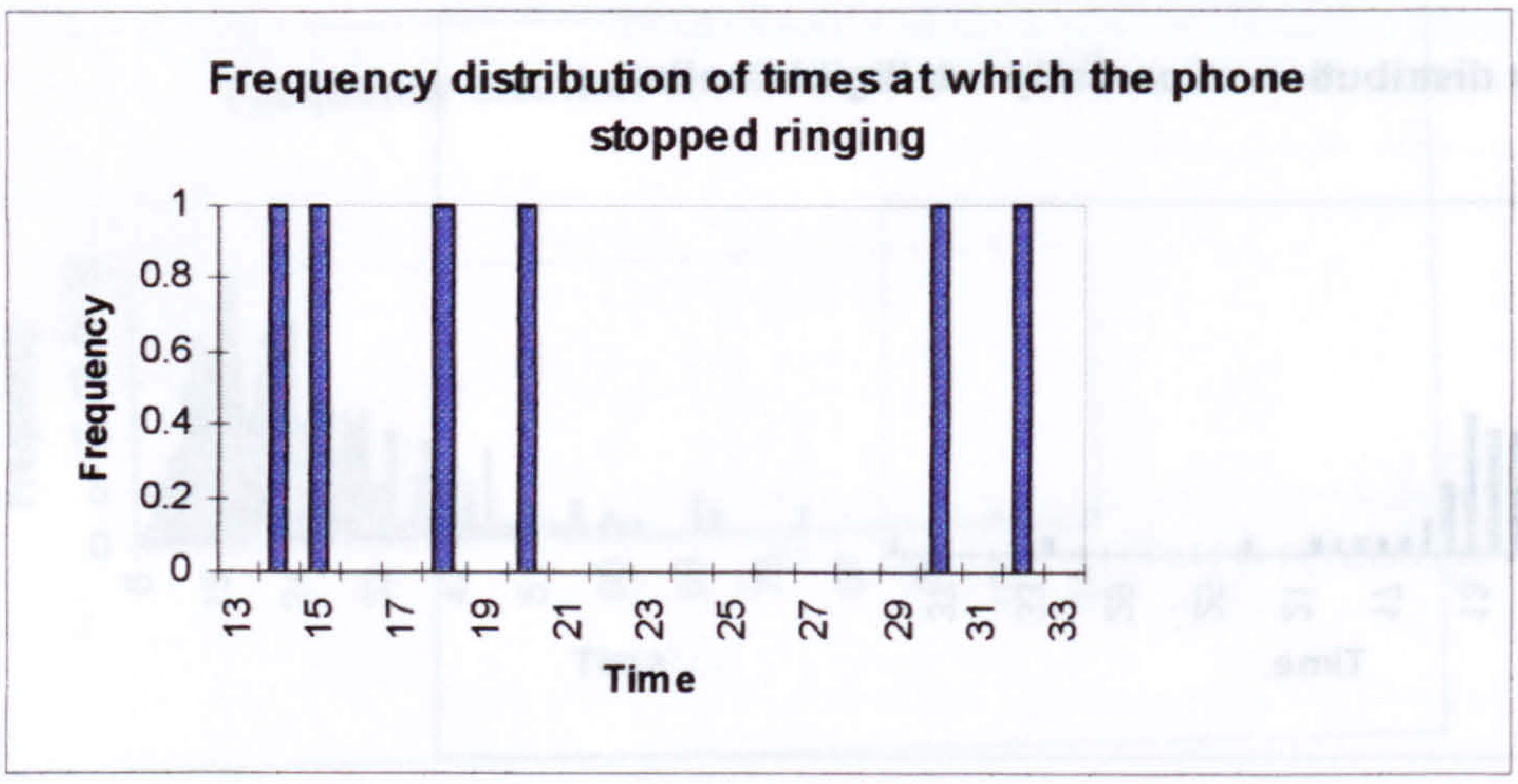

Frequency distribution of times from saying standby to calling back
Frequency
3
2
1
0
1
21
41
61
81
101
121
141
161
181
201
221
241
261
281
301
321
341
361
381
401
421
Time

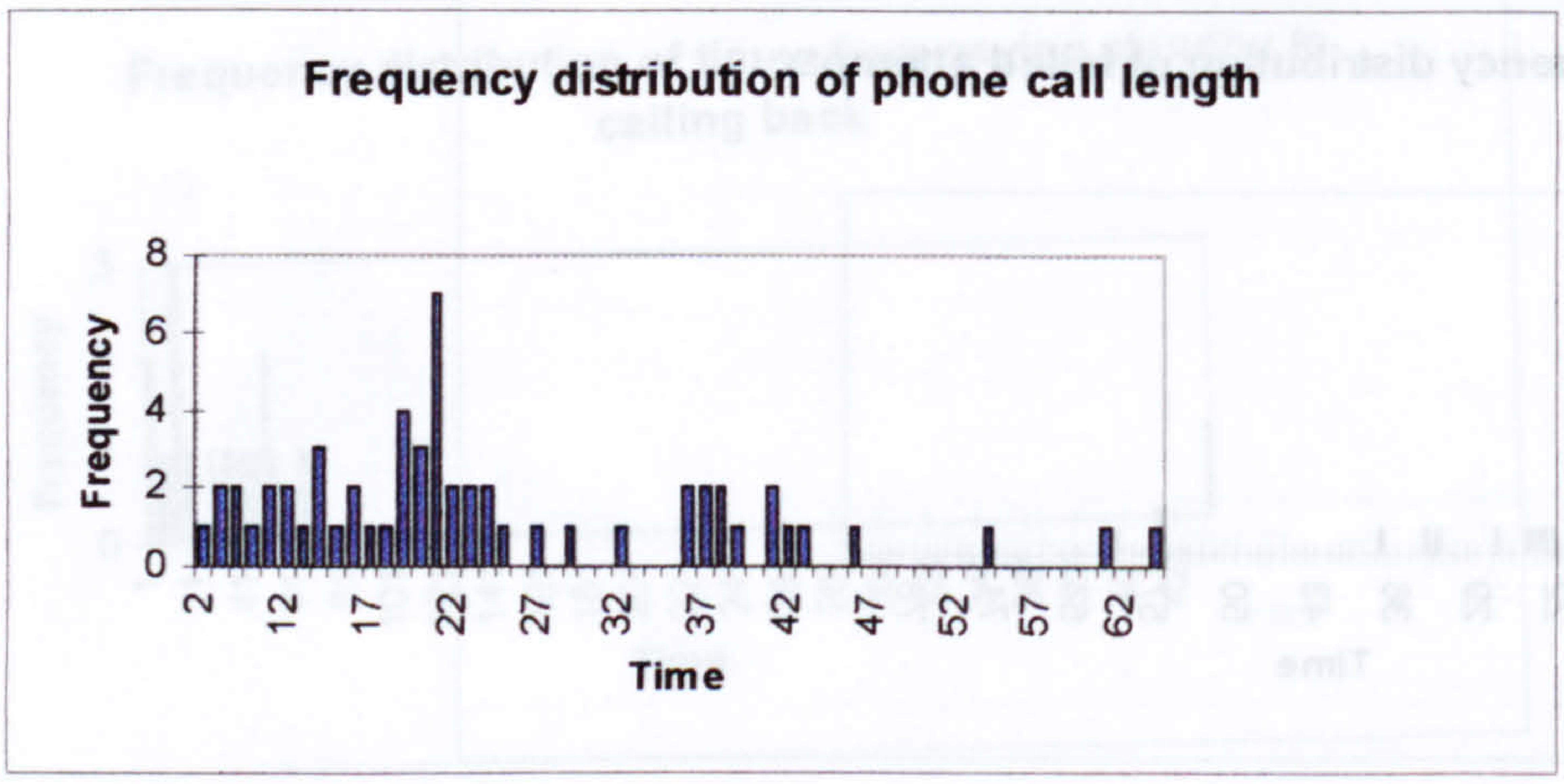

Frequency distribution for unintelligible calls
Frequency
12
10
8
6
4
2
0
1
3
5
7
9
11
13
15
17
19
21
Time

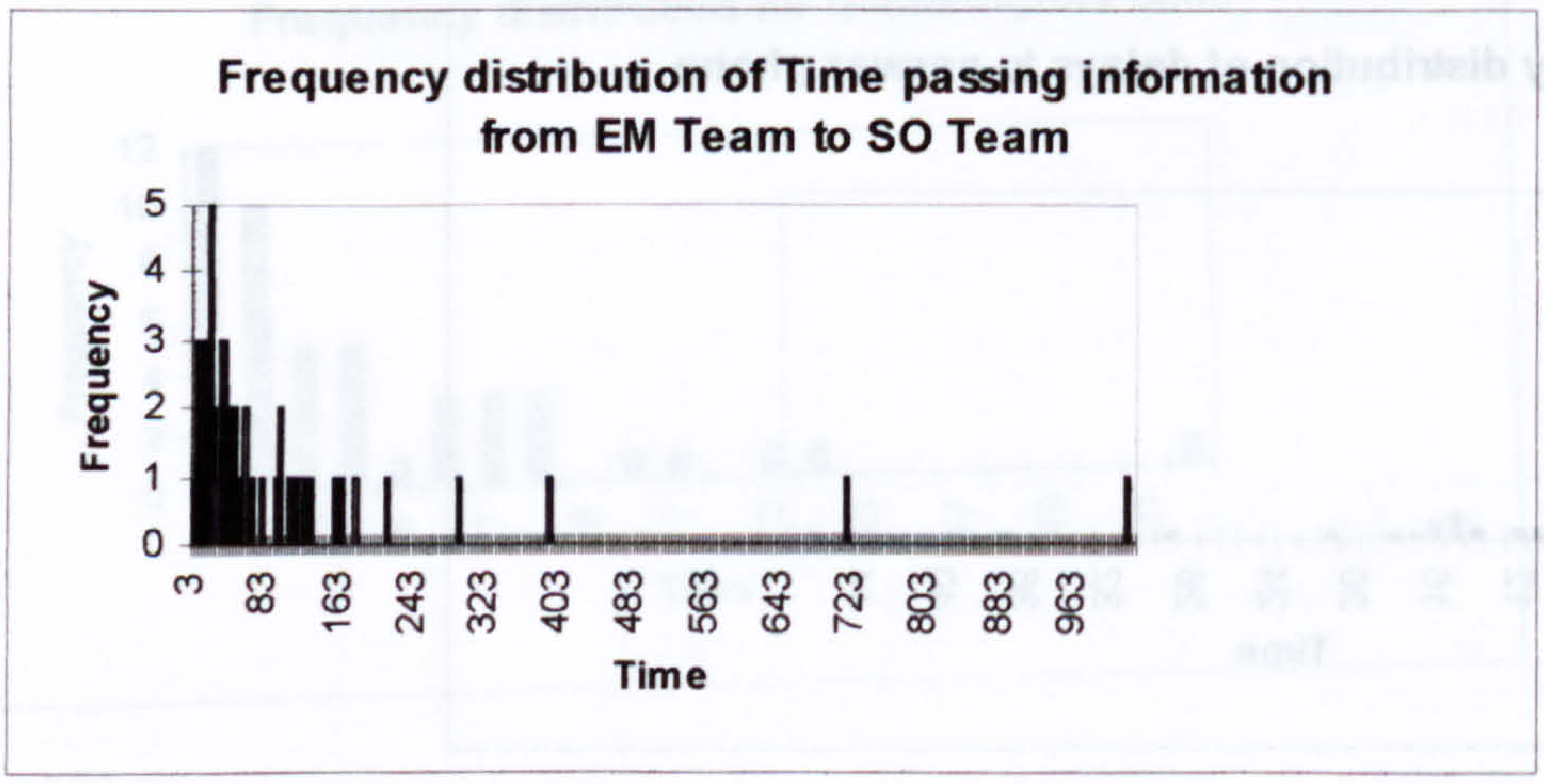

Frequency distribution of partially intelligible calls

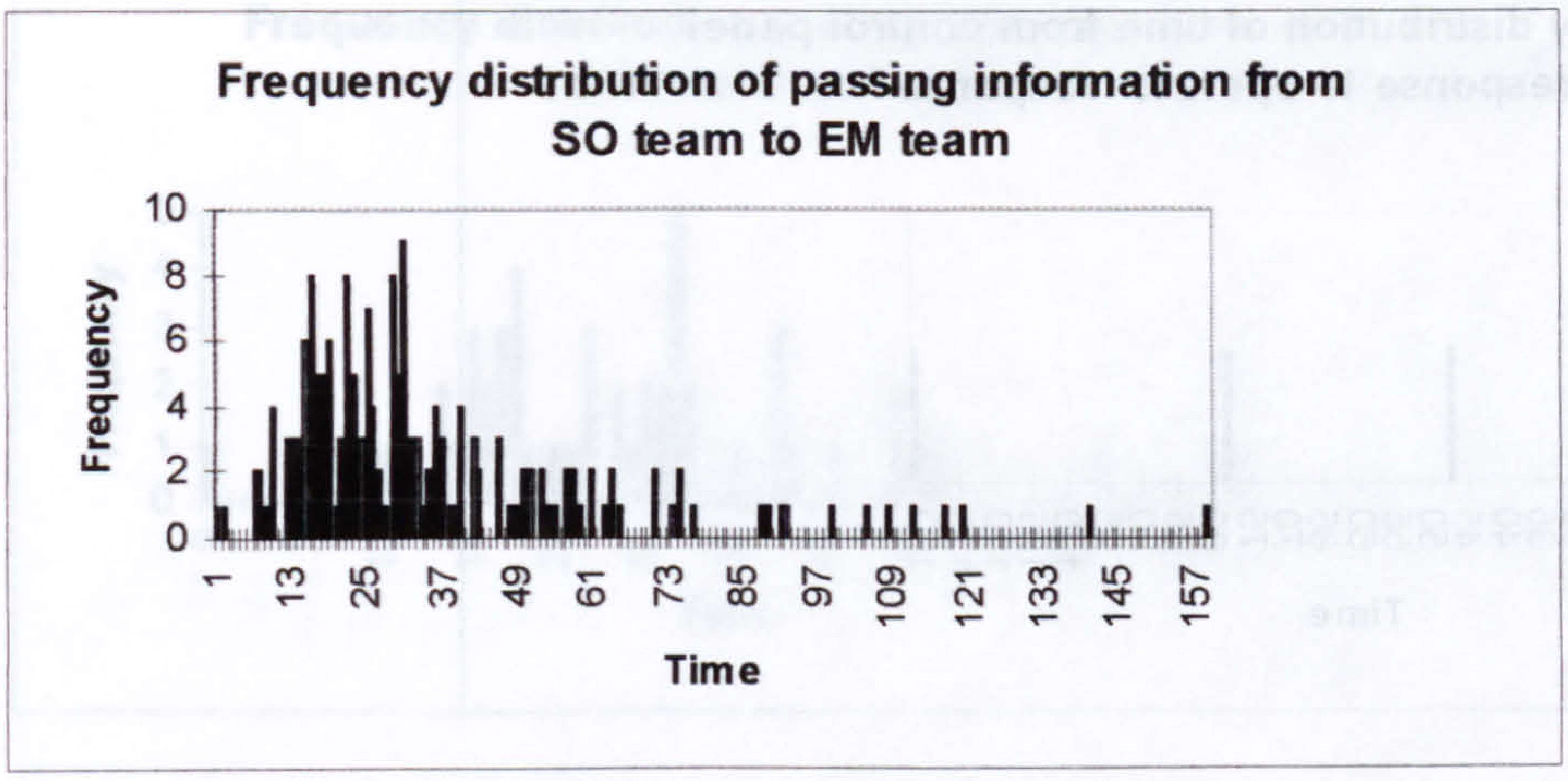

Frequency distribution of failed attempts

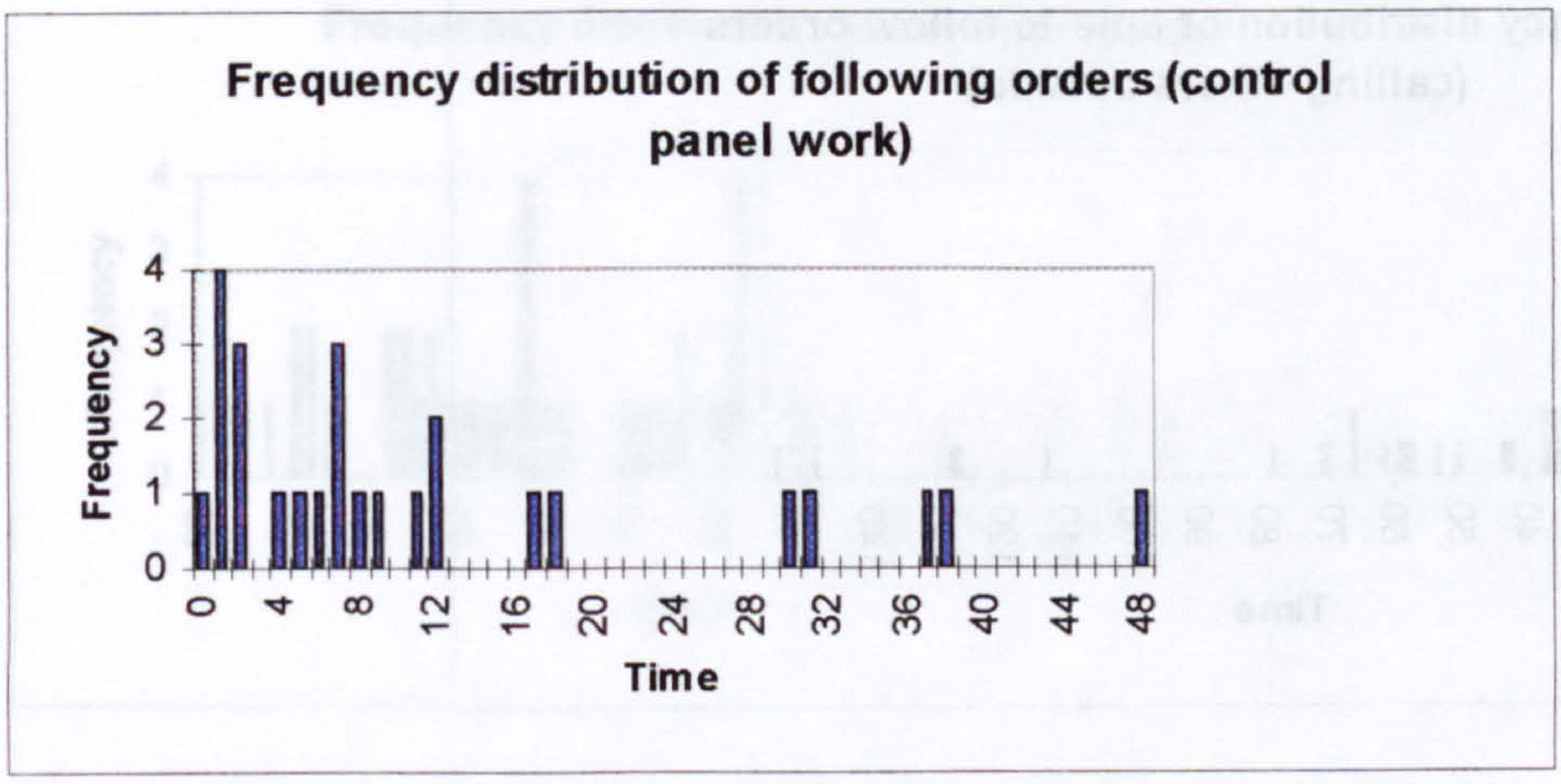

Frequency distribution of delays to answer phone

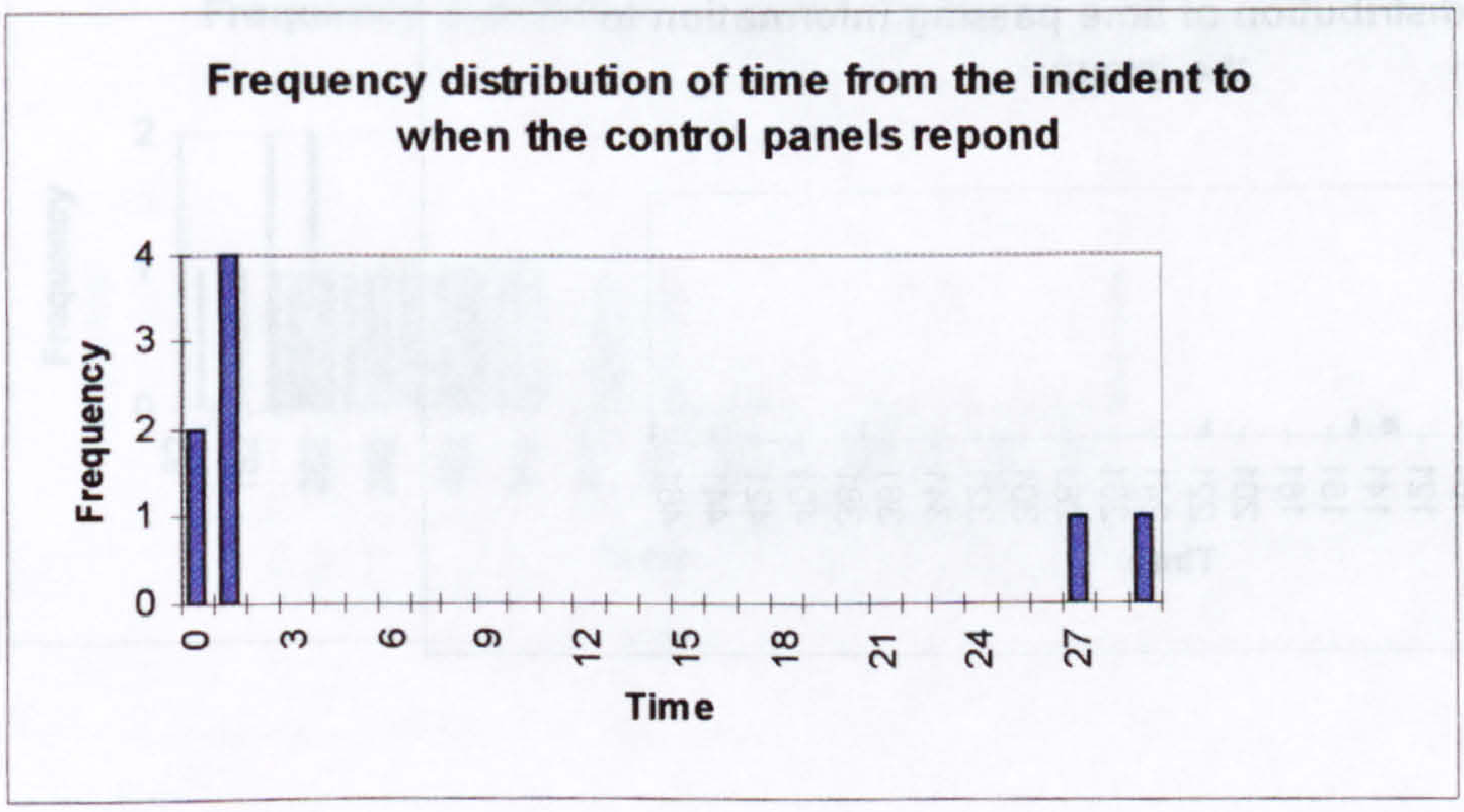

Frequency distribution of times at which the phone stopped ringing

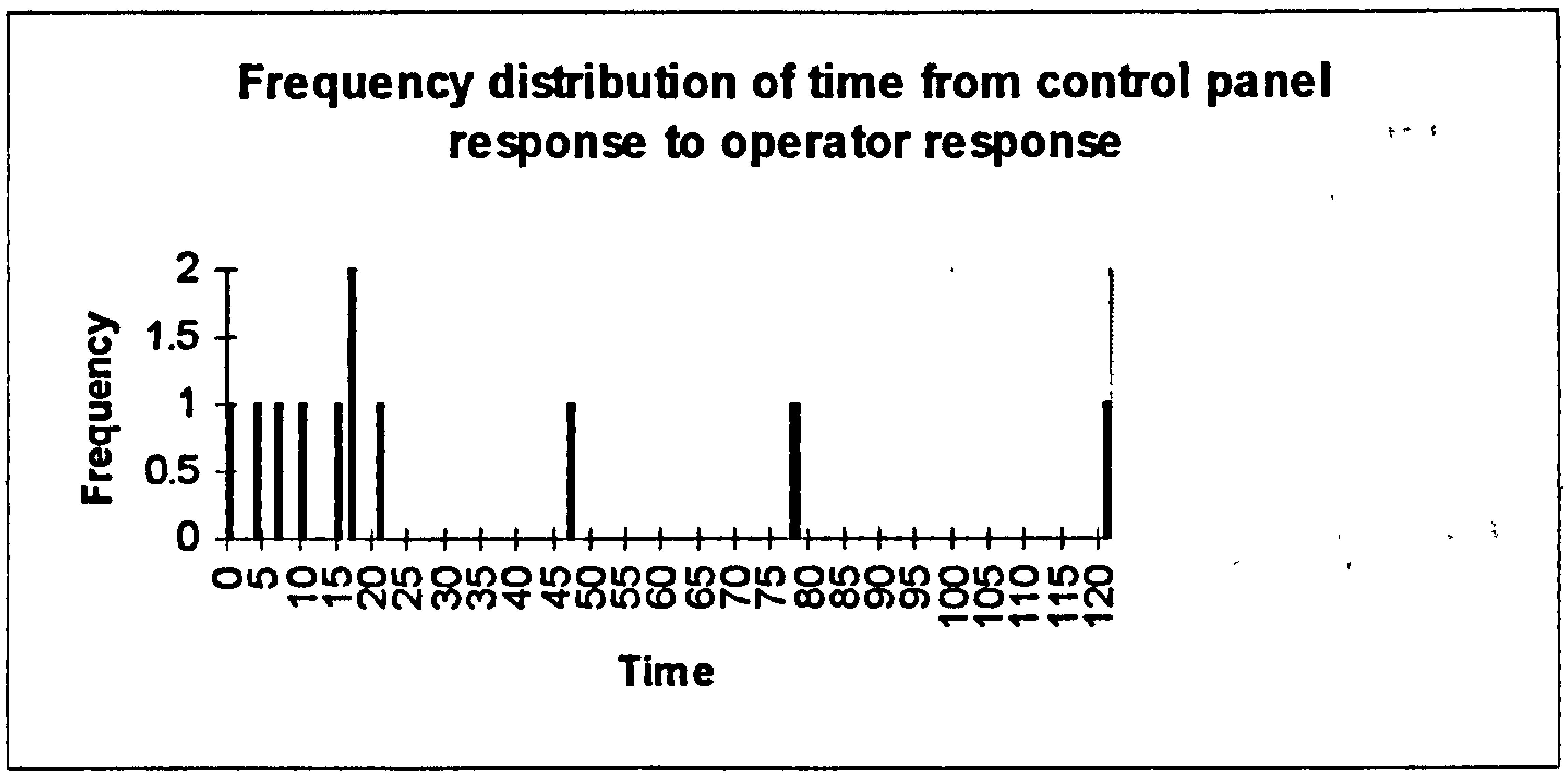

Frequency distribution of phone call length


Frequency distribution of Time passing information from EM Team to SO Team

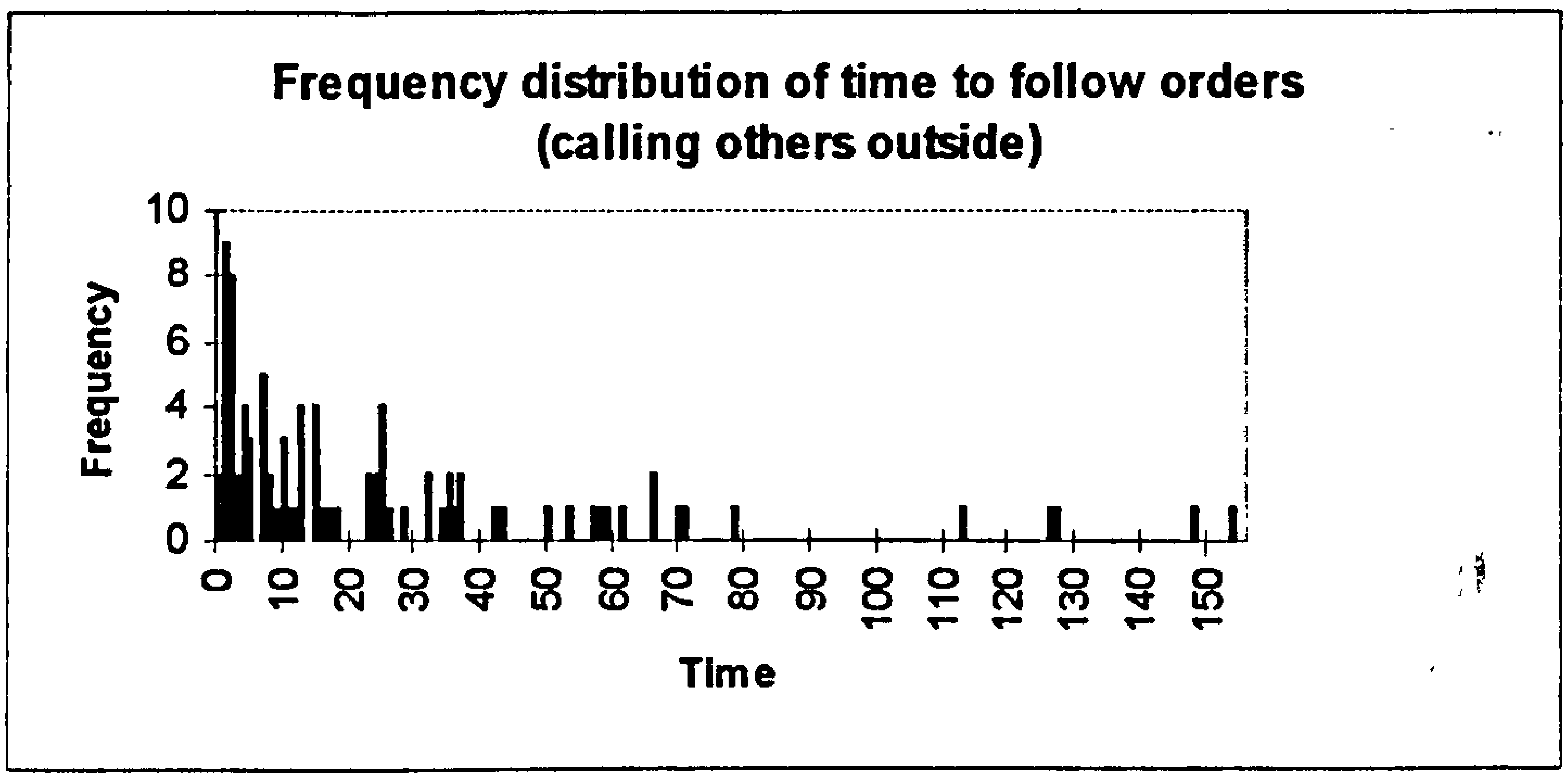

Frequency distribution of passing information from SO team to EM team


Frequency distribution of following orders (control panel work)

