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Development of a Team Human Reliability Assessment Tool (ROCCI)

By Isabel Helen Smith

A Master's Thesis submitted in partial fulfilment of the requirements for the award of Master of Philosophy of Loughborough University

October 2010

Loughborough University

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Abstract

Human Reliability Assessments (HRA) have been developed so designers and users can understand how likely it is for a human to make an error when using a product or system in the workplace. This is called the reliability of the product. Approximately twenty-six techniques exist to assess the reliability of an individual human in a process. However, often a team of people interact within a system and not just one individual on their own. Hence a new generation of HRAs is needed to assess the effects of teamwork on reliability.

This EPSRC CASE studentship, supported by BAE systems, develops a prototype, which enables a designer to quantify and answer to the question: “If I allocate this team to execute that task in System X, how likely is it that they will succeed?”

This prototype assumes that a process can be defined in the form of a flow diagram and that roles can be allocated to execute it. Then, using one of those twenty-six techniques, individual reliabilities can be calculated. These are then modulated, by considering how the team interaction affects the three core elements of Trust, Communication and Decision Making Power Distance. This creates an ‘interactive reliability’ factor for each individual in the team. These individual reliability factors are combined according to the team architecture for the process in order to determine the overall team reliability factor.

The methods of development include: stakeholder interviews; the evolution of requirements specification; sensitivity analysis; and a stakeholder review of the tool. The information from these analyses produced a model about team interaction and the requirements for the new tool together with statements and algorithms that need to be used in the new tool: ROCCI.

This technique is useful for use in the early stages of the design process. The successful prototype can be extended into applications for operations and used to assess and adapt products and systems, which involve teams.

Acknowledgements

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In particular I would like to thank my supervisors, Dr Carys Siemieniuch, Murray Sinclair for you have given me lots of knowledge, guidance and help over the years and I appreciate everything that you have done with regards to the work at EEC and BAE Systems, and all the contacts that you have helped me to make. My gratitude to you is large. My final supervisor Dr Sue Hignett, who has pushed me over the last hurdle.

I would also like to thank those that have supported and believed in me, when I have had doubts. Including Kiri-Maree Taggart and Christine Pordham, that have been my shoulders to lean on. Caroline, Ella and Tom Morris, each of you have helped me in your own special way, Ella by reminding me that there is only one thing that matters in life, and that is life itself. Caroline for making me come back to the UK, Tom for allowing me to intrude on his family and write sensible unemotional emails. Those New Zealanders who helped me realise that life is hard and you have to work for what you want, and you will be happier earning what you get than by just receiving it. Those that are looking down on me now, Helen Smith, Sir Edward O'Brien Esq. OBE, Mamita, I know you are all looking after me. Rocky for keeping me company on the sofa. My wonderful parents Dr David Smith H.E., and Lucia Smith, who have proof read, copy typed, baked, made me numerous cups of tea and supplied champagne when needed. I know that at times my choices have been hard for you, but could not have done this and still had my sanity without your support.

Contents

Figures

Tables

Abbreviations

APJ	Absolute Probability Judgement
ASHRAM	Aviation Safety Human Reliability Analysis Method
ATC	Air Traffic Control
ATHEANA	A Technique for Human Error Analysis
BU	Business Unit
CREAM	Cognitive Reliability and Error Analysis Method
CRM	Crew Resource Management
CPC	Common Performance Conditions
CTS	Communication – Trust Matrix
DCSC	Dependable Computing Systems Centre
DIF Analysis	Difficulty Importance Frequency Analysis
ELC	Engineering Life Cycle
EPSRC	Engineering and Physical Sciences Research Council
GEMS	Generic Error Modelling System
HAZOPS	Hazard and Operability Study
HEART	Human Error Assessment Rating Technique
HEP	Human Error Probability
HEROS	Human Error Rate Assessment and Optimising System
HF	Human Factors
HFI	Human Factors Integration
HMI	Human Machine Interface
HoQ	House of Quality
HRA	Human Reliability Assessment
HTA	Hierarchical Task Analysis
IDEF0	Integrated Definition
ITT	Invitation To Tender
JHEDI	Justification of Human Error Data Information
LARP	Low As Reasonably Possible
LCM	Life Cycle Management
MMI	Man Machine Interface
MoD	Ministry of Defence
NARA	Nuclear Action Reliability Assessment
NII	Nuclear Installations Inspectorate
PC	Paired Comparisons
PD	Decision Making Power Distance
PSA	Probabilistic Safety Assessment
PSF	Performance Shaping Factors
QFD	Quality Function Deployment
RAF	Royal Air Force
ROCCI	Reliability of Collaborative Crew Integration
RYA	Royal Yachting Association
SHERPA	Systematic Human Error Reduction and Prediction Approach
SLIM-MAUD	Success Likelihood Index Method using Multi-Attribute Utility Decomposition
SME	Subject Matter Expert
STS	(Team) Skills – Trust Matrix
THEA	Technique for Human Error Assessment

THERP	Technique for Human Error Rate Prediction
TRACEr	Technique for Retrospective and Predictive Analysis of Cognitive Errors
TTA	Tabular Task Analysis
UAVs	Unmanned Aerial Vehicles

Chapter One: Introduction

This research develops a "proof of concept" HRA tool prototype that assesses the reliability of a team of people. This research is an EPSRC (Engineering and Physical Sciences Research Council) CASE Study award with sponsorship from BAE Systems.

Chapter One is an introduction to the issues that originally identified the problem. It clarifies the limitations of the existing HRA tools and identifies why there is the need for conducting this research to developing a HRA tool, which would quantify the reliability factor of a team (Section 1.1). The aims and objectives of the research are specified (Section 1.2), followed by a brief description of the methodology. Chapter One concludes with an outline of the structure of the thesis (Section 1.3).

1.1 Introduction to the Problem

There are two aspects of human behaviour that are central to this thesis. The first is that human beings have an outstanding ability to make any system function well even in difficult and dangerous circumstances. The second is that they can also make errors which cause the system to malfunction. These are known as 'human error'. It is precisely this dilemma which needs to be addressed by this HRA tool on team reliability. This leads on to the presumption of this thesis, that systems need to be designed so that the human tendency to error is anticipated and so capable of being engineered out of the system. This is a better solution than simply assigning people's skills set to fit a system's application.

BAE systems had already sponsored an initial study, which investigated how a product, known as a capability, is developed (Ng et al., 2004c). This also explored where HRA might fit into the process (Figure 1.1). Then BAE Systems Advanced Technology Centre (ATC) initiated a second project that was to explore the use of HRA techniques across the military domain (Ng, 2003c), in particular those that are used within BAE Systems.

The first task was to ascertain which HRAs were suitable and then determine which were actually being used. In total, there are seventeen HRA techniques that are applicable to individuals. The ones available to BAE Systems were: HEART, SHERPA, HAZOPS, THEA and CHLOE. These include both quantitative and qualitative methods.

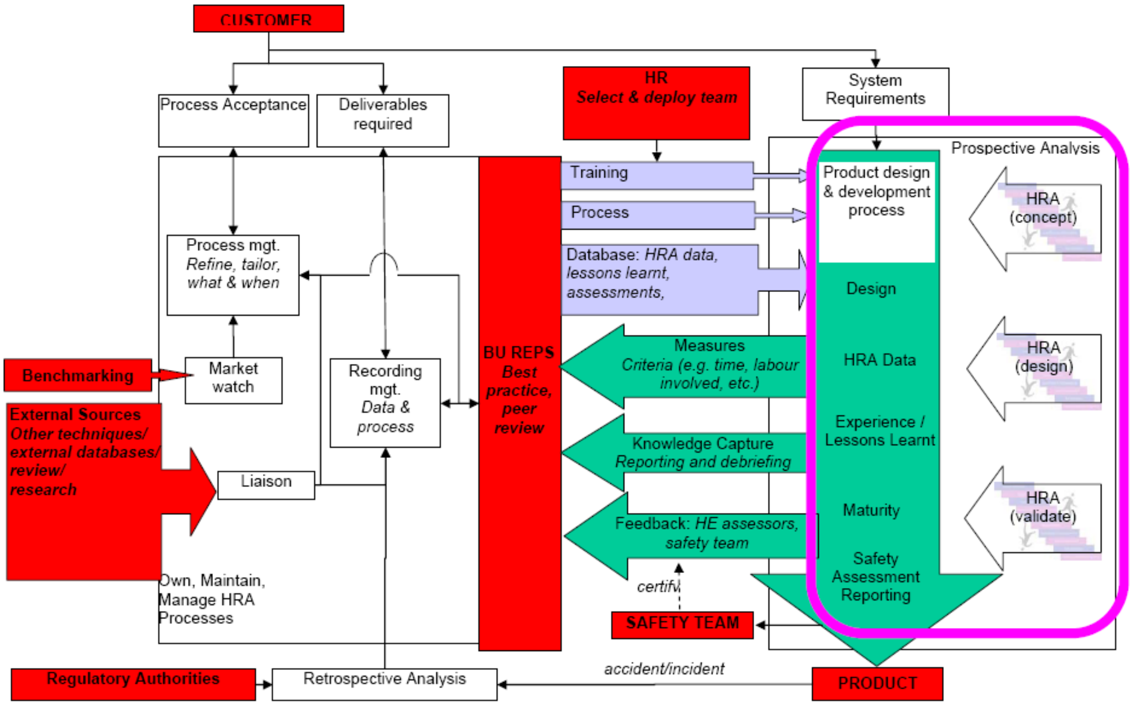


Figure 1.1: Capability Maturity Process, with HRA Highlighted (Ng, 2003)

There is a need for quantitative HRA techniques as:

> *'In safety critical systems and indeed complex systems, the customer is beginning to specify reliability levels. There will be further reliance on the quantitative techniques of which there are only a limited number.'(Ng, 2004b, p.6)*

An early stage in the project was to compare the efficiency and benefit of the four quantitative methods that were available to BAE Systems: HEART, CREAM Basic, CREAM Extended and Air Systems' technique. These four techniques can be put into two sets. The first set takes a high level approach, namely: HEART and CREAM Basic. The second set also considers the sub tasks, namely: CREAM Extended and Air Systems (Ng, 2004a). The four techniques provided similar values for the reliability of the overall task assessed: (left engine failure during takeoff on a Eurofighter); but Air

Systems' was the more reliable for predicting the reliability of the sub tasks, compared to CREAM Extended.

HRA techniques have been developed for designers and users so they can assess and understand the technical difficulties of using a product or system. Human error occurs when it is human action which is the ultimate cause of an incident and it is believed that the individual is culpable for causing the incident. Humans will inevitably make errors. The number of errors made (the reciprocal of this being the reliability) by a system can be quite predictable, but the reliability of the human element of the task can vary. The human reliability is found using HRA techniques. Designers should anticipate this variability when they design systems by seeking to reduce the likelihood of human error occurring. This is done by designing the systems around the person, rather than placing the person into the system. They should also create mechanisms by which errors can be resolved and rectified by feedback and review.

BAE Systems want to move forward with their HRA techniques. They wanted to provide a technique that deals with the dependency within a system operated by a team or teams. They could see a benefit in team feedback. For example: If an operator is performing a repetitive task and makes an unconscious error the first time, it is likely that this error will be repeated each time. It is not advisable to decrease the reliability for each repetition.

There was, however, a second dimension to the dependency when there are multiple operators. Some of the operators may perceive errors that are made by their colleague operators. They may be in a position to help correct the error and need to communicate how to rectify the situation or just execute the action themselves. This team feedback has the potential to increase the reliability of the whole process. Accounting for multiple operators is not this simple. There are other factors that can affect the interaction of multiple operators. There is one HRA that looks at these factors, which is CHLOE (Miguel et al., 2002; Miguel & Wright 2002a). But its limitation is that it is a qualitative, not a quantitative, technique. There was a gap in the HRA field for a quantitative collaborative technique and there was a distinct need for such a tool (Ng et al., 2004).

1.2 Aims and Objectives

The aim of this research had two components. The first and primary component was to develop a proof of concept prototype of a quantitative team HRA (THRA) tool. This THRA tool is called ROCCI (Reliability of Collaborative Crew Interaction). The second component was to evaluate whether the process could be implemented further.

To achieve these aims the work consisted of a number of objectives:

1. To explore, using interviews with stakeholders, requirements based on current experience and future expectations
2. To develop a model for team reliability using information from Objective One and produce team structures and algorithms for use in sensitivity analysis
3. To carry out sensitivity analysis on ROCCI algorithms
4. To validate ROCCI concept through stakeholder reviews.

Aspects of these objectives were approached using semi-structured interviews; selected case studies and sensitive analysis.

The semi-structured interviews were for collecting information from the stakeholders. This method was used twice, once at the beginning of the study to provide information on what the stakeholders want from the tool developing the requirements specification and again at the end of the research when ROCCI was taken back to the stakeholders for their feedback on the tool.

The Sensitivity Analysis was used to check the sensitivity of the algorithms underlying the quantitative method.

The five guiding principles below are a starting point for this research. It is through the acceptance and application of these principles that the reliability of individuals within teams can increase and so enhance the reliability of the whole team's interaction when they are working together. These are the five guiding principles for human performance as identified by the Institute of Nuclear Power Operations (INPO) (Davis, 2002, p.9):

1. People are fallible – even the best make mistakes
2. Error-likely situations are predictable, manageable and hence preventable
3. Organisational processes and values influence the behaviour of individuals
4. People can achieve high levels of performance based largely on the encouragement and reinforcement received from leader, peers and subordinates
5. Events can be avoided by understanding the root causes of mistakes and spreading the application of the lessons learned.

These principles provide an insight into the background behind the decision by BAE Systems to explore further how to develop the HRA tools for teams.

1.3 Thesis Structure

Chapter One is an introduction to the issues that originally highlighted a problem. The research structure has two stages (Figure 1.2). The development stage leads to the formulation of the team HRA tool, ROCCI. The testing stage validates the benefits of ROCCI in applications.

1.3.1 The Development Stage

A literature review, Chapter Two, reveals and highlights the important topics that should be considered when developing a HRA technique. Chapter Three is a description of methods used in the research. Chapter Four produced the Requirements Specifications. Understanding the requirements of the stakeholders are vital to producing a prototype that is suitable for future development. Chapter Five is the development of various components. These are: the model for team reliability; the initial development of ROCCI; and the algorithms and statements.

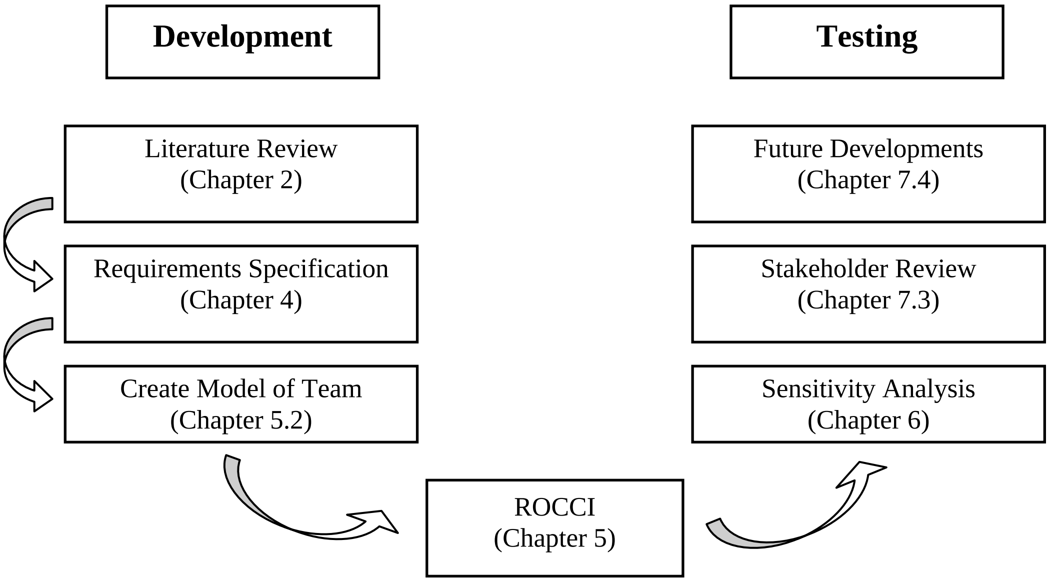


Figure 1.2: Model of Research Stages: Development and Testing

1.3.2 The Testing Stage

Chapters Six and Seven describe the stages of the testing of ROCCI with iterative development. Chapter Six is a sensitivity analysis of the algorithms. Chapter Seven includes the stakeholder reviews of ROCCI.

1.3.3 Conclusion

Chapter Seven discusses the development of the team HRA tool (ROCCI): how it fits within HRA; reflects on the completion of the aims and objectives of the research; presents solutions to the limitations of ROCCI and suggests possible methods of further development.

1.4 Summary

Chapter One has provided an overview of the origins and structure of the thesis. As indicated in Section 1.3, Chapter Two now turns to the literature review, which highlights the important topics that need to be considered when developing a HRA technique.

Chapter Two: Literature Review

This literature review examines the main areas of research relevant to designing a HRA tool. These are error classifications (Section 2.1), HRA techniques (Section 2.2), design life cycle (Section 2.3), team structures and attributes (Section 2.4) and ends with a summary of all the information that is taken forward to aid the further development of ROCCI (Section 2.5).

2.1 Error

After research into defining error Reason's (1990) definition is the most concise, yet broad definition:

> *'Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failure cannot be attributed to the intervention of some chance agency.' (Reason, 1990)*

Three elements of a system can produce an error: the task, the environment and the individual/people involved in performing the task. When considering human error all these elements are important. An adverse environment could be the cause of the error. The user of the system or the human at the sharp end can either cause an error to occur or be the symptom of the error (Reason, 2000). There are often several antecedents to an error, (Moray, 2000; Shappell & Wiegmann 2001). In the past, human error has been seen as the largest cause of incidents (Salminen & Tallberg, 1996), but recently organisational factors have featured prominently as the main contributor to error (Cullen 2001; Gehman et al., 2003).

2.1.1 Classifications of Error

There are several approaches to classify error. Kletz (1999) concentrates on five classes of errors that a human can make. Rasmussen (1982) concentrates on human cognition and its affects on human error. Whereas Reason (2000) shows how the person and the system are both present in causes of incidents. The many taxonomies demonstrates that errors can be multifaceted and that deciding up on what error has occurred and why, can become complex. Below are some of these classifications.