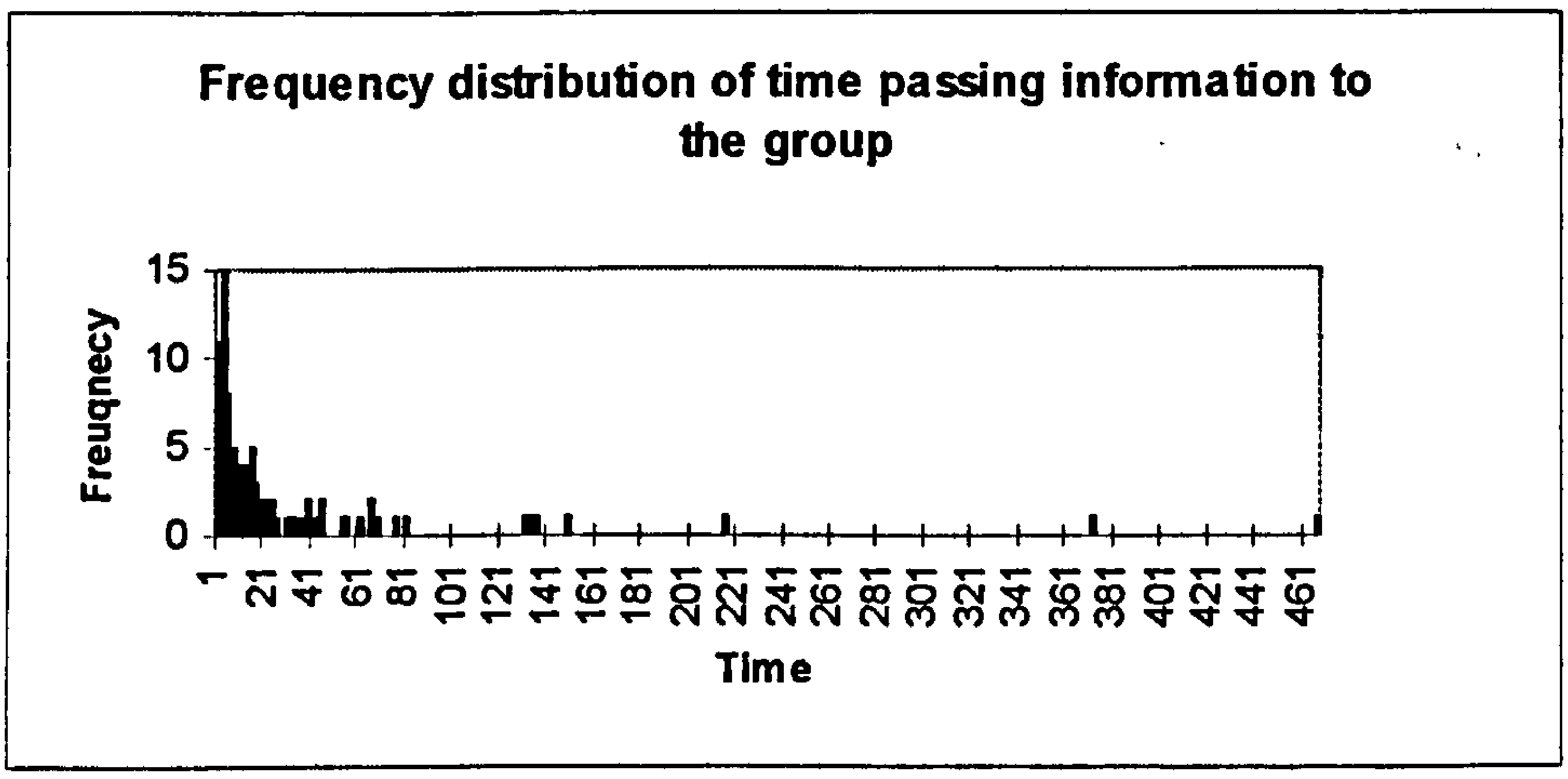

Frequency distribution of time from the incident to when the control panels repond



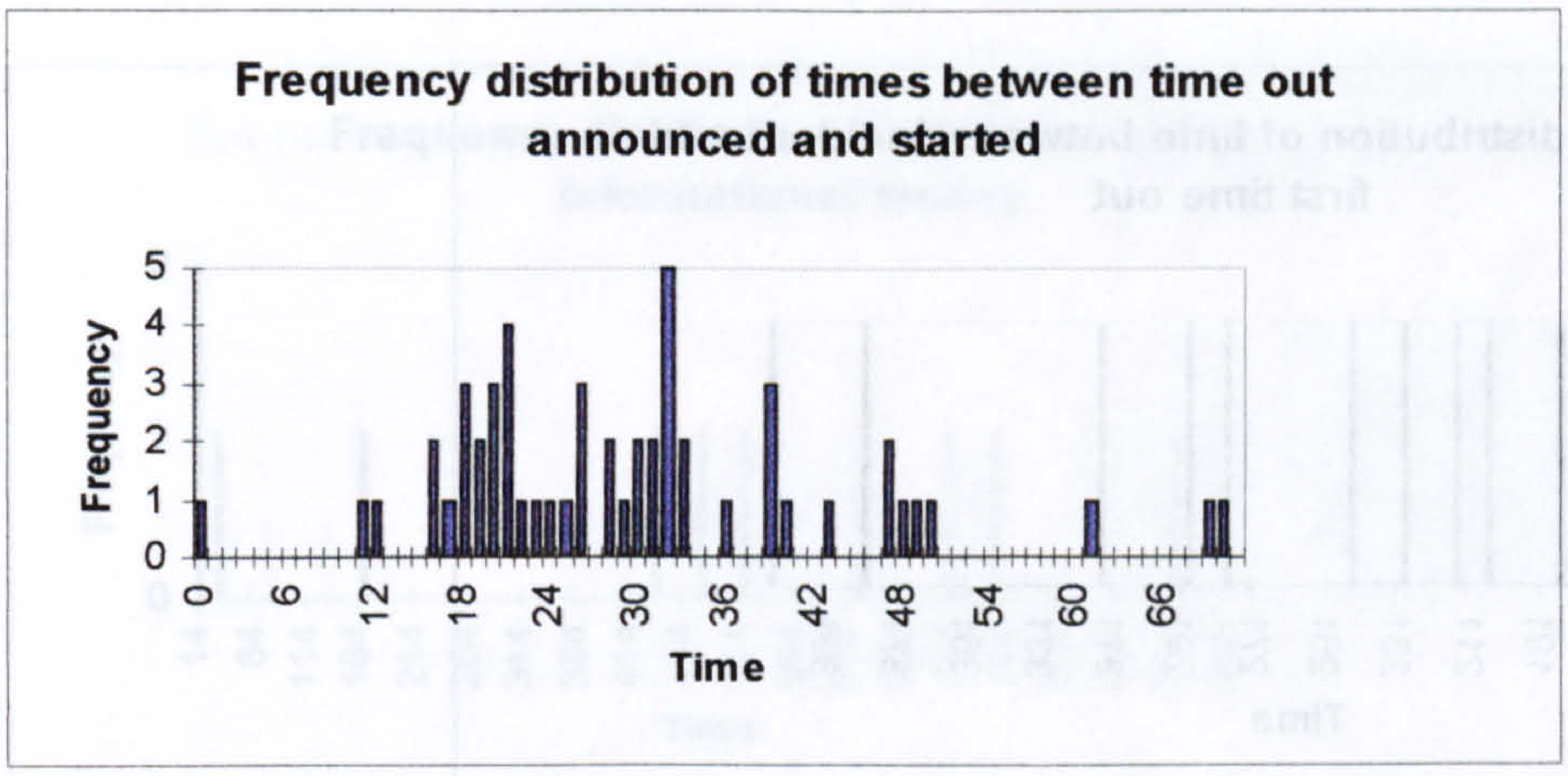
Frequency distribution of time from control panel response to operator response

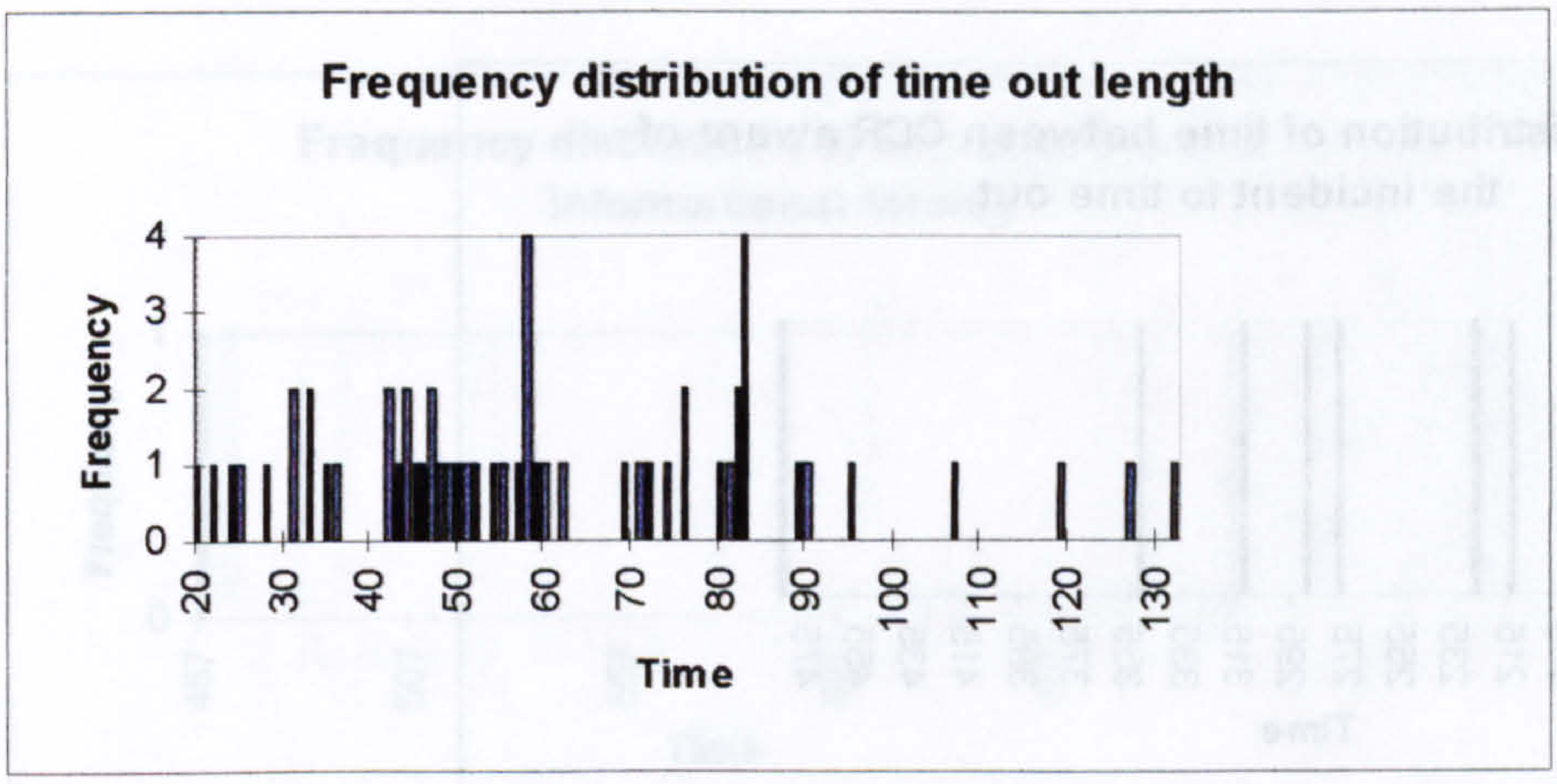


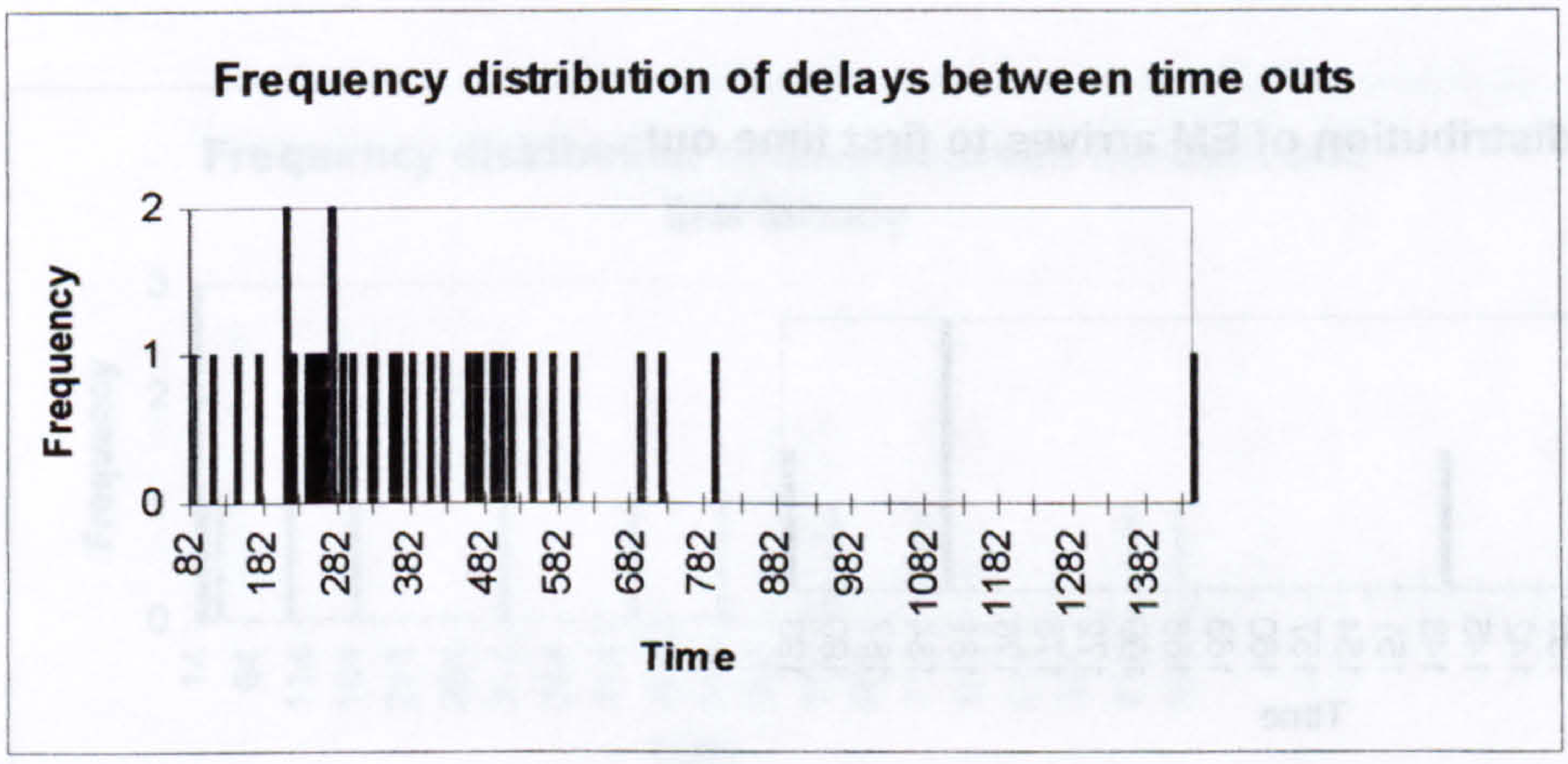
Frequency distribution of time to follow orders (calling others outside)

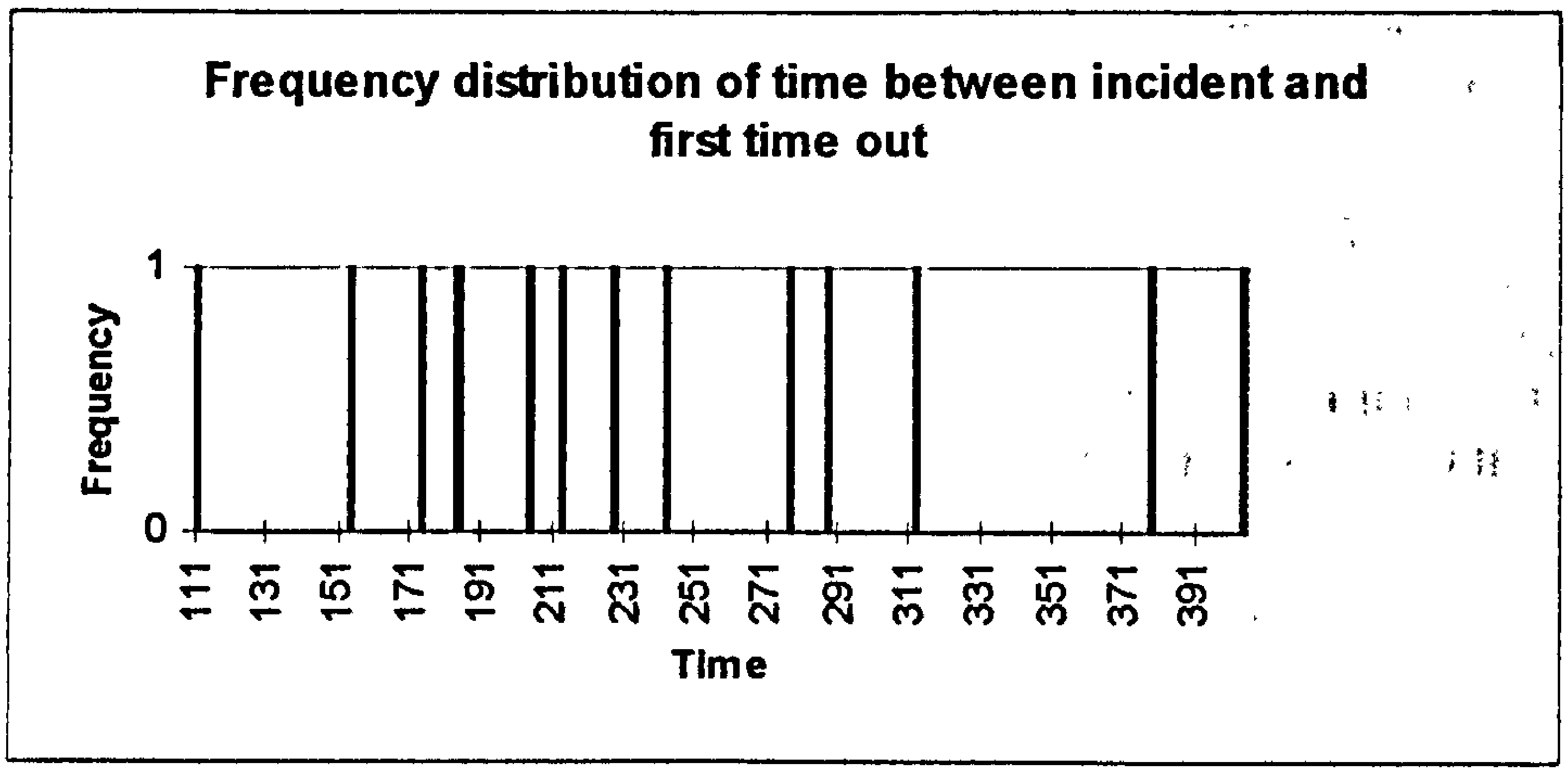


Frequency distribution of time passing information to the group

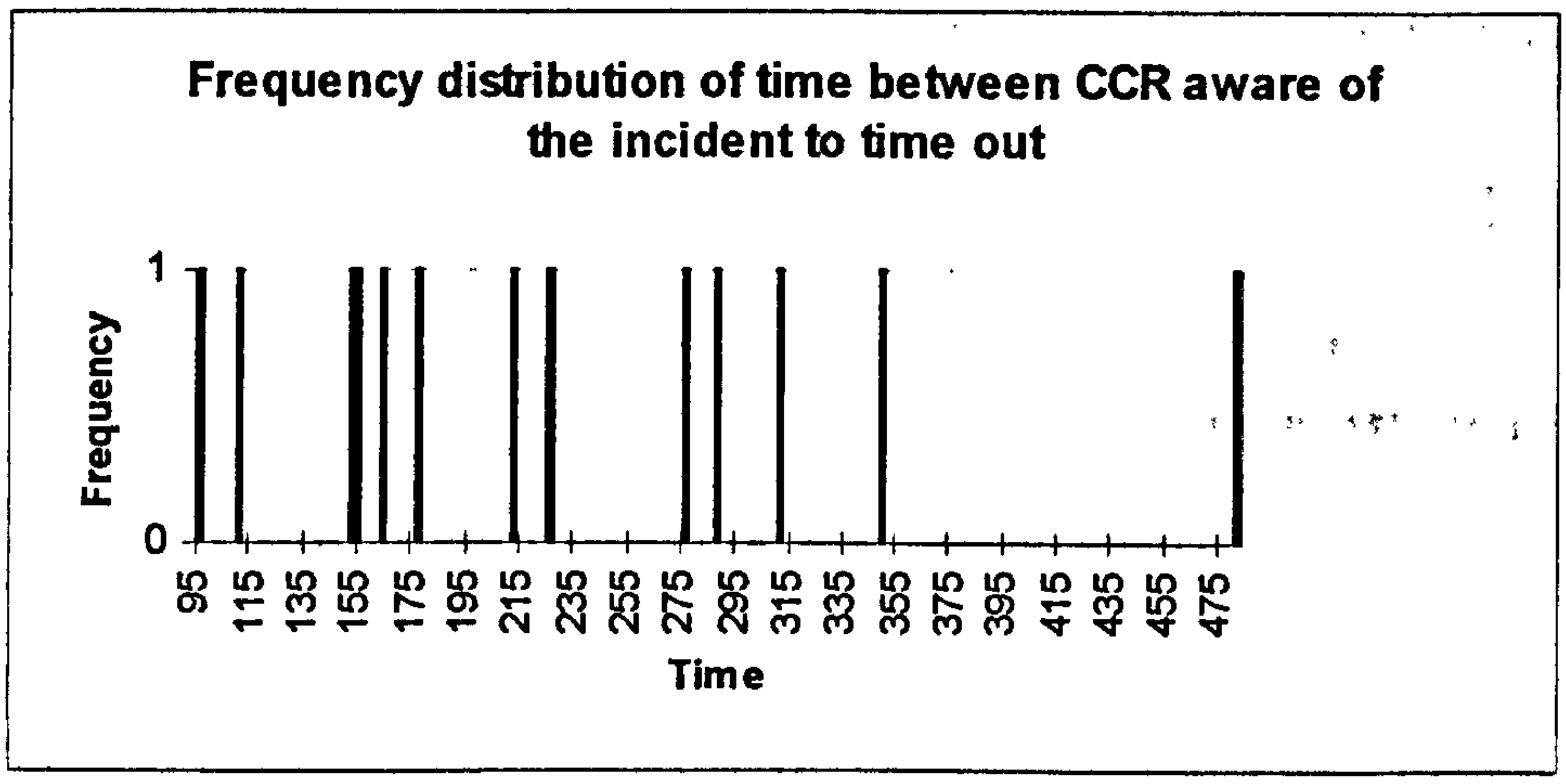

Frequency distribution of times between time out announced and started
Frequency
5
4
3
2
1
0
0
6
12
18
24
30
36
42
48
54
60
66
Time


Frequency distribution of time out length
Frequency
4
3
2
1
0
20
30
40
50
60
70
80
90
100
110
120
130
Time


Frequency distribution of delays between time outs
Frequency
2
1
0
82
182
282
382
482
582
682
782
882
982
1082
1182
1282
1382
Time

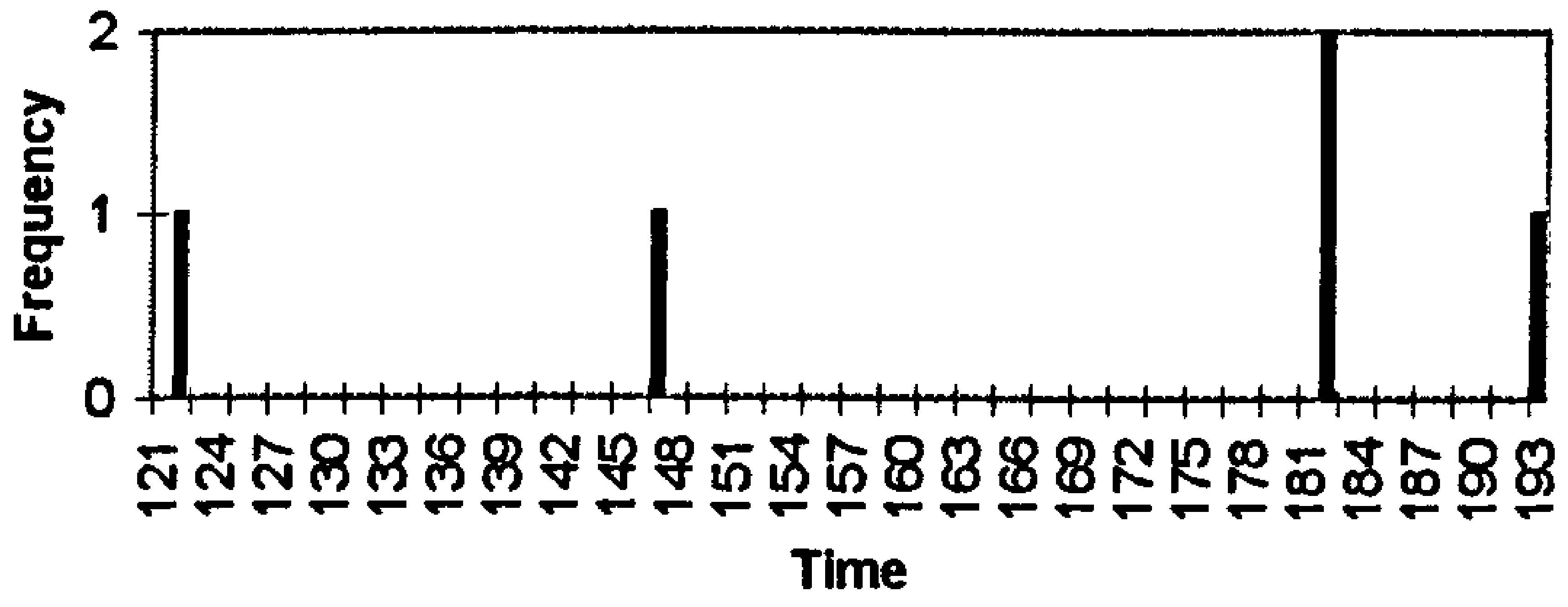


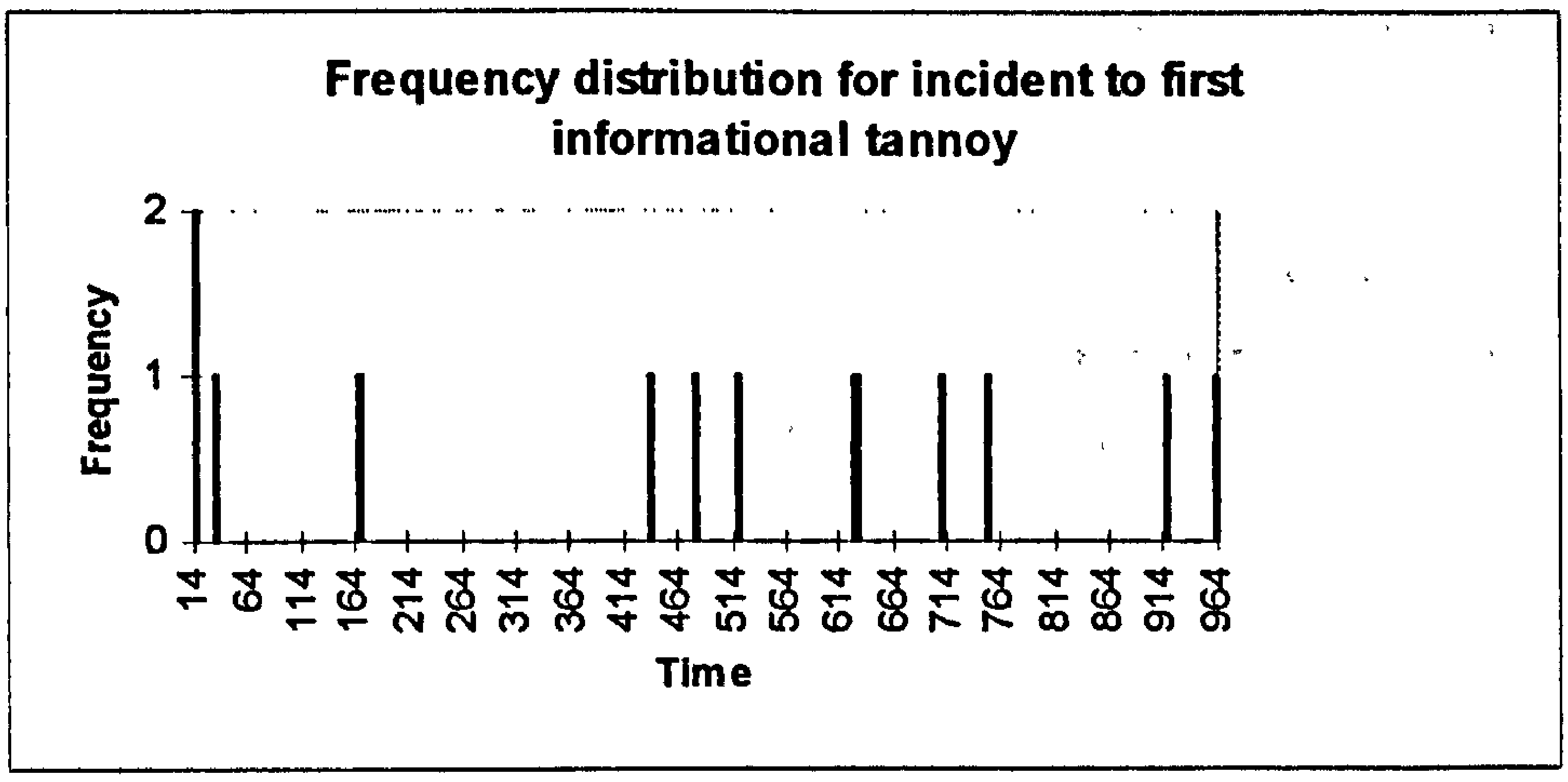
Frequency distribution of time between incident and first time out