Kletz (1999) classified five errors of actions:
Mistakes are errors that occur because the correct procedure is not known and the intention of the action is wrong.
Violations are actions that are known to be wrong, but are thought of as being the most suitable action at the time given with the information known.
A **mismatch** occurs when the task and the cognition of the operator are not compatible, for example, the operator could be overloaded or may have established a habit and cannot change their viewpoint when new information is offered.
A **slip** occurs when the intention is correct but that action is wrong, for example pressing the wrong knob on a control panel.
A **lapse** is where an action is missed, e.g. due to an interruption.

There is cognitive reasoning behind these errors. But there could be other causes for the errors, which would not be errors of cognition. In his classification, Kletz does not discuss the effect of the environment, organisation, or equipment issues on the error. His is a general classification, best used as guidance for understanding different forms of **human** error. This is general and high level, it is not sufficiently precise. The discipline has moved to a finer level of focus, as seen in Norman (1988).

2.1.1.1 Norman

Norman (1988) errors have distinct behavioural, contextual and conceptual reasoning. This more detailed classification makes the errors easier, than Kletz's, to detect and differentiate their causes. Consequently, preventing these errors is simpler (Strauch, 2002).
Capture errors: a frequently done activity takes control over the intended one. For example; automatically driving from work to home, when the intention was to go to the dentist.
Description errors: when similar objects become confused or an action is based on a wrong object. This is because the cognitive description of the object is ambiguous, often due to tiredness and lack of concentration. For example; putting the coffee in the fridge and the milk in the cupboard.

Data-driven errors: 'data driven' behaviour is an automatic response to sensory information. These actions can interfere with pre-planned behaviour and lead to errors.

Associative activation errors: internal thoughts and associations can trigger unwanted actions. For example sending a text message to a person mentioned in the text rather than the intended receiver.

Loss-of-activation errors: this occurs when some part of a process is forgotten due to decay in the 'activation' of the goal. For example, forgetting the reason why you have entered a room.

Mode errors: a computer or machine has different modes. The operator believes it is in one of its mode but it is actually in another. This causes incorrect data input and confusion. For example, trying to open a presentation in a word processing programme.

2.1.1.2 Rasmussen

Rasmussen (1982) wanted to address 'human functions and capabilities and their limitations' (p.312). Previously, physical errors had been the focus of reliability assessments with little consideration of the cognitive aspects.

Skill based errors: are errors related to variability of force, space or time; e.g. pushing something too hard.

Rule based errors: are errors, such as classification, recognition, or recall, that relate to cognitive mechanisms.

Knowledge based error: are errors in planning, prediction and evaluation.

The level of performance for each error increases down the list. Skills are actions that can be learned by rote. To apply rules the user must be able to interpret situations and apply the appropriate rule. Knowledge based performance is applying learnt skills and rules to a novel situations, with an understanding of the consequences. This kind of knowledge cannot be taught.

2.1.1.3 Reason

There is growing evidence that accidents are not always due to human error. Fujita and Hollnagel (2004) found that more accidents occur due to error-prone situations and error-activities, than error-prone people. Reason (2000) resolved this change in thinking by presenting two approaches to error.

The first is the **person approach** where the focus of the error is on unsafe acts performed at the sharp end. The person approach can be classified as ‘active failures’. These are errors of actions, such as the Kletz’s classification, that are ‘direct and shortly lived’.

The second is the **system approach** which acknowledges that humans are fallible, so system defences, i.e. barriers, should be used to prevent the occurrence of errors. Similarly the system approach is also referred to as ‘latent conditions’. These are the factors that can influence how the human interacts with the system. Errors arising from decisions that affect the design of the system, the maintenance of the equipment and the ethos of the company, which can either produce ‘error provoking conditions or long lasting holes or weaknesses in the defences’, making the system basically unsafe (Dekker, 2001).

Organisational errors can be deep rooted and, even once a disaster has occurred, they can be hard to eradicate. The unfortunate disasters of the Challenger and Columbia NASA space craft are linked (Gehman et al., 2003). After Challenger, the organisational issues that came about from the Presidential report were thought to be rectified; however, it was similar organisational factors that were the cause for the Columbia incident. Reasons model of error (Figure 2.1) is like a piece of cheese with holes. The block of cheese is the environment and system in which the actions occurs. The holes are the potentials for errors to occur, such as unsafe acts and psychological precursors. The number and size of holes are the possibility of latent and active errors to occur. Defences, such as double checking, ‘undoing mistakes’ and safety procedures are represented as the bulk of the cheese. Where there are fewer holes there are more defences in place to reduce the error from occurring. An error will only go through the whole system if all the holes are lined up and there is no prevented by a barrier. There is always the possibility for an error to occur.

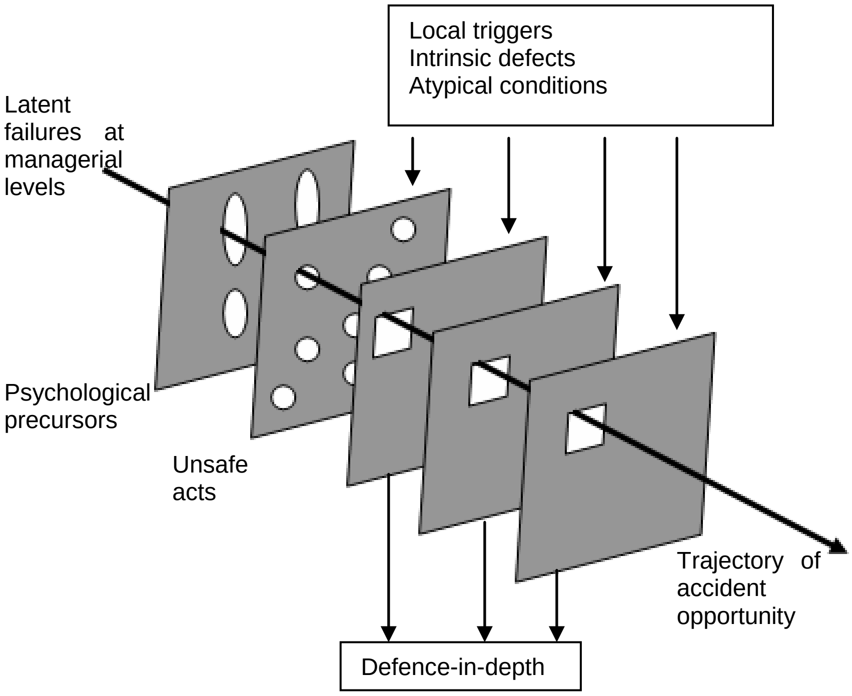


Figure 2.1: Reason's (1990) Model of Error

2.1.1.4 Systematic Error

The decisions that designers and engineers make can have a long-term effect on a system. Decisions made in the design process cannot easily be revised once the piece of equipment is in use. Similarly, once a training programme is in place each person going through that training programme will respond to the same situation in a similar way. Therefore, if the environment, equipment and individual are constant then the likelihood of an error recurring is high. Reason called these types of errors systematic errors. An example of systematic error is the Ladbroke Grove train collision (Cullen, 2001). Between August 1993 and 5 October 1999 there had been eight Signals Passed at Danger (SPADs) on the railway signal SN109. These incidents had been recorded and preventative action had been suggested. But the organisation had decided not to implement them. On 5th October 1999 a Thames Trains train driver passed a signal at danger (SPAD) resulting in a collision with a First Great Western Train: 31 people lost their life.

Current emphasis for error and the reasons for disaster have been on organisational issues, as shown in accident reports: Challenger (Anon, 1986), Columbia (Gehman et al., 2003), Bhopal (Cullen, 2001; Gupta, 2002) Ladbroke Grove (Cullen, 2001). This augmentation of organisational and cultural culpability has been justified by recent forms of classifying error, such as Reasons **Latent Failures**. Due to the current emphasis on organisational issues, there has been little research into understanding the effects of team collaboration on reliability. There is then an opportunity to investigate further this perspective of error.

2.1.2 Individual / Human Error

Human error occurs when human action is the real cause of an incident and it is believed that the individual is culpable for the incident. Human error is the main cause for accidents, at a level of 60-90% (Degani & Wiener, 1993; Davis, 2002; Shappell & Wiegmann, 2001). Who is the human that creates an error? Within the lifecycle of a system there are many people involved who could create an error. The initial designers of the system may have inadvertently designed an aspect that will often allow an accident to occur (Figure 2.2).

Rucksack Waistband Design Fault

Recently I have been backpacking around New Zealand. I had just brought myself a new rucksack, which is modern, comfortable with many pockets and clever devices for the experienced backpacker. This rucksack had been developed over many years and has come along way from the metal frame, bag and two arm holds that is sitting in my attic.

However, one day the waistband broke on me. I was not sure what had happened (which is often the case in the initial stages after a disaster). Had I misused the bag in some way? Been to rough with it? It should be sturdy. I wasn't sure if I needed to be responsible and mend the rucksack myself, as if I had caused it to break, or to take it back to the shop and ask for a new one.

As I had nothing to loose, I went to the shop. There they instantly replaced the waistband. During the design and testing stages of the rucksack, a fault had gone undiscovered. A pivot joint was a weak spot on the rucksack and was likely to break. This had happened to other people before, and the manufacturer had investigated the problem and new waistbands were to be installed. I had not done anything unexpected to the rucksack, although I was the last person to touch the rucksack before it broke. Often the end user is not the cause of the error. *[Author's own field research 2008]*

Figure 2.2: Example of a Design Not a User Error

Human errors, such as reacting inappropriately to a warning signal, misreading dials, or using the wrong controls, are not always the fault of the user at the sharp end. There are others involved in the design and use of the system. Moray (2000) model of error (Figure 2.3) shows that there are many conditions that affect a situation and can result in an error. Humans will inevitably make errors. Designers should anticipate these when designing systems. This reduces the likelihood of errors and creates a means to resolve errors. Employers can also reduce errors by ensuring that the environment is appropriate to good working conditions.

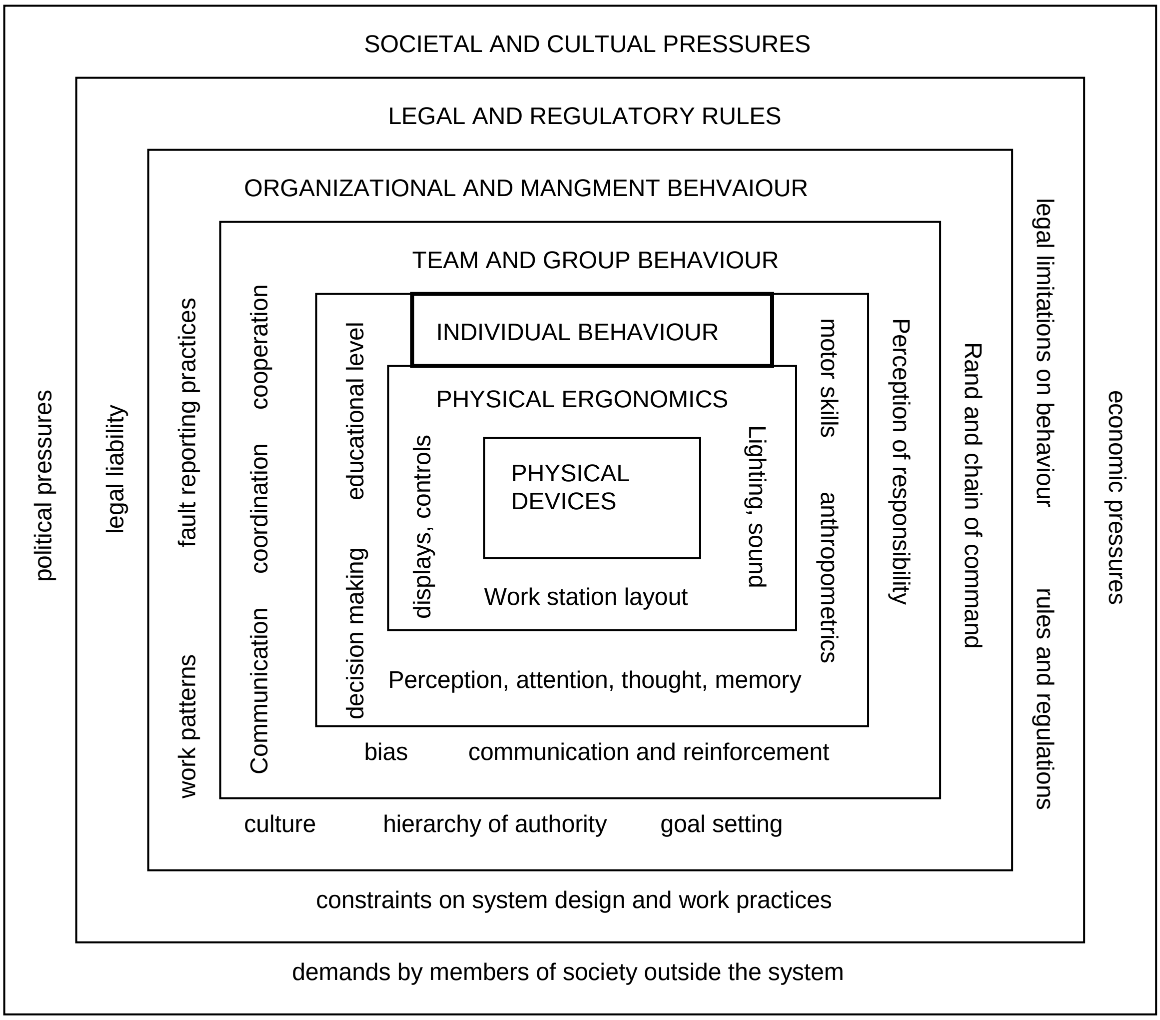


Figure 2.3 Moray's (2000) Model of Error

When an individual performs a procedure or part of a procedure there are several aspects that are present. Each procedure is made up of a series of tasks, as can be identified by creating a task analysis. These tasks are often hierarchical. Each task has a goal, which leads towards the overall goal for the whole procedure. Completing the tasks and achieving the goals correctly and efficiently would make an individual or team very reliable. Errors can be made at any or all stages of the procedure. Some errors may be rectifiable or insignificant. Other errors may go unnoticed. Several insignificant errors together may create a significant error in response.

Humans are not always the villains in a system. If they cause up to 90% of errors, then it would appear to be a good idea to remove the human from the system. However, humans can also be the hero in preventing a disaster,

> *'People in complex systems create safety. They make it their job to anticipate forms of and pathways toward failure. They invest in their own resilience and that of their system by tailoring their tasks, by inserting buffers, routines, heuristics, tricks, double-checking, memory aids.' (Dekker,2001, p.206).*

A system, even one that has cutting edge technology, cannot cope with having to interpret new and unexpected information (Mital et al., 1994). In these cases, a human can interpret information, creating new ideas that deal with unique and possibly volatile situations. The human is able to decide on the appropriate action and possibly prevent a disaster.

Due to free choice, humans are able to cause disasters deliberately. These actions are sabotage they are not classified as an error. Only actions that are non-malicious shall be discussed in this document.

2.1.3 Summary

Many accidents have been blamed on human error. However, there are various antecedents to an error occurring. These include aspects of organisation, environment and design. Kletz, Norman, Rasmussen and Reason have classified what errors occur: whether they are due to human actions, psychological dysfunction, or system issues. Understanding the type of errors humans make and that this is predictable, improves design of man-machine interfaces (MMI), training, manuals and organisations. There has been thorough investigation into individual and system errors. But the description of team errors has been deficient. This provides an opportunity for further study into team errors.

2.2 HRA Techniques

Below is a history of HRA and account of HRA methods.

2.2.1 HRA Background

> *'People's knowledge is limited, their awareness is finite and multiple goals may compete for their attention … the point in learning about human error is not to find out where people went wrong. It is to find out why their assessments and actions made sense to them at the time.' (Dekker, 2001, p.255)*

A human interacting with a system can be analysed to determine which errors could occur, what factors could help mitigate these errors and the probability of these errors occurring. This is done by using HRA techniques. HRAs are qualitative and quantitative measurements of the risks and errors that can occur in a system because of human actions, not by a fault of the system. HRA have been developed for designers and users to understand the technical difficulties of using a product or system. As, no matter how good the product is, it is impossible to make the product error proof: humans are inevitably fallible.

As a field of research HRA has been around since the 1960s (Shorrock et al, 2005). Predicting the probability of error can be a controversial topic because probabilities are based on random behaviour and humans are not random; some factors that can affect them are consistent (Redmill, 2002) e.g. training. HRA techniques have accounted for factors that influence the error probability in the form of "performance shaping factors" (PSFs). The task, the individual and the environment define the performance shaping factors. There are three main approaches to HRA (Kirwan, 2002):

- Human error identification – what can go wrong?
- Human error quantification – how often will a human error occur?
- Human error reduction – how can human error be prevented from occurring or its impact on the system reduced?

HRA analyse systems (with varying degrees of accuracy), determine the errors that could occur within the system, what factors could help mitigate these errors and the probability of these errors occurring. Below are the different HRA methods that are available to BAE Systems. This is not an exhaustive list but it covers those methods for which information is available. One of the interviewees did explain that air systems had created their own HRA method but that information is not currently available to the investigator and so has been excluded from the current research.

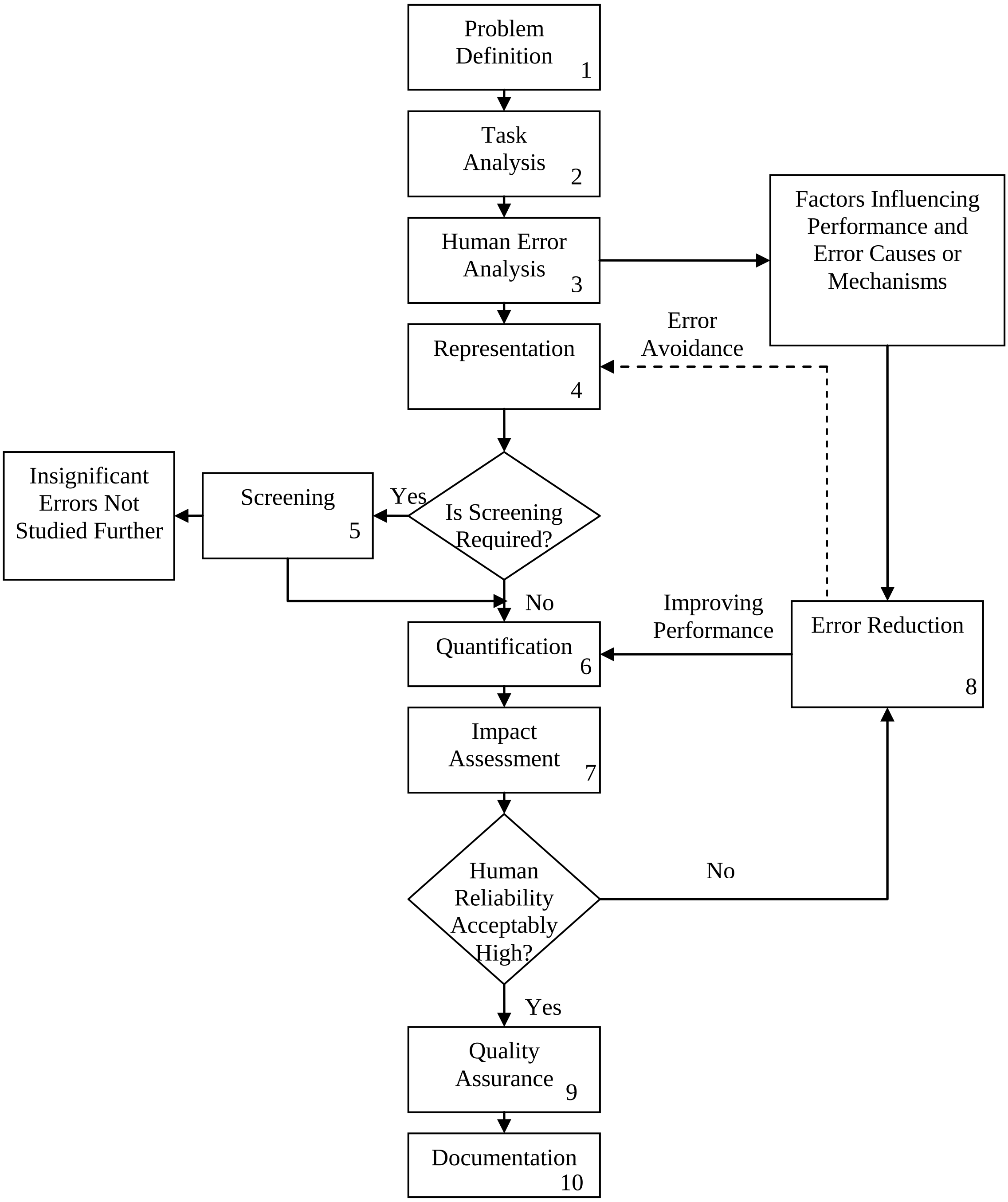


Figure 2.4: The 10 HRA Stages (Kirwan, 1994)

The methods below range from 1st generation techniques through to 3rd generation techniques, these are: THEA, CHLOE, SHERPA, TRACEr, ASHRAM, HFACS, HEROS, TAFEI, HEART, CREAM basic and CREAM extended. The process and usability for each method shall be described. There are ten stages that can assessed by HRAs (Figure 2.4). One of the developments that occurred with the second generation is that more stages were covered by each technique.

2.2.2 First Generation Techniques

The first generation of HRA techniques began in the 1970s, e.g. SHERPA (Embrey, 1986) and HEART (Williams, 1986). These are generic prospective techniques. They assess physical, organisational and psychological aspects, but cognitive reasoning is not used to explain the possible errors.

2.2.2.1 Systematic Human Error Reduction and Prediction Approach (SHERPA) (Embrey, 1986):

SHERPA is a mature, computerised method that uses questions to identify where an error may occur (Ng, 2003a,b,c; Ng, 2004). The questions address both psychological and external errors. The output is a list of errors that could occur and why they occur. The assessor uses this list to mitigate the errors. SHERPA is a good technique as a variety of errors are considered and it also accounts for error recovery. The computer based questionnaire means that the technique is simple to use. But the psychological terms need comprehension and can lead to different assessors generating different results. The assessor must also have a good understanding of the system. No Human Error Probabilities (HEPs) are produced by SHERPA, therefore it would be hard to adapt to a quantitative method.

2.2.2.2 Human Error Assessment and Reduction Technique (HEART) (Williams, 1986):

HEART is a commonly used technique, as it is quick and simple to use. The first step is to choose the ‘generic task’ statement, which will assign the scenario with a baseline HEP. The assessor then works through lists of statements of PSFs, choosing the most relevant. The statements have multiplying factors, which vary depending on the importance and severity of the error forcing condition. The baseline HEP and the multiplying factors are then calculated to produce a final HEP for that scenario. The severity and importance of the error forcing conditions are clear from the multiplying factor. So the assessor can concentrate their efforts to reduce error on these areas. The statements do not need human factors experience to decipher and so the method is usable by all. The major concern with this technique is that the probabilities and multiplying factors are not always representative of the situation. It has been commented on that the final probabilities could be out by a factor of 2. The statements used means that there is room for developing this method to include team working errors. As it is currently used at the moment it would be easier to encourage the use of the new tool in the workplace.

2.2.3 Second Generation Techniques

Second-generation techniques such as, TAFEI, TRACEr, CREAM, THEA, have improved the reliability of the HRA for individuals. These techniques are often contextual and consider many influences of human reliability and error, such as organisational, environmental, psychological and cognitive issues.

These second generation techniques have been widely used, but they have not been validated. It was becoming apparent that these techniques were not fulfilling their potential. Dougherty (1990) criticised the first generation techniques. The points that he believed should be addressed were (Dougherty, 1990, p.294-296):

The necessary stochastic nature of things; the tool should be compatible with a probabilistic framework.

The necessary time-dependence; including the operators perception of time and their anticipation of events.

The need to model complexity; there are many factors that influence human behaviour and they all should be modelled.

The need for better error analysis; the error modes, types, mechanisms and causes must be identified more realistically

The making of peace with planning; planning is an important element of error mitigation.

The integral incorporation of influences; ad hoc changes to techniques should not be made, as all aspects of reliability should be designed into the tool

An extended paradigm:

The need for validation; models should be validated.

These comments made the field review the techniques and provided inspiration for a new aim to find a method that fulfils Dougherty's criteria and included the most recent knowledge of error and human behaviour (Redmill, 2002).

2.2.3.1 Task analysis for error identification (TAFEI) (Baber & Stanton, 1994, 1996):

TAFEI qualitatively predicts erroneous interactions between people and machines. It consists of an HTA displaying human activity; State-Space Diagrams describing machine activity; and Transition Matrices that determine potential for errors that occur at the interaction of the human and machine.

2.2.3.2 Technique for Retrospective and Predictive Analysis of Cognitive Errors. (TRACEr) (Shorrock & Kirwan, 2002):

TRACEr is a method that is designed to be used in the air traffic control (ATC) industry. This immediately limits its used as a basis for a collaborative tool, however it is a modern, second generation technique with few shortcomings. This is a computer based tool that uses statements, flow diagrams and tables. Statements and taxonomies are used to describe the context of the system, production of errors and the recovery of errors. These taxonomies are ATC oriented. The context of the system produces performance shaping factors (PSF) that are unique to the particular situation. Once the errors have been established the cause, including cognitive and behavioural error modes, are ascertained so that appropriate mitigating factors can be utilised. The method can be used retrospectively and prospectively which facilitates learning throughout the lifecycle of the system.

2.2.3.3 Aviation Safety Human Reliability Analysis Method (ASHRAM) (Miller, 2001):

A second generation technique, ASHRAM, is developed by Sandia National Laboratories. It is designed for use in aviation both prospectively and retrospectively. The method uses a cognitive model that helps to categorise rather than describe behaviour, consequently human factors expertise is not required. Assessors follow the step-by-step method of ASHRAM. Firstly the system and scenario are described and the error forcing contexts (based on the scenario and PSFs) are identified. Either a singular or all deviant scenarios are found, these are recorded and mitigation of the errors can occur. The ASHRAM method does not measure the severity of the errors, nor contains HEPs, so developing this tool into a quantitative method could be challenging.

2.2.3.4 Human Factors Analysis and Classification System (HFACS) (Wiegmann & Shappell, 2001):

HFACS is a retrospective and prospective tool for military and commercial aviation. It contains a hierarchy of taxonomies which the assessor uses to decipher what errors may or have occurred. Reason's model of accident causation (Reason, 1990) creates the final section of this taxonomy. Although most of the errors are for an individual, Crew Resource Management (CRM) is considered. This is a taxonomy and so the method does not promote error mitigation, it just highlights the state of the error. As there is currently only a taxonomy the method requires great development to produce a quantitative method that can guide engineers to improved design.

2.2.3.5 Human Error Rates and Optimising System (HEROS) (Richei, Hauptmann & Unger, 2001):

HEROS uses fuzzy set theory, a complicated mathematical technique, to produce HEPs. The method is computer-based to increase its usability. There are several steps to the analysis. Initially the system and context of use are described resulting in a task analysis. This is then used to produce fault trees. The fault trees combined with PSF information are manipulated by HEROS to produce HEPs. This is a thorough technique and considers organisational, environmental and psychological aspects of the system. It also takes into account the severity of the errors to aid the design of mitigation factors. As the technique it is often used as a 'black box' but it can be used to support qualitative techniques, by providing quantitative output. There is no consideration of human-human interaction so there is little scope for development into a collaborative tool. The complexity of the fuzzy set theory would also produce difficulties for developing the technique.

2.2.3.6 Cognitive Reliability and Error Analysis Method (CREAM) (Hollnagel, 1998):

CREAM can be divided into two sections basic and extended. CREAM basic focuses on the environment in which the operator works rather than human error. The first step of CREAM is to produce a task analysis of the system. Then 'Common Performance

Conditions' (CPC) are determined. CPCs provide information of the organisation, environment and working conditions. This information is used to determine the 'probable control mode', this is the reliability of the overall working conditions. There are four modes: scrambled, opportunistic, tactical and strategic, each mode has a probability of a failure occurring, giving the CREAM Basic probability. This is a simple technique and does not take long to perform, it provides an estimation of the overall reliability of the system.

CREAM Extended focuses more on the human, but the above information is the basis for the technique. Each task performed is assigned a cognitive activity, e.g. observe, from this types of errors can be ascribed and each error has a probability. These probabilities are then weighted for the effect of the control mode and the CPCs. Several tasks can be collected together to produce an overall probability. This probability is more specific to the scenario chosen than CREAM Basic. CREAM Extended is complex, time consuming and experience is needed to allocated the cognitive activities correctly. However it can be tailored to different industries. Because each task can be done separately the assessor can ascertain where there is a high risk of error, but the severity of the error is not shown. It could be possible to extend the CPCs and cognitive activities to involve team working.

2.2.3.7 Techniques for Human Error Assessment (THEA) (Wright, Fields, Harrison and Wright, 2001):

THEA is a technique that has been developed by the Dependable Computing Systems Centre (DCSC) at York university. It is a tool that is designed to be used by system engineers, therefore, human factors expertise is not required. This tool is to facilitate the evolution of the safety, usability and functionality of design requirements, for this reason is should be used early in the design lifecycle. THEA consists of six stages (Figure 2.5).

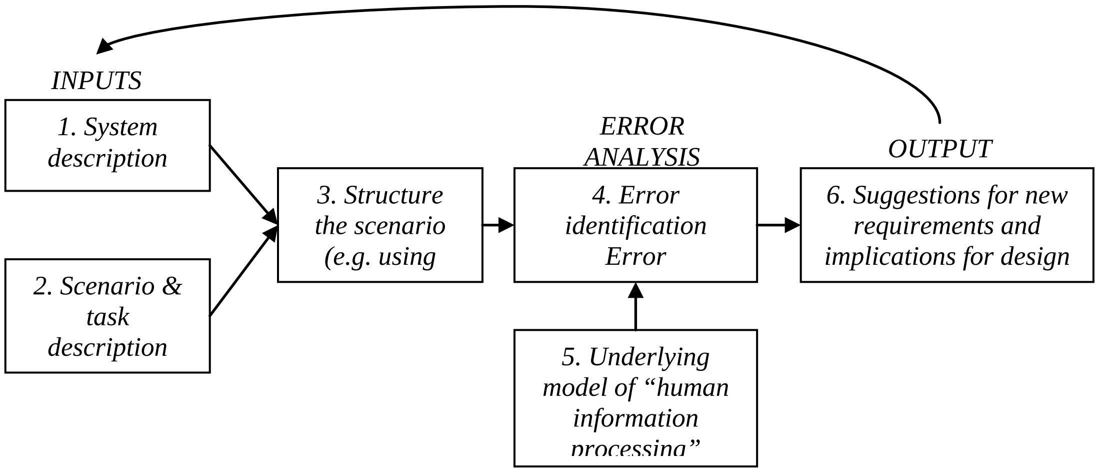


Figure 2.5: The THEA Process.

System Definition; to improve the understanding of the system being design.

Scenario & Task Description; a) To improve the understanding of how the system will be used. b) To facilitate the system designers representation of the system statements that have been produced, these provide hints so that stages 1 and 2 can be expressed completely.

Structure the Scenario; a decomposition of the system into goals.

Error Identification, Error Consequence	improve the understanding
Underlying model of "human information processing"	of how errors can evolve.

THEA uses Norman's 1988 model of human information processing (Figure 2.6) to evaluate the errors that may be due to the human in the system. The system designer answers questions on four stages of the model;

- Goals, triggering and initiation
- Plans
- Performing actions
- Perception, interpretation and evaluation.

The answers should provide a list of possible errors that may occur or situations that may cause errors. From this barriers can be introduced into the system to prevent errors from occurring or to reduce the severity of the errors.

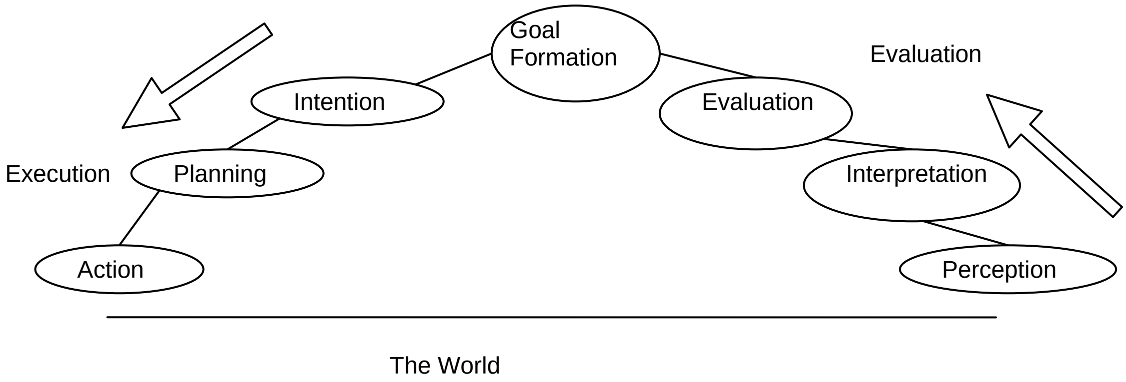


Figure 2.6: Norman (1988) Human Information Processing Model.

THEA is a qualitative HRA, this is consistent with being used at the beginning of the design lifecycle. THEA concentrates on cognitive errors and will not discover behavioural errors, or account for joint decision making (Topic V, 1997). For THEA to be usable goals and plans for the system must be available. If plans are available, THEA can produce coherent results with the need for expertise in human factors.

For the purposes of creating a tool to predict team error the statements produced could be adapted to account for team working. However there is no possibility of turning this method into a quantitative method. Also, the DCSC has already developed THEA into CHOLE, which is a collaborative HRA technique.

2.2.3.8 Third Generation Techniques

Often a team of people interact with a system, not just an individual. There is now a call for a new generation of HRA to account for when a product is used within a team (Miguel & Wright 2002a). The interactions between the team members can increase and decrease the reliability of each individual and overall the reliability of the team. Some of the PSFs of team reliability are communication, trust and resource management (Sasou & Reason, 1999).

CHLOE (Miguel & Wright., 2002a) has been developed to take into account the effect of teams on reliability. Miguel et al (2002a; 2002b), wrote ‘collaborative errors may be caused by factors such as a lack of [situational awareness, SA], misunderstandings between participants, conflicts and failures of co-ordination’ (p.4). CHLOE is a qualitative method and in a time when corporate manslaughter is becoming more prominent and system reliability is measured in probabilities then human reliability also needs to be quantitative.

2.2.3.9 A Technique for Analysing Collaborative Systems (CHLOE) (Miguel & Wright, 2002a):

CHLOE is designed to identify failures in collaborative work, whether this is direct human – human communication or human – computer – human communication. Like THEA, CHLOE consists of four stages;

- Scenario Description
- Task Identification
- Error Analysis, produced using a list of questions
- Design Suggestions.

Sequence diagrams are used to ascertain the interaction that occurs between the agents and the system. The assessor then answers questions on the possible breakdown in communication within the system. CHLOE is to be used by system engineers and so psychological and human factors experience is not required. Error analysis and design suggestions should be performed concurrently. The assessor creates design solutions through conducting the assessment and inputting this information into a table similar to that in (Table 2.1).

No behavioural errors are considered, the results are qualitative, do not consider the severity of the errors and so the safety of the system cannot be determined.

Table 2.1: CHLOE Consequences and Design Issues Table

Questions	Consequences	Design Issues

2.2.4 Summary

Using the requirements that have come out from the interviews and discussions with employees at BAE Systems the techniques that are most suitable to be developed in to a tool that can be used to look at collaborations must have the following qualities:

- They must be quantitative methods
- They must be prospective methods
- They must be simple for engineers to use
- They should not be time consuming
- They must be able to fit into the engineers current method of working.

There are only a few quantitative methods these are HEROS, HEART and CREAM. All of these are prospective methods. HEROS is not suitable for further development as the fuzzy set theory is beyond the capabilities of the MPhil and the researcher. The technique needs to be one that engineers can use easily. CREAM basic is a simple technique and will not provide any suggests to improve design of equipment, CREAM extended is complex and time consuming, engineers are unlikely to create time to fit this method into their designing of equipment. Conversely, CREAM would be a good method to use as some research has been done on developing CREAM in to a collaborative technique (Smith, 2003). Hollnagel has developed high-quality models that consider a large proportion of the factors that produce errors. These should be considered in the future.

HEART is a quantitative method that is easy to use and helps engineers to find where the highest areas of risk are. This is essential if the tool is to aid development rather than just provide overall probabilities. HEART contains many statements and adding more may encumber the list and reduce the usability of the tool. Another important aspect of HEART that needs to be contemplated is the probabilities used. Currently these are not accurate and have not been validated. HEART is used by some employees at BAE SYSTEMS and so using this method will reduce the amount of learning and integration time required to ensure use of the new tool. HEART is chosen as the method that will be the foundation for the new tool.