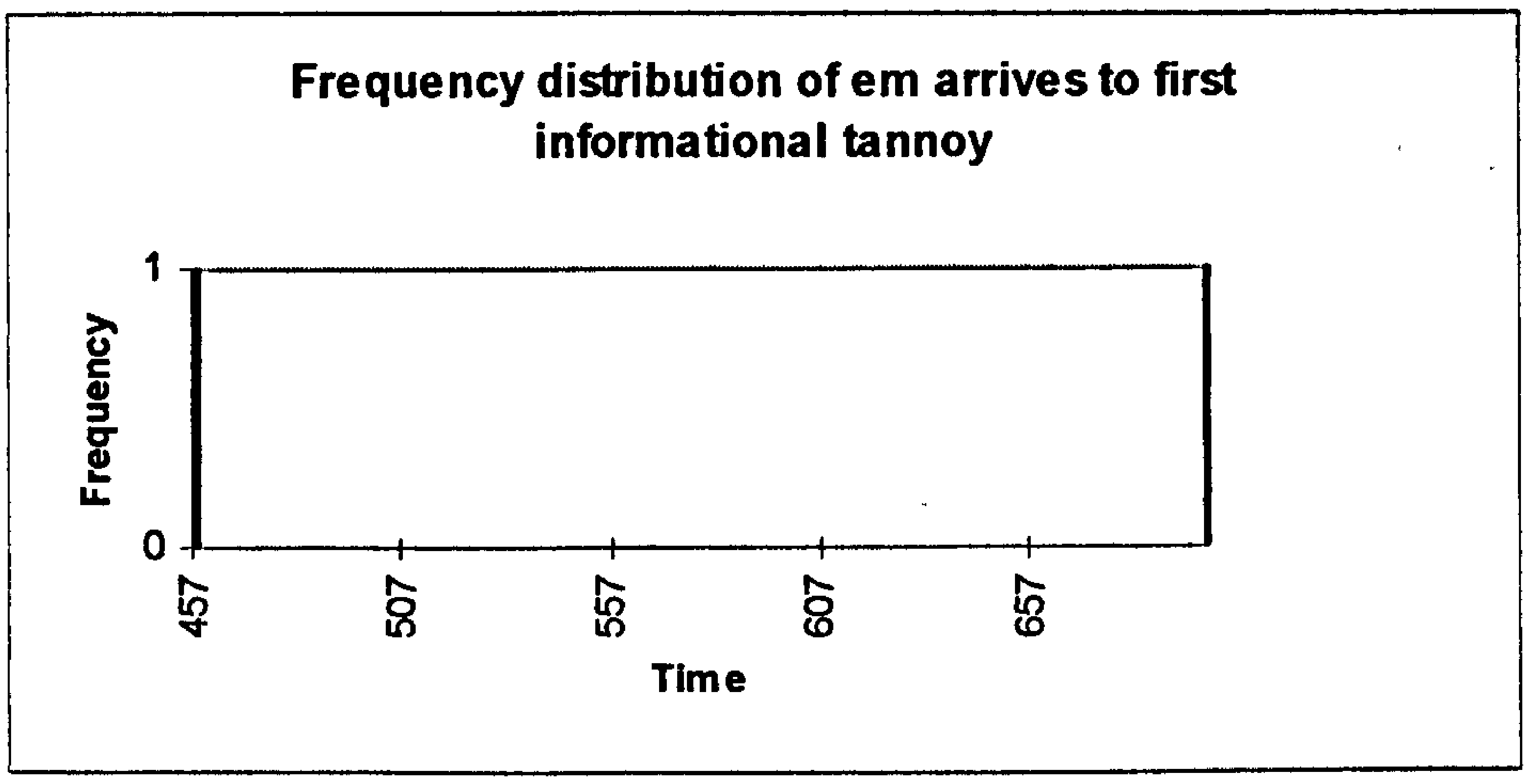


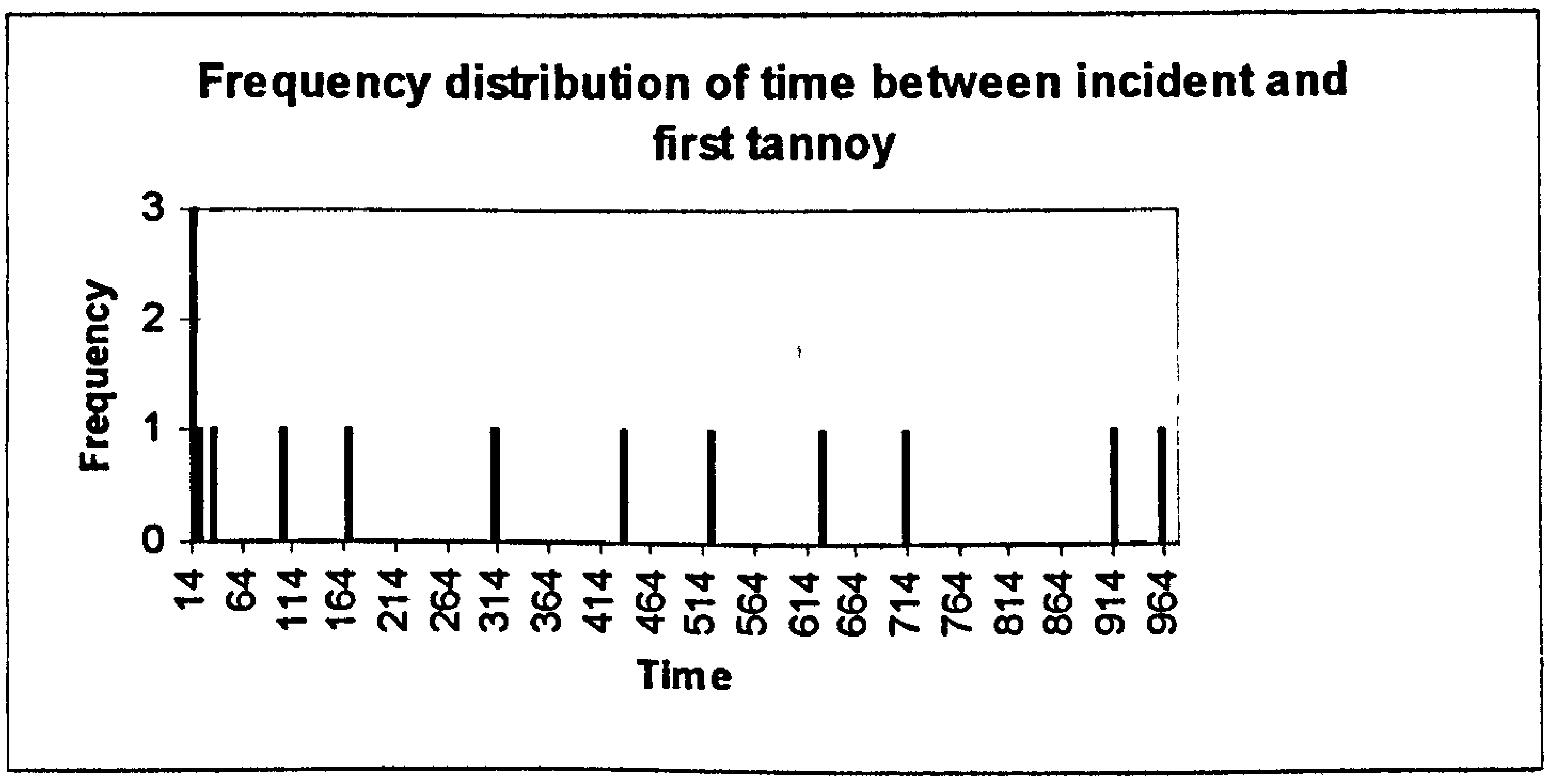
Frequency distribution of time between CCR aware of the incident to time out

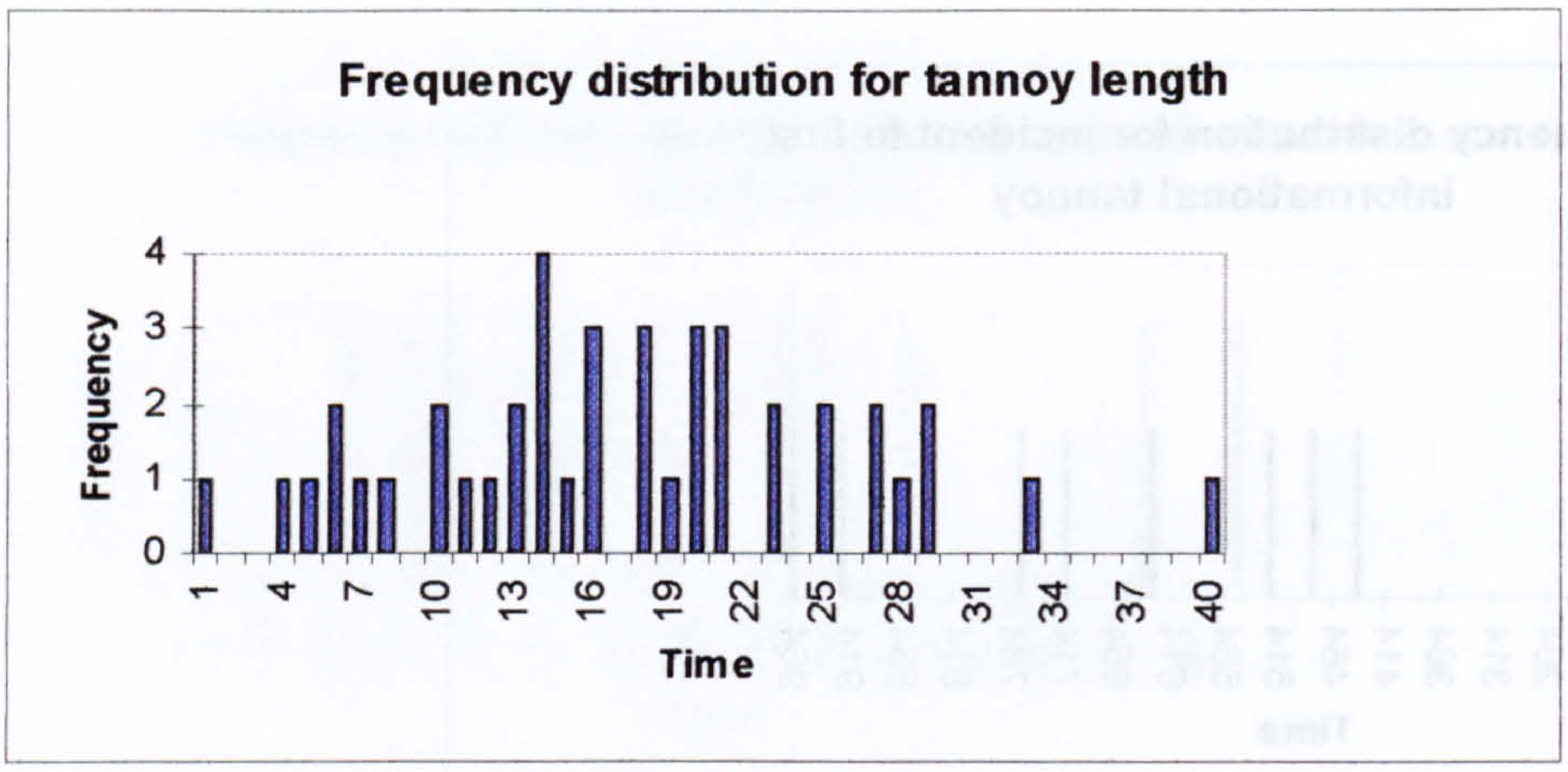
Frequency distribution of EM arrives to first time out

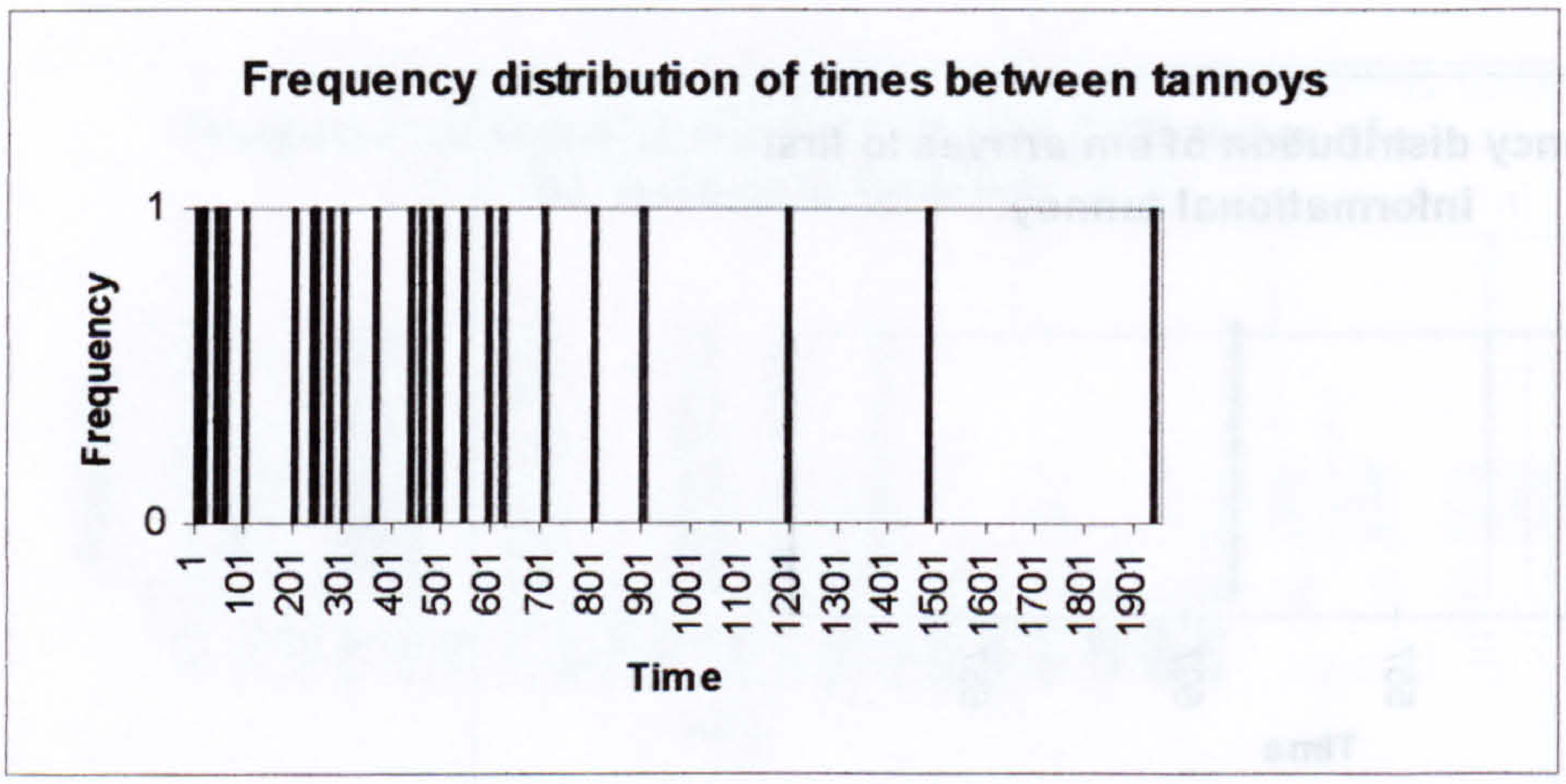


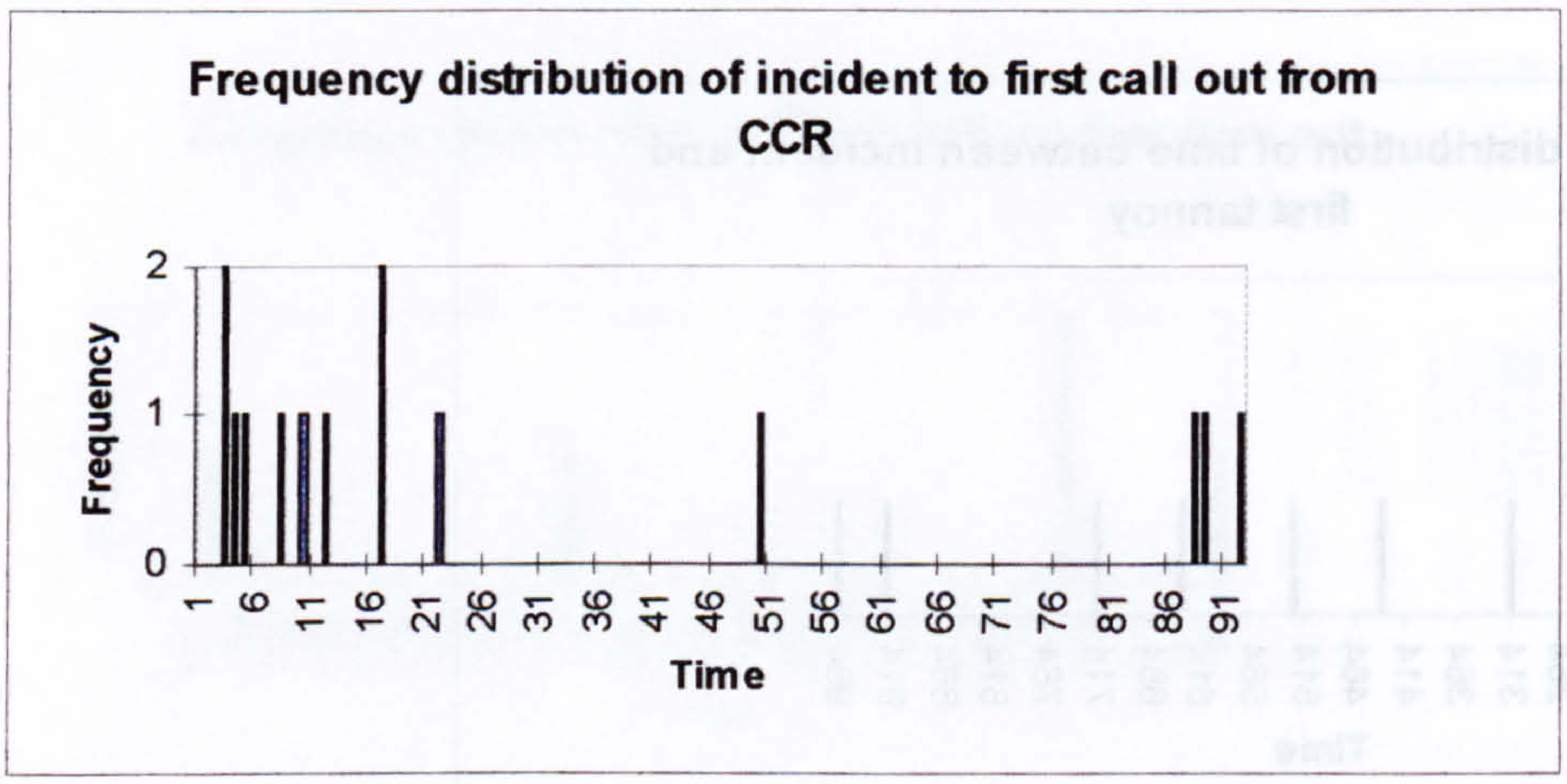

Frequency distribution for incident to first informational tannoy
Frequency
2
1
0
14
64
114
164
214
264
314
364
414
464
514
564
614
664
714
764
814
864
914
964
Time

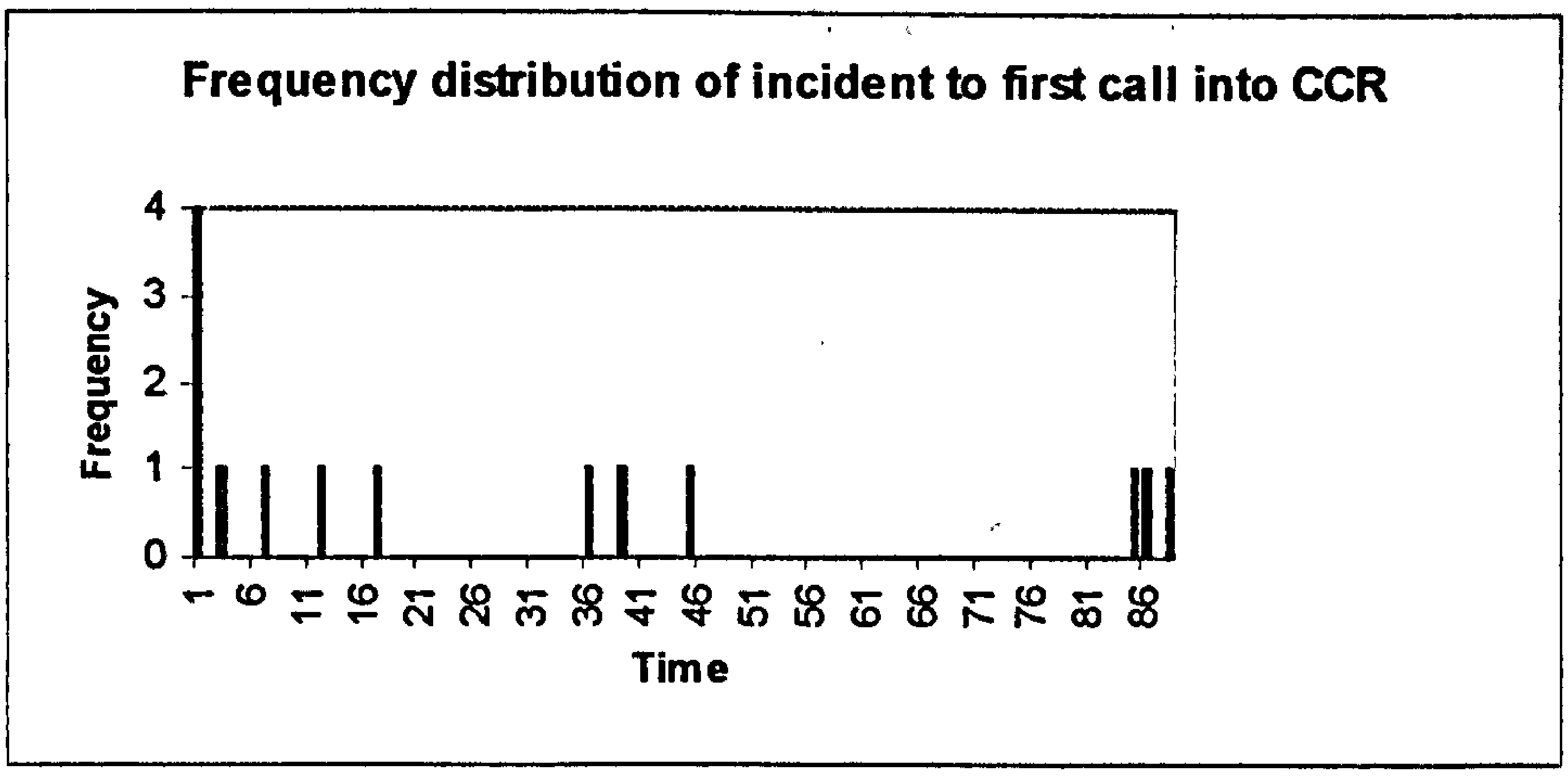

Frequency distribution of em arrives to first informational tannoy
Frequency
1
0
457
507
557
607
657
Time

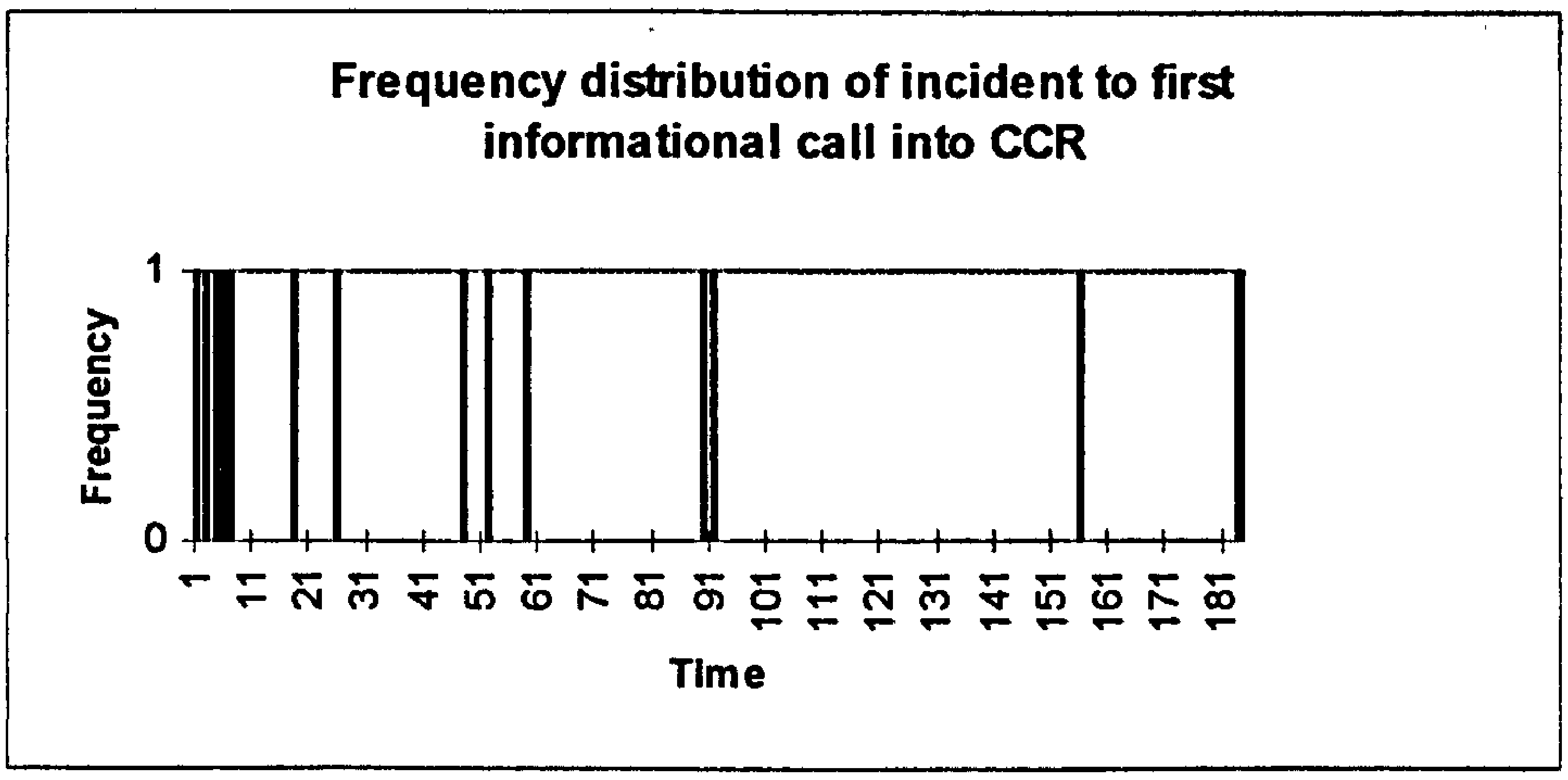

Frequency distribution of time between incident and first tannoy
Frequency
3
2
1
0
14
64
114
164
214
264
314
364
414
464
514
564
614
664
714
764
814
864
914
964
Time