2.3 Design Life Cycle

Knowing how a product is designed and managed throughout its lifecycle will provide understanding of the stakeholders of the product, the various stages that a product will go through and how human factors will fit into the design process. The design lifecycle process is broken down into four stages: 1) product definition (Section 2.3.1.1), 2) product design development (Section 2.3.1.2), 3) product acceptance (Section 2.3.1.3) and 4) post design (Section 2.3.1.4). There are generic models (Section 2.3.2.1) that are used to plan the lifecycle management. These are, the spiral model, the waterfall model and the ‘V’ diagram,. BAE Systems Air System BU has created a model to aid the design for human usability (Section 2.3.2.2). All the models will be portrayed and how the type of HRA that would be appropriate to used at each stage will be discussed.

2.3.1 Lifecycle Stages

Below are the descriptions of the lifecycle stages.

2.3.1.1 Product Definition

The first stage instigates the production of information. Before any product can be designed the need must first be defined. This will enable the designer/engineer to understand the context in which the product will be used, ensuring that the correct product is designed. The need is defined in terms of:

- The role, task and context that the product will be used in
- The behaviour, functionality and interfaces of the product
- The engineering qualities that the product must have
- The programme imperatives in which the product will be designed.

Once the wider context has been determined, the product concept requirements need specifying. It is important that the product and context definitions are set to ensure a smoother design process. If the design requirements are not properly explored the product will not suit the use and so design changes will be needed. The later on in the design process changes occur, the more costly they are to implement. Aspects that should be considered are:

- the definition of the function and decomposition of the product
- the definition of the roles of each component

- the definition of the interface required
- the capabilities of the skills and technologies.

The information of the product available at this stage is general. The environment and when the product will be used is understood. The type of HRAs that can be used at this stage are qualitative, they will be able to highlight major risk areas, but will not be able to define the risk as a level of probability. The product definition stage is the ‘early stages’ of the design process and it is also referred to as the ‘front end’. Only when the concept has been defined and the boundaries set can the design process begin.

2.3.1.2 Product Design Development

Once the product requirements are known, the designer has sufficient information to generate an initial design and assess it for its appropriateness to the context of use. The product is tested throughout the design process to guarantee that the product is reliable and that it can integrate with other systems. This is an iterative process consisting of the following steps:

- Creation of the detailed design
- Creation of the drawing set
- Analysing the behaviour and performance of the design
- Analysing the robustness of the product throughout its manufacture, operability, environment tolerance/impact, and supportability
- Assessing the configuration management.

To ensure that the product stays true to the original design specifications some aspects of the design are reviewed at the end of the design stage:

- Conformance to drawings
- Material traceability
- Process quality.

Designing a product can take many years and there may be changes to the personnel working on the product, so it is important that all designs, modifications and justifications are recorded. At the end of this stage the final product has been designed, it is functioning and can be integrated within a system. All predictive HRA techniques are suitable for use at this stage of design. Qualitative and quantitative methods will provide appropriate information that can beneficially affect the design. It is important to use HRA recurrently throughout the design process as changes in the design may affect the human reliability in unforeseen manners and an improvement in reliability can be shown as the design progresses.

2.3.1.3 Product Acceptance

Before the product can be put into regular use, the safety of the product and the fulfilment of the requirements need to be assessed. Much of this stage should already have been assessed in the previous stage, but this is a formalisation of this information. The designers/engineers must answer a series of questions:

- Doe the product solve the right problem?
- Does the product solve the defined problem correctly?
- Has the stated problem been solved competently considering all operating conditions and environments?
- What are the limits to use of the product?
- What are the hazards of the product?
- What is the products reliability?

Quantitative HRA techniques can provide values that will tell the project manager or the buyer of the product, the reliability of the product and if this is an improvement on a predecessor product and or a similar product already on the market. HRA techniques highlight areas of risk, limitations of the product. If any changes to the design need to be made at this stage, this could be costly and is not advisable. When all the questions have been answered satisfactorily the product can be employed.

2.3.1.4 Post Design

Once the product is in use the lifecycle of the product is still managed. The product will need maintenance and repairs. The frequency of these needs to be assessed and recorded so that this information is retrievable when needed. Appropriate training for the operators, maintainers and repairers needs to be set and implemented. It is feasible that the context in which the product is used may alter, so that new needs are fulfilled.

This means an ongoing assessment of the use and operability of the product, leading to design modification updates.

There could also be cases where the product is involved in an accident. In this case a retrospective HRA method would be used to determined why the error occurred, to prevent the incident reoccurring. Any problems that occur during the use of the product, that did not come about in the design stage need to be rectified.

When the product is retired, it needs to be dis-assembled, recycled and all ordinary and hazardous materials need be disposed of safely. Any lessons learnt from the complete lifecycle of the product should be recorded and they should be accessible to aid future designs.

2.3.2 Lifecycle Process Models

2.3.2.1 Generic Lifecycle Models

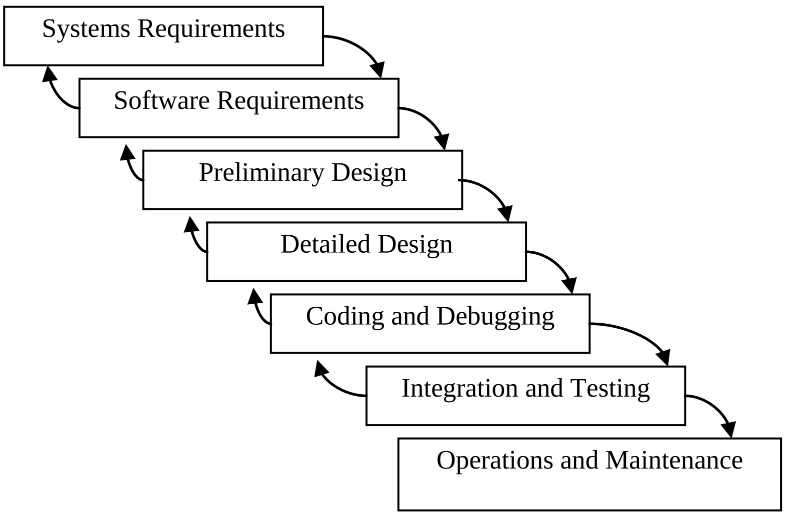


Figure 2.7: Waterfall Lifecycle Process Model

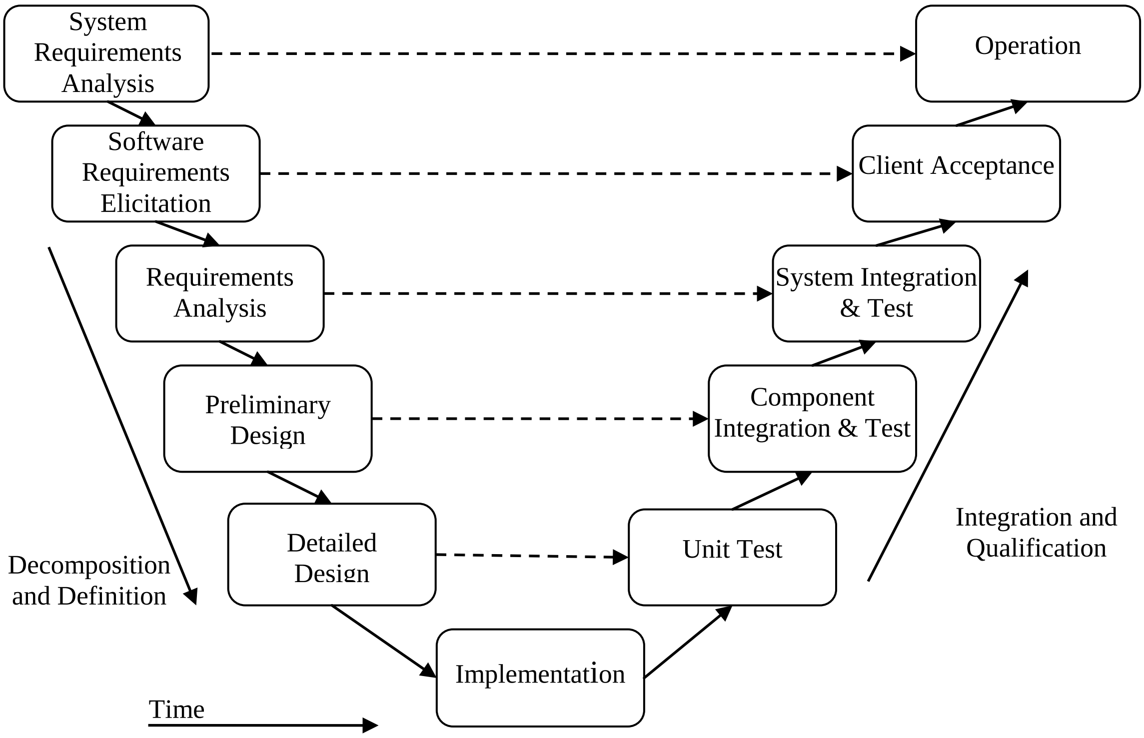


Figure 2.8: 'V' Diagram Lifecycle Process Model

There are different types of project management. There is the Spiral model where there is continuous enhancement and convergence to the point of satisfaction. There is also the waterfall model (Figure 2.7). This is a sequence method where each step is performed one at a time, in order, although iteration can occur. Finally, there is the ‘V’ diagram (Figure 2. 8), where requirements formed in the development stage are compared to the design outcomes, this is also a hierarchical method.

It is down to the individual or team designing the process to decide which model to use. The benefit of ‘V’ Diagrams over the Waterfall model is that the information from the requirements and initial design stages are fed into the later testing stages. This ensures that the product will always do what was initially asked of it. Some companies adapt these model to suit particular methods of working. An adapted model is discussed in the next section.

2.3.2.2 Formalised Lifecycle Models

There is no set lifecycle process model within BAE Systems, as each BU is independent. Air Systems are forward thinking in their approach to human factors and have developed a model to incorporate human usability into the design process (Figure

2.9). This is a waterfall approach, with iteration occurring during the design stage. A document accompanies this diagram informing the users of the inputs and outputs required at each stage.

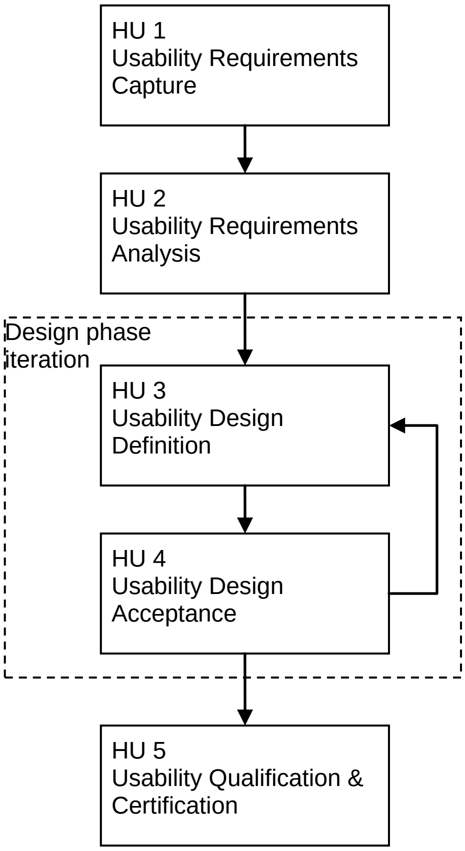


Figure 2.9: Air System's Lifecycle Process Model

2.3.3 Safety Case

A Safety Case is process to argue how safety of a system will be developed, achieved and maintained (DEF STAN 00-250, DEF STAN00-56). The argument is compiled from a variety of sources of information including the human factors input of hazard analysis, accident mitigation, and error analysis. Its intent is to produce a compelling and comprehensive case that a system is safe for the intended environment. Prospective HRAs can highlight areas of risk in the system informing the engineers of these areas and highlighting where mitigation is required to increase the safety of the system.

A Safety Case is produced for any system that is incurring any design changes such as being developed, upgraded or refitted. It covers the whole lifecycle of the system. The Safety Case information is summarised into a Safety Case report. This provides a record of the intended environment of the system, highlights the areas of risk of the system and informs of mitigation to reduce the risk.

2.3.4 Summary

Project management is complex. Whilst the tool created in the MPhil is not used to predict the suitability of a project management style, but to ensure usability of the tool then the process in which it is used must be understood. Different stages require different levels of detail and output from an HRA. The aim of the tool is to be used in all stages of the design process. The detail of the information available increases in complexity throughout the design lifecycle, therefore the tool must start simple and also increase in complexity throughout the stages to emulate the development of the product.

2.4 Team Structures and Attributes

2.4.1 Team Structures

Teams are used in commercial and military settings (Fitzpatrick & Askin, 2005; Helmreich, 2000) as, under the right circumstances, a team can out-perform any single member, whether this is through physical strength, knowledge or decision making. Collaboration can improve situational awareness, understanding of a situation and decision making (Noble, 2004). Companies use teams to handle complexity that emerges in global industries.

2.4.2 Definition of Team and Team Work

This research uses Eason's model of teams (Eason, 1995; Sinclair, 2003)

A definition of a team is

> *'two or more individuals who must perform distinct, complementary or independent tasks in pursuit of a common, specified goal. Teams must communicate as well as share information and resources in order to meet their goal(s). The ability of each individual member to adapt and adjust through reliance on other team members determines the level of a team's coordination and thus teamwork' (Salas et al., 2005 p.794)*

Huczynski & Buchanan (1991) have defined two types of teams, formal and informal groups. How the team members are chosen and the relationships within the teams differ. But how a person perceives when they are part of a group or team is the same. The attributes of a group are:

- that there must be at least two people
- they should interact with each other
- they should be psychologically aware of each other
- each individual should perceive themselves are being in a group.

These attributes apply to all groups whether they are formal or informal.

A **formal group** will have a formal structure. It will be task oriented and the activities of the group will contribute directly to the organisations collective purpose. The group is consciously organised by some person for a reason. An **informal group** forms when individuals develop interdependencies with each other, need each other and influence each other's behaviour. In a work environment people will be placed in formal groups by supervisors or managers, but they will create their own informal groups, which may have stronger influences on behaviour than the formal group.

A team has characteristics (Huczynski & Buchanan, 1991) that should be considered when developing systems that are to be used by a team. These are listed below:

- An increase in members leads to an increase in the number of possible relationships within the group, which will mean there is an increase in the communication required and therefore there is an increase in the amount of structure needed to operate the group.
- There is a shared communication network
- There is a shared sense of collective identity
- There are shared goals and the members of the team must feel obliged to achieve the shared goal
- There is a group structure, individuals will have different roles and they will abide by group rules.

Noble (2004) cites the ‘Bay of Pigs’ Fiasco (Janis, 1972) where a battle plan went wrong due to inappropriate rules of the team. The members of the team did not discuss doubts and were not given the opportunity to test assumptions in the plan. There was a lack of knowledge sharing, communication and trust within the team. This caused the plan to fail leading to the deaths of many and the surrender of the rest. Salas et al (2005) corroborates with this, by describing that for collaboration to be effective there needs to be co-operation, openness, sharing and trust.

2.4.3 Previous Teamwork Experiments

2.4.3.1 The Early Days

The Hawthorne studies (Sundstrom et al., 2000) performed between 1924 and 1932 were an early investigation into teamwork and team motivation. The experiments, performed by the Harvard Business School, are some of the most extensive experiments to date. The resultant information was that an individual is motivated by more than just money. A person has a need for recognition and a sense of belonging. In the Hawthorne factory, people were divided into formal groups and they formed social, informal, groups. To gain a sense of belonging into either of these groups an individual can shape their attitude to work, so that it corresponds with the rest of the group. One example of this is, if a group had decided that they will work only as hard as they need to, to get the days quota through, then anyone working faster or slower than required was ‘punished’ by the group, thus moulding an individual’s workrate to suit the group. Huczynski & Buchanan (1991) believe that this effect of motivation should not be underestimated.

2.4.3.2 Military Studies

Whilst the above interactions affect team morale, studies in the 1950’s and 1960’s have looked at improving the function of military teams. These went beyond looking at how teams worked socially, to how their ability is diminished under extreme conditions of a battlefield. Some of the aspects studied were time pressure, stress, ambiguous or incomplete information and severe consequences for actions taken (Paris, 2002). These factors are still the topic of investigations, with studies looking at workload and situational awareness.

2.4.3.3 Current Team research

> *"Some of the emerging research themes that are of particular interest to ergonomists comprise of analysing team tasks and measuring team performance, assessing the effects of team structure and roles and evaluating workplace design and team workload" (Annett & Stanton, 2000, p.1046)*

Annett and Stanton (2000) define team accomplishment as the product of the team and how the team behaves is known as the team process. They believe that communication and co-ordination are crucial processes. Team spirit and cohesion can influence team performance. Team process is effected by the structure and role differentiation within the team, for example the division of leadership and responsibility within the team. Work place design and the workload of the team are also important to team effectiveness (Artman, 1998; Paris et al., 2000,). The current research is taking place in command and control (e.g. battlefield) or process control environments. Some of the issues important to team work in 2000 are stress, decision-making, mental models, workload, SA, morale, cohesion, performance measurement, communication and team skills.

Paris et al. (2000) writes that there are three primary categories for team work, cognitions, skills and attitudes. They also say that "teamwork skills are not readily quantifiable" (p.4) and that team behaviours evolve over the lifecycle of the team. Team architecture has three attributes, member proximity, communication modality and allocation of functions. Member proximity and communication are two of the three team attributes that are in ROCCI.

2.4.3.4 Teamwork Dimensions

Both Noble (2004) and Salas et al (2005) describe three elements that are fundamental to effective team work. Noble describes them as; adequate resources, the right kinds of knowledge and motivation, whereas Salas has produced the knowledge, skills attitudes (KSA) model (Figure 2.10). Noble (2004) focuses on the importance of knowledge, he believes that 'knowledge is central to collaboration and teamwork' (p.4) if individuals do not have the correct information, they cannot work effectively together. The knowledge must also be shared amongst the team, no one person should know everything (as that could result in knowledge overload), but every team member should know enough to do their own work. Team members should interact and communicate with each other to discuss ideas and increase understanding of a situation.

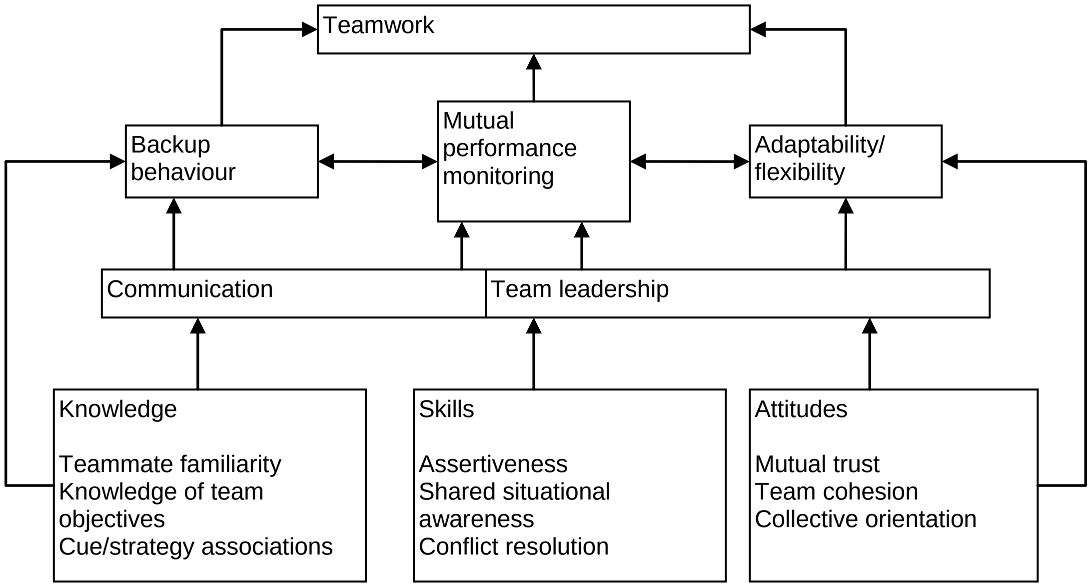
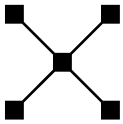
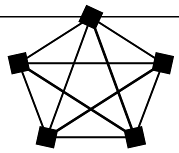


Figure 2.10: Illustration of how KSAs Contribute to Teamwork (Salas et al., 2005, p.795)

2.4.4 Communication

Communication is essential for sharing knowledge, making decisions, developing trust and improving SA in a team. Appropriate group communication can lead to greater homogeneity of the group, increased frequency and effectiveness of actions. Deciding upon the structure of the communication, i.e. who communicates with who, depends upon the complexity of the task (Table 2.2). Having all information going to one person for a simple task, or where one person is performing the task, is beneficial as there will be little repetition of information, if the information was spread amongst the team, then the person performing the action may not have all the correct information. Where a complex task is being performed by several people and there is great volume of information, a comcon model would be more appropriate as the information would be shared amongst the team members and so no one person would become saturated (Baron & Greenberg, 1990). This is a simplified model of communication. There are many types of teams and tasks which may not fit into Baron and Greenberg's (1990) models.

Table 2.2: Two Communication Models and their Suitability to Simple and Complex Tasks (Huczynski & Buchanan, 1991, p.206)

	Communication Model	Simple Tasks	Complex Tasks
Wheel		Central person has all information	Central person becomes saturated
Comcon		No one person has all information	Information flows, no one become saturated with information

The structure of the communication is not the only aspect that should be considered, frequency, content, language, bandwidth (Carron & Hausenblas, 1998) and the cognition of communication, also influence the effectiveness of communication. The appropriateness for each of the aspects varies with each situation, there are no precise parameters for team communication. An overview of each of the four aspects shall be discussed below.

2.4.4.1 Frequency

The relationship between frequency of communication and the effectiveness of working is not linear, but U-shaped. If there is very little communication then there will not be enough sharing of knowledge for correct decision making, but if there is too much communication there will not be enough time to thing about the decisions, or to perform work. Too much communication may be a sign of lack of trust, as one team member may be over monitoring the other's performance.

2.4.4.2 Content and Language

Where direct orders are given, the quality of the communication is low and there is a high risk situation, then formal language and topics of conversation should be used. This optimises the availability of the communication and reduces the strain on other cognitive processes. If the aim of the communication is to discuss ideas and share knowledge and there is no immediate time frame, then informal communication, which not only discusses the relevant issues, but also personal information is appropriate. Understanding another team member's character, interests, strengths and weaknesses will increase the trust in the relationship, ultimately producing more effective team working.

2.4.4.3 Bandwidth

Bandwidth refers to the method of communication used and how much information can be portrayed at any one time. Face to face communication has high bandwidth, as the verbal communication is supported by body language and facial expressions. Having face to face communication means that there are several methods of communicating available, if one type is inappropriate, e.g. in a noisy environment hand signals are used to convey information. Distributed teams are common and they communicate through telephones, email and computer supported networking. Each method of communication should be appropriate to the environment and the resources available.

2.4.4.4 Cognition of Communication

Communicating is a cognitive act. A person hears/reads the information, processes the information, acts on this knowledge and then may initiate another communication. These processes may cause a modification to the understanding of the communication. When sending or receiving information there are four aspects that could lead to this modification:

- **Levelling** this is the reduction or simplification of communication
- **Ordering** this is remembering the first and last sections of the communication and the middle section will be lost, or not understood completely
- **Sharpening** this is putting an emphasis into a communication, that may not have previously been there
- **Assimilating** this is were the meaning of the communication shifts to match previous information.

These forms of error should be considered when measuring the reliability of team working.

2.4.5 Situation Awareness (SA)

Endsley (2000) simplifies the definition of SA ‘as knowing what is going on around you’ with the understanding that you know what is important. SA is a process of monitoring the environment to gain comprehension from the information being received, so that the current and future status of the environment can be understood. SA is not something that can be given to someone, each person has their own perception of the environment and the information that they receive. In a team it may be beneficial for each person to have a different SA, as each person will perform different tasks, and therefore need different information to perform that task, this is distributed SA (Stanton et al., 2005). Some information needs to be shared amongst team members. All team members should understand how the eleven pieces of information below should be used:

- goal understanding,
- understanding own and team members roles,
- understanding tasks and schedule,
- understanding relationship and dependencies,
- understanding team members background and capabilities,
- understanding business rules,
- task knowledge,
- activity awareness,
- understanding of the external situation,
- task assessment,
- plan assessment,
- understanding decisions drivers.

SA can be built by observation, communication and the use of shared artefacts such as computers or a whiteboard (Artman & Garbis, 1988). These should be designed into systems and the use of them should be taught to the team members so that they are taken full advantage off, without overloading anyone with information. If this occurs then inappropriate information may become the focus and incorrect decisions could be made.

2.4.6 Collaboration Maturity

The length of time that a team has worked together as a team will affect how well the team works together. Below are three models of group development.: the linear model, the pendular model and the lifecycle model. Each shows that a team improves with time (Figure 2.11), but not all in a continuous, progressive manner.

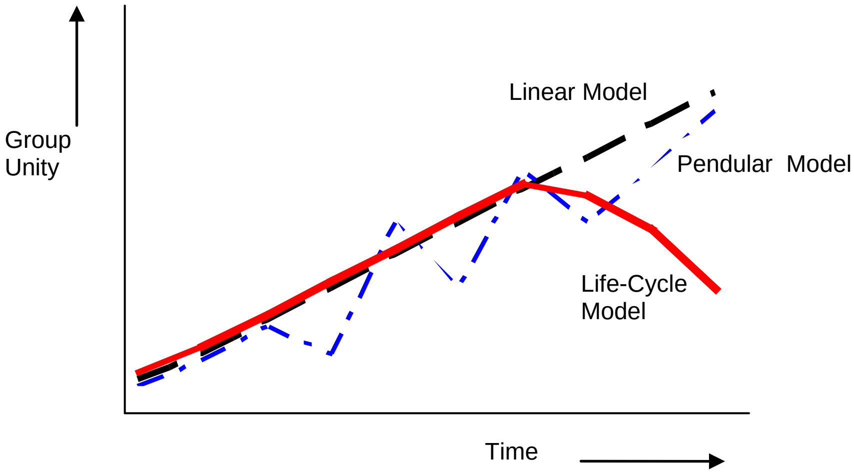


Figure 2.11: Models of Group Development

(Huczynski & Buchanan, 1991)

The 'life-cycle' model shows deterioration in the group after a period of time, whereas the pendular and linear models are ultimately progressive. This is supported by the five stages of group development (Tuckman & Jensen, 1977, as cited in Huczynski & Buchanan, 1991).

2.4.6.1 Group Development

Table 2.3: Stages in Group Development (Tuckman & Jensen, 1977)

Stage	Interpersonal Characteristics	Task Characteristics
Forming	Individuals become familiar with each other and bonds develop within the group	Members determine what the group task is and what methods are suitable to carry it out
Storming	Tension develops and conflict occurs among group members and with the leader	Resistance arises to group methods and the group task
Norming	Cohesiveness and group harmony develop and group roles are established	Task cooperation among members is prevalent
Performing	Relationships are stabilized	The group's orientation is on productivity and performance
Adjourning	Member contact decreases and emotional dependency among individual members is reduced	The task of the group is completed and the duties of members are finished.

The stages are forming, storming, norming, performing and adjourning (Table 2.3). For a team to work effectively they must go through the first four stages. The stages are for both the interpersonal characteristics of the team and the task characteristics, it takes a varying amount of time to go through these stages. However, the more time the team takes to work through these stages the better each stage is developed. Therefore the longer a team has been together the more efficient they will be. Also, if a team has developed the interpersonal characteristics to the 'performing' stage, they should be able to perform the task stages quickly for each new task, as some of the team tensions would not be present. These stages are appropriate for both co-located and distributed teams.

2.4.6.2 Distributed Development

Table 2.4: Development of Distributed Teams

Team Description	Indicators
Unstructured	• Some work forms are employed but inconsistently • A few collaboration tools are occasionally used, such as e-mail, file sharing and Lotus Notes databases. • Face to face process disciplines are ongoing, but virtual processes are not common.
Seeking collaboration	• Some collaboration is being implemented; early forms of training, largely unstructured, are conducted to improve collaboration. • An array of collaboration tools is introduced. • Efforts to establish common processes and practices are underway
Building collaboration	• Collaboration is implemented significantly more effectively than in earlier phases; progress in personal competency working with collaboration tools and processes is appreciable. • More sophisticated collaboration tools are beginning to be used. • Some common processes are generally defined.
Using collaboration	• Collaboration culture of excellence is taking root. • All collaboration tools and supporting infrastructure essential to the team's work are deployed and in use. • Common processes and practices are established and defined
Sustaining and leveraging collaboration	• Robust and disciplined team is working seamlessly and effectively at a distance in a common operative environment; it continuous improves and readily adapts to innovations in a workforce culture of excellence. • The right collaboration tools are used for the right task at the right time- without fail. • Common work processes

Carver (2005) has developed a more detailed model for distributed teams (Table 2.4). This is not a time-related model, but a team can develop through the stages with time. This model also suggests that, with training and experience, a team could come together for a short amount of time and work efficiently together, if a supportive organisational culture is present. Also, if the right culture, training and tools are not available a distributed team will not be able to develop to its full potential.

2.4.6.3 Trust

Within a team there must also be a trust. Trust is the ability to:

- feel confident that other team members can and will perform that task effectively, efficiently and on time;
- discuss apprehension to tasks,
- admit to mistakes or inabilities to perform a task
- discuss with other team members when they may make mistakes, or unable to perform a task
- to have faith in the motives of other team members and that they will not betray you
- have confidence that any benefits accruing will be shared equitably.

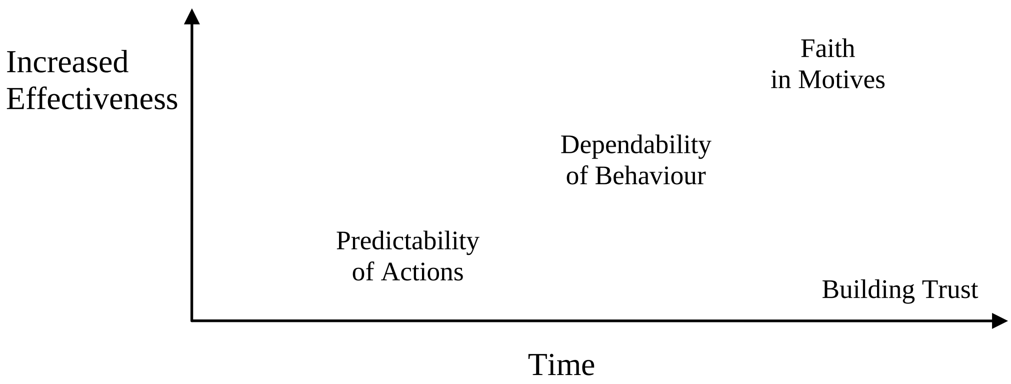


Figure 2.12: The Relationship of Trust, Time and Effectiveness. (Carver, 2005, after Muir, Barber, 1983 and Rempel et al, 1985)

Trust, between suitable people, can develop with time (Figure 2.12). The first level of trust is the '**predictability of actions'**. This is when an individual will perform tasks when they say they will, although monitoring maybe required. The second level is '**dependability of behaviour'**. This is when an individual is assured that other team members will perform tasks when they say they will, without interference. The third level is '**faith in motives'**, collaborators have ethical behaviour when working in competing environments. With an increase in trust there will be a decrease in the level of communication, giving more time to performing tasks rather than monitoring other team member's behaviour.

2.4.7 Culture

Individual national organisations are different as the culture of the nation varies. Hofstede(1984) has defined national culture on four dimensions:

Power Distance: "degree of inequality among people" (P5)

Uncertainty Avoidance: how structured situations are and how many rules.

Individualism / Collectivism: "degree to which people in a country prefer to act as individuals rather than members of a group" (P6)

Masculinity / Feminism: this is the degree to which people have either masculine or feminine qualities. Masculine qualities include assertiveness, performance, success, competition. Feminine qualities include maintaining warm personal relationships, service and care for the weak.

Hofstede focuses on the culture of a nation, but culture can be more localised to between companies in the same country, in fact it can relate to any group of people (Siemieniuch & Meese, 2006). Power distance of an organisation is not dependent on the hierarchy of the organisation, but on the level of power leaders and subordinates have. Siemieniuch describes power distance as *"the degree of inequality in power between a lower ranking individual (I) and a higher ranking Other (O) in which I and O belong to the same social system which is required to achieve a particular operational goal."*

The responsibility of members in a team to make decisions and to be accountable for decision and for the decision to be followed by other team members varies between the members of the team. But the level of responsibility is dependent on the power distance of the organisation / team in which the person is working. This will be known as the decision making power distance.

Decision Making Power Distance (PD) differs from Hofstede's or Siemieniuch's definition as it focuses on the distance between two individuals only.

2.4.8 Summary

Teams are commonly used in civil and military environments. There must be at least two members in a team who interact with each other and perceive themselves as being part of a team. Achieving the appropriate frequency, content, language and method of communication has a high effect on team reliability. Each team member must have suitable SA and an understanding of other team member requirements for them to have suitable SA. Generally team work improves with time and for stability of team working to occur.

The study of team work is not a precise area. There are many variables that effect reliability of a team. Throughout the MPhil this section will increase in size. As the tool develops my knowledge of team reliability will increase, as this section is the justification for each statement in my tool.

2.5 Conclusions

HRA have been developed so designers and users can understand how likely it is for a human to make an error when using a system, i.e. the reliability of the product (Kirwan, 1994). The current HRAs only consider one person using a system. However, in many workplaces people work in teams, not as individuals (Fitzpatrick & Askin, 2005). Interactions between team members can increase reliabilities. For example, in a cockpit the pilot may forget to set the flight level, the co-pilot may notice and inform the pilot, thus increasing the reliability of the pilot. But interactions can also decrease reliabilities, e.g. as there is an increase in volume of communication occurring which creates added tasks and stress. To fill this gap a new generation of HRAs is being developed.

After reviewing several methods HEART (Williams, 1986) is thought to be the best method to use as foundation for the new tool. It is a quantitative method that is easy to use and helps engineers to locate the areas of highest risk. A second reason for its adoption is pragmatic; it is a widely-used and is familiar to the engineers. This is essential if the tool is to aid development throughout the design process rather than just provide overall probabilities. HEART contains statements, which means qualitative justifications of error are plausible. However adding more statements, to account for the team interactions, may encumber the list and reduce the usability of the tool. Another important aspect of HEART that needs to be contemplated is the probabilities used. Currently these are not known to be accurate and have not been fully validated albeit the values are considered to be plausible. It is undecided at this stage whether validation is required. Employees at BAE Systems already use HEART and so using this method will reduce the amount of learning and integration time required to ensure correct use of the new tool.

HEART is being expanded into a new tool that will quantitatively evaluate the reliability of a team using a system. Aspects that can affect team function such as, trust, communication methods and cultural issues will be accounted for in the calculation.

The tool will quantitatively predict reliability, highlight areas of high risk and educate designers on the importance of human factors to produce high usability and reliability products.

Chapter Three: Methods

This chapter describes the methods used in this research. Several techniques could be used to find out this information. The three techniques considered are literature search (Section 3.1), observational methods (Section 3.2) and semi-structured interviews (Section 3.3). After this initial assessment, the preferred method was semi-structured interviews, which was then chosen. This method involves transcript coding (Section 3.4) and matrices (Section 3.5).

3.1 Literature Search

A literature search is a valid method to finding most forms of information. Some documents written by BAE Systems pertaining to lifecycle management and HRA methods (Ng, 2003b, 2004a, 2004b, Wilkinson, 2000) have been read by the researcher. But, what is reported in these texts was in fact different from what was actually happening with the use of HRA methods within the individual business units. For example Miguel & Wright (2002) is a document produced by BAE Systems, which describes the HRA method CHLOE (Miguel and Wright, 2003, Miguel *et al.*, 2002), has been used to predict the outcome of two scenarios that could occur on a Nimrod. This would suggest that CHLOE is used within air systems, yet following discussions the researcher has had with people from Aerosystems, it appears that this paper was a one-off experiment and is not representative of the usual methods used. This approach does not provide the correct information, so other methods were then investigated.

3.2 Participant Observational Methods

Each business unit (BU) works differently. Time spent on projects in several BUs gives the researcher the opportunity to observe in detail the actions taken by the engineers and human factors experts. The researcher becomes a '*participant as observer*' (Robson, 2002) where the fact that the researcher was observing the team would be known. The researcher takes part in as many activities as possible. This enables the researcher to get a thorough understanding of the approach to human reliability within the BU and the advantages or disadvantages of methods used by the team. An additional advantage is that the close working relationship could be a basis for future testing of the tool.

There are two big disadvantages to this technique: time and security clearance. These are not related to the reliability or validity of the technique. The first disadvantage relates to the availability and timing of the researcher's own time. The presence of the researcher working within a business unit during the development or modification of a product requires the allocation of long periods of time as well as precise planning of the timing of the researcher's visit to coincide with the business unit activities.

Six different placements would be required to attend at all areas of BAE Systems: Naval, Missiles, Submarine, Aircraft, Land based and Aerosystems. It would be necessary to co-ordinate between the different BUs and the researcher to ensure that the researcher was present for the relevant stage in the development process when human reliability was being considered and yet visit all teams in the minimum of time.