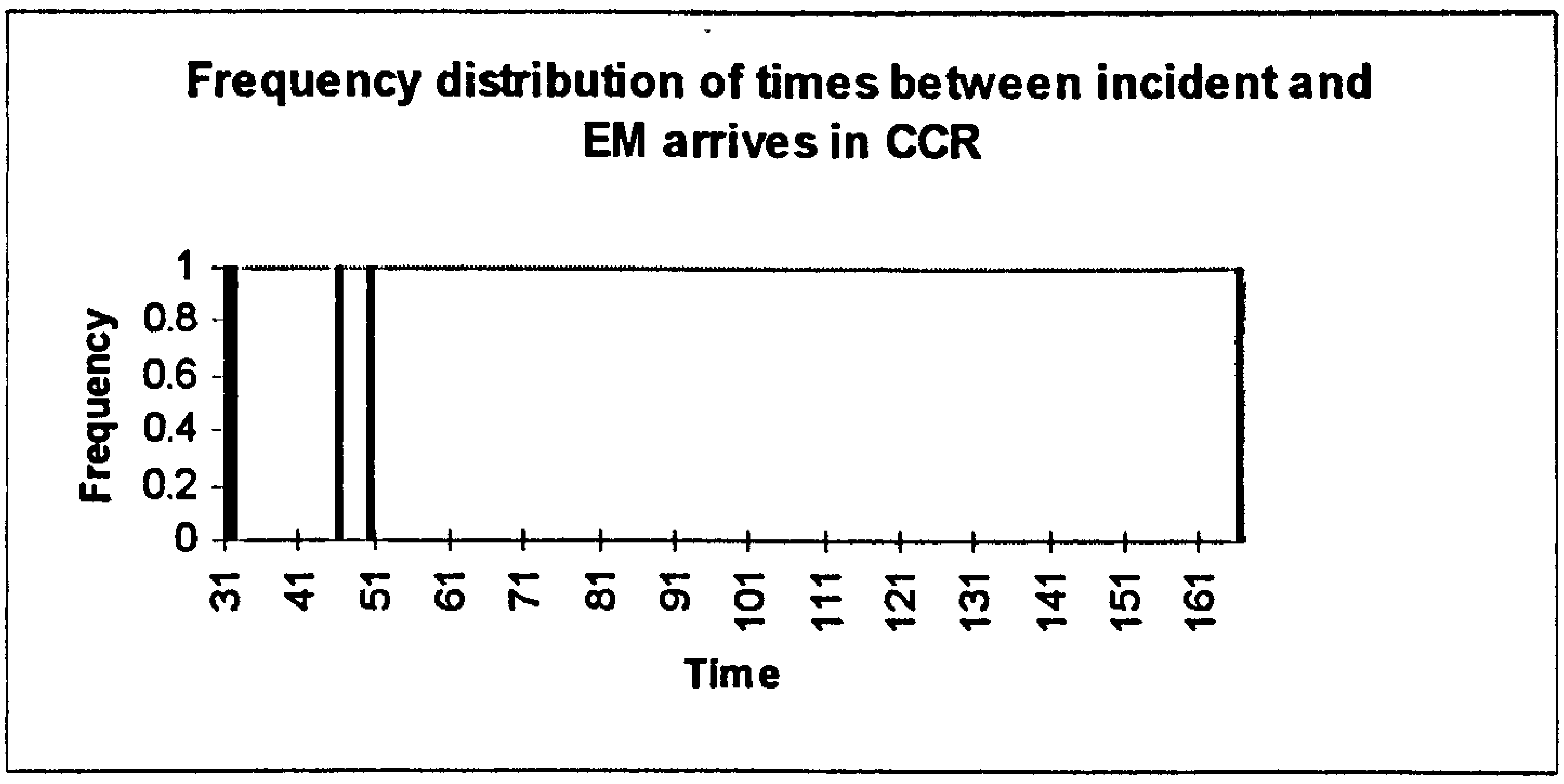

Frequency distribution for tannoy length

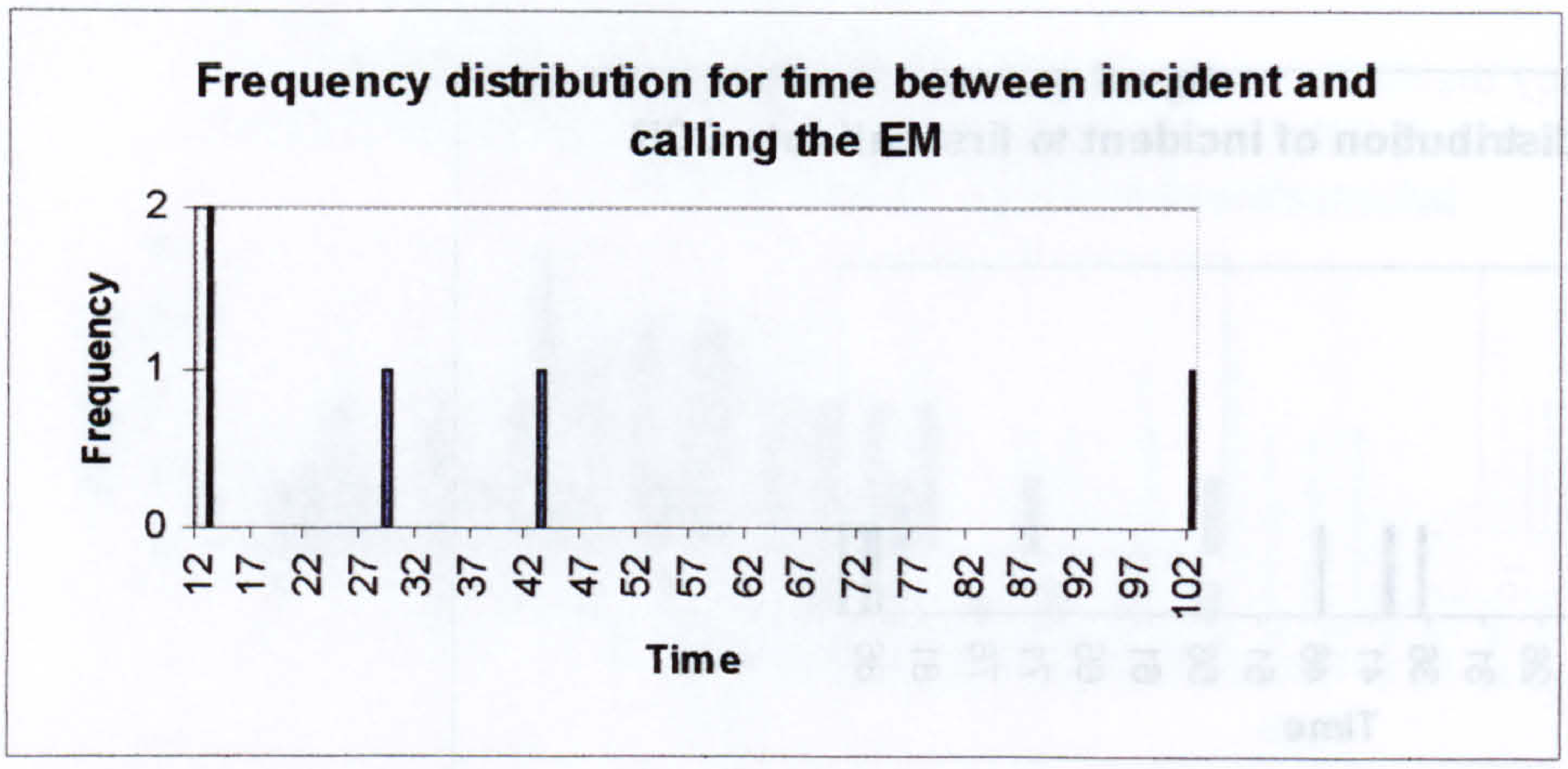

Frequency distribution of times between tannoys

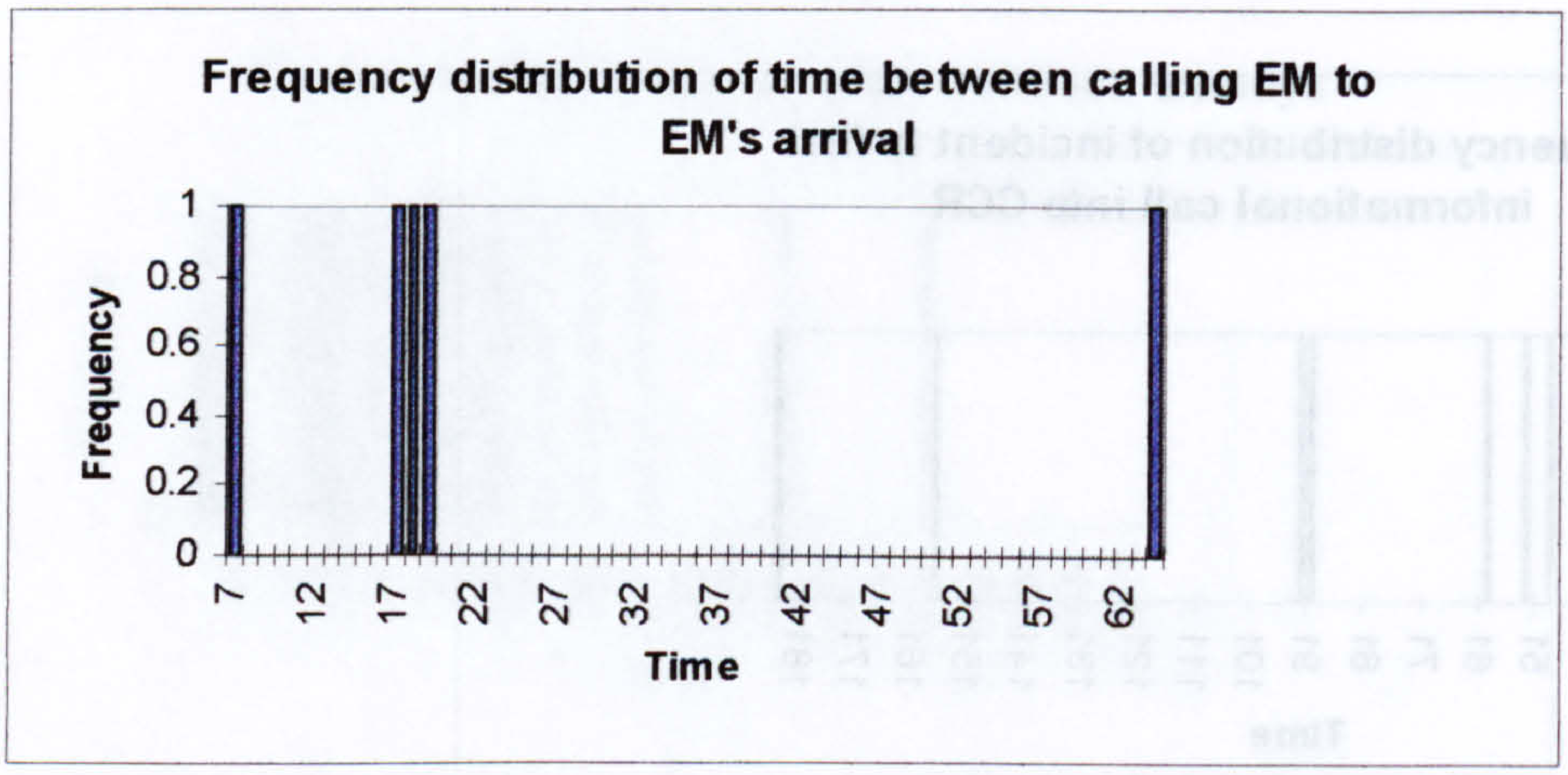

Frequency distribution of incident to first call out from CCR

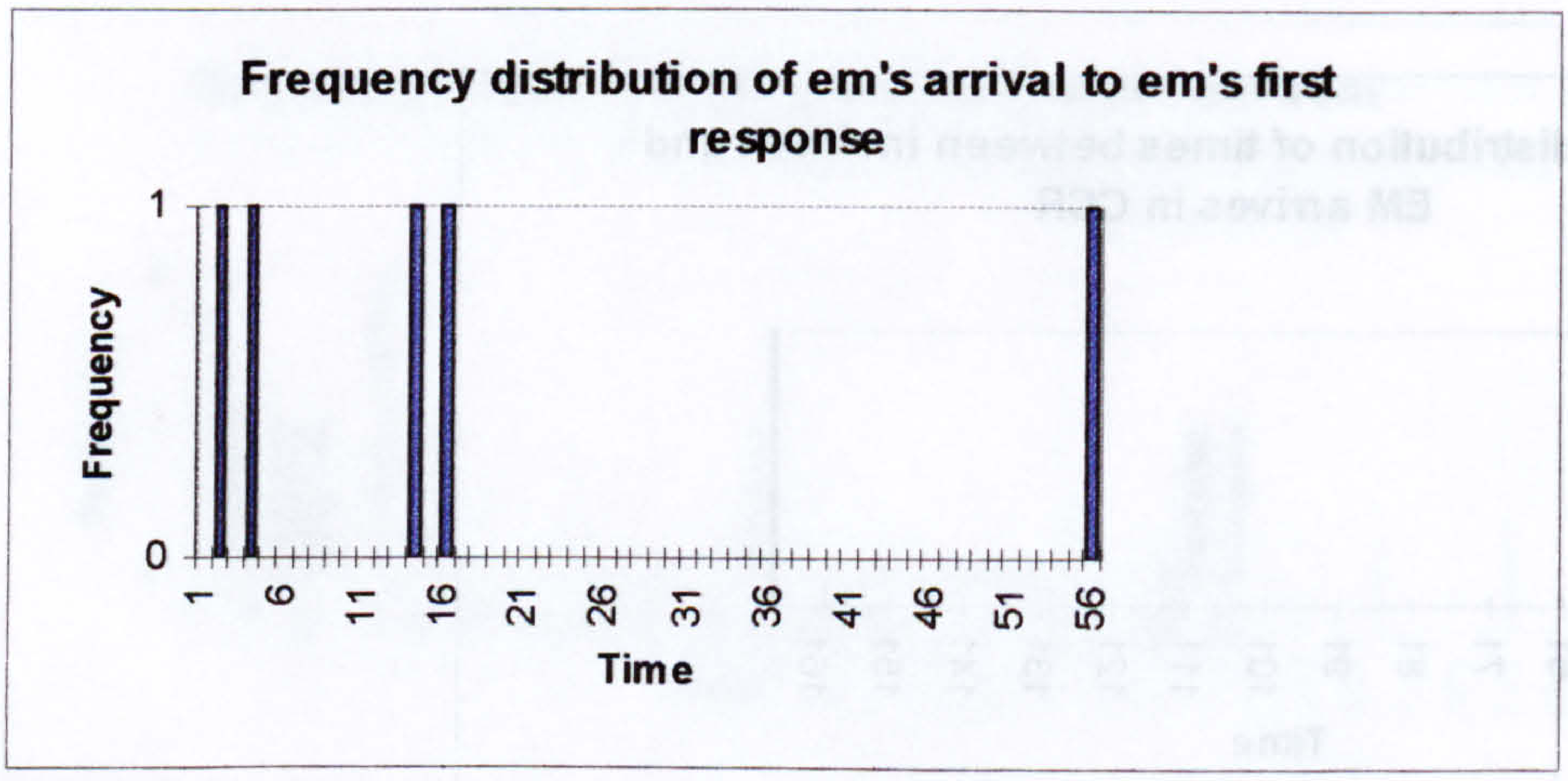

Frequency distribution of incident to first call into CCR

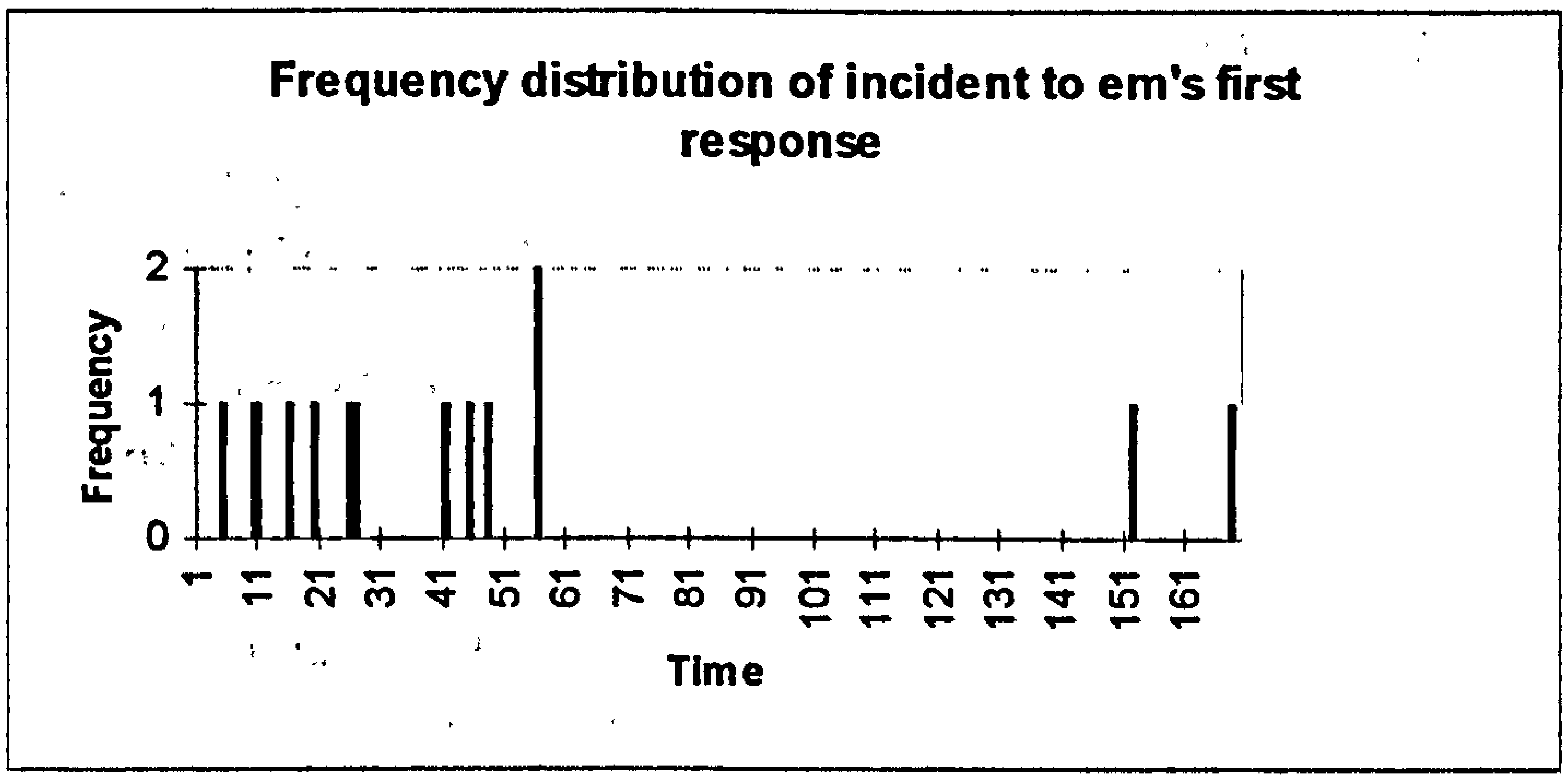

Frequency distribution of incident to first informational call into CCR


Frequency distribution of times between incident and EM arrives in CCR


Frequency distribution for time between incident and calling the EM
Frequency
2
1
0
12
17
22
27
32
37
42
47
52
57
62
67
72
77
82
87
92
97
102
Time


Frequency distribution of time between calling EM to EM's arrival
Frequency
1
0.8
0.6
0.4
0.2
0
7
12
17
22
27
32
37
42
47
52
57
62
Time


Frequency distribution of em's arrival to em's first response
Frequency
1
0
1
6
11
16
21
26
31
36
41
46
51
56
Time


Frequency distribution of incident to em's first response
Frequency
0
1
2
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
Time

APPENDIX 12: PUBLICATIONS

Dr J E Strutt, M. Lyons & K Allsopp (Cranfield University UK), J Larken (OCTO UK) & Professor Ragnar Værnes (NUTEC Norway) "Development of Models and Data for Quantification of Human Reliability on Emergency Management". 5th ERA Technology Conference "Risk Assessment of Offshore Installations". Church House Conference Centre, London UK. 18th November 1997. Presented by Rear Admiral Jeremy Larken and Melinda Lyons.

M. Lyons, Professor J E Strutt & K Allsopp (Cranfield University UK), J Larken (OCTO UK) and Robin Heels (Kværner Oil and Gas UK) "Development of a methodology to assess the impact of design performance parameters on offshore emergency management". 7th ERA Technology Conference "Design and Field Developments on Offshore Installations". Church House Conference Centre, London UK. 1st December 1998. Presented by Melinda Lyons.

Development of Models and Data for Quantification Human Reliability on Emergency Management

J E Strutt, M Lyons and K Allsopp (Cranfield University, UK)
J Larken (OCTO, UK)
R J Værnes (NUTEC. Norway)

ABSTRACT

Effective emergency management is necessary to assure senior management and regulators that incidents and their escalation can be controlled and losses to personnel, plant and the environment can be mitigated. Industrial experience suggests that emergency management training is extremely effective in improving the capability of emergency management teams. However, quantification of the risks and benefits is difficult and limited by currently available techniques. Recently, a task performance - resource constraint model (TPRC) has been developed in which the probability of successfully performing a set of human tasks is formulated in terms of an incident scenario. Such models provide a capability to predict the probability of a success outcome under conditions of uncertainty and time stress. The paper will describe the TPRC model its application to major accidents and the testing of the model in emergency management training exercises in collaboration with OCTO and NUTEC. An example scenario will be described to show how the model can be used to quantify the impact of human reliability, escalation and emergency management variables on the probability of a successful outcome. Finally, the paper will discuss the key role of emergency management training as a means of generating model data and its relevance to quantitative risk analysis.

1. Introduction

Major accidents offshore, although rare, can and do occur. Accidents such as the loss of the semi-submersible Alexander Keilland and the fire and explosion on the Piper Alpha installation serve to remind us of the risks faced by the offshore industry. Unless appropriate actions are taken to manage incidents and prevent escalation, minor incidents can become major accidents.

It is now widely recognised that effective emergency management is necessary to assure senior management and regulators that incidents and their escalation can be controlled and losses to personnel, plant and the environment can be mitigated. Industrial experience suggests that emergency management training is extremely effective in improving the capability of emergency management teams. However, quantification of the risks and benefits is difficult and limited by currently available techniques.

Various models have been considered for examining emergency management decision making. Klein (1995)[1] has developed a generic Recognition-Primed Decision model to focus on problem-solving in the real world. This involves examining familiar attributes of a situation and basing the response on previous experiences. Flin (1996)[2] has collated emergency decision making research from a number of application areas and finds considerable support for the Klein Model. Both Orasano (1995)[3], researching pilot decision-making and Fredholm (1995)[4], researching fire-fighter's decision-making, consider the importance of situation awareness and limitations in available time and resources. However, there has been little attempt in any of these studies to quantify the effectiveness of emergency management.

In this paper, we address the problem of assessing the impact of emergency management on risk reduction and introduce the concept of a task performance - resource constraint model (TPRC) to predict the probability of successful outcome of emergency management under conditions of uncertainty and time stress. For the purposes of modelling, a major accident is regarded as a sequence of critical events in an escalating incident, resulting in one or more outcomes quantified in terms of fatalities, damage to plant or damage to the environment. The frequency of major disasters depends on the frequency of initiating events, the probability of losing control, the probability of escalation and the probability of failing to evacuate/escape. Given an initiating event, the task of emergency management is to minimise the probability of loss by reducing the rate of escalation and increasing the likelihood of successful evacuation, escape or rescue.

2. Model Concept

The task of emergency management is considered to be a time and resource constrained decision making process, made by an emergency management team (EMT). Once an accident has occurred, this process generates prioritised actions intended to minimise the risk to personnel, the public, the environment and plant assets. Emergency management decisions are made with the intention of controlling future events such that a more desirable outcome is achieved. The interaction between the management team and the evolving scenario can be considered therefore as a control system as conceptualised in Fig.1.

Decisions are made by the emergency management team (EMT) based on their perception or (mental model) of an evolving and often complex accident scenario (the reality). Perception of reality is updated as new information and data on "the reality of the situation" are brought to the attention of the EMT. The reality may be dominated by factors outside the control of the EMT and the degree of control is likely to decrease with increasing rate of escalation. However, timely intervention can often lead to a decrease in escalation rate with a consequent gain of time to organise evacuation, escape, rescue or physical damage limitation measures. The quality of decision making is crucially dependent on the perception of reality, hence accurate information, timely communication and clarity of situation assessment are vital to achieving a rapid and appropriate management, which in turn, is the key to risk reduction.

2.1. The Task Performance - Resource Constraint Model

The model, currently under development at Cranfield, is based on the limit state concept and provides a basis for assessing the impact of time stress, work load, decisions and message transmission. These are recognised as important error promoting features in human reliability research[5,6].

The principal idea is that the probability of a successful outcome of a particular emergency management task, such as (but not limited to) evacuation, escape or rescue, depends on the difference between the time available and the time required to complete the task, as shown schematically in Fig. 2. The task succeeds if the *time required* to complete the task i.e. accumulate knowledge, make a decision and act on it, is less than the *time available* to perform the task. These two times need to be quantified if the risk is to be assessed quantitatively.

The time required is dominated by the management task to be carried out, and is modelled in terms of the task demand (task requirement) and its rate of execution or response, which in practice may be preceded also by a delay. The reliability of the management or the probability of successful completion, is the probability that the actions performed exceed those required to complete the task to the required level of adequacy. Given enough time, this probability will eventually reach unity. However if time is limited, then the probability will reach some maximum and then decrease when the available time has expired.

The time available can be modelled as resource consumption, as escalation or simply as an imposed time constraint i.e. in terms of the following criteria :-

- Incident severity, S at time t is less than the tolerable severity, S*
- Resource, R, consumed by time t, is less than the available resource, R*
- Actual time consumed, t, is less than the available time t*

Resource consumption rate and escalation rate have equivalent meaning in that either can be translated to calculate management response time availability. A rapid incident escalation rate or resource consumption rate will result in a shortage of available time, while a low escalation or resource consumption rate provides a larger time availability.

The term "resource" is a general term which can refer to time or external physical resources, including personnel, machines and information generation systems, availability of safe haven for the personnel, ECC and Internal psychological and physical resources. In turn, psychological and physical resources can include such items as the level of prior knowledge, intelligence, physical strength, coping capacity etc. and so can influence both the time required and the time available. However, for certain incidents, the time available to complete a task may be dominated by the resource availability i.e. by the total resource available and its consumption rate[5].

2.2. Impact of time stress on probability of management success

With reference to Fig. 3, the probability of success evolves with time. For a scenario in which there is an approximately linear response rate and a relatively slow escalation rate, the probability of task success can be expected to grow as illustrated in Fig. 3a. However, since escalation results in a decreasing probability of time availability (Fig.3b), the joint probability of success exhibits a maximum, as shown in Fig. 3c. The time at which the maximum occurs and the maximum probability depends on the rate of task execution and the rate of escalation. The faster the rate of incident escalation, the greater the requirement for a rapid rate of knowledge accumulation and management to achieve task success.

2.3. Situation Awareness, Decision, Communication, Action and Response (SADCAR)

Time is chosen as the key variable in the model and so the time to initiate a response and the speed of response relative to escalation rate will dominate the likelihood of reducing the risk.

Significant events in the real world sooner or later lead to an awareness of the situation. The process of becoming aware then leads to a decision to respond so as to achieve a desired objective. The response itself is often initiated by a communication message or an instruction to perform a particular task which is then followed by an action which brings about the response. For instance, in an offshore context, awareness of a methanol leak should lead to a decision and an instruction to "stop all hot work". Likewise, awareness of an escalating fire might first lead to an instruction to send "personnel to muster stations" and later, if control of the situation is lost, an instruction to abandon the platform. The required action then involves the performance of the task which will invariably take time to execute e.g. switch off welding sets and initiate blow down, and finally the response of the system /situation (hot sources will take time to cool down and process system will take time to blow down). Thus, the time between the initial event and the management instruction, and the subsequent time taken to carry out instructions and generate a system response are parameters which have an important bearing on the probability of a successful outcome.

In summary, the time between the initial event and the physical response involves the following stages: Situation Awareness, Decision to act, Communication of instructions followed by a physical action which generates a response. The overall time to achieve the desired goal is the sum of these times. In the paper we shall refer to these as SADCAR timings.

3. Example Scenario: Rescue of a Crane Driver

Currently, emergency management exercises are being used to develop model concepts, generate model data and assess the impact of emergency management decisions on risk reduction. The following describes a typical offshore accident scenario which has been used as an emergency management exercise and is here used to demonstrate the utility of the TPRC method.

3.1. Observed Events and Emergency Management Responses

During a lifting operation a crane driver (CD) drops a methanol tote tank which is damaged causing methanol to leak. The crane driver reports the initiating incident to the control room immediately. After 31 seconds the control room operator sends a tannoy message to stop all hot work. A leak is confirmed after 56 seconds and after a further 20 seconds the deluge is activated on the surrounding areas. The Offshore Installation Manager (OIM) is called 42 seconds into the incident and arrives almost immediately i.e. 6 seconds later. Fire is detected after 96 seconds. The OIM orders fire teams away to investigate and attempt to control the fire and asks the radio operator to order helicopters for evacuation of non essential personnel(NEP). NEP are called to muster stations with a tannoy after 153 seconds. After 192 seconds, some 96 seconds since the EMT became aware of the fire, the crane driver reports that the cabin is getting very hot and finds himself trapped by the escalating fire. The control room operator tells him "stay where you are, help is on the way". The OIM orders a second fire team to the helideck to reduce risk of fire interfering with helicopter evacuation should this be necessary. The heat of the fire around the crane driver's cabin continues to increase until, 83 seconds later and unknown to the EMT, the crane driver is forced to jump from the crane cabin into the sea. Luckily he is spotted by the stand-by vessel who reports a MOB to the EMT 44 seconds later and a fast rescue craft is launched to pick up the crane driver. It takes some time to work out that this is the crane driver. In the event, he is rescued alive, but unfortunately dies later in the Fast Rescue Craft (FRC).

3.2. Post Exercise Analysis of EMT Performance

The key question, is the extent to which the emergency management team is able to influence the progress of the incident and the outcome. If the risk reduction can be estimated then this can be used as a measure of performance of the team as well as providing a useful input to the QRA and the installations safety case.

The post exercise analysis requires an estimate of the probability that the task is achieved within the time available and requires an estimate of the following data.