The second disadvantage was that the researcher needed access to the information on the products being developed. This requires security clearance from a high level. This takes time, is costly to obtain and is not guaranteed. This participant observation method was considered to be better suited, once the new HRA model had been produced.

3.3 Semi-Structured Interview

The definition of semi-structured interviews is:

> *'pre-determined questions, but the order can be modified based upon the interviewer's perception of what seems most appropriate, question wording can be changed and explanations given; particular questions which seem inappropriate with a particular interviewee can be omitted, or additional ones included' (Robson, 2002, p270).*

There were potential disadvantages to interviews: the interviewees might recall information incorrectly and give opinions instead of facts (Sinclair, 2005). However, in this investigation, opinions were a benefit. The reliability of semi-structured interviews was low: each interview contained different questions and even different topics. The flexible nature of the interview meant that relevant information was gleaned. Becoming a proficient interviewer required practice and guidance from experts. The interviews required preparation and following the interview, the transcripts needed coding. These were time consuming, but less time consuming than an observation technique. The semi-structured interview was chosen as the method to ascertain the information on HRA use and attitude. They provided a means of finding out relevant information from the pertinent people.

Table 3.1: Possible Research Methods

Method	Advantages	Disadvantages	Chosen
Literature search	None	Produces irrelevant information	No
Observation	Rich data gathered	Time consuming	No
Interview	Pertinent information retrieved quickly	Lack of realism, interviewer bias	Yes

3.4 Transcript Coding

There are two phases to the process of transcript coding. The first phase is transcribing the interview (Section 3.4.1). The second phase is coding the transcripts (Section 3.4.2) so that they can be analysed.

3.4.1 Transcribing the Interview

The researchers' notes and the transcripts of the interview were written up for three reasons. First, to have a soft record of the interview for future reference and to ensure the information was preserved. Second, to check that the notes written by the interviewers matched the content of the interview. The final reason was to resubmit the content of the interview back into the researchers mind. This helped to reinforce what was said in the interview soon after it was performed, aiding memory of the interview. The information from the interview can be retrieved more readily during a discussion of the topic, where it may be relevant in future interviews. Notes taken by the researchers during the interviews were also added to the documents.

Performing semi-structured interviews are only worthwhile if there is an efficient method of retrieving information from the interview that will help with the development of the tool that is to be created. Here efficiency means a method that does not consume too much time to perform and also a method that provides data that can be analysed without ignoring portions of the conversations.

3.4.2 Transcript Coding

Coding transcripts provides a framework for the data from which analyses of a conversation can be performed. Some coding methods such as discourse analysis (Willig, 2003) or conversation analysis (Drew, 2003) study the intonations and phrasing of words. However, understanding the content of the conversation was most important in this investigation. Miles and Huberman (1984) suggest how to build a conceptual framework to organise the information.

Data analysis: make a contact summary sheet list of what is needed quickly. A sheet of information from each interview should be made. The information required includes: the BUs, HRAs used, future contacts, name, contact details. This is to 'serve as the basis for data analysis itself' (Miles and Huberman, 1984, p51) and is attached to the analysis of interview.

Codes and coding: 'a code is an abbreviation or symbol applied to a segment of words in order to classify the words' (Miles and Huberman, 1984, p54). Codes are categories. They usually derive from research questions, hypotheses, key concepts, or important themes. They are retrieval and organising devices that allow the analyst to spot quickly, pull out, then cluster all the segments relating to the particular questions, hypothesis, concept or theme. Clustering sets the stage for analysis. The codes can be grouped so that similar topics can be together at different levels and are adaptable during the analysis process. For example Figure 3.1 shows coding of literature with HRA, LCM and Products with a further level of coding for HRA methods, use and dislikes.

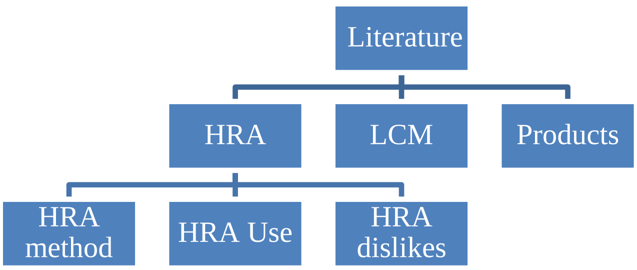


Figure 3.1: Example of Coding (Tree Codes)

3.5 Matrices

A Requirements Matrix (Table 3.2) shows that each BU has different demands for HRA and explains why they want them, e.g. lack of people, no need for complicated tool, customer needs numbers. The information from each interview was put into the matrix so that the different requirements can be compared. The contents from each interview was analysed and formatted into a requirements matrix.

Table 3.2: Requirements Matrix

Typical requirements	Why these are needed	
	Not enough people	Customer wants it
Simple technique	yes	Yes
Quant technique	no	yes

From this, a House of Quality (HoQ) (Table 3.3) could be produced. This shows how the tool manages the requirements. The requirements will help to create the model, which is a bottom up approach. The Requirements Matrix and House of Quality are available for future referral and to ensure as many requirements as possible are featured in the tool.

Table 3.3: House of Quality Matrix

Typical requirements	How this will be accounted for		
	User interface	Quantitative	Computerised
Simple technique			
Quant technique			

3.6 Summary of Methods

The methods used to provide information for this research are outlined in Table 3.4. Background information was collated prior to the beginning of the research and a gap analysis was produced (Ng, 2003a). This provided information for the original research into a THRA, Team HRA, CREAM-T (Smith, 2004). This information was supported by a thorough literature search in the fields of importance for developing an HRA (Chapter 2).

Key for Table 3.4

Personal Tool Development
Tool Reviewed by SMEs
Changes made to ROCCI
No changes made to ROCCI

Section	Methods	Reason	Outcome
Background history	Gap analysis by NG Smith MSC	Gap in HRA Development of model Model testing and development HRA, LCM, teams	Team HRA needed Initial model CREAM-T CREAM-T tested and future improvements suggested. Information gathered
Stakeholder interviews	Semi structured interviews House of Quality Requirement matrix	Basic model of team reliability presented. Discussed HRA use, team and reliability experiences	Approved model of team reliability Provided requirements for the tool (ROCCI)
Model development	Literature search Personal communications	Provides basis for ROCCI, work out how team members interact	Algorithm developed Interaction structures developed
Sensitivity Analysis	Monte Carlo testing	Test interaction structures and algorithms for their sensitivity to different P(E) and CTM ratings	Interactions and algorithms sensitive to change. No adjustments to model made at this time
Peer review presentations	Presentation of ROCCI to peers, ergonomists, system engineers, psychologists	To get feedback on ROCCI from experts	No significant problems suggested
Stakeholder validation interviews	Semi structured interviews Scenarios Based on DELPHI method	Check CTM values Check wording of statements Check ROCCI overall.	Suggested changes to CTM values Wording should be adaptable to scenarios Overall ROCCI is good

Table 3.4: Methods Summary Chart

The next stage of the research was to gain insights from the stakeholders about the tool that was being developed. This was in the form of semi-structured interviews. These provided the opportunity for the Model of the Team to be developed and assessed and to increase the researcher's knowledge on the issues that affect reliability and teams.

Following the interviews, the "Model of a Team" (Figure 5.1) was defined and the initial team attributes and algorithms were assessed. To test the sensitivity and logic of the algorithms a sensitivity analysis was performed. This was the Monte Carlo method of testing the algorithms, i.e. as many formations of data were inputted in to the algorithms as possible to test their stability.

Throughout the period of research the prototype, ROCCI, was presented to a wide range of audiences. The main areas were at Loughborough University; the Ergonomics Society (Smith *et al.*, 2006, Smith *et al.*, 2007a); Systems Engineering Conference (Smith *et al.*, 2007b); and also at BAE Systems meetings (Appendix 2). This provided the opportunity for ROCCI to be scrutinized by peers and experts and gave the researcher the opportunity to defend and develop the prototype.

The final assessment method used was a Stakeholder Review of ROCCI where the tool was taken back to the original interviewees for them to assess the nearly finished prototype. Semi-structured interviews and the Delphi method (Turoff and Linstone, 1975) were used for this process. The Delphi method is where an individual assesses a product privately and then a group come together to discuss the assessments. This occurs repeatedly until all of the individuals agree on the outcome. It was not possible to perform a complete Delphi assessment of ROCCI but an initial assessment was performed and this provided suggestions to be made to the tool in the future.

The next chapter describes the process for the creation of the Requirements Specification.

Chapter Four: Requirements Specification

This chapter describes the process of creating a requirements specification and the development of the THRA tool. It begins with the aims of the stakeholder interviews (Section 4.1), followed by a description of the participants (Section 4.2) and the method of data collection (Section 4.3). It continues with transcribing the interviews (Section 4.4) and the interview results (Section 4.5). The chapter ends with a description of the requirements specification of the tool and the initial development of the tool (Section 4.6).

4.1 Stakeholder Interview Aims

Stakeholder interviews were performed to gather information that would provide a thorough understanding of the current use of HRA in the different BUs at BAE Systems, specifically, and in the design process of the defence industry, more generally. Additionally the interviews gathered knowledge on what would be useful to Human Factors (HF) engineers in the design of a new HRA tool and the future HRA needs within each business unit.

The aims of interviewing HF experts and HRA users are:

- To determine which HRAs are currently being used
- To determine how HRAs are used
- To find where there is a gap in the HRA suite of techniques
- To determine the requirements of a future HRA tool
- To review the current model of team reliability.

The information gleaned from these interviews was utilised in the requirements matrix. It provided the basis for some critical decisions that were made about the model. For example, which BU and piece of equipment the model was designed for; whether a paper and pen tool or a computerised tool was more suitable; whether a qualitative or quantitative method or combination is more appropriate.

4.2 Participants

The key stakeholders for this project are BAE Systems personnel: their engineers, designers, HRA experts, HF engineers. Although non BAE Systems personnel, such as BAE's customers, the MoD are also stakeholders, for reasons of Intellectual Property, only BAE Systems personnel where interviewed.

Ten potential interviewees were contacted. Nine actually participated at different times across six interview sessions. The interviewees had experience in projects such as naval, missile, submarine, aircraft, land-based and Aero systems. The interviewees did not receive any payment for taking part in the interviews.

4.3 Data Collection

4.3.1 Developing the Interview Schedule

There was an evolving iterative design of the interview questions. A lengthy list of interview questions was generated. These were sorted into relevant groups, such as interviewee details, HRA use, lifecycle management. Repeated questions were removed and some questions were rephrased to become more succinct.

The interview questions were piloted with two experienced interviewers and amended to provide flexibility in questioning. After each interview, further adaptations were made to the questions as required. This demonstrated the iterative nature of the "qualitative" approach. There were twenty-four open-ended questions divided between seven sections (Figure 4.1). As this was a semi-structured interview some questions were omitted if they were irrelevant or if they had already been answered .

4.3.2 Interview Structure

The interview began with an introduction of the interviewers themselves and the purpose of the discussion, followed by warm-up questions relating to the interviewees job and experience with HRA. The main bulk of the interview was divided into the following sections;

- application of HRA techniques
- selection criteria of HRA techniques
- HRA requirements from either internal or external customers

The interview closed with a discussion about the future of HRA.

4.3.3 Conducting the Interview

There were two interviewers, myself, who was the primary researcher and my supervisor as the secondary researcher. The secondary researcher provided some guidance during and after the interview.

Before the interviews, the interviewer gave the interviewees information sheets (Appendix 2) informing them that the interviews were confidential and that they could withdraw at any time, following Loughborough University Ethics. Consent forms (Appendix 2) were read and signed by the interviewees, thus ensuring that they understood their rights as participants.

The interviews were recorded on a tape recorder and varied in length from 40 minutes to 90 minutes. The use of tape recording improved the transcripts of the conversations but could lead to a reduction in note-taking during the interview.

4.4 Transcribing the Interview

4.4.1 Interview Notes

The researchers handwritten notes from each interview were typed up into a word document. All identifying information was removed to maintain confidentiality required for ethical reasons. There is a separate document that contains the participant information.

4.4.2 Interview Transcripts

The data on the tapes were transcribed so that the information could be coded. To ease understanding and coding each person presented was displayed in a different colour of text.

<u>Questions for Interview</u>

Introduction: Previous work done by Loughborough with BAE Systems has revealed that there are a few holes in the HRA field. It would be helpful to know some information about your experience with the HRA process. The aim of the discussion is to get as much information and ideas as possible for a requirements specification for a new HRA tool. The objective is to create a tool that will help and not disrupt current processes. There would be advantages in talking to a few people that would actually be using the tool to get them on board and encourage others.

Interviewees role

1) Can you briefly describe what field of work you are in, what your department makes and how you are involved in that process?
2) Within your field who are your main contacts for HRA. (Names, positions, brief description of job.
3) Can you give me an example of the HRA process?

Current HRA process & requirements

4) What is your current approach to HRAs? This is so that we can be know what to expect in the future, e.g. to understand how complex the tool needs to be.
5) Which HRA techniques do you currently use.
6) How do you decide which HRA techniques to use?
7) Is there are list of techniques available to you, and you pick from the list? Does the customer have an input into the techniques use?
8) Are there any techniques that are favoured, either by yourself or those within you department? If so please can you explain why.
9) Are there any techniques that are less frequently used or disliked and no longer used? If so why? Can you suggest any ways to improve these techniques.
10) At what stage in the design process are the assessments performed, who decided this and, why,? Do you agree with this?
11) Who performs the assessments?
12) Who are your stakeholders?
13) Do you have any HRA requirements, either internal or that are customer or government oriented.
14) Can you foresee the introduction of any requirements in the future (five years)? Is there any ‘best practice’ in your field of work?
15) Who assesses the techniques for validity, suitability and up-to date-ness?

Info needed for HRAs

16) What data do you have access to in order, to help you with using HRAs?
17) Where do you get your HEP’s?
18) Where do you get your PSF’S?

HRA Issues

19) Do you have any worries about the HRA techniques used, or how they are used and documented with your dept.?
20) Do you have any requirements that you would like from an HRA technique? Can you foresee any new requirements in the near future.

Why use CHRA

21) How would they define collaborative work for them, when do they think they would need a collaborative tool.
22) What aspects are most relevant for analysis by a collaborative tool?
23) Have you tried/used a CHRA previously, e.g. CHLOE, or have you tried to adapt a normal HRA to a CHRA.
24) Do you feel that there is a gap in the HRA area?
25) The main issues that the tool would be covering, so far, are communications, and knowledge sharing, inc. SA. Can you think of any other aspects that are important to be tested.

Specific to my tool

26) What would you like to get out of a new tool?
27) What information can you foresee going into this tool and what information would you like to see coming out of it.
28) When including a new tool into the design process, it would be predicted that this may come against some resistance. How can the tool be designed to overcome this resistance. (This can also include what the tool must produce, i.e. its purpose)
29) Is there a need for a predictive or diagnostic tool?
30) Who would use the tool is it engineers or human factors experts? What would their level of skill be and their domain of expertise?
31) Would it be more useful to be a pen and paper tool, or a computer based tool. What would the reactions of the user be if it was the other?
32) What would the effect of their work load mean, are they doing something similar already and so it would either replace it, or become part of it, or would it be something new altogether?
33) Any their any other aspects of the BU that need to be observed?
34) Would a new tool be maintained by the same person who maintains all the other tools, there may also be a database to add information too, so that improvements and knowledge can increase and not be lost, would this also be managed by the same person?

Closing

Thank you for your input.
Would it be possible to contact you again in the future for further questions?

YES / NO

If so what is the best way to contact you?

Email, Telephone, Address

Figure 4.1: Interview Schedule

4.5 Interview Results

Below are summaries of the information and opinions that came from the interviews.

4.5.1 BU 1: Naval

This is a naval BU where it is rare to completely redesign a new platform. New issues are identified when queries come from users of the platform, where they have had a problem, or when a new process is added to the platform. These are normally addressed, under the control of the in-house team of HF experts, using subjective tools, such as workload analysis, DIF analysis, or HAZOP.

Some of the HRA is contracted out. The contractors choose the method of assessment that they feel is appropriate. There are usually four HF both in-house and contractors, who often work together as a team. Most of the reliability scores come from previous experience. The important features of a HRA tool are: that it occurs early in the design process; it is usable by anyone; that it is concise, e.g., so it can be pinned to a notice board i.e. two sides of an A4 sheet (Figure 4.2).

> *'Early is the key thing. One of the problems we have with the tools is that they are very often very sophisticated, put it this way academics love them. By the time we have the data from the model, the results cannot affect the design. If it can't affect the design it is pointless doing it. So we need things that can run early.'*
>
> *'If we can't get some human factors requirements into the ITT they are sending out, then the responses from suppliers will not have human factors implications in.'*
>
> *'Ideally it should be usable by anyone.'*
>
> *'A piece of paper that they can pin up on their notice board or have on their desk is more likely to be referred too than a software tool which they have to go somewhere else on the network to.'*
>
> *'Two sides of A4'*

Figure 4.2: Quotation from Interview BU1

4.5.2 BU 2: Missiles

This was a joint interview with BU 1, so some information may overlap. They have between seven and nine HF employees that are all internal. The main form of assessment is task analysis. The HRA tool that they developed and used was based on THEA (Wright et al., 1994), but they did not actually use the original version of THEA (Wright et al., 1994). The interviewee from BU 2, who had experience of writing various types of tools to be used by HF and design engineers, gave the advice that the tool should be on two sides of A4. This is so that it looks simple to use, can easily be referred to and can be laminated, which make it is less likely to be lost or destroyed. The HRA tool would be best if it can be used ‘cheap and early’ in the lifecycle process. The benefit is that changes can then be made at relatively lower cost. HF is not a priority when it comes to the design process. It needs to be possible for the human factors integration (HFI) to be flexible and fit with the systems engineer’s process. The implication is that anything that is simple and quick will be better than a more complex tool, delivered later in the process. The time scales are short (Figure 4.3).

> *‘That is the basis of all the work we do with HFI, the systems engineer, and you have got to fit it with. They are going to go ahead whatever, you have to make sure that you have the right bits at the right time.’*

Figure 4.3: Quotation from Interview BU2

4.5.3 BU 3: Submarine

Currently one HF engineer assesses the whole submarine, so high level tasks are the priority and lower level tasks are not addressed. There is a hierarchical working structure on board the boat. There are eight or nine small teams within the big team, which consists of one hundred people. The SA within the small teams is very good, but communication between the various small teams can take time, as there is a military hierarchical working structure, which explicitly forbids the horizontal communication between the smaller teams. The submarine provides a restrained environment, so that personal characteristics are controlled to create a sound working environment. The tool should be quantitative and qualitative and should include opinions from several SME and HF experts (Figure 4.4).