1. Times to initiate management action
2. Distribution of time required to achieve the goal/objective
3. Distribution of time available

Time to initiate management action: The first stage of analysis is to determine the SADCAR timings. These are obtainable from the exercise if it is carefully and continuously monitored (indeed the emergency management team itself has the task of recording this information) However, the exercise controllers must have accurate independent measurement of all timings to support this analysis.

Time required to achieve EMT Objective: The first stage is to identify the goals that the EMT were trying to achieve. There are a number of these throughout the incident, some specific and others more general. As the incident progresses, new situations emerge which generate new goals but each goal is associated with a desirable outcome which after the exercise can then be analysed to generate a decision tree. In the exercise the major goals identified by the EMT were:-

1. Check to see if there is a methanol leak
2. Prevent ignition of the methanol
3. Prevent loss of life, given the ignition and fire
4. Prevent escalation of the fire
5. Rescue of the crane driver from the cabin
6. Rescue of the MOB (crane driver) from the sea

Each situation and goal has a corresponding set of SADCAR timings which must be completed within the time demanded by the particular circumstances. The analyst has the task of identifying and measuring these as inputs to the model.

Check Methanol Leak: The first goal was to check whether the dropped tank had resulted in a leak. In this particular scenario there was no possibility of preventing the leak since it was decided that the leak would occur at the same instant the tank was dropped and it was also assumed that the leak rate could not be reduced. However, the action to check was worthwhile since it provided early evidence of the need for emergency management to prevent ignition and fire escalation.

Prevent ignition : An important goal identified early in the exercise was to reduce the likelihood of ignition. Action was taken to stop hot work and moments later to initiate deluge which would have a large effect on preventing ignition. The impact of the leak → ignition SADCAR timings on risk reduction were estimated by measuring the management response times during the exercise and using this in combination with statistical data on the probability of ignition, with and without hot work in progress and with and without deluge. If such data are not available for the installation in question then efforts should be made to obtain these data. However, for the purposes of an exercise, expert judgment can be used to estimate the probability as shown in Fig. 5.

Reducing the potential loss of life. With a large number of POB (In this scenario, POB are assumed to be 40), should the fire escalate out of control, the potential loss of life would be significant. The OIM correctly ordered NEP to muster stations ready for evacuation should it be required and ordered helicopter support for evacuation. At this stage of the incident, none of the POB were considered to be immediately threatened by the fire.

Prevent Escalation of the Fire: Once the EMT were aware that the methanol had ignited, the next goal was to prevent escalation of the fire. The EMT activated the deluge on the areas at risk. They also deployed a fire team to extinguish the fire or at least reduce its rate of escalation.

Rescue of Crane Driver from the Crane cabin: The first time that the EMT became aware that the crane driver was at risk was when he reported that the cabin was getting hot some 192 seconds into the incident and some 96 seconds since they became aware that the methanol had ignited. Interestingly, up to that time, the team, although theoretically aware that the crane driver would be exposed to and threatened by the fire, had appeared to forget that he was still in the cabin. Once they were aware however, the EMT considered that the best approach was for the crane driver to stay put and hope to control the fire sufficiently to rescue the driver from the cabin. The only other alternatives being for the crane driver to escape down the ladder or jump into the sea, both of which they considered a greater risk. However, their ability to succeed with this strategy depended strongly on the discrepancy between reality and their perception regarding the rate of fire escalation and the speed with which fire team 1 could control the fire.

However, the risk perceptions of the crane driver are unlikely to be the same as the EMT. After all, he is the one directly exposed to the fire. The key decisions in the scenario affecting the crane driver become:-

1. Attempt to escape by the ladder
2. Stay put and wait for the fire to be extinguished
3. Jump to sea and hope for rescue by FRC

Contrary to the instruction from the EMT to stay put, the crane driver believed his best chance of survival was to jump into the sea. His decision was not communicated to the EMT.

Rescue of the crane driver from the sea. The first time that the EMT were aware that the crane driver was in the sea was when the standby vessel reported "man over board" (MOB). A fast rescue craft (FRC) was launched within 6 seconds of sending this message but initially the EMT were unaware that this was the crane driver and were confused by the fact that everyone was accounted for according to the muster data. In the event, the speed of rescue was in fact unaffected by this confusion. However, the sea rescue was only made possible because the stand-by vessel saw a man in the water. This was contrived by the scenario developers as pure chance. However, there was no evidence from the EMT behaviour to suggest that they were aware of this possibility.

4. TPRC Model results for the Crane Driver rescue

A decision tree describing potential accident outcomes and the crane driver's decision options is shown in Fig. 4. The decision tree is the first stage of quantification and provides a visual representation of options and decisions. There are four paths leading to the eight final outcomes, namely the attempted ladder escape, the attempted rescue from the cabin; the attempted rescue from the sea (i) assuming MOB seen and (ii) assuming MOB not seen. In this case, the EMT decisions are reflected by the values put into the TPRC model rather than in the decision tree. For the purpose of the paper only one will be examined in detail, namely the ladder escape attempt.

Fig.6 shows a composite graph of the probability of escaping by the ladder, for various delay times from the initiation of the incident. This is theoretical since it was not actually realised in the exercise. However, it gives useful data for post incident valuation. As expected, the probability of escape depends strongly on the delay before the escape attempt is made. If the escape from the crane had been attempted immediately after the incident, then his maximum probability of escape would have been close to 1. However, the probability of escape after 210 seconds delay is reduced to about 0.3 and represents poor odds on survival. Had the crane driver been instructed by the EMT to come down from the crane by the ladder immediately, his chance of survival would have improved. This is a decision that the EMT or the CD could have made but, in the event, did not.

Sensitivity tests were carried out to assess the impact of speed of escape down the ladder with speeds ranging from 1m/s to a somewhat unrealistic 10m/s. It was found that the probability of survival was little influenced by this ranging from 0.31 to 0.39.

Fig. 7 shows the effect of increasing the available time. This is equivalent to reducing the escalation rate or increasing the protection around the ladder. The EMT's action to send Fire Team 1 to spray cooling water over the ladder area would have the effect of increasing the available time. The exercise designer must decide in advance how much time to allow and what the allowance should be given for the effects of fire team deployment. This can be chosen using expert judgment. However, if realistic available times are required, some idea of time scales are obtainable from QRA escalation studies.

Similar curves can be obtained for the probability of being rescued and from the cabin and for the probability of being rescued from the sea.

The particular response times measured during the emergency exercise are measured and provided as model input. For example, the time available for escape by ladder was taken to be about 240 seconds (as decided by the exercise controller) with a coefficient of variation of 30% since this was how long it took for the heat in the cabin to exceed the tolerance limit of the crane driver. If it is assumed that the crane driver not attempt to escape down the ladder until 192 seconds into the incident, the corresponding probability of survival curves are Figs 6(d) and 7(b).

The probability of survival in the sea is shown in Fig.8. Two situations were theoretically possible, namely the probability of survival given that the CD was (a) seen by the stand-by vessel and (b) not seen by the standby vessel. Only one path was observable, namely the one which occurred in the simulation in which he was seen. The time available and its coefficient of variation can be obtained from published data on the survival times of different humans in sea water. For the purposes of this exercise, it was assumed to be 120 seconds with a coefficient of variance of 0.3. For a 30 second delay the maximum probability of survival was estimated as about 0.8. However, for a 60 second delay this fell to a probability of survival of 0.55.

The probability of rescue before dying of hypothermia, given that he was not seen in the water, is small and dependent on how soon the EMT realise that the crane driver has jumped into the sea as well as on the search strategy and the search resources. Clearly a rapid response i.e. within one minute is vital to give a reasonably acceptable probability of survival even when the MOB has been seen.

5. Discussion

Major incidents, although rare, can and do occur. Given an initiating event it is the task of the emergency response team to reduce the rate of escalation, minimise loss of life, and reduce damage to the installation and the environment. Industrial experience suggests that emergency management training is extremely effective in improving the capability of emergency response teams. However, quantifying the improvement in performance in numerical terms is recognised to be a difficult problem and to date has rarely if ever been attempted. The models and data presented in this paper represent one of the first attempts to tackle this problem and when used in conjunction with emergency management exercises and training sessions, may be used in two ways.

(i) EMT Performance Standards: In principle, the TPRC model can be used to measure the effectiveness of the emergency management team and hence support trainers in competency assessments and in performance improvement training. It is envisaged therefore that these models may be further developed to complement existing competency assessment criteria. The Offshore Petroleum Industries Training Organisation (OPITO) have published an industry wide OIM competency standard. This includes the following elements; (i) evaluation of the situation and anticipation of needs (ii) maintenance of communications (iii) delegation of Authority and (iv) dealing with stress in self and others. These are usually dealt with qualitatively by emergency management trainers. The TPRC Model raises the possibility of using measurements to quantify some of the key performance parameters.

(ii) Scenario Based QRA: The TPRC model in conjunction with emergency management exercises can be used to generate useful data for use in scenario based quantified risk assessment (QRA) studies. As with all risk-based models, acquiring the necessary input data to predict a realistic outcome probability is a major project in its own right. Some of the data required for the TPRC model are easily measurable during exercises and are therefore realistic measures of performance. Some of the timing data, however, may need to be assumed by the exercise designers and controllers. To be realistic, the latter data would need to be measured prior to the exercise; typical examples include: muster times, helicopter arrival times, FRC launch times, ESD and F&G system management times, blow-down times etc. If the exercise is full scale, then realistic times can be generated during the exercise itself. However, for smaller scale exercises, these timings must be assumed. Fortunately, these sorts of data are generally available.

The data which are more difficult to obtain are those corresponding to "available time" i.e. the time stress. These data are related to escalation rate and tolerance level (e.g. tolerable levels of heat, smoke etc.) or rate of consumption of available resources. How these change as a result of decisions, actions and emergency management is not a simple calculation and currently, for the emergency management exercises in this study, these data are based on expert judgment. However, it should be possible to improve on this situation in the future by using the results of escalation studies which would provide through, example scenarios, more realistic estimates of time available for management response. The TPRC model could then be used in conjunction with escalation studies to assess the risks associated with the various scenarios. This would also separate those scenarios which are in principle "manageable" from those which happen so quickly that it is not humanly possible to respond in the time scale demanded.

The Risk Picture: QRA studies are used to predict the probability (or frequency) and consequence of all significant events identified. Scenario based approaches using event trees in conjunction with fault trees are widely used for this purpose. The method described in this paper is complementary to these conventional analytical tools. The decision - event tree such as that illustrated in Fig.4 is similar to a conventional event tree. Decisions point to an event and the probability of the event has to be calculated. Traditionally, event data or fault tree models are used to estimate the branch probability. However, these are limited when the branch probability is time dependent. The TPRC model therefore provides a useful additional tool for predict branch probability and hence the probability of the eventual outcome. Once all the paths have been examined these can then be combined to generate a more complete risk picture.

Not all of the paths in the tree however will have been subjected to emergency management exercises. For those that have, useful realistic SADCAR data can be generated. For other cases assumed SADCAR data must be used. It would be prudent, therefore to select for emergency management exercises those scenarios which represent the greatest risk and with the greatest potential for risk reduction by emergency management intervention. In the light of the above comments, emergency management exercises should, ideally, be based on the installation safety case which will contain many relevant data for TPRC analysis. Typical major accident scenarios examined in safety cases and included in emergency management procedures include; major fire and explosion, impending ship collision, structural failure, subsea blow-out, diving incident, helicopter crash. The research team have plans to examine each of these scenarios, in detail, both for model development and to generate data for QRA.

Integration of the SMS into QRA: The ultimate performance measure of any safety management system is the extent to which management response reduces risk. The current research project has focused attention on this particular point. The TPRC methodology models the impact of time stress (time available) and the timing of decisions, actions and system responses (time required) on the probability of a particular outcome in an accident sequence/scenario. The model, therefore provides a means of measuring the effectiveness of emergency response in terms of the risk. In the view of the authors the ability to measure emergency response and assess its impact on risk is unique at this time and represents a significant development in that it provides a means by which to begin the more complex task of integrating Safety Management System effectiveness into the quantified risk assessment process.

6. Conclusions

A prototype TPRC model addressing emergency management response has been developed. At this stage model application is still within the research domain and has not been used as part of any commercial competency assessments outside the research environment. However the model is practical and is currently being used to investigate and model real emergency management exercises. Research is in progress to develop and broaden the scope of the model, particularly in its practical application, and to gather experience in its use.

7. References

[1] Klein, G. A. (1995) *Naturalistic Decision Making: Individual and team training.* Seminar presented at the Offshore Management Centre, Robert Gordon University, Aberdeen, March.

[2] Flin, R. (1996) *Sitting in the hot seat: Leaders and teams for Critical Incident Management.* Wiley, Chichester.

[3] Orasano, J. (1995) *Training for aviation decision making: the naturalistic decision making perspective.* In Proceedings of the Human Factors and the Ergonomics Society 39th Annual Meeting, San Diego, Santa Monica, CA: The Human Factors and Ergonomics Society.

[4] Fredholm, L (1995) *Decision making in fire fighting and rescue operations.* Paper presented at the Third Emergency Planning and Disaster Management Conference, Lancaster University, July, pp. 22-30.

[5] J.E. Strutt, Wei-Whua Loa and K. Allsopp *Progress toward the development of a model for predicting human reliability:* 13th ARTS. Advances in Reliability Technology Symposium, University of Manchester, April 1996.

[6] Williams, J.C. *HEART - A Proposed Method for Assessing and Reducing Human Error*, 9th Advances in Reliability Technology Symposium, 1986.

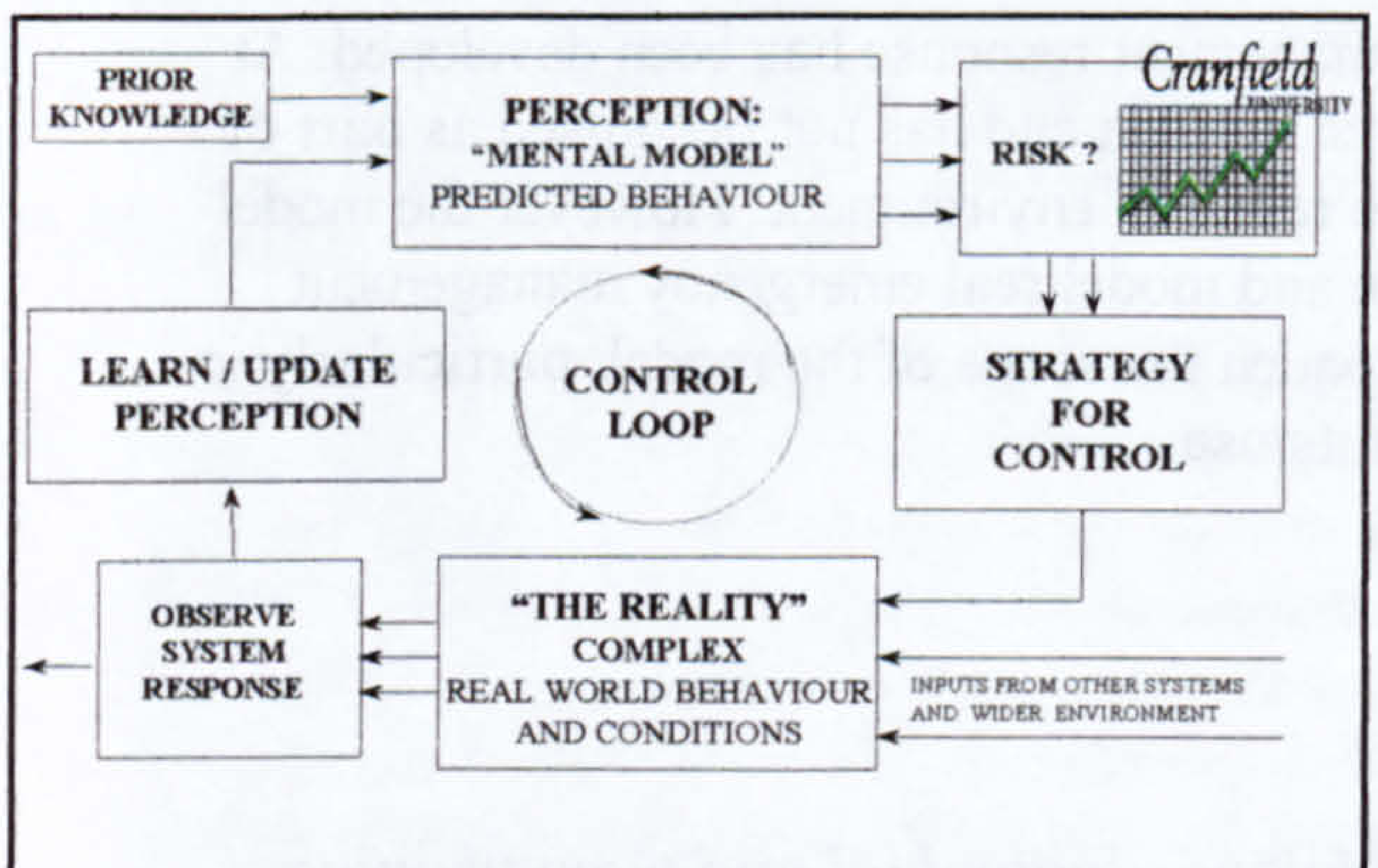


Figure 1: THE RISK CONTROL LOOP

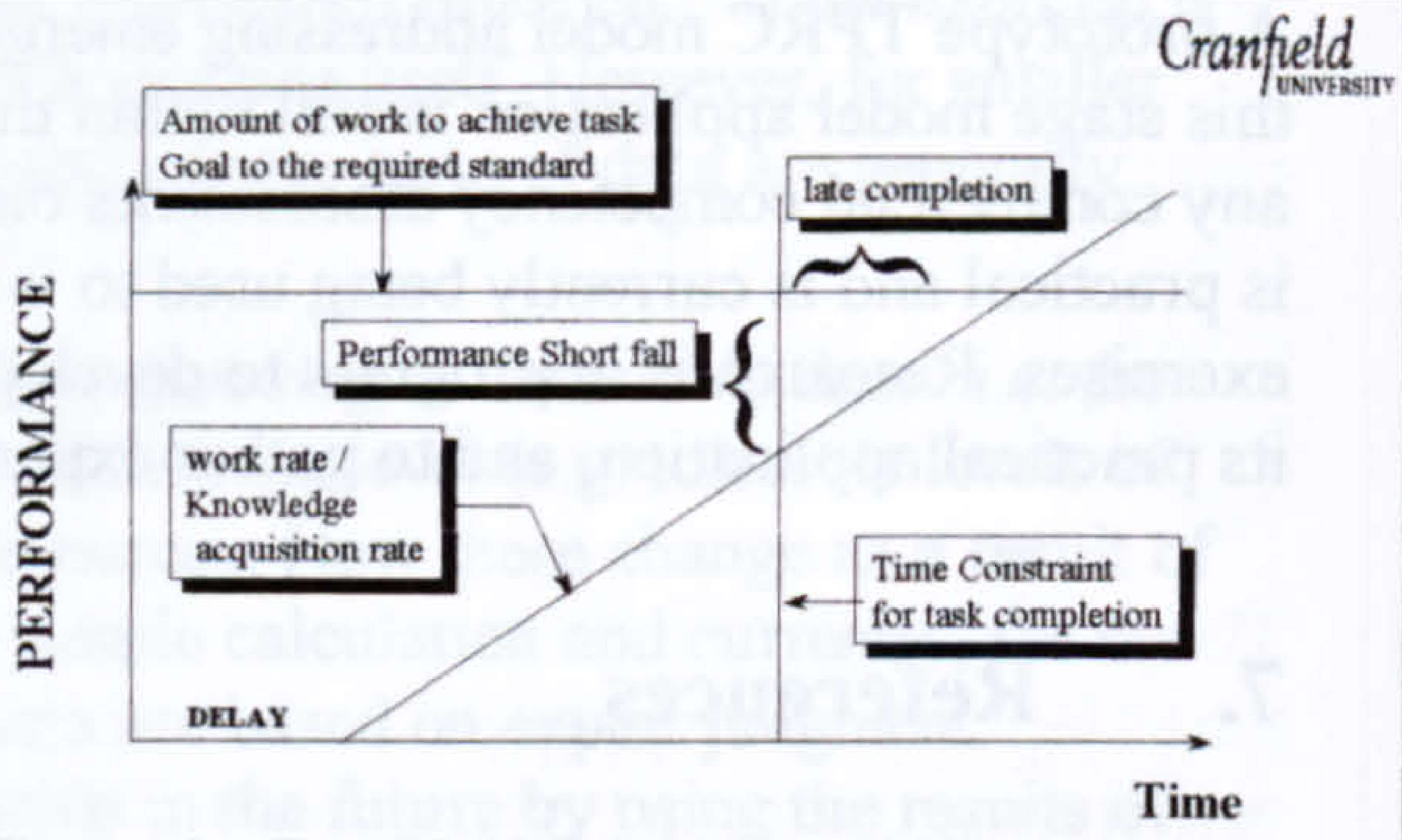


Figure 2: TASK PERFORMANCE - RESOURCE CONSTRAINT MODEL CONCEPT

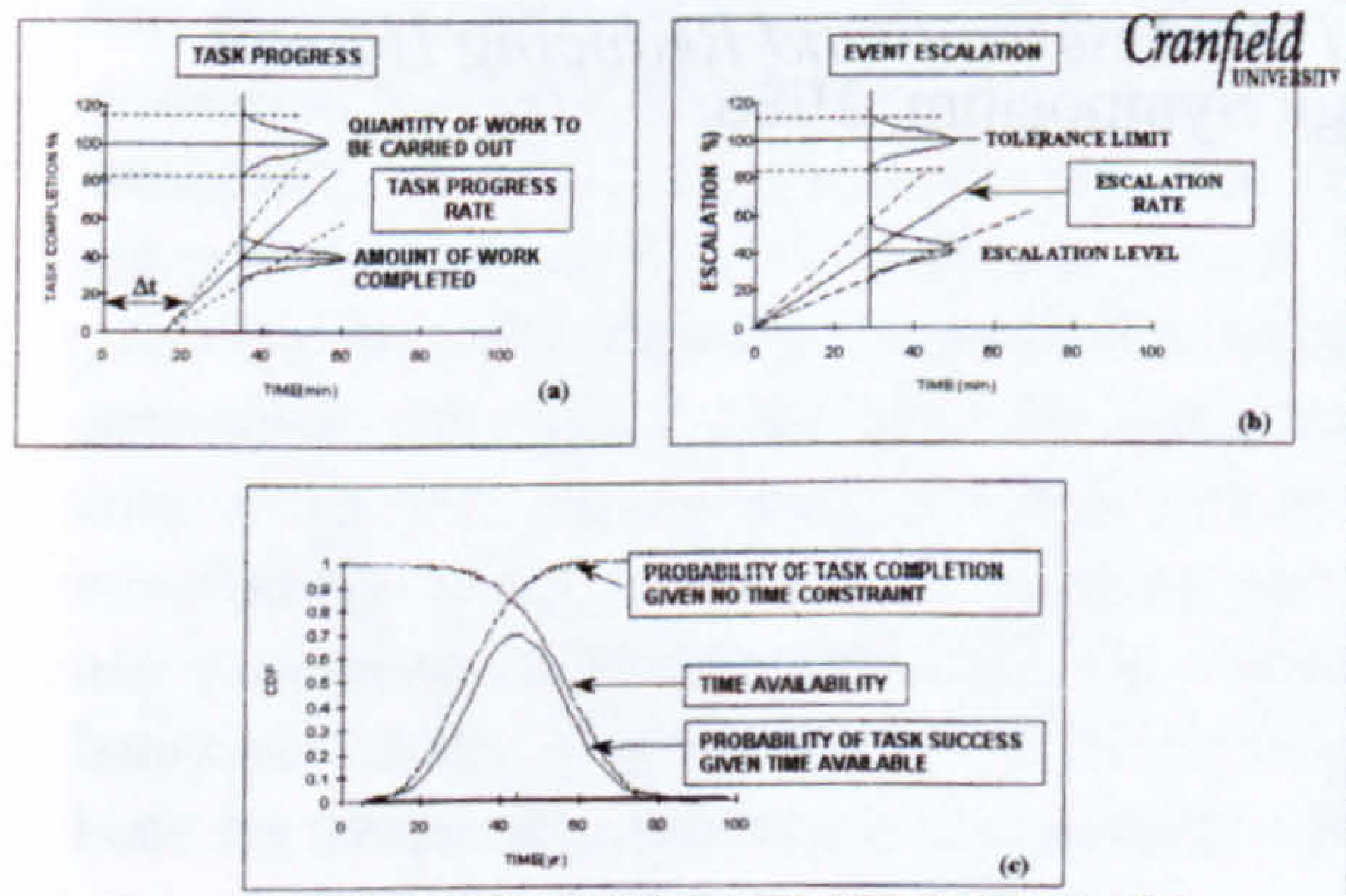


Figure 3: PROBABILISTIC TASK PERFORMANCE - RESOURCE CONSTRAINT MODEL

I: Ignition and start of fire
DN1: Attempt escape ?
D11: yes
D12: No, stay in cabin
DN2: Jump into sea ?
D21: No stay in cabin
D22: Yes, jump
EN1: Escape suceeds ?
E11: Yes
E12 : No
EN2: fire extinguished in time ?
E21: Yes:
E22: No
EN3: CD seen jumping to sea ?
E31 Yes
E32 No
EN4: CD rescued alive ?
E41 Yes
E42 No
EN5 CD rescued alive ?
E51 Yes
E52 No