'High level HRA at the moment as there are too many to do everyone. Use DIF and LARP [low as reasonably possible] to calculate risk."

'We have requirements that include undertaking reliability analysis.'

'[HRA] Actual numbers, human error probabilities and things like that. I think there is going to be a demand for more, full stop. Not just numbers but qualitative argument as well. And I get the impressions from our regulators like the NII [Nuclear Installations Inspectorate] they want an argument around [the numbers].'

'[ROCCI] needs to have independent peer reviews'

'Communications systems are certainly very important'

Figure 4.4: Quotations from Interview BU3

4.5.4 BU 4: Aircraft

This is a single seater cockpit, so there were no teams within the plane and they personally did not perform HRA (Figure 4.5). They did see the need for a larger use of HRA, but as the aircraft was coming to the end of its lifecycle, it was not a priority.

'So workload is a big issue, but pilots hate the term workload. There is a very high workload in the aircraft.'

[SA] 'Some things are more important to some people, so they don't necessarily want exactly the same. But the common information has got to be [the same].' [e.g. talking about the same target on a screen, as they look different on different screens]

[talking about LCM] 'They see a weapon they would quite like to use but they have no idea how they are going to use it. We work out how they want to use it and how they want to integrate it with the rest of the avionics system. We say 'these are your requirements', so they have a look and say 'yeah they seem good enough'.

Figure 4.5: Quotations from Interview BU4

4.5.5 BU 5: Land Based

The interviewee has had experience in the design of parts for a variety of different platforms. The customer gives BAe Systems a list of system requirements, '*we want* *the system to do this, and we want it to be this good*.' These are often about pieces of equipment that go into the system and the human being is not always considered. The interviewee believed that the development process should consider the human as part of the system (Figure 4.6). That is not yet the case, so the interviewee had very little work experience with human reliability to date. He suggested that the tool should consider changes to the physical conditions of the platform, when it is at different stages or levels of alert. The tool should be simple and consist of only seven statements. Types of land-based teams on which the tool could be used are either, a team of three using a single piece of equipment, or a large team on the ground where the relationships may be disorganized.

> *'We are looking at making systems more useable'*
>
> *'When we talk about the human we start talking about decisions, cognitive loading and all of these sorts of things'*

Figure 4.6: Quotations from Interview BU5

4.5.6 BU 6: Aerosystems

> *'Current method that we use for human reliability assessment are part of the development process for that.'*
>
> *'we wanted to get human factors embedded into the design process, including HRA'*
>
> *'A quantitative method to try and put it into a wider systems engineering process, where there is a lot of human reliability processes and stand alone, are qualitative'*

Figure 4.7: Quotations from Interview BU6

An in-house HRA method is currently used for individuals. It is important that it fits with the current design process (Figure 4.7). The requirements that are worked to are DEF STANS (UK MoD defence standards) and US military standards. Customer 2 (the user of the product) is a critical part of the design process, and as they are SMEs, they suggest improvements throughout the design process. The cockpit only consists of one or two people, a very small team and the HF of the team is already well established.

UAVs are seen as the future in Aerosystems and they could be a need for a new collaborative HRA.

4.5.7 Summary of Interview Results

The aims of interviewing HF experts and HRA users are:

- To determine which HRAs are currently being used
- To determine how HRAs are used
- To find where there is a gap in the HRA market
- To determine the requirements of a future HRA tool
- To approve the current model of team reliability.

The Table 4.1 shows the response from each BU about the main aims of the interview. All interviewees thought that the model of team reliability was a good basis for a team HRA and they were all interested in the developments of the tool. It was expressed several times that the human as part of the systems should become more important and included as a consideration in the design process.

Table 4.1 Interview Aims for Each BU

	HRAs in Use	How is HRA Used	Gap in HRA Market	Requirements for Future HRA
BU1	Contractors decide, DIF or HAZOP.	Early in design, must be included in ITT.	Yes there is one	Usable by all, 2 sides of A4.
BU2	THEA, but not used.	Flexible to designers timescale.	n/a	2 sides A4, cheap and early.
BU3	DIF LARP	High level, Need justifications and reasons, not numbers.	n/a	Communication, quan. & qual. Incl. SME opinions.
BU4	None	Equipment reliability is known	n/a	n/a
BU5	None	n/a	Development process part of human system	Easy,7 questions.
BU6	In –house HRA tool.	Quantitative, included in design process, use DEFSTANS	n/a	Quantitative Supported by qualitative.

4.6 Development of Model

4.6.1 Requirements Specification of Model

The information from the interviews was processed to create the Requirements Matrix (Table 4.2) for the tool. The Requirements Matrix is a list of requirements and the reasons that each needs to be addressed. From this, a House of Quality (Table 4.3) is produced. This checklist shows that the requirements will be accounted for in ROCCI.

The Interviews, Requirements Matrix and House of Quality revealed that the tool should:

- be usable at a variety of levels
- quick and easy
- up front with a qualitative yes/no answer
- usable by a wide variety of people
- progressing towards a more quantitative complex tool for the later stages of the development process
- to be used by HF experts.

This information provided a foundation for the development of the tool. Instead of creating a new HRA, an existing method should be expanded.

The requirements showed that the original HRA must have the following qualities:

- a quantitative method
- a prospective method
- simple for engineers to use
- not time consuming
- be able to fit into the engineers current method of working.

4.6.2 Choosing an HRA

After reviewing several methods, HEART (Williams, 1986) was selected as the best method to provide a foundation for the new tool. It is a quantitative method that is easy to use and it helps engineers to locate the areas of highest risk. This is essential if the tool is to aid development throughout the design process, rather than just provide overall probabilities.

Table 4.2: Requirements Matrix for ROCCI

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Tool Output											Tool Mechanics											Tool Users			Stage of LCM when tool is used				Tool Support
Requirements → / Reasons ↓	tool should identify risks	tool should identify no hopers	quantitative and qualitative argument	tool should inform designers of MMI	tool should highlight level of hazard	tool must fit with reliability requirements not figures	tool should consider complexities of teams not used to working together	quantitative method needed	quantitative method needed	tool should help document rationale	combination of a check list and a help list	need non-rigorous tools	not computerised tool	tool should be task analysis based	tool should be two sides of A4	HEART is a good basis for the tool	tool should fit with different HRAs	tool can be computer or paper based	tool should consist of 5-9 statements only	tool can use fault trees, probabilities	needs to be a simple tool	computer based	tool should use SMEs	tool should be useable by everyone	tool needs to ensure involvement of designers	cheap and early tool needed	tool needs to be scalable	tool needs to be fit with project manager Gantt chart	tool should be used early in design	HF should be at end of phone
easy to analyse	✓	✓			✓				✓		✓	✓							✓							✓				
if analysis performed quickly it can influence design process	✓	✓										✓														✓		✓	✓	
few resources available																			✓		✓		✓	✓						
ready access to SME's																							✓	✓						
so tool is useful throughout whole of design process																								✓			✓			
tool needs to be readily available to users													✓		✓									✓						
users of the tool are too busy					✓								✓		✓															✓
lot of effort required to network tool													✓																	
TA is readily available to designers														✓						✓										
HF low on priority list when developing																												✓		
users should be able to contact HF easily to answer queries																														✓
to ensure most influence on design																													✓	
justification of changes to design are needed			✓							✓																				
designers and ship builders need educating of HF				✓																										
Aerosystems HRA tool to be used																	✓													
HEART is increasingly being used for HRA																✓	✓													
designers know the system well																									✓					
designers are responsible for the system																									✓					
designers need to understand that bad design affects usability																									✓					
no preference on presentation of tool																		✓												
so changes can be actioned quickly					✓																									
too difficult to find figures for humans						✓																								
increasing for ad hoc teams to be used in battlespace							✓																							
so that it is attractive to users											✓	✓			✓				✓			✓				✓			✓	
figures important								✓	✓											✓										
little respect/ use of qualitative methods								✓																						
safety team would use this									✓																					

Table 4.3: House of Quality for ROCCI

How ↓ / Requirements →	1	2	3	4	5	6	7	8	9	10	11
	Tool Output										
	tool should identify risks	tool should identify no hopers	need quantitative and qualitative argument	tool should inform designers of MMI	tool should highlight level of hazard	tool must fit with reliability requirements not figures	tool should consider complexities of teams not used to working together	quantitative method needed	quantitative method needed	something to help document rationale	combination of a check list and a help list
the tool shall highlight areas that have a high probability for error	✓	✓			✓	✓					✓
this will be a computerised tool, but there will also be a simple paper based version.											
the tool uses TA as a basis for calculating the probabilities											
the tool is simple and quick to use if the TA has already been performed.											
the wording of the statements shall be clear and concise											
A probability of error shall be calculated by the tool using a computer programme			✓					✓	✓		
areas of high risk shall be highlighted and design changes shall be encouraged			✓	✓	✓					✓	✓
the tool has a similar structure to HEART											
the statements used in the tool cover many situations that affect team working							✓				
not sure of the answer for this one											
this has not yet been included in the design											
the tool can be used qualitatively early in design process.			✓								
this is not covered by the tool											

How ↓ / Requirements →	12	13	14	15	16	17	18	19	20	21
	Tool Mechanics									
	need non-rigorous tools	not computerised tool	tool should be task analysis based	tool should be two sides of A4	HEART is a good basis for the tool	tool can be computer or paper based	tool should consist of 5-9 statements only	tool can use fault trees, probabilities	needs to be a simple tool	computer based
the tool shall highlight areas that have a high probability for error										
this will be a computerised tool, but there will also be a simple paper based version.	✓	✓				✓	✓		✓	
the tool uses TA as a basis for calculating the probabilities			✓	✓						
the tool is simple and quick to use if the TA has already been performed.									✓	
the wording of the statements shall be clear and concise										
A probability of error shall be calculated by the tool using a computer programme						✓				✓
areas of high risk shall be highlighted and design changes shall be encouraged										
the tool has a similar structure to HEART					✓					
the statements used in the tool cover many situations that affect team working										
not sure of the answer for this one	✓									
this has not yet been included in the design								✓		
the tool can be used qualitatively early in design process.										
this is not covered by the tool								✓		

How ↓ / Requirements →	22	23	24	25	26	27	28	29	30
	Tool Users				Stage of LCM when tool is used				Tool Support
	tool should use SMES	tool should be useable by everyone	tool needs to ensure involvement of designers	tool should be able to use SMES	cheap and early tool needed	tool needs to be scalable	tool needs to be fit with project manager Gantt chart	tool should be used early in design	HF should be at end of phone
the tool shall highlight areas that have a high probability for error									
this will be a computerised tool, but there will also be a simple paper based version.		✓							
the tool uses TA as a basis for calculating the probabilities									
the tool is simple and quick to use if the TA has already been performed.		✓					✓		
the wording of the statements shall be clear and concise							✓		
A probability of error shall be calculated by the tool using a computer programme									
areas of high risk shall be highlighted and design changes shall be encouraged			✓						
the tool has a similar structure to HEART									
the statements used in the tool cover many situations that affect team working									
not sure of the answer for this one						✓			
this has not yet been included in the design	✓			✓					
the tool can be used qualitatively early in design process.					✓			✓	
this is not covered by the tool									✓

HEART uses a standard set of statements. The benefit is that the qualitative justifications for the probability of error are credible. However, only one of these statements relates to crew collaboration. Another benefit is that HEART is already used by some employees at BAE Systems. This will reduce the amount of learning and integration time needed to start using the tool.

One component of HEART, the probabilities, was not accurate and had not been fully validated (Dougherty, 1990, Kirwan, 1997a, 1997b). They needed to be reassessed and revised. However, given that within the HRA industry, many tools are not fully validated, HEART values are within the normal range of variation for the industry. This, therefore, is not a serious obstacle to its use.

The researcher had an initial reaction to the fact that HEART only has one statement relating to crew collaboration. This initial reaction was the idea of creating an additional list of statements about crew collaboration within HEART, But, on reflection, it was realised that this would make HEART itself too cumbersome for general use. The solution and way forward, chosen by the researcher, was to create an alternative method of assessing team attributes. This was developed as the CTS Matrix (Section 5.3.3.3).

Use of tool: given that this is an industry where there are few brand new designs being made, as most are modifications, e.g. the *next* frigate, rather than a brand new one. So it is not expected that this tool will be used on designing new products or capabilities, but on developments or revisions. This means that the tool will be used for comparisons between the old product and new products. The tool can be used on old capabilities to show where there are problems and then on a variety of new designs in order to select the best design.

The tool can be used in two ways. The first way is early in the design process, to evaluate the benefits of various design options. The second way is later in or at the end of the design process, for a product that has been developed or already exists, to make assessment of a range of design solutions for a new version of the product or for a simple improvement in the product.

4.6.3 Future Developments to ROCCI

Given the different fields within BAE Systems and the formation of the various teams, decisions will need to be made about where/when/how and by whom the tool is going to be used.

Here is a list of questions that were raised through the interviews.

- How big should the team be and does this matter?
- How important is access to the teams using the product/system? And how easy is it to get this access?
- How important is the structure of the team? A team that has worked together for a long time will have fewer variables than a team that is comes together sporadically. This may be important for the early development stages of the tool.
- Can a non-human be part of a team? Which leads onto how far should the equipment be taken into account.

The above questions will be addressed in the following chapter, which takes the information from the Requirements Specification to produce the model of team reliability, team structures and algorithms for the ROCCI tool.

Chapter Five: Development of ROCCI

This chapter describes the development of ROCCI. It includes the tool vision (Section 5.1), the model of team reliability (Section 5.2) the interaction factors (Section 5.3), communication and trust matrix (Section 5.4), interaction algorithm (Section 5.5), team algorithm (Section 5.6) and how to perform ROCCI (Section 5.7).

Reliability of Collaborative Crew Interactions (ROCCI) assesses a group of individuals, who are interacting with the same system or piece of equipment and whose procedures are all critical in achieving the same overall goal. A model of team reliability (Figure 5.1) is used as a basis for the tool. From this, the interaction factors and algorithms were developed.

5.1 Tool Vision

It was envisioned that the tool would:

- quantitatively assess the reliability of a team.
- qualitatively predict areas of high risk
- be usable and accessible to those who are not experts in human factors
- be able to fit into the engineers current method of working
- not be time consuming
- educate designers in the importance of the human factors to produce high usability and reliability.

It is important that the tool is usable by those who are not experts in human factors. Therefore the tool should not contain human factors jargon or require an interpretation from an ergonomist. The tool should be transparent, so that designers and engineers can understand how the tool calculates team reliability. The calculations need to be straightforward to use and it will contain simple algorithms.

To facilitate this simplicity some assumptions must be made:

- the process can be defined
- a team/individuals can be allocated to roles
- the team has stability
- equipment used has 100% reliability.

Stability of the team is necessary for a representative reliability value. When a team is first brought together, there is a period of introduction to each other's skills, abilities and personalities (Section 2.4.6; Littlepage et al., 1997). During this period relationships and personality differences are frequently changing and so the reliability of the team may be inconsistent. The interaction attributes require team members to have relationships and personal perceptions of the other team members, which are stable and established (Figure 2.11; Huczynski & Buchanan, 1991).

The ROCCI tool provides three sets of data to help assess the team:

- Individual probability of error P(E)
- Interactive probability of error P(I)
- Team probability of error P(T).

Potential users of the tool are anyone from the Engineering Life Cycle (ELC), from concept designer to engineer including:

- An ergonomist that is trained in using the tool
- The customer to reassure themselves that the product reaches standards
- Maintenance personnel using the tool retrospectively.

5.2 Model of Team Reliability

The development of the model of team reliability (Figure 5.1) was part of a BSc project (Reid, 2005). The model is based around a procedure. The procedure is made up of a number of tasks. These task (1-6) are performed by people in a team (A, B, C). A, B and C all have an individual probability of error (P(E)) for performing their given tasks. This is calculated by an HRA, e.g. HEART. As A, B and C are in a team they interact with each other. These interactions change the P(E) to become P(I). The variable component being the interaction factors. These P(I) then amalgamate to become P(T).

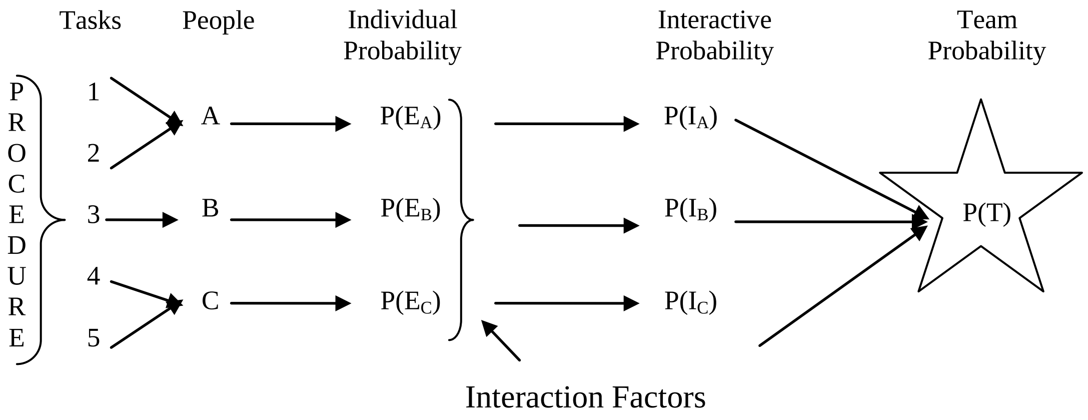


Figure 5.1: Model of Team Reliability

5.3 Interaction Algorithm

5.3.1 Introduction

To develop this model into a tool the following factors needed to be decided:

- Which interaction factors would be used e.g. communication (Section 5.3)
- How the interaction factors would be combined e.g. a mathematical equation (Section 5.3)
- How the effect interaction factors would be found e.g. expanding an HRA (Chapter 7)
- How the amount of interaction between team members would be presented e.g. lines of communication (Chapter 7)
- How all team structures would be accounted for in the tool e.g. hierarchical structure (Chapter 7).

The answers will be described in the following sections.

5.3.2 Number of Attributes

The model of team work is the basis of ROCCI. It needs to include quantitative measures. The use of algorithms is a method of getting from a qualitative model to a model that included a quantitative probability of error. This is where the researcher had to confront the practical problem of including too many variables in the algorithms for the tool. The next paragraph is a demonstration of the reasoning behind the decision to eliminate a model with too many variables.

The interaction attribute scores for the individuals in the team would be used as a weighting factor to the P(E). This would be a multiplier: e.g. P(I) = P(E) x Interaction Attribute Score$_1$ x Interaction Attribute Score$_2$ x Interaction Attribute Score$_{n.}$ Having many attributes, each being a weighting factor, would reduce or increase P(E) indefinitely, and the P(I) would become meaningless (Figure 5.2). This also implies that all the attributes effect P(E) separately, but it is likely that there is an interaction between them.