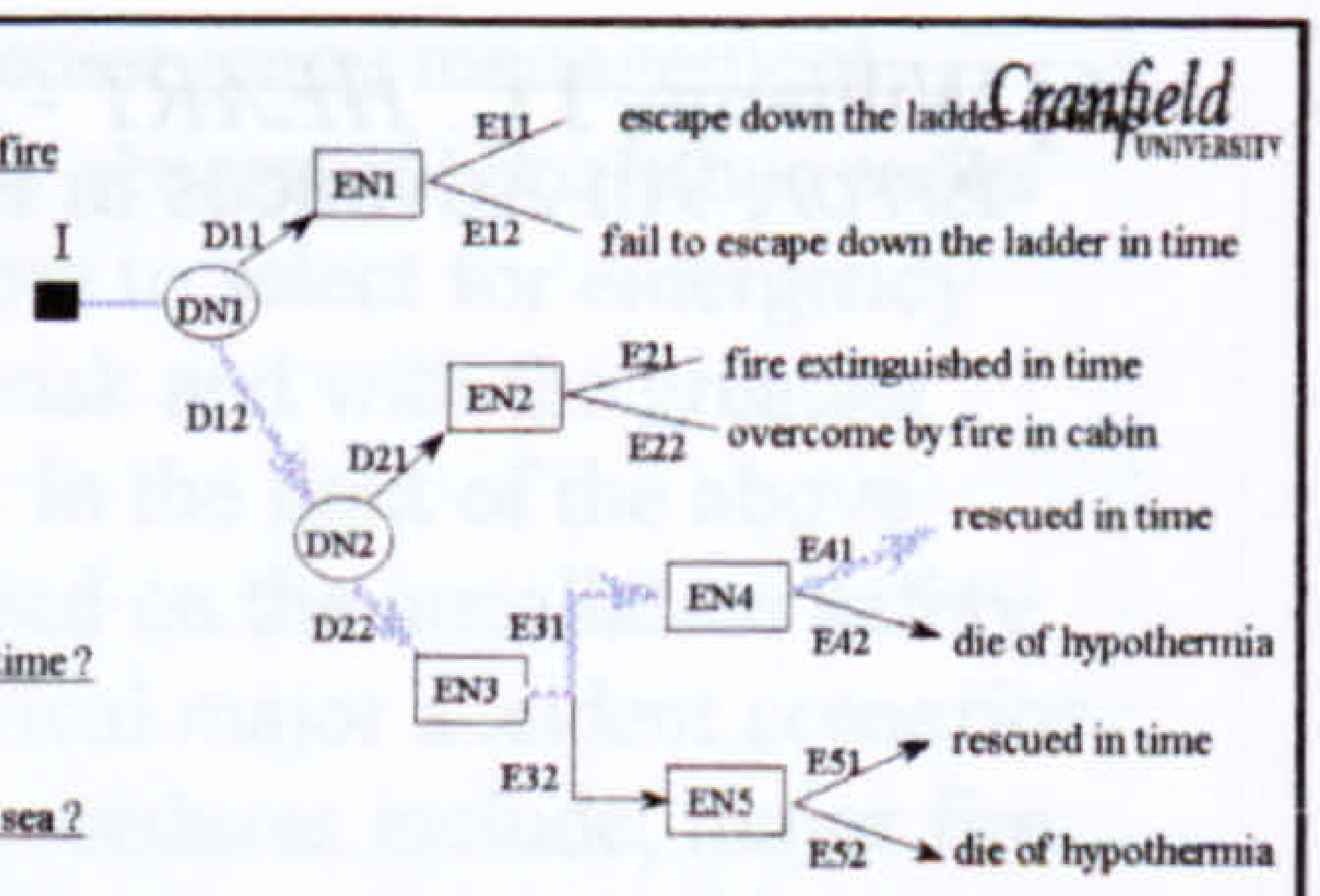


Figure 4: EVENT TREE FOR CRANE DRIVER INCIDENT

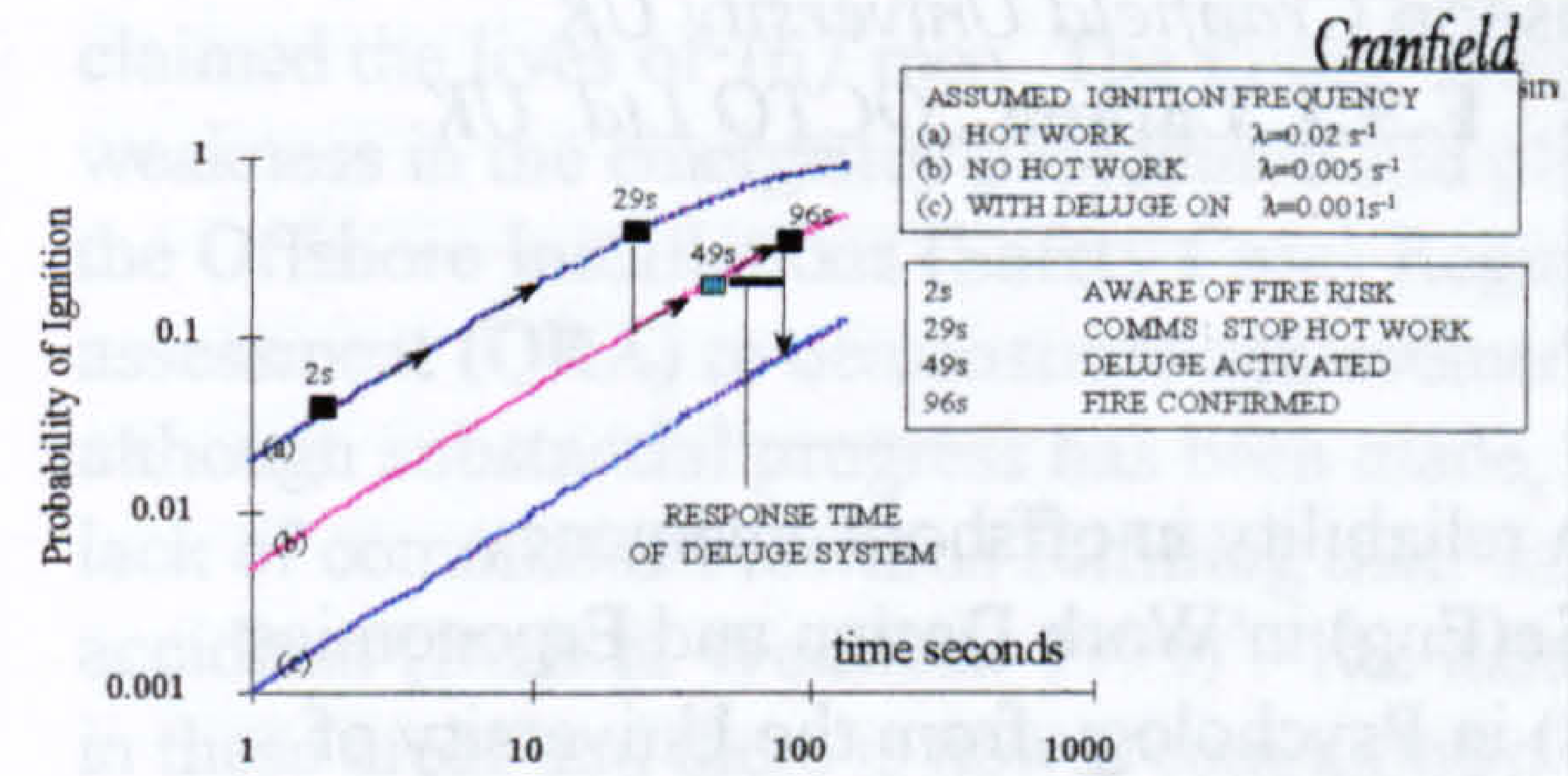


Figure 5: VARIATION OF PROBABILITY OF IGNITION WITH TIME AND IMPACT OF EMT ACTIONS AND RESPONSES

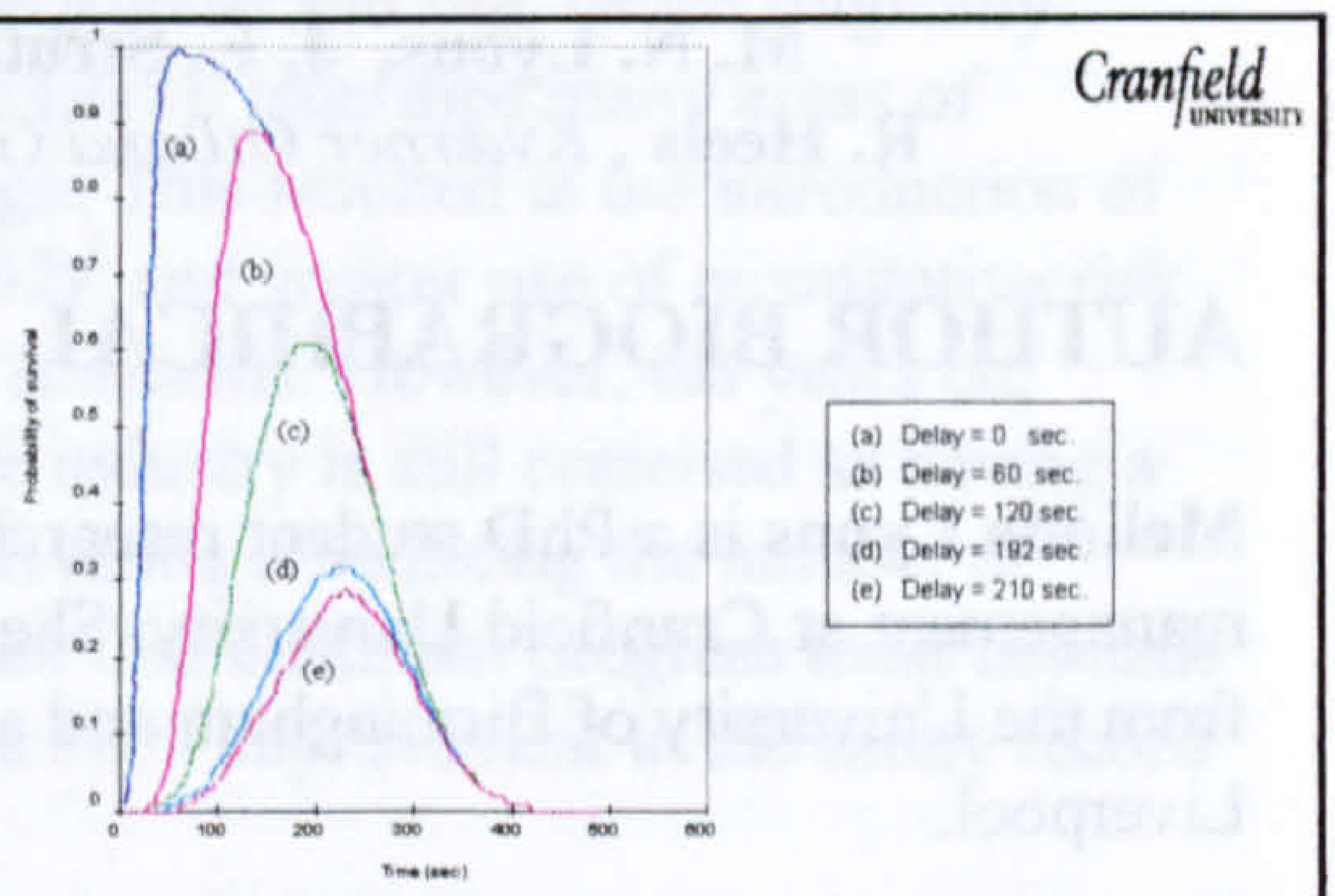


Figure 6: PROBABILITY OF SURVIVAL BY CRANE LADDER ESCAPE AS A FUNCTION OF TIME FOR VARIOUS DELAYS IN INITIATION OF ESCAPE ACTION

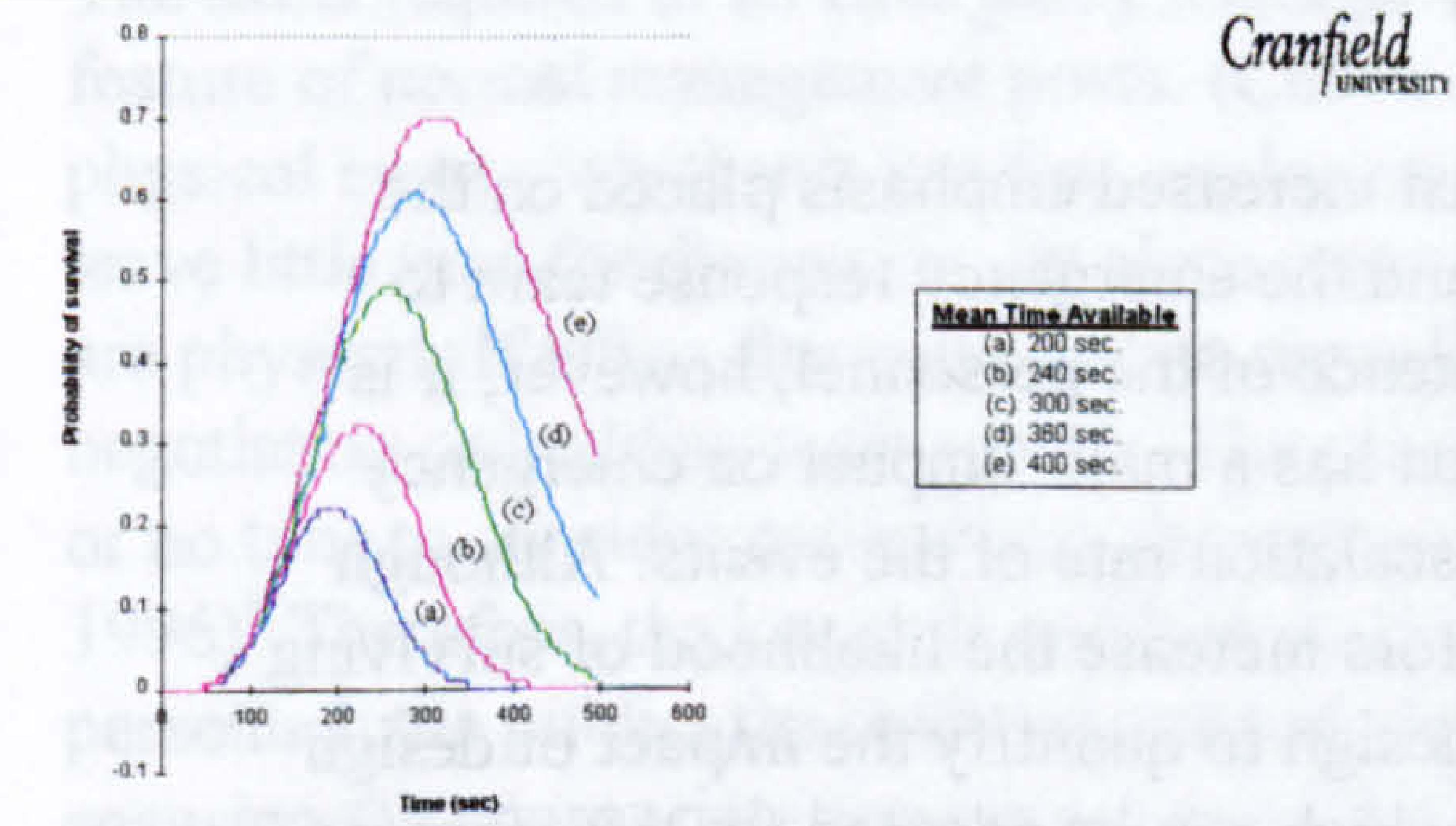


Figure 7: PROBABILITY OF SURVIVAL BY CRANE LADDER ESCAPE AS A FUNCTION OF TIME FOR VARIOUS MEAN AVAILABLE TIMES

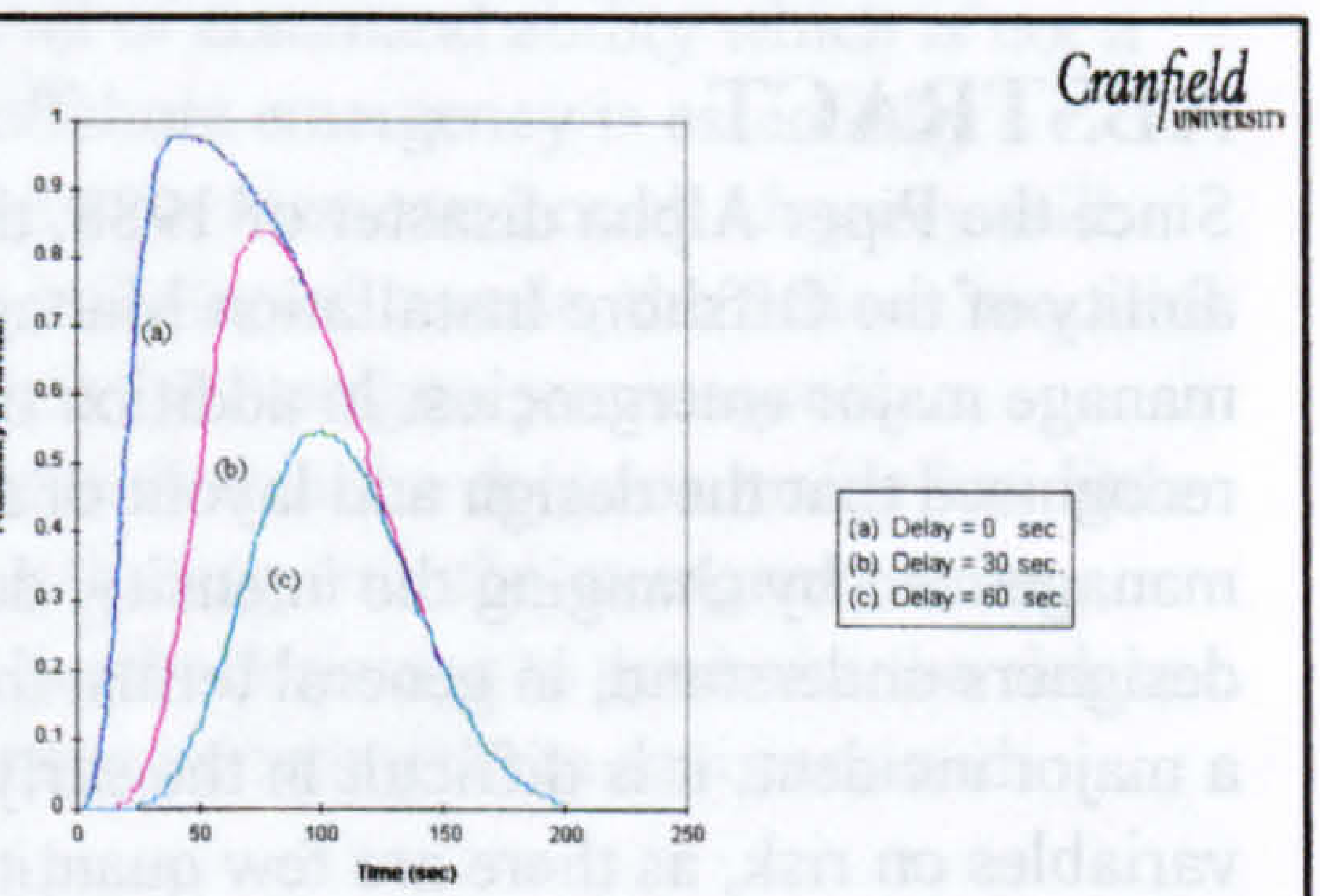


Figure 8: PROBABILITY OF SURVIVAL IN THE SEA AS A FUNCTION OF TIME GIVEN A MEAN SURVIVAL TIME OF 120 SEC. FOR VARIOUS DELAYS IN INITIATION OF RESCUE

DEVELOPMENT OF A METHODOLOGY TO ASSESS THE IMPACT OF DESIGN PERFORMANCE PARAMETERS ON OFFSHORE EMERGENCY MANAGEMENT

M. N. Lyons, J. E. Strutt & K. Allsopp *Cranfield University UK*
R. Heels , *Kværner Oil and Gas Ltd. UK,* **E.S.J. Larken** , *OCTO Ltd. UK*

AUTHOR BIOGRAPHICAL NOTES

Melinda Lyons is a PhD student researching human reliability in offshore emergency management at Cranfield University. She has an MSc(Eng) in Work Design and Ergonomics from the University of Birmingham and a BSc(Hons) in Psychology from the University of Liverpool.

John Strutt is Professor of reliability engineering and risk management at Cranfield University. He has more than 20 years research experience in the application of reliability engineering methods to offshore systems.

Keith Allsopp is a Senior Research Officer at Cranfield University with over 30 years experience in the area of mathematical modelling of physical processes.

Robin Heels is a Principal Safety Engineer with the offshore design house of Kværner Oil and Gas Ltd. He has over 20 years experience in the safety field and is currently responsible for safety analysis and design on development projects.

Jeremy Larken is a Managing Director of OCTO Ltd, a consultancy which specialises in crisis and emergency management. OCTO's spectrum of advice is from board level to major hazard plant. The key skill is the provision of direct support to those in charge and their teams.

ABSTRACT

Since the Piper Alpha disaster of 1988, there has been increased emphasis placed on the ability of the Offshore Installation Manager (OIM) and the emergency response team to manage major emergencies. In addition to the competence of the personnel, however, it is recognised that the design and layout of an installation has a major impact on emergency management by changing the intensity, duration or escalation rate of the events. Although designers understand, in general terms, that such factors increase the likelihood of surviving a major incident, it is difficult in the early stages of design to quantify the impact of design variables on risk, as there are few quantitative tools which can be adapted for this purpose. Recently, Cranfield have developed a Task Performance Resource Constraint (TPRC) model that provides a basis for estimating the probability of success in emergency management tasks. The model, which generates a time dependent probability of success, is based on the fundamental premise that a task may be completed successfully if the time required to complete the task is less than the time available to perform it. Therefore, it can be used for comparison with subjective assessments of emergency management performance. This model is conceptual rather than detailed and includes both human and design variables. This paper introduces the concept of the TPRC model, and describes, with examples, how data from emergency management exercises can be used together with conceptual design data on such parameters as intensity, duration and escalation rate to assess the impact of design on successful emergency management. This paper will include comparisons of subjective emergency management performance with that predicted by the model.

1 INTRODUCTION

In 1988, the Piper Alpha platform was consumed by an explosion and fire, which tragically claimed the lives of 167 men. The Public Inquiry (Cullen 1988)[1] identified many areas of weakness in the emergency procedures and platform design. This resulted in the introduction of the Offshore Installations (Safety Case) Regulations (1992)[2] and greater use of quantitative risk assessment (QRA) to demonstrate achievement of safety standards. However, ten years on, although substantial progress has been made, the offshore industry is still criticised as having a lack of commitment towards fulfilling their safety goals in terms of reducing the number of accidents (Beck & Woolfson 1995)[3]. The industry is aware that continual progress must be made in these areas and there is now a commitment to achieve a 50% improvement in the safety record over the next 3 years (Davies 1998)[4].

Considering the work that has been carried out over the past decade, one of the areas where there appears to be a notable lack of QRA is in the area of human reliability and emergency management. Emergency management may be the last line of defence against a major disaster and yet there is still no objective methodology to assess the competency of the emergency response team. Some researchers have worked to identify the critical personality attributes associated with good emergency management for use in selection procedures. Few of the attributes, however, were found to correlate with subjective ratings of performance (Flin & Slaven 1995)[5]. Therefore, the only reliable data currently available to assess emergency management competency is performance in simulations of the emergency tasks themselves. The guidelines prepared by the Offshore Petroleum Industry Training Organisation (OPITO 1992)[6] and approved by the UK Offshore Operators Association Ltd (UKOOA 1997)[7] set criteria for standards of competence in emergency simulation for the industry. However, they are essentially subjective, relying on observational techniques and emergency management experience and so are unlikely to be developed into a quantitative methodology.

The skills required of an emergency manager demand a level of command ability which is not a feature of normal management posts. (Cullen 1988)[1] An offshore emergency is essentially a physical event - whether it is a fire, explosion, dropped object or man overboard. Urgency will leave little time for discussion, let alone negotiation or the building of morale, the actions required are physical. If left, a fire will escalate regardless of whether the emergency manager is negotiating or building team morale. The time constraint is such that the decision maker has little or no time to consider options and alternative strategies for dealing with the emergency (Flin 1996)[8] Therefore, the key skill involves making good and timely decisions to minimise the risk to personnel, the public, the environment and plant assets, communicating these decisions and ensuring the appropriate actions are carried out quickly.

In Strutt et al (1997)[9], the Task Performance - Resource Constraint (TPRC) concept was introduced as a method for objectively testing emergency management team (EMT) competency. This concept involved the modelling of the speed of the emergency management task against the time constraint of the escalating emergency and gives a result in terms of a prediction of the probability of success in the task. For example, the task may be that of rescuing casualties from a fire, the constraint in that case might be the level of escalation at which the fire would be impenetrable. Using the response times of the emergency management team, given this task, the model provides the probability of the team completing successfully this aspect of the emergency and rescuing the casualties before the fire becomes impenetrable. Clearly, the designer can have an enormous impact on the ability of the EMT to control an incident. The designer can reduce risks by extending the time available and/or reducing the time required to deal with an emergency. This may involve increasing the precision of detection systems, enhancing communications systems and improving the effectiveness of fixed fire-fighting systems and barriers to limit escalation. Further to this, the design of the installation must also facilitate the impact of emergency management. If the installation design is poor, there may be limited time for a good emergency management decision to have its desired effect. The Regulations have now been updated to include requirements for Performance Standards in the Safety Case of an installation (HSE 1996)[10]. These Standards define the Safety Critical Elements in terms of criteria against which their performance can be verified. In the case of emergency systems, these must show that they are resilient and reliable in the worst possible scenario. For example, The Cullen Report (1990)[1] recommended that the TR (temporary refuge) should remain secure for 1 hour. Using data on the potential of human performance, we can assess how the human factor can cope with an emergency. Once these measurements, in terms of realistic performance of personnel in emergencies, have been established with confidence, they can be used as performance standards. They should then contribute to the design of installations, with a view to promoting a positive outcome to foreseeable emergencies. Assuming that, with practicable levels of training, personnel cannot improve their performance beyond certain limits, designers need to ensure that such worst-case emergencies will not threaten these limits. These Safety Performance Design Indicators would therefore specify the minimum levels of acceptability for all aspects promoting survivability and emergency control. Using a distribution of the human performance data obtained in the emergency management scenarios and a generic escalation model, the design aspects can now be assessed to identify their impact on the emergency management team's probability of success. This means that future installation designs can be tested for their emergency survivability potential and if necessary, rejecting certain aspects at the design stage rather than making more expensive changes at the installation phase. This paper describes how the TPRC concept can be used to assess the impact of both emergency management and design changes using a helicopter crash scenario as an example to demonstrate the program's potential capabilities.

2 RESEARCH METHOD

The method involves the collection of both theoretical and practical data to be used within the TPRC model described below. The flow of data in the modelling process is described in Figure 1. For example, in an emergency management competency assessment, scenarios are role-played as if it was a real emergency. The details of the scenario, such as the initiating event, weather conditions, the planned progress of the incident, the expected actions of the emergency management team and the worst possible outcome can be established before the assessment has started. In addition, the design criteria, such as the size of the platform, available safety systems and possible risks can be identified from the plan of the installation. Finally, the scenario is run and the human performance data may be recorded, such as the reaction times in giving and obeying orders and responding to incoming information. Following the solid arrows in Figure 1, these pieces of information are brought together to identify the events and tasks present in the scenario. In some cases, the emergency management team may have overlooked tasks that were identified as necessary in the scenario plan. In other cases, the emergency management team may have surpassed the expectations of the examiners and may have pre-planned for certain eventualities hence preventing their occurrence in the scenario. Once the events and tasks have been identified, the numerical values corresponding to their performance are evaluated using the TPRC model. These include speed of actions, time delays, distances and so on. This process will be described in further detail in the next section. The TPRC model will then produce a probability of success graph for each task. However, this flow of data describes only the primary role of the

TPRC concept. As can be shown in Figure 1, the model shows data flowing not only from the boxes showing Scenario Data, Design Criteria and Human Performance Data, but following the dotted arrows, it may also flow back into them. This can be used to facilitate the identification of Safety Performance Design Indicators. For example, the Human Performance Data over a number of scenario performances using many emergency management teams can be recorded in terms of generic tasks, e.g. Given that an incident has occurred, the average time delay before ordering a muster. Using standard scenarios, for example, gas explosion, ship collision, helicopter crash, these human performance data may be fed into the TPRC model without requiring the assessment of an emergency management exercise. Therefore, it is possible to manipulate design data, for example, lengthening the distances between muster point and incident, and examine its impact on the probability of success in respective tasks. If the Probability of Success graph is given a lower limit at which the risk is considered to be "Acceptable", this could provide information on the acceptability of future designs at the conceptual stage. New designs may also provide new risks that must be considered in the Scenario Data – hence providing new scenarios for evaluation. The following sections describe the changes to the TPRC model to enable this process, the data which must be collected for the TPRC model to work and an example scenario explaining how these two main applications work

2.1 Review of the TPRC Concept

The principal idea of the model (shown in Figure 2 and described in more detail in Strutt et al 1996)[11] is that the probability of a successful outcome of a particular emergency management task depends on the difference between the time available and the time required to complete the task. Such a "Task" may involve getting a fire team to an incident, stabilising a casualty for evacuation or activating process controls. The time available involves the upper limit (i.e. a deadline) before which the task must be completed. The time required is modelled as a combination of a time delay preceding a task. The total time is delay plus task duration and is an uncertain variable. The task time is calculated from the rate of execution and target performance level. The probability of successful completion is the probability that the actions performed exceed those required to complete the task to the required level of adequacy. Given, enough time, it is assumed that this probability will eventually reach unity. However, if time is limited, then the probability will reach a maximum and then decrease to zero as the available time expires. The time available can be compared to either a resource consumption rate or an escalation rate, depending on the task to be evaluated. For example, in a task involving the use of breathing apparatus, the resources being consumed are air, and also the physical and mental capacity of the user to function effectively in these conditions in the vicinity of the actual fire. However, in a fire-fighting exercise, the time available may be determined by the escalation of the fire. With reference to Fig.2., the probability of success evolves with time. For a scenario in which there is an approximately linear response rate and a relatively slow escalation rate, the probability of task success can be expected to grow. However, since escalation results in a decreasing probability of time availability, the joint probability of success exhibits a maximum, as shown in Figure 3. The time at which the maximum occurs and the maximum probability depends on the rate of task execution, the rate of escalation and the initial delay. The faster the rate of incident escalation, the greater is the requirement for a rapid rate of knowledge accumulation and management to achieve task success. This model provides the main body of the processing in the final program structure to be described in the next section.

2.2 Data Collection

The data required by the program involve both theoretical and practical knowledge of generic emergencies and the installation including; data on human performance, the scenario, the installation design and layout and escalation data.

Human Performance data: The data on human performance in the emergency management tasks are mostly provided by the continuous video-recording of emergency management assessment scenarios. These data include delays in making particular decisions, the times taken to communicate these decisions and reaction times to respond to alarms. This involves the SADCAR (Situation Awareness, Decision, Communication, Action and Response) concept whereby each task may be split into these parts. In an emergency, once an event has occurred, there is a delay before the EMT are aware of the event, then a decision must be made to response to the event. This decision must be communicated resulting in an action. Finally, the system will respond to the action, perhaps producing another event.

When observing the scenarios, the situation awareness and decision provide a delay. If there is no response to an event, it may be unclear whether the emergency manager is deciding what to do about an event or is simply unaware of it. The communication and action are observable and so can provide some indication of emergency management performance. In some cases, the action itself may be a communication, for example, to warn personnel not to enter a hazardous area. The data on the scenario and escalation data should have been pre-planned before the exercise is run. This involves information on the initiating event and the expected progress of the emergency. The plan has to be flexible to reflect the potential for different actions by the emergency management team.

The data can mostly be recorded from observation of the emergency management scenario including times for movement of personnel and actual times for fire escalation and casualty status changes. For example, the time at which a casualty is beyond the help of medical assistance. In training exercises, these may not always be appropriate or based on accurate real-life information as unexpected events provide a challenging test for an emergency management team. However, such times reflect a <u>possible</u> situation and such data may also be available from examination of real incidents and alternative models - for example, fire escalation models - to validate the scenario. Some of the required information may not be obtainable by observation but must be inferred from theoretical knowledge on human performance and the recommended emergency procedures - for example, the expected breathing rates and time limits for using breathing apparatus and walking speeds.

Design Data: The model uses installation design data. Typically this includes; the number of personnel on board, the distances from the safe haven to incident, the distance to the closest helicopter rescue and other support facilities, the availability and redundancy of safety, warning and control systems, and the degree to which protection is provided by safe havens. This also considers the system performance - for example, the time taken to shutdown or blowdown and the respective speed of rescue helicopters.

Qualitative Analysis: Data for the qualitative assessment of emergency management performance was recorded using a questionnaire (Appendix 1). For each unit action, the examiner(s) were asked to evaluate whether it was the best response given at the most appropriate time. These questions were then compared to the values recorded for the TPRC modelling process, e.g. where the decision was appropriate, the delay in making a decision, the speed of the task and the time at which the task must be completed. If there were any discrepancies between the emergency management team's performance and the ideal response, the examiner was asked to indicate these. For each unit action, the examiner was asked to indicate the task performance using a choice of "Highly Competent", "Competent", "Notable Shortfalls" and "Not Competent" consistent with the OPITO method of assessing emergency management competence. Finally, they would also use these terms to give an indication of the performance in the whole scenario.

2.3 Example Scenario: Crew-change helicopter crash

The following section describes an example of how the TPRC method can be used to assess emergency management and design changes.

2.3.1 Summary of scenario description

This particular scenario involves the crash of a crew-changing helicopter on the helideck of an small installation (POB around 40). The impact is felt throughout the platform and one-second later a fire is detected on the helideck. 12 seconds after the impact, the production supervisor orders a shutdown and blowdown of the platform and orders the control room operator to announce a muster. This is carried out and 19 seconds later, the Offshore Installation Manager (OIM) arrives in the control room to assume command of the situation. 31 seconds later, a radio message is received giving details that the helicopter has hit the deck and fallen on top of the power generation package. There are two casualties on the helideck and a great deal of wreckage, but most of the wreckage is still burning. 1 second after this message is received, the OIM orders the deluge on the whole platform and this is activated within 2 seconds. However, at the same time, all power fails on the platform. 25 seconds later, 71 seconds after being initiated, the muster, although not complete, is adequate to provide a fire team to provide help on the helideck. The fire team leaves 30 seconds later - led by the on-scene commander. They now are aware that there should be 10 on the helicopter including the pilot.

Meanwhile, 35 seconds after losing power, the helideck team request a medic plus four people. The fire team takes 1 minute to arrive on the helideck and 32 seconds later, the on-scene commander realises that they will need the assistance of another fire team. 10 seconds later, the muster is confirmed complete and it takes 98 seconds before the second fire team is sent. Obviously, the loss of power causes some delays in the process as no alarms, controls or tannoy systems are available. 5 minutes and 18 seconds after being requested, the medical team confirms that they are with the casualties on the helideck. The main route from the hospital has been blocked. 3 minutes and 50 seconds after the power loss, some 4 minutes and 55 seconds into the incident, the OIM asks for helicopters to be ordered to evacuate the platform. It takes 1 minute and 13 seconds for the second fire team to arrive on the helideck. Meanwhile, the on-scene commander announces that the fire in their current position is getting too intense for them to continue fighting the fire. There are diesel, oil and helifuel fires, though the methanol lay down area currently looks safe. They decide to move to the GCD (gas compression deck) and to use the hoses from there. Once the second team arrives, they both leave the GCD, taking 2 minutes and 48 seconds to get there. 1 minute and 14 seconds later, they order yet another fire team, which is sent 37 seconds later.

Meanwhile, the medical team requests a stretcher team. Personnel resources are now at a minimum and it is 3 minutes and 18 seconds before this team is actually sent. It is now 1 minute and 3 seconds after the 3rd fire team was requested and the on-scene commander reports that there was penetration of a blade and that the helifuel supply is now on fire. He advises that there should be no entry to the accommodation, particularly the hospital below the helideck. 1 minute and 8 seconds after this is reported, the OIM decides to dump the methanol storage and this response is initiated within 10 seconds. 49 seconds later, the on-scene commander suggests that the fire has destroyed most of the power generation area, the lay down areas and no further survivors should be expected from inside the helicopter. 1 minute and 22 seconds later, he adds that the lifeboat on that side of the platform should also be considered as too dangerous to attempt to use. 17 seconds later, he adds that they are laying down a foam and water blanket on the bridge to the gas compression deck. 20 seconds later, the medic asks for a safe haven to work on the casualties. 11 seconds later, the medic is told to move the casualties to Muster point 3 on the separate well-tower and is provided with a safe route. 54 seconds later, the OIM decides to move Muster point 2 near the unusable lifeboat to Muster point 3. Muster point 2 now only includes one man as all the others were required in fire or medical teams. 1 minute and 29 second later, the on-scene commander advises that no helicopters should land on the main helideck in its current state. This order is announced to the helicopters within 8 seconds of the message. 1 minute and 32 seconds later, the OIM orders the medic to prepare the casualties to be winched-off by helicopter. 5 seconds later, the medic reports that it will take 15 to 20 minutes before the casualties have been stabilised enough for evacuation. 23 seconds later, the blowdown is complete and the scenario ends 34 seconds later without further incident. The first helicopter is expected a minute later than the end of the scenario.

2.4 Scenario Analysis

2.4.1 Emergency Management Team Objectives

In general, emergency management teams are required to bring the situation under control, reduce the rate of escalation and/or spread of the incident and to minimise the loss of life and limb. These decisions should ideally be the right decision but it is also necessary for them to be timely, as a good but late decision may result in an poorer outcome than a poor early decision. From this scenario description, it is evident that the emergency management team has a number of objectives. For use in the model, these may be described in terms of tasks and resources in Table 1. It is notable that trying to regain normal power functioning is NOT included in the above tasks. Following the scenario, it was agreed that such a power failure would not have been a likely occurrence in a real situation of this kind. However, as a test scenario, a total power failure is a useful exercise. It presents a situation of extreme damage with a serious risk of further ignition occurring.

2.4.2 Design Objectives

A number of design features can be identified as having an impact on the outcome of the emergency management decisions in this scenario. In general, the design objectives are to reduce the likelihood of ignition and loss of life and to reduce the rate of escalation. This involves complex analysis of the flow of events in an emergency. However, using the scenario, assumptions can be made about the abilities of emergency managers and these can be fed back into the design process. For example, if it is observed that it takes a minimum of 3 minutes to get a fire team to an incident, the design should attempt to ensure that a fire cannot escalate to a level where fire teams are unable to set up hoses or monitors. This involves analysing the problem from two perspectives; the effectiveness of the fire water systems once operating and the potential escalation of the fire (fuel inventory and materials).

Currently, there is a move away from the use of large heavily-manned platforms towards small, unmanned platforms. This is seen to reduce overall risk as the average number of personnel on board over time is very small. However, once these personnel are present, they are at a larger exposure to risk, with very little assistance and very few resources available to meet an emergency. In addition, it must be noted that such unmanned installations may not be subject to the same criteria as a large manned installation. Using the recommendations made by Cullen (1990)[1], TR integrity should cover the time required to muster all personnel, assess and control the situation and evacuate if appropriate. The HSE state that an endurance time of at least 1 hour is likely to be necessary. For not-normally-manned platforms the facilities should be available for rapid evacuation and so the TR endurance time may be less than 1 hour. If such standards are lowered to cater for more efficient systems that are not present, there is a risk that when the systems are NOT ideal, the lower standards may still apply. For example, if we consider the current emergency, Table 2 shows a list of some of the factors that could be adjusted by design changes. Overall, this describes the main impact that design has on this particular scenario.

3 RESULTS AND DISCUSSION

The results must be considered in 3 main sections. The first section considers the data that were actually used for input to the model. The second involves TPRC modelling of the implications of design changes on such decisions. The third section includes the TPRC results of these emergency management decisions and the subjective opinions of these decisions with examples of TPRC modelling of ideal decisions.

3.1 Data Input

Some of these data have already been introduced in the description of the observed scenario. These will be split into two sections; those data that are the responsibility of the emergency management team and those that are the responsibility of the scenario organisers, i.e. those data that are indicative of the team's performance and those that are outside of their control. The rest of the data is obtained from theoretical information on performance, some assumptions on performance and the design criteria.

Casualty survival data: To date, there have fortunately been no helicopter incidents that follow the specific pattern of events described in the scenario. Therefore the level of injuries are difficult to predict. The data on the expected survival of the casualties in the scenario must therefore be calculated using model parameters. Hymes (1983)[12] suggested values at which thermal radiation of various levels produced pain, second degree burns and finally, death. It was suggested that thermal radiation over 5 kW/m^2 would cause pain in about 10 seconds and second degree burns on exposed skin after 2 minutes. Levels over 12.5 kW/m^2 would produce pain after 4 seconds, second degree burns on exposed skin and 50% lethality after 2 minutes. Additionally, the values of Carbon Monoxide are also considered. Stensaas (1991)[13] suggests that a CO concentration of 6000 ppm would cause dizziness in 1-2 minutes and danger of death in 10-15 minutes. A concentration of 12800 ppm would cause unconsciousness in 2-3 breaths and danger of death in 1-3 minutes. The casualty survival times are shown in Table 3.

Fire Escalation data: These data are based solely on the scenario description and so are at the discretion of the scenario organisers. Fire escalation is based on reported events – in this case, the spread of fire across the area of the platform. See Table 4 for timings and full descriptions.

Observed data (responsibility of emergency management team): These data are shown in Table 5.and represent the performance and decisions of the emergency management team. These have been extracted from the description of the scenario as shown in section 2.3.1

Observed data (organised by scenario organisers): These data are shown in Table 6 and represent the timings that were under the control of the scenario organisers. This could involve the deliberate manipulation of the resulting events to test the emergency management team.

Design data: This includes the data that can be affected by designers and is shown in Table 7. This includes information on both the installation and relevant moving vessels, e.g. standby boats and helicopters. It includes distances and system potential.

3.2 TPRC Results

Using the times recorded in the scenario and the given design criteria of the platform, the TPRC program can be run to give the probability of success, P(S), in each task. This provides a curve that shows a maximum probability of success at a point in time. Due to the uncertainties in the tasks and resources being incorporated into the model, over time the probability will change. However, the maximum value is a good general indication of the overall probability of success in the task. In the observed scenario, the maximum results obtained are shown in Table 8. These results show a wide variation in the P(S) in the tasks, which in some cases may be due to delays in reaction from the emergency management team and in other cases due to the pure design of the scenario. For example, the first four results show the maximum P(S) in arriving and treating the casualties in time. These are dependent on the injuries sustained by the casualties and so, would normally be out of the control of the emergency management team. However, in theory, shorter distances, faster responses, a larger medical team with better medical training could all improve these results. The tasks with the highest P(S) are those tasks which require only a short duration, for example tasks involving giving short pieces of information (informing personnel that the lifeboat should not be used before this is attempted) or using equipment in the control room (activating deluge). The tasks that resulted in low maximum P(S) were generally tasks involving movement or gaining control of situations (eg. Stabilising casualties or controlling fire) which are generally more uncertain or take longer to execute. These results only give information that is specific to the observed scenario. Therefore they are indicative of emergency management performance and do not give the full potential spread. Given a scenario that escalates into a tragedy in seconds, even the best emergency manager would show low maximum probabilities of success. It is only with comparison with idealised results or subjective data based on the same given scenario that they can give an indication of either emergency management problems or design deficiency.

Impact of emergency management improvements: The TPRC results for those with emergency management changes are shown in Table 9. Improvements in emergency management skill are not shown for every task as in some cases there was very little improvement to be made (e.g. Shortening the delay before the first fire team was sent to the site by a few seconds). However, the results demonstrate where improvements can be made in terms of the P(S). In comparison with each of the TPRC results for the Scenario data, it can be seen that the emergency management improvements all show increased maximum probabilities of success. Most of the improvements are based on simply reducing delays from events to ordering actions or making communication. In the case of the task of stabilising casualties, the task involves providing more medical assistance which would allow the each member of the team to concentrate on each casualty exclusively. This may require the fire team 3 to be brought back from the GCD to assist with casualties instead of fire-fighting.

Impact of design improvements: The TPRC results for those with design changes are shown in Table 10. Again, design changes are not shown for every task as in some cases, such improvements would not make a substantial difference as other factors play more of a key role. In comparison with each of the TPRC results for the scenario, again the design improvements all show increased maximum probabilities of success. One of the particular improvements is the probability of achieving control of the fire before escalation level 2 (ignition of diesel and helifuel) from 0.23 to 0.96 by using an improved foam monitors and a fire-retardant design of the helideck. Most of these improvements are made by increasing the effectiveness of fire control systems which would have the combined effect of increasing the task progress of fire-fighting and decreasing the escalation time.

Improvements in both Emergency Management and Design: The TPRC results for those with emergency management and design changes are shown in Table 11. Again, these show improvements from when either the emergency management practice or the design was changed. In the case of the probability of success of getting the stretcher team to the casualties before the fire impinges on the Weather and Mezz decks, given emergency management and design changes, the maximum value is 0.98. However, just because the maximum probability of success is so high does not mean there is no room for improvement. Even when this maximum value reaches values higher than 0.99, the time at which the maximum is reached can be brought forward and the duration over which the probability of success is high can be sustained. It is now that the use of a curve shows its merit. A single value giving the maximum probability of success is unrealistic where tasks show uncertainty. This point is illustrated in Figs 4,5 and 6 which show examples of the impact of design and training improvements on the probability of success in emergency management tasks. It can be seen that the influences of emergency management generally affect the leading edge of the curve, i.e. the speed of the task. Whereas, design generally influences the tailing edge of the curve i.e. the time available or the escalation of the incident. From these 3 examples, it would seem that the design (and hence escalation speed) has a stronger influence on the probability of success than emergency management, but of course, ideal design and emergency management practice produces the optimum results.

3.3 Subjective Assessment

The results obtained from the questionnaire are shown in Table 12. Further to this, the assessment team judged the candidate as being "Not Competent" as there was no clear strategy and vital decisions were missed. They believed the candidate was responding to the events in the situation rather than predicting them and preparing for them. Further to these, there were additional comments on the decisions that should have been made. These include:

- Management of fire-water capacity – the initial decision to employ deluge over the whole platform was poor.
- There was no plan for the safe reception of casualties on the gas compression deck to assist with stabilisation of casualties for evacuation.
- There was no considered decision to continue with fire-fighting or to remove fire teams from risk and concentrate the resources on the casualties or to prevent escalation by cooling the methanol tanks.
- There was no plan made for casualty evacuation and how it could be achieved safely.
- There was no plan for escape routes for the many personnel deployed on the platform.

Comparing the subjective assessments to the TPRC results, there appear to be some inconsistencies that require further investigation. Some of the low "probability of success" tasks appear to indicate difficult tasks rather than poor emergency management. For example; moving casualties to the evacuation point was considered a good but late decision. The maximum p(success) in moving casualties to the evacuation point given the scenario timings was 0.71. With emergency management improvements (i.e. a good and timely decision), this probability increased to 0.95. Similarly the task of dumping methanol was judged to be good but too late. The scenario data gave a maximum p(success) of 0.02 whereas the improved emergency management gave a value of 0.18.

4 GENERAL DISCUSSION

This paper presents a model for assessing the impact of design and emergency management response on risk reduction in quantitative terms. However, the research team accepts that the scenarios studied may not be the most likely in practice. Emergencies often involve unexpected events and the ability to "expect the unexpected" is a key skill for emergency managers to acquire. In the case presented in this paper the total loss of power on the platform, although unlikely, provides a valid test of emergency management skills and reactions since it covers a situation which is unlikely to be covered in the manual of procedures.

The subjective results show some differences from the model results. This occurs because subjective assessments capture features of human performance that are not included in the model. The model results are based on simple time-based performance variables. The model makes no judgements on the quality of the timing or the decision. This must be inferred from the end result on probability of success. However, it has to be accepted that sometimes a seemingly good decision may result in a low probability of success if the situation being managed has a very short time available to respond; a good decision in the circumstances but with no real chance of success. This would indicate that success can be made more likely only through design improvements.

To date, the main focus of the research effort has been to quantify the impact of emergency management training on risk reduction and the tool has being developed to meet this need in a variety of emergency management tasks. However, the model also enables the analyst to visualise the impact of a number of key design variables on the ability to manage an emergency. We see the model therefore as a tool for the generation of performance indicators for both emergency management and design.

Fig. 7 shows the potential for interaction between emergency management assessment and the design process. In order to meet the current regulations, the design process must develop a safe installation and demonstrate that the risk of a major accident is as low as reasonably practicable. The purpose of risk analysis in design is to identify the risk of major accident hazards and their relationship to the installation design so that the risks can be minimised before committing expenditure to construction. The earlier this can be done in the design cycle, the greater are the potential benefits in terms of reduced cost and increased safety. Our research highlights the importance of establishing a connection between design and emergency management early in the design process and before the design freeze stage. There is no reason why design concepts cannot be assessed for their impact on emergency management at an early stage in the design process. Plausible accident scenarios can be developed and assessed using table top exercises or simulations. The TPRC model can be used at this stage to assess the impact of expected response times and escalation rates on the probability of success in typical emergency management tasks.

Essentially, the model as it currently exists is a method of transforming a set of time-based performance indicators into a risk value. If the probability of success is too low, then the model can be used to generate a plausible set of response times and escalation rates which lead to an acceptable probability of success. These updated parameters can be used to inform the design function and emergency management training functions on the targets to be achieved. At the conceptual stage, the model considers only how the time performance variables affect the risk. Once the acceptable timings have been established, it falls back on the designers and the emergency management training functions to create the systems and training that meet these targets. Common examples include the designer's plans to increase awareness, reliability and speed of emergency response e.g. communications, fire and gas, ESD and distance to TR etc. and to slow down rates of escalation e.g. active and passive fire protection systems, reduced inventory and so forth. Emergency management training improves the ability to make good and timely decisions to control/reduce escalation e.g. activate ESD or water deluges when automatic systems fail, and rescue/evacuate personnel. Research continues to develop the model as a conceptual design tool connecting the needs of emergency management with design provision.

5 REFERENCES

1. Cullen, The Hon Lord (1990) The Public Inquiry into the Piper Alpha Disaster. HMSO.
2. Health and Safety Executive (1992) A guide to the Offshore Installations (Safety Case) Regulations 1992.
3. Beck, M & Woolfson, C (1995) The Hidden Deregulation of Britain's Offshore Oil Industry. Centre for Research into Industry, Enterprise, Finance and the Firm (CRIEFF) Discussion paper Number 9511
4. Davies, Frank (1998) In: HSE Conference moves towards new agenda for offshore safety. HSE Press Release E174:98 - Conference on "Changing Health and Safety Offshore – the agenda for the next ten years" Aberdeen Exhibition and Conference Centre. 22-24 July 1998.
5. Flin, R & Slaven, G (1995) Identifying the right stuff: selecting and training on-scene emergency commanders. Journal of Contingencies and Crisis Management. Vol. 3, No. 2.
6. OPITO(1992) Units of Competence governing the management of offshore installations. Montrose: Offshore Petroleum Industry Training Organisation.
7. UKOOA(1997) The Management of Competence and Training in Emergency Response.
8. Flin, R. (1996) Sitting in the hot seat – leaders and teams for critical incident management. Wiley, Chichester, UK.
9. Strutt, J E, Lyons M, Allsopp, K, Larken, J & Væmes, R J (1997) Development of models and Data for Quantification of Human Reliability on Emergency Management. 6th International Conference on Risk Assessment of Offshore Installations. Church House Conference Centre, London. 18th November 1997.
10. Health and Safety Executive (1996) A guide to the installation verification and miscellaneous aspects of amendments by the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 to the Offshore Installations (Safety Case) Regulations 1992.
11. Strutt,J.E., Loa, W and Allsopp, K (1996) Progress toward the development of a model for predicting human reliability: 13th ARTS. Advances in Reliability Technology Symposium, University of Manchester, April 1996.
12. Hymes, I (1983) The physiological and pathological effects of thermal radiation. Safety and Reliability Directorate Report R275, September 1983.
13. Stensaas, J.P. (1991) Toxicity, visibility and heat stresses of fire effluents. Human tenability limits. SINTEF Report STF25 AP1022, May 1991.

TABLE 1: TASK AND RESOURCES USED IN THE SCENARIO

TASK	RESOURCE
Rescue casualties: Send medical team(s) Treat casualties on site Move casualties to evacuation point Evacuate casualties	Time before casualties die of injuries - a combination of burns, smoke inhalation and crash injuries
Promote fast evacuation : Order evacuation helicopters early Warn helicopters of moved landing point Move muster point Move casualties	Time before platform is totally uninhabitable and impossible for the helicopters to reach – forcing an undesirable sea-evacuation
Prevent ignition / fire escalation: Shutdown Blowdown Activate deluge on whole platform Dump methanol Send initial fire team Provide extra fire team(s)	Time before fire escalates and impinges on new area at risk / injures further people
Prevent further risk to personnel: Muster Advise that lifeboat 2 unusable Move muster point 2 Advise no entry to accommodation Advise not landing helicopter on helipad due to wreckage Move fire team to GCD Advise not to push wreckage off into the sea	Time before personnel at risk in current situation / would carry out undesired activity of their own accord

TABLE 2: FACTORS INFLUENCED BY DESIGN CHANGES IN THE SCENARIO

SYSTEM	POTENTIAL OF DESIGN CHANGES
Deluge	Time to initiate deluge – may result in earlier control Quantity of throughput – Effect of deluge activation throughout platform (eg. reduction in pressure)
Hose effectiveness	Time to set up equipment Available water pressure
Location of equipment	Power generator package location would have not been affected if in alternative location – hence would have not resulted in Level 4 shutdown (although it must be noted that on the real platform, this would not have occurred). Designs may be able to cater for this possibility by using redundant systems. Helifuel relocation would be difficult but stronger storage system to withstand blade penetration may be possible Methanol lay-down area relocation possible
Protection of equipment	Fire retardant design of helideck is now available – This works by channelling the fuel away from the deck. Temporary Refuge effectiveness and availability must also be considered.
Distances	Distances from incident to temporary refuge may be reduced or increased. Reduction would lead to faster times to get medical and fire teams on location Increase would lead to safer TR areas, due to being further from the incident.
Medical equipment availability	More equipment on site could possibly reduce treatment time. The medical team on site required a stretcher bringing to the site. If this was already on site the current medical team could have used it to evacuate the casualties.
Number of personnel	Naturally the number of personnel is dependent on the size of platform. The move away to unmanned platform reduces the number of personnel at risk but also means that there are less people available to assist in an emergency
Location of platform	The further away from shore or helicopter support, the longer a platform must be "self-sufficient" in an emergency. In a worst case scenario, if helicopters cannot get to the site quickly, an undesirable lifeboat evacuation is necessary, which provides further risk to personnel
System changes	Faster shutdown and blowdown prevent further risk.
Availability of alternative helideck	The evacuation site was not strictly a helideck and could have produced further risk to the landing helicopter or the personnel waiting for assistance.

TABLE 3: ESTIMATED CASUALTY SURVIVAL TIMES FOLLOWING INCIDENT

STATUS	ESTIMATED TIME OF DEATH (No treatment)
Casualty 1	180 sec
Casualty 2	360 sec
Casualty 3	600 sec

TABLE 4: FIRE ESCALATION LEVELS DEFINED IN THE SCENARIO

LEVEL	DESCRIPTION	TIME OF OCCURRENCE
1	First Ignition	0 sec
2	Ignition of diesel and helifuel – helicopter completely on fire	5 minutes and 48 seconds
3	Helifuel storage ignites	11 minutes 32 seconds
4	No survivors to be expected in the fire	13 minutes and 46 seconds
5	Fire impinging on Weather and Mezzanine decks	17 minutes and 49 seconds
6	Platform uninhabitable	1 hour (estimated)

TABLE 5: OBSERVED DATA (RESPONSIBILITY OF EMERGENCY MANAGEMENT TEAM

TASK	TIME
Delay from crash to ordering shutdown and blowdown	12 seconds
Delay from crash to sending medical team	2 minutes 24 seconds
Delay from crash to sending stretcher team	10 minutes and 59 seconds
Time from fire detected to deluge activated	1 minutes and 4 seconds
Delay from fire level 3 to order for methanol to be dumped	1 minute and 8 seconds
Delay from order for methanol to be dumped to completion of order	10 seconds
Delay from crash to first fire team sent to site	2 minutes
Delay from second fire team being ordered to being sent	1 minute 47 seconds
Delay from third fire team being ordered to being sent	37 seconds
Delay from stretcher team being ordered to being sent	3 minutes and 18 seconds
Delay from crash to ordering evacuation helicopters	4 minutes and 55 seconds
Time from fire escalation level 4 to moving casualties to MP3	2 minutes and 48 seconds
Time from ordering casualties to MP3 to ordering move from MP2 to MP3	54 seconds
Time from fire escalation level 4 to order to advise helicopters not to land on the main helideck	6 minutes and 15 seconds
Time taken to warn helicopters not to land on the deck in its current state	6 seconds

TABLE 6: OBSERVED DATA (ORGANISED BY SCENARIO ORGANISERS)

TASK	TIME
Time from helicopters being ordered to expected arrival	20 minutes
Time from crash to Level 4 shutdown	1 minute and 5 seconds
Time for OIM to arrive in Control room	31 seconds
Time for first fire team to arrive on deck	1 minute
Time for second fire team to arrive on deck	1 minute and 13 seconds
Time for 2 fire teams to move to GCD	2 minutes and 48 seconds
Time for Fire team 3 to get to GCD	2 minutes and 41 seconds
Time from fire escalation level 4 to advising lifeboat unusable	1 minute and 22 seconds
Time from fire escalation level 4 to helicopters expected landing time	10 minutes and 14 seconds
Estimated time to stabilise casualties once on helideck	15 to 20 minutes

Time from crash to muster complete	3 minutes 42 seconds

TABLE 7: DESIGN DATA

TYPE	MEASURE
Distance from fire team to incident	60 metres.
Distance from medical team to casualties	60 metres
Distance from fire team to GCD	80 metres
Distance from Muster point 2 to WT1	150 metres
Distance from incident to alternative helicopter landing site (Well Tower 1)	150 metres
TR impingement time	1 hour
Helicopter cruise speed (based on S61N)	115 Nts
Helicopter mobilisation time (based on daytime recommendations)	15 minutes
Time to detect fire	1 second
Time to complete automatic shutdown and blowdown	22 minutes
Time to dump methanol	15 minutes
Number of personnel on board	40
Distance from shore	75 km

TABLE 8: TPRC RESULTS ON SCENARIO DATA

TASK	Maximum Prob.(Success)
Arriving at casualties before they die (180 sec)	0.22
Arriving at casualties before they die (360 sec)	0.96
Treating casualties before they die (600 sec)	0.77
Treating casualties before they die (400 sec)	0.37
Activating deluge before fire team arrive on site	>0.99
Fire team 1 arriving on site before escalation level 2	0.81
Fire team 2 arriving on site before escalation level 2	0.29
Fire team 1 putting out fire before it reaches escalation level 2	0.04
Achieving control of fire before fire escalation level 2	0.23
Completing muster before escalation level 2	0.74
Stretcher team arriving before heli-evac	0.89
Given Level 2 escalation, dump methanol before level 5 escalation	0.02
Advise of moving to GCD before fire escalation level 3	0.69
Fire team 3 arriving on GCD before escalation level 3	0.30
Stretcher team arriving before fire escalates to level 5 Weather and Mezzanine deck dangerous	0.44
Moving casualties to evacuation point before helicopters arrive	0.71
Moving muster point to evacuation site before helicopters arrive	0.69
Advising lifeboat is unusable before it is likely to be used	0.99
Advising no entry to accommodation before they go in	0.44
Stabilising casualties for evacuation before helicopters arrive (given survival time of either 15 or 20 minutes)	0.01
Helicopters arrive at plat. before fire escalation level 6 (within 1 hr)	0.99

Inform helicopters that they should land on helipad before they try it	>0.99
Blowdown complete before helicopters arrive	0.46

TABLE 9 RESULTS OF TPRC WITH EMERGENCY MANAGEMENT CHANGES

TASK	CHANGES MADE	P(SUCCESS)
P(success) arriving at casualties before they die	Assuming survival time of 180 seconds, if a medical team was sent at 1 minute and 4 seconds after the incident occurred (ie when the initial message about the casualties was received)	0.77
P(Success) fire team 2 arriving on site before escalation level 2	Using quicker response time to send fire team out	0.49
P(success) stretcher arriving at casualties to move them before helicopters arrive	Assuming shorter delay before sending stretcher team and readiness of medic = 10 minutes	>0.99
P(success) stretcher team arriving before escalation level 5	Assume reduced delay before sending stretcher team	0.60
Given level 2 escalation, P(success) dumping methanol before level 5	Assuming no delay from level 2 to ordering to dump methanol	0.18
P(success) advising no entry to accommodation before someone goes in	No delays in informing personnel of the danger	0.82
P(success) moving casualties to evacuation point before helicopters arrive	Decision time reduced from 11 minutes and 14 seconds to 2 minutes and 8 seconds (assuming that it could be predicted that the helideck would be unavailable by the time the helicopters were due to arrive)	0.95
P(success) stabilising casualties before the helicopter arrives	Given 3x extra medical assistance (ie work rate x3)	0.09

TABLE 10 RESULTS OF TPRC WITH DESIGN CHANGES

TASK	DESIGN CHANGES	P (SUCCESS)
P(success) fire team 1 arriving on site before escalation level 2	Given that escalation level 2 occurs 10 minutes after first ignition	0.95
P(success) fire team 1 putting out fire before escalation level 2	Assuming fire escalation level 2 slowed to 10 minutes	0.34
P(success) achieving control of fire before fire escalation level 2	Assuming stronger and fire escalation slowed to level 2 at 10 minutes by fire retardant helipad	0.93
P(success) completing muster before escalation level 2	Given that escalation level 2 occurs 10 minutes after ignition	0.89
P(Success) fire team 2 arriving on site before escalation level 2	Given other mechanisms of control of fire	0.68
P(success) advising movement to GCD before fire escalation level 3	Given that escalation level 3 occurs 20 minutes after first ignition	0.89
P(success) fire team 3 arriving on GCD before escalation level 3	Given that level 3 occurs 20 minutes after first ignition	0.69
Given Level 2, P(success) dumping methanol before level 5 escalation	Level 5 escalation 30 minutes after level 2 and faster methanol dumping system	0.72
P(success) stretcher team arriving at casualties to move them for heli-evac before escalation level 5	Given that escalation level 5 occurs 40 minutes after the initial ignition	0.94
P(success) blowdown complete before helicopters arrive	Blowdown complete in 18 minutes	0.59

TABLE 11 RESULTS OF TPRC WITH COMBINED EMERGENCY MANAGEMENT AND DESIGN CHANGES

TASK	CHANGES	P (SUCCESS)
P(success) fire team 2 arriving on site before escalation level 2	As above	0.87
P(success) given level 2, dumping methanol before level 5	As above	0.90
P(success) stretcher team arriving on helideck before escalation level 5	As above	0.98

TABLE 12: RESULTS OF SUBJECTIVE ASSESSMENT

TASK	SUBJECTIVE ASSESSMENT
Sending Medical Team 1	Good, timely, communicated well and carried out well
Sending Medical Team 2 (stretcher team)	Good, timely
Treat casualties on site	Decision made by scenario - No choice for EMT
Move casualties to evacuation point	Good but late
Evacuate casualties	Good, timely
Order evacuation helicopters	Good, timely
Warn helicopters of moved landing point	Good but late and poorly communicated
Move muster point	Good, timely
Move casualties	Decision made by scenario - No choice for EMT
Shutdown	Automatic, timely
Blowdown	Automatic, timely
Activate deluge on whole platform	Bad – reduces water pressure at main area of incident and impedes rescue attempt
Dump methanol	Good but too late – should have been made as soon as the fire was known to be beyond the helideck area. Poorly communicated.
Send initial fire team	Good, timely
Send fire team 2	Good, timely
Send fire team 3	Bad – fire escalated beyond the capabilities of fire teams - put more people at risk unnecessarily.
Muster	Good, timely
Advise MP2 that the lifeboat 2 is unusable	Good, timely, Communicated well.
Move muster point 2	Good, timely, Communicated well.
Decision to change route to avoid to accommodation	Good, timely, Communicated well.
Advise not landing helicopter on helipad due to the wreckage	Good, timely, Communicated well.
Move fire team to GCD	Decision of scenario – No choice for EMT
Not push wreckage into the sea	Good, Timely
OVERALL	**NOT COMPETENT**

FIG.1 THE ROLE OF THE TPRC MODEL IN EVALUATING EMERGENCY MANAGEMENT TRAINING AND DESIGN CHANGES

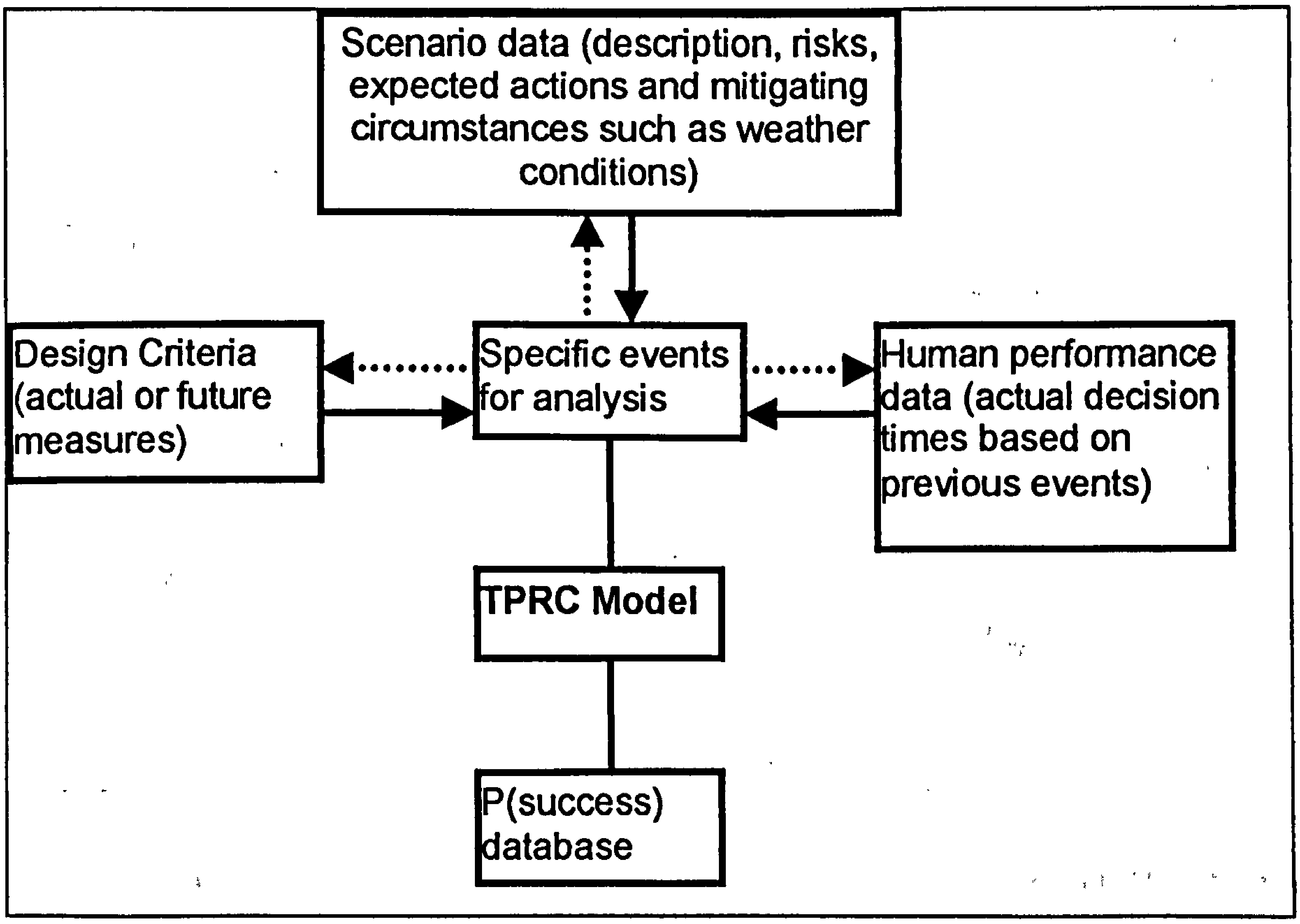


FIG. 2 THE TASK PERFORMANCE - RESOURCE CONSTRAINT MODEL CONCEPT

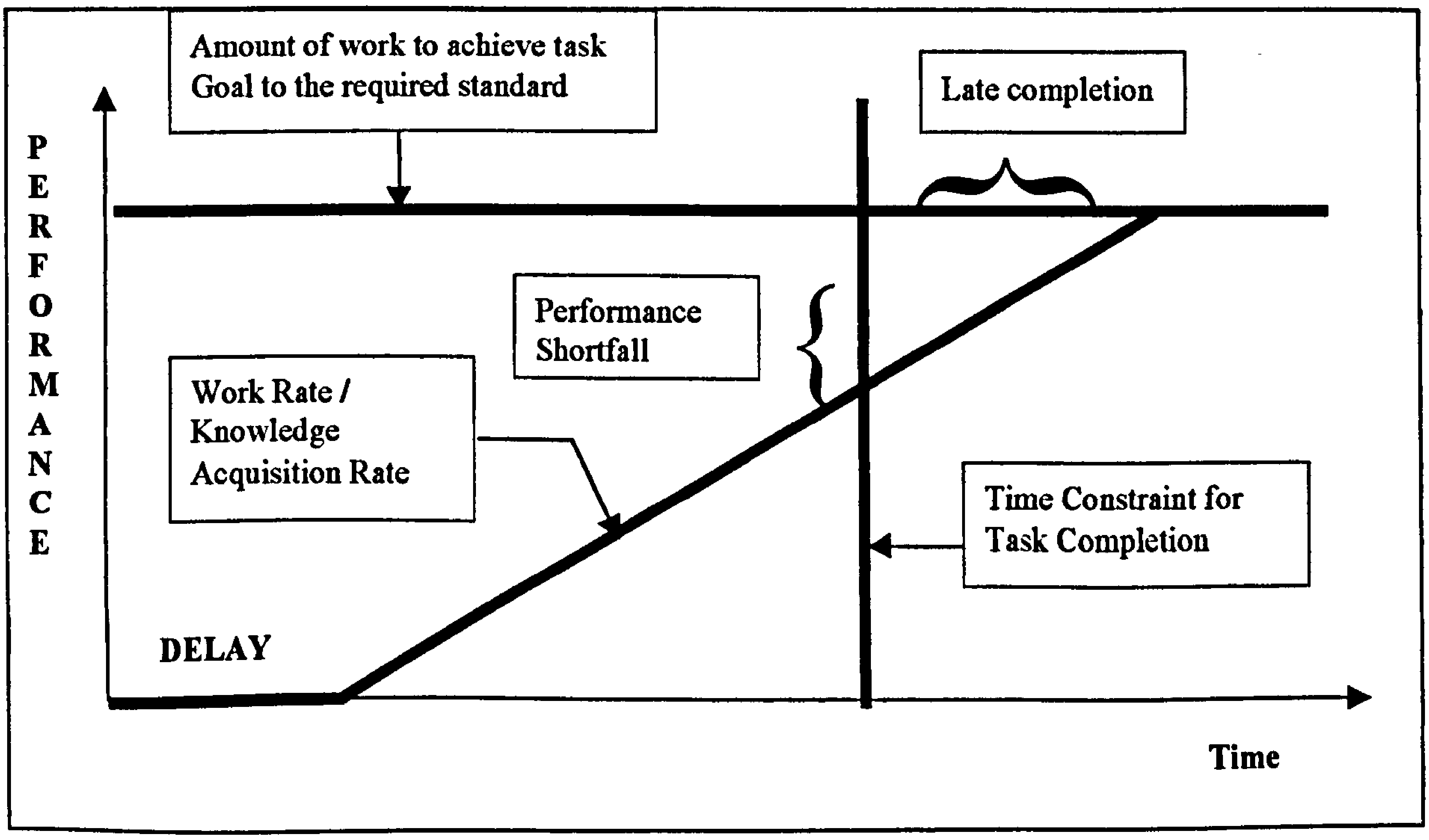


FIG. 3 THE TASK PERFORMANCE RESOURCE CONSTRAINT MODEL – FORMAT OF RESULTS

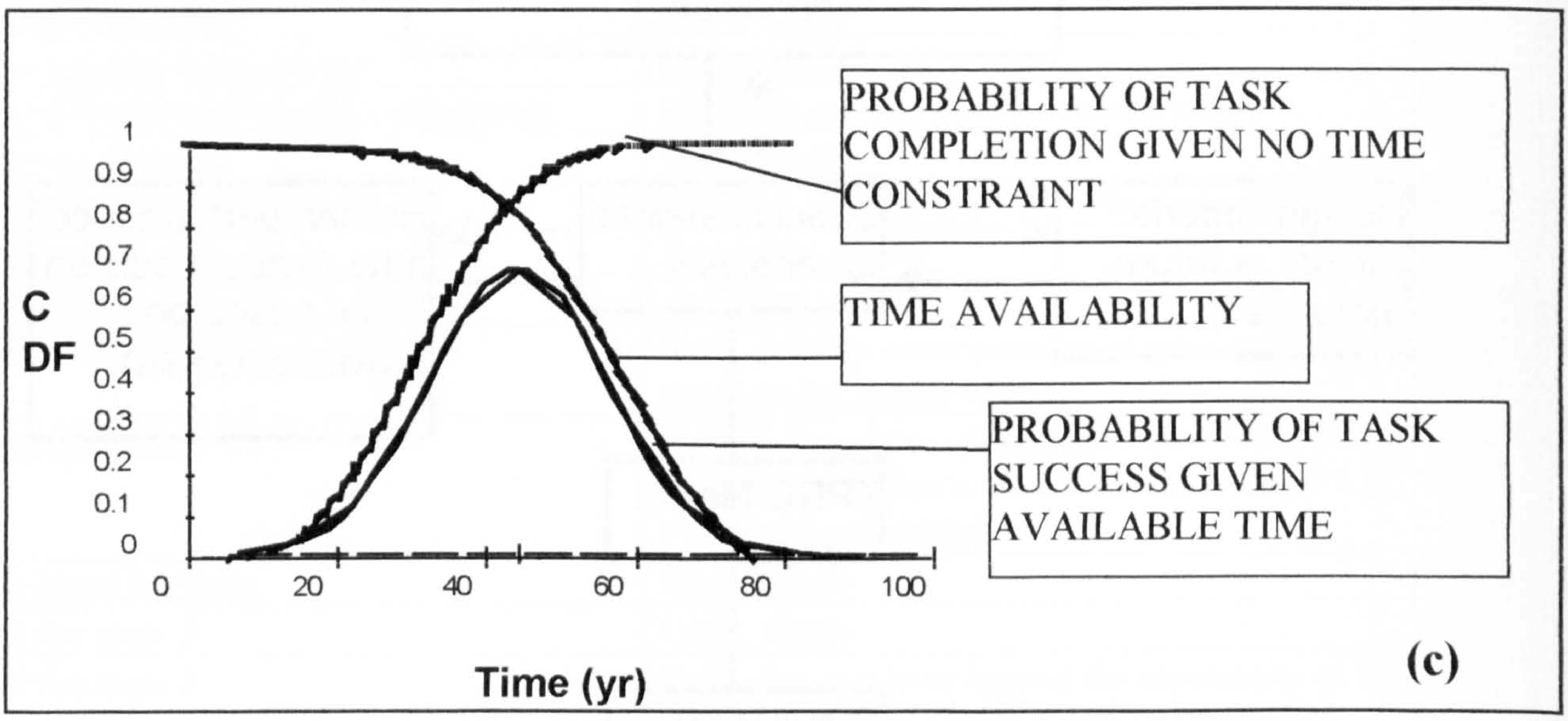


FIG. 4 THE PROBABILITY OF SUCCESS OF FIRE TEAM 2 GETTING TO SITE BEFORE IGNITION OF DIESEL AND HELIFUEL

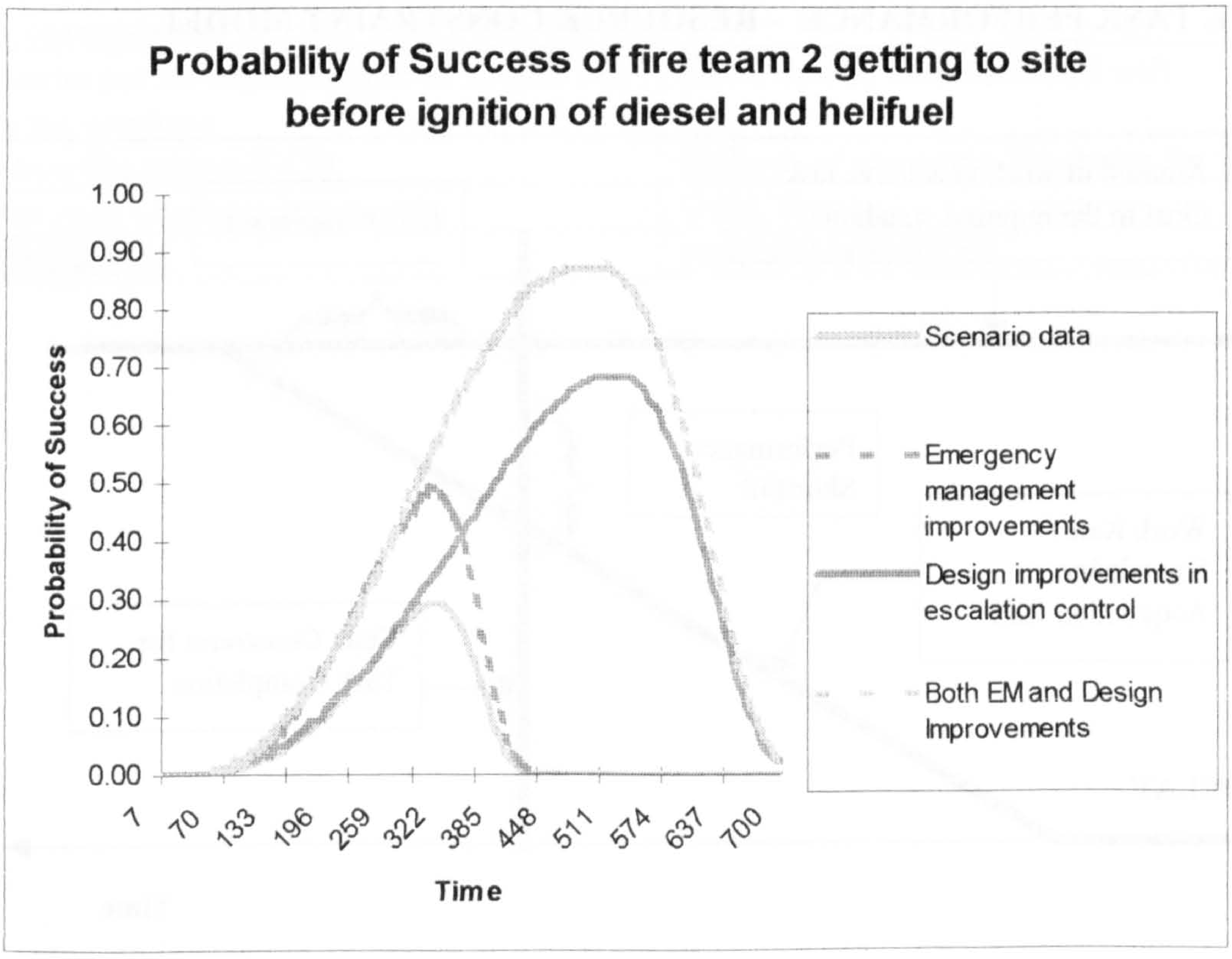
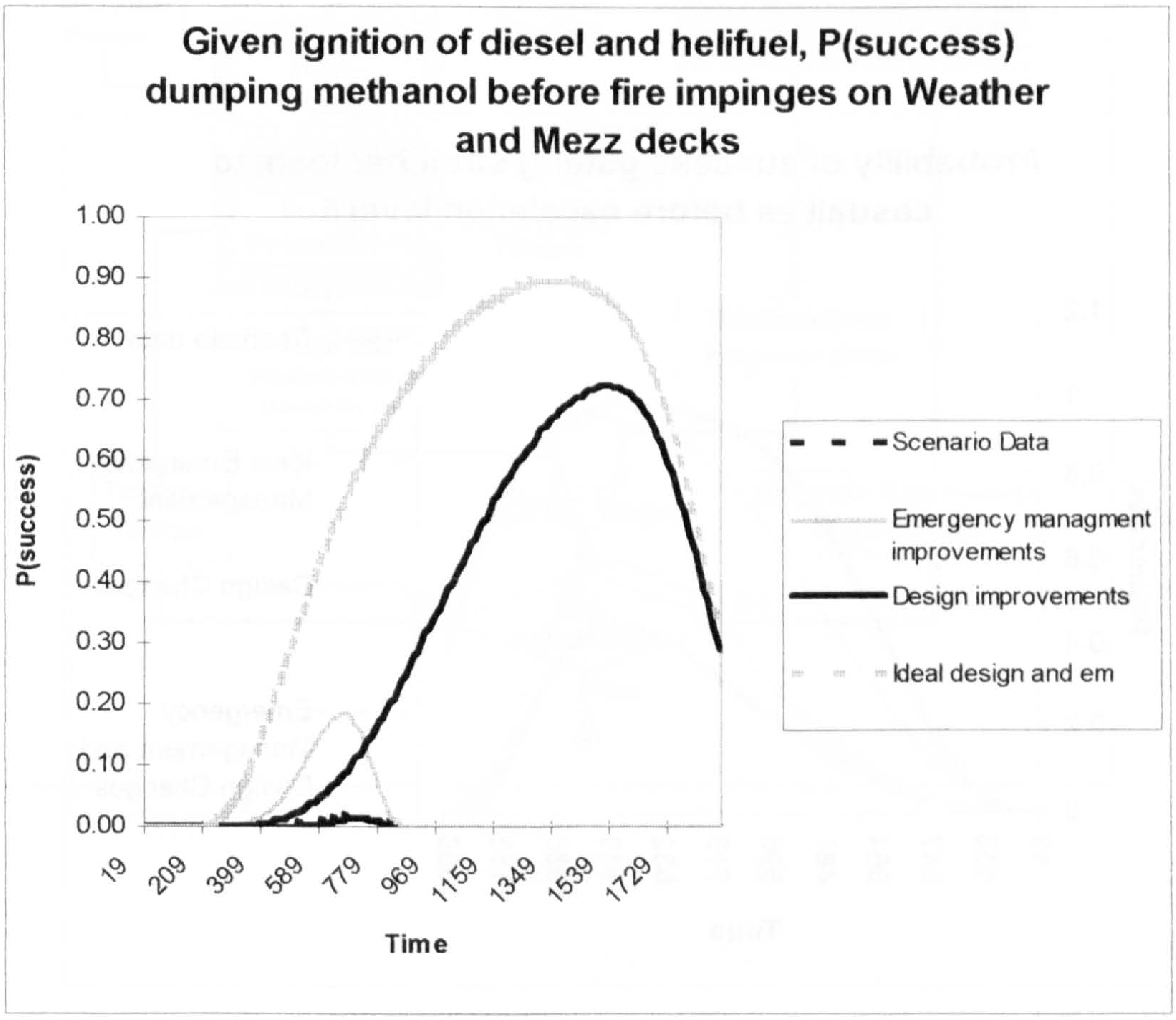


FIG. 5: GIVEN IGNITION OF DIESEL AND HELIFUEL, THE PROBABILITY OF SUCCESS IN DUMPING METHANOL STORE BEFORE FIRE IMPINGES ON THE WEATHER AND MEZZ DECKS



DATA	Max Values
Scenario	0.02
Emergency management improvements	0.18
Design improvements	0.72
Emergency management and design improvements	0.90

FIG. 6 THE PROBABILITY OF SUCCESS GETTING THE STRETCHER TEAM TO THE CASUALTIES BEFORE FIRE IMPINGES ON WEATHER AND MEZZANINE DECKS

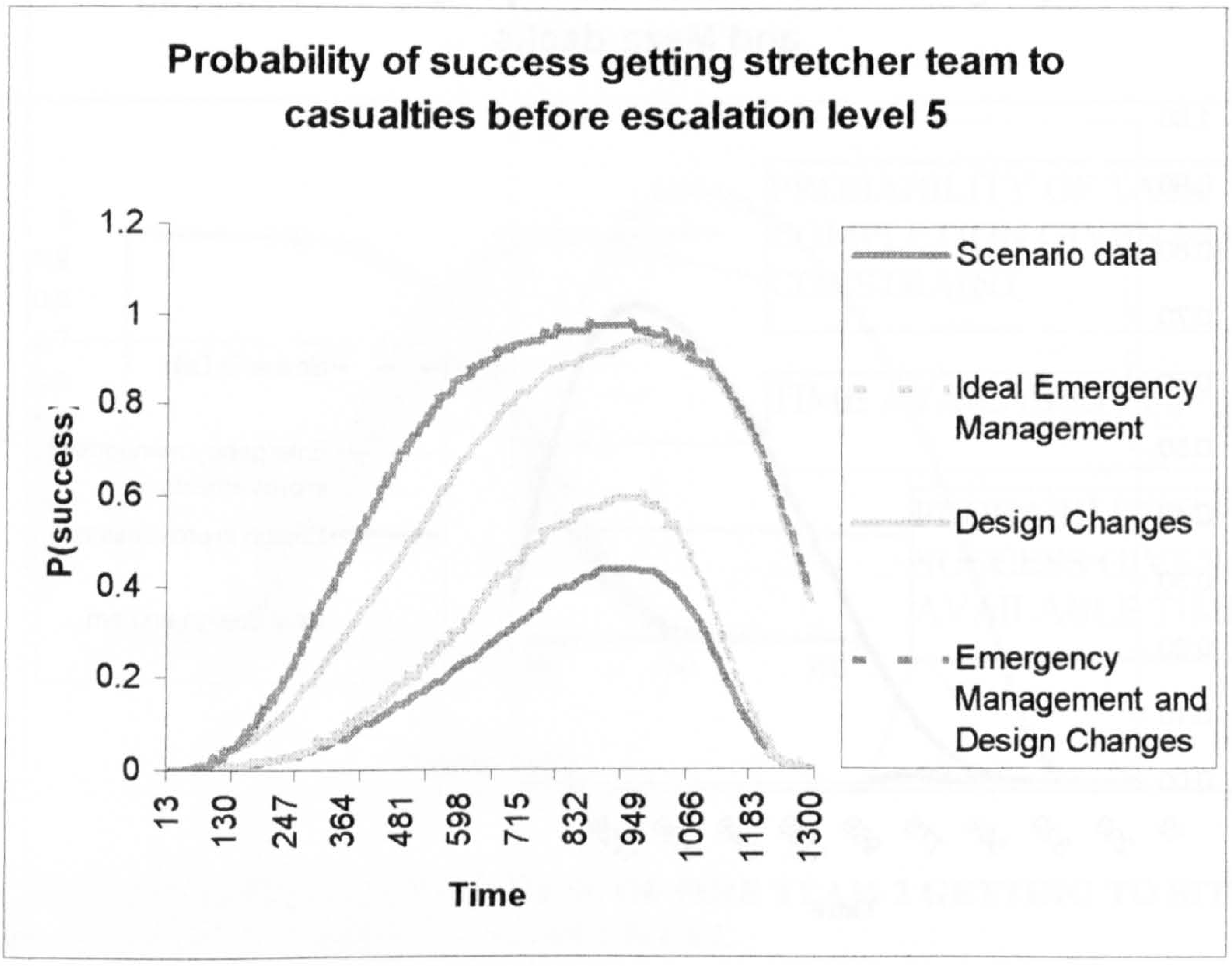
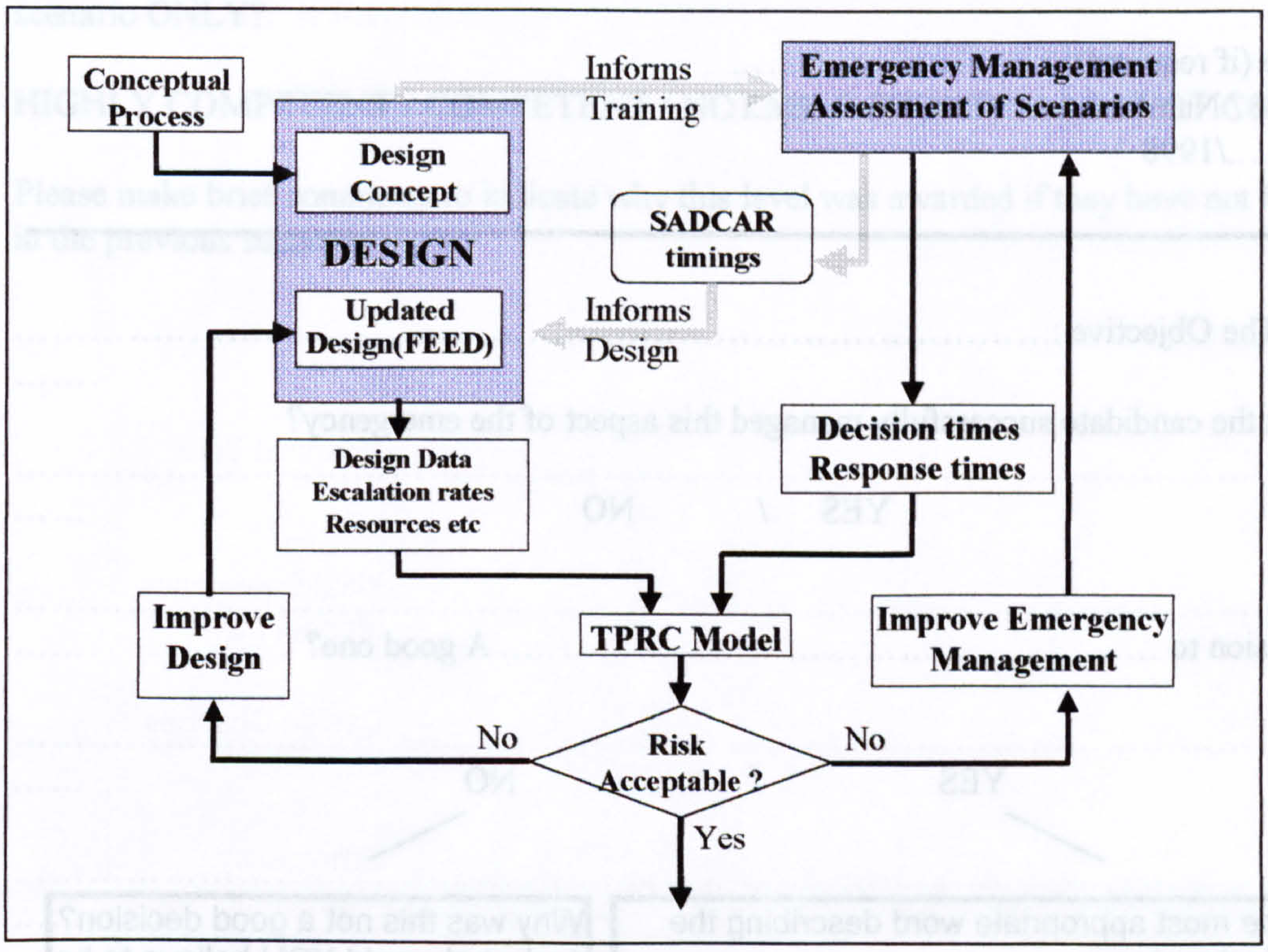


FIG.7 THE RELATIONSHIP BETWEEN EMERGENCY MANAGEMENT AND DESIGN



APPENDIX 1:

Questionnaire for Examiners in Emergency Management Training Exercise

Examiner No (if required):.........................
Scenario Title / Number..........................
Date:....../...../1998

Concerning The Objective :..

Do you think the candidate successfully managed this aspect of the emergency?

YES / NO

Was the decision to .... A good one?

YES / NO

Underline the most appropriate word describing the timing of this decision

TOO EARLY, EARLY, TIMELY, LATE, TOO LATE.

If you believe the decision was mis-timed, when would YOU have carried out this decision (make relation to the events that occurred)?

....

....

Was this decision communicated in such a way that the people who were designated to carry out the actions could respond immediately?

YES / NO

Did the people who were designated to carry out the action respond to the communication correctly and immediately?

YES / NO

If NO, why do you believe this was the case?

....

....

Why was this not a good decision? And what would YOU believe to be the correct decision (please continue overleaf if required)

....

....

....

....

....

....

....

....

....

In your opinion, what was the overall level of competence displayed by the candidate in THIS scenario ONLY?

HIGHLY COMPETENT / COMPETENT / NOTABLE SHORTFALLS / NOT COMPETENT

Please make brief comments to indicate why this level was awarded if they have not been covered in the previous sections

....
......

....
......

....
......

....
......

....
......

How does this compare to the previous scenarios managed by this candidate?

NOT AS GOOD AS BEFORE / SAME AS BEFORE / BETTER THAN BEFORE

....
......

....
......

Thank you VERY much for your time in answering this questionnaire