Here is an example of Multiple Attributes. If all five attributes decreased the P(E) by 0.1, with the initial P(E) = 0.2, then the final P(I) is unrealistically low:

P(I) = 0.0002 x 0.1 x 0.1 x 0.1 x 0.1 x 0.1
P(I) = 2 x10^{-9}

Figure 5.2: Example of the Effect of Multiple Attributes on P(I)

The consequence of the impracticability of using this type of algorithm in the Model was that the researcher had to select a very small number of core attributes, which were central influencers or indicators of team reliability.

5.3.3 Interaction factors

Each person in a team brings different attributes that can influence how the other people operate. It is these factors that make the effect of the whole team better or worse than the sum of its parts.

A long list of factors that effect team work was created. These included: organisational structure, training, team cohesion, location, task resources, MMI, environment, culture (Hofstede, 1984, 1994), trust (Bonini, 2005), communication, language, personalities. This is too many variables and would have made the tool too complex and prevented it from being transparent. It was not known which of the factors would more significantly influence the quality of the team work. There was the risk that the tool could become too impracticable to use, or develop in to a “black box” solution, where the calculations were hidden within a computerised tool. Of these permutations, neither would be understood by designers or engineers. For these reasons of clarity, only core attributes were considered for inclusion in the model. The list of factors was reduced to two, after a review of the literature (Chapter 2) combined with the discussions with SME's (Chapter 4).

The two core factors that were initially considered to have the greatest effect on the reliability of a team were: communication and trust, as defined below.

5.3.3.1 Communication

The effectiveness and efficiency of the communication and passing of information between team members. The method of communication or passing of information should be appropriate for the interaction.

In some cases hand gestures that are taught is all that is needed to communicate, so for effective communication the team members must be able to see each other at all times, and be trained sufficiently in the meaning of the hand gestures. Another case would be the use of radio communication. Here are some issues that should be considered when deciding the method of communication is sufficient: are the environmental conditions at both ends of the radio quiet enough so that information is not misunderstood; is there a specific technical language in which the radio operators should speak, if so are they trained sufficiently; are there many users of the radio communication trying to speak at the same time resulting in disconnected communications and loss of information.

5.3.3.2 Trust

This is a measure of the level of trust that exists between the team members and their confidence that each will perform the actions required, successfully and on time. It is also the trust between team members to check, give and receive advice or criticism about the tasks they are performing and their ability to act on this information (Bonini, 2005).

A person who is known not to be sufficiently skilled to contribute fully to the team goal, may be given tasks that are at a lower level of skill, in order to sustain a reliable level of trust for the completion of these tasks. The rest of the team then have to adjust to compensate. Without both aspects of this adaptation, a team member may be placed in a situation where they are expected to perform a task in which they are not adequately skilled or trained. The consequence could well be that they will fail or fall short and so lose the trust of the other team members. If serious, the whole success of the team goal could fail or fall short.

The ability to monitor or check each other's work and provide feedback is very important to prevent such errors being made. When team members are informed of the potential for risk or failure of their actual or intended actions, they can either correct them or justify how their actions or decisions will still achieve the success of the team goal.

5.3.3.3 Development of CTS Matrix

Communication and trust are factors that interact each other. If a leader does not trust the work of a subordinate, there will be an increase in communications to ensure work is being done correctly. This increases the workload of the leader and therefore could increase the probability of error. At the other end of the spectrum, if two team members completely trust each other's work, there may be only a small amount of communication occurring, but this could also lead to errors occurring and so increasing P(I). The relationship of communication and trust are calculated in the CTS matrix.

Communication and trust for ROCCI are measured on a Likert Scale of 1 to 4 to create a matrix. The values in the CTS (Communication Trust Score) matrix (Figure 5.3) are the interaction multipliers. When deciding upon the multiplication factors in the matrix, several options were considered:

- should the lowest multiplication factor be 1 (teams can only worsen)
- should the highest multiplication factor be 1 (teams can only improve)
- what should the range of values be (how much can team work change probability of error)
- should the values vary equally across the table (do trust or team skills effect the team equally).

Through SME discussions and literature review, it was decided that team work can both improve and worsen, depending on individual reliability. As the team are working together, they are checking each other's work and noticing mistakes that may have been made. But sometimes errors may slip through that are not detected by other team members. Clear lines of communication, which minimises the amount of 'noise', would increase the likelihood of mistakes being detected. If an error is made by a person and it is detected and commented on by another team member, then it is expected that the person will react correctly to the team member's information. For this to occur there must be enough trust between the team members to know whether the comments are valid or not.

		Trust			
		1	**2**	**3**	**4**
Communication	**1**	2	1.9	1.8	1.7
	2	1.9	1.8	1.7	1.2
	3	1.8	1.7	1.2	0.7
	4	1.7	1.2	0.7	0.5

Figure 5.3: CTS Matrix

The final interaction factors are between 0.5 and 2, i.e. the reliability could be halved (0.5) or doubled (2). At this stage, the prototype scores were divided equally in the matrix.

5.3.4 Interaction Algorithm

P(E) is multiplied by the CTS to produce P(I). This is the interaction of each of the individuals in the team (Figure 5.4).

$$P(I) = P(E) \times CTS$$

Figure 5.4: Relationship Between P(E) and CTS

However, a person will interact with more than one person. This could be a very large number or theoretically, an unlimited number of people. The average of all the interaction is P(I). Compiling an algorithm for this could have some difficulties. As explained earlier, having a multiple of P(E) x CTS has the same effect as having multiple attributes (Figure 5.2). It would be a challenge to formulate an algorithm that considers the sum total of just one person interacting with a very large number of people.

The researcher had to find a method of resolving this problem. A simplistic solution is to divide the sum of the individual influences by the total number of persons with whom that one individual interacted.

$$P(I_A) = \frac{(P(E_A)CTS_{AB}) + (P(E_A)CTS_{AC}) + \cdots (P(E_A)CTS_{AN})}{n}$$

Figure 5.5: Interaction Algorithm

This algorithm can be used for any number of people that someone interacts with and any team structure. It also ensures that the tool can manage various team structures, decision systems, and any number of people executing actions.

5.4 Team Algorithm

The main issue for consideration was how best to combine the individual reliabilities to create a credible and realistic team reliability. Different ways of combining the P(I) were considered. For example:

- should they be linked as a fault tree
- should they be averaged out with equal weighting.

Various hierarchy structures, decision systems and the number of people at the 'sharp end' (those executing the actions of the team) all affect how the team is influenced by the individuals. A series of algorithms have been produced to ensure that the tool can manage various team structures, decision systems and a variable number of people executing the actions.

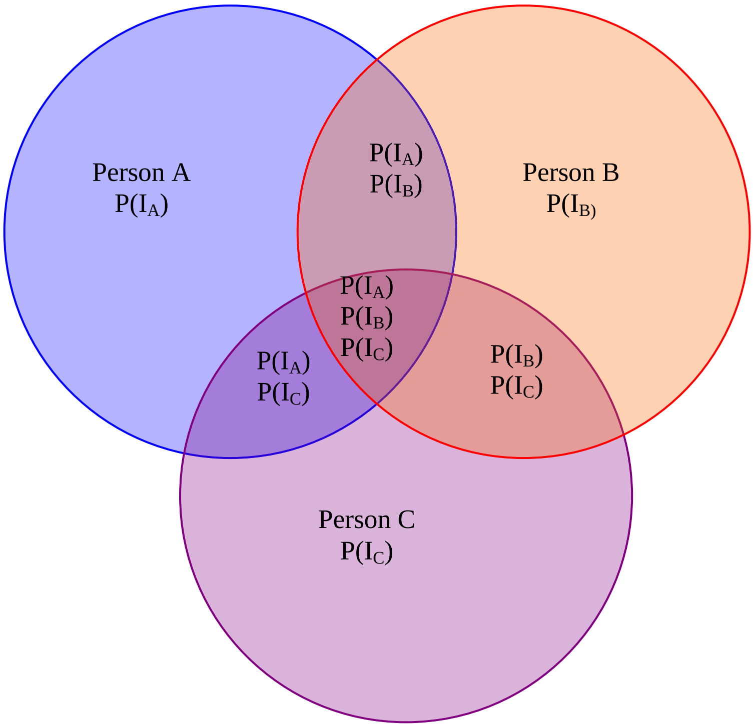


Figure 5.6: Venn Diagram Showing Probabilities of Team Error

There are various options for compiling the algorithm used in calculating the team probability of error. The method of calculating P(T) in CREAM-T is to use a fault tree diagram with the associated mathematics. This method is only partially appropriate for ROCCI. For the team success to take place, only one person needs to successfully detect or correct the mistakes of the other team members. Failure of the team only occurs when every member of the team makes an error (Figure 5.6), which is unlikely. P(T) can be found using the algorithm: $P(T) = 1\text{-}(1\text{-}P(I_A))(1\text{-}P(I_B))(1\text{-}P(I_C))$.

However, if a team consists of many people the P(T) could potentially be low. Some method of accounting for the number of people in the team was needed. This was done by dividing the probability score by the number of people in the team.

$$P(T) = \frac{1 - \left(1 - P(I_A)\right)\left(1 - P(I_B)\right) \dots \left(1 - P(I_N)\right)}{n}$$

Figure 5.7: Algorithm for Team Reliability

For the team to be successful in attaining the goal, everyone one in the team must be successful. The P(I) scores are the probability that an error is made, which is 1- the probability of failure = 1-P(I). As everyone one must be successful, the success scores are multiplied together and then divided by the number of people in the team (Figure 5.7). This algorithm is only performed once and must include all active members of the team.

5.5 Conclusion

This chapter has portrayed the evolution of the research through the phases of the tool vision, model of team reliability, team attributes and the creation of the interaction and team algorithms. It has been explained that their application is through the seven steps of ROCCI. The next stage addresses the need for any quantitative measure to be verified before it is accepted as a valid operational tool for use in simulated or real life scenarios. This early version of ROCCI was now ready to be tested through a sensitivity analysis (Chapter Six).

Chapter Six: Sensitivity Analysis

Any quantitative measure needs to be verified through sensitivity analysis (Petzold et al., 2006), if it is to be accepted as a valid operational tool for use in simulated or real life scenarios. This chapter addresses this necessary stage of improving the applicability of the Team HRA tool ROCCI. In order to proceed in a logical manner through this stage, it is presented in two main sections: Interaction Structures (Section 6.1) and Sensitivity Analysis (Section 6.2).

The first main section (Section 6.1) addresses the difficult topic of selecting Interaction Structures from the variations that can exist. This examination begins with a look at the core structures themselves (Section 6.1.1). It then elaborates these structures with flows of interaction and power influences (Section 6.1.2). Only then is it possible to formulate the application of Interaction Structures for ROCCI (Section 6.1.3).

The second main section (Section 6.2) is the Sensitivity Analysis testing itself. This is a complex test but a very important and central component of this research project. It was precisely an absence of a quantitative tool for a Team HRA that had been identified as the gap in the Tools needed by BAE Systems (Ng, 2003a, 2003b). The researcher formulated the various algorithms so that they are not only valid and verifiable but, most importantly, they can be used by designers and engineers who are not HF experts.

6.1 Development of Interaction Structures

This section on the development of team structures begins with an examination of the core structures themselves (Section 6.1.1). It then builds on this by making explicit the interaction flows, as well as the varying power influences (Section 6.1.2). These two subsections were developed by the researcher specifically to apply to ROCCI (Section 6.1.3).

6.1.1 Leavitt (1951)

Two sets of team structures have been identified in the literature. These show how information is shared between team members. The first set consists of four team structures of five people, in various configurations, which are described below.

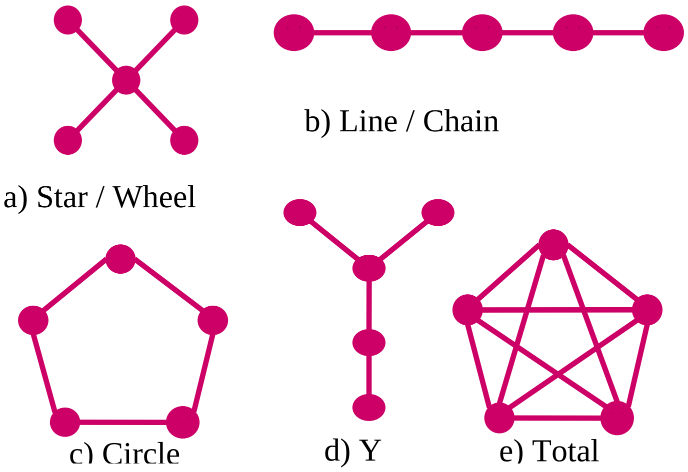


Figure 6.1: Interaction Structures (Leavitt, 1951)

The **Star or Wheel** (

Figure 6.1a) shows a central person with whom the other four people will talk. The central person receives all the knowledge from all of the four other people. The other four people do not talk to each other. They only know their own information and any information, which is passed to them through the central person. The central person has the control over the information flow.

The **Line or Chain** (

Figure 6.1b) is similar to a chain of command where information can go up and / or down the chain. Like a conveyor line in manufacturing, each person talks to the persons either side of them. This can be a controlled form of information transfer.

The **Circle** (

Figure 6.1c) is similar to the line or chain, but there is no beginning or end to the information flow, or top and bottom to the hierarchy. Information can flow back and forth, but each person will only talk to the two closest people.

The **Y** (

Figure 6.1d) is mixture of the Star or Wheel and Line or Chain. The central person talks to only three of the four people. The fourth person receives information from only one source, increasing their degree of separation from the other team members.

The **Total** (Figure 6-1e) is a development of the circle. Lines of communication link each member of the team to each other. This means that there is complete information flow between the team with no formal structure.

6.1.2 Eason (1995; Sinclair, 2003)

Eason's team structures (Sinclair, 2003, Personal Communication), are more than communication lines and information flow. They also represent power structure.

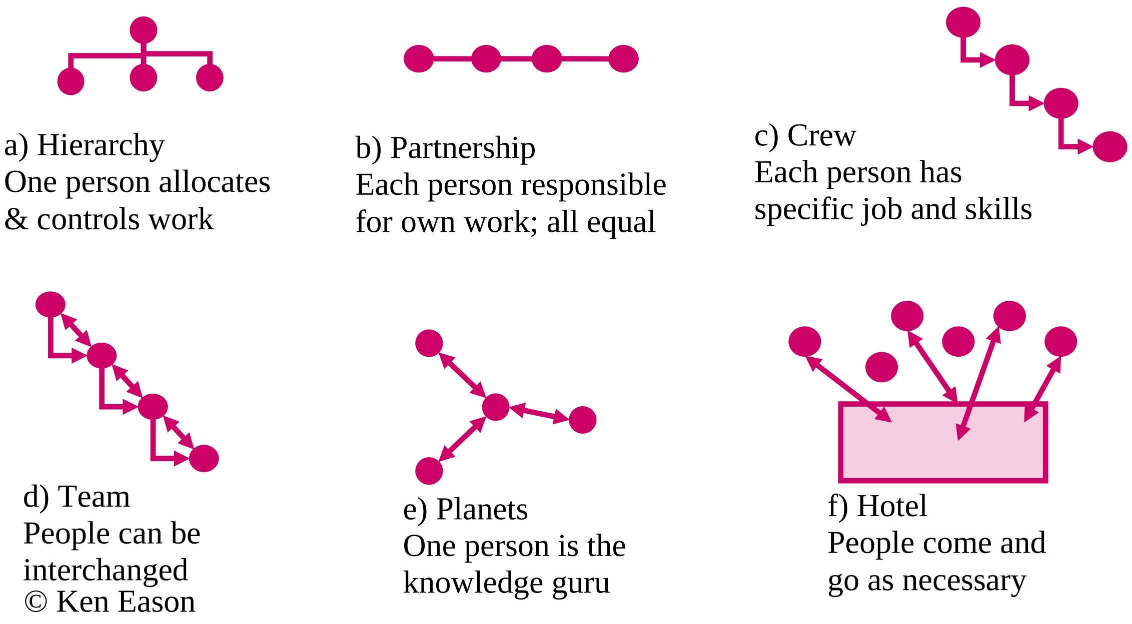


Figure 6.2: Eason's Team Definitions

(Sinclair, 2003; based on Eason, 1995)

The **Hierarchy** (Figure 6.2a) consists of a superior and several subordinates. One person allocates and controls the work that is being performed. The subordinates have little direct communication with each other. This is strongly used in a military environment.

The **Partnership** (Figure 6.2b) is where each person is responsible for their own work, and they are all equal.

A **Crew** (Figure 6.2c) is where each person has a specific job to perform that requires specific skills. The result is that the people are not interchangeable. There is a specific flow of information down the crew, but this is not due to a hierarchy of power. This would be like a conveyor belt manufacturing line, where there is no flow of information back up the crew line.

The **Team** (Figure 6.2d) is not a hierarchical structure. However, each person performs roles, but the people can be interchanged and information can flow easily both ways between the people.

The **Planets** (Figure 6.2e) are representative of planets circling the sun. The “sun” is a central person on the team that holds information from all other team members, who are the “planets”. The sun is the knowledge guru. The planets must approach the sun for information that is required, but they cannot contact the other planets. This type of team is used in the manufacture of a product where parts are being outsourced to different companies and the main company is the central link between all the plants and contacts.

The **Hotel** (Figure 6.2f) is a team where people can come and go as they are needed. There is not a strict structure, hierarchy or communication flow. An example of this would be in Social Care. Here a person requires different resources, such as a social worker, doctor, psychiatrist, lawyer, probation officer, to help them, but these will change for each individual’s situation.

6.1.3 Interaction Structures for ROCCI

For ROCCI the interaction and flow of information between the team members is the critical element for the team structure. Leavitt’s set of team structures (Section 6.1.1) does not show lines of information flow. Eason (Section 6.1.2) placed hierarchical structure as the key focus of the team definition. The interaction links in ROCCI were to be represented by a new set of team structures, created by the researcher (Figure 6.3).

A ROCCI team consisted of four, rather than five, people. As all interaction combinations can be represented by a minimum of four people in a team. If there are more than four people in the team a combination of team structures could be used, or individual people can be added to the team structures. During the creation process of the Interaction Structures the researcher identified that there were no teams that could not be described by these structures.

When performing ROCCI the structure of a team does not need to fit into one of the twelve ROCCI Interaction Structures. These interaction structures were created so that the algorithms could be tested in each possible interaction structure. When performing ROCCI the number of interaction links between team members is fundamental to the calculations.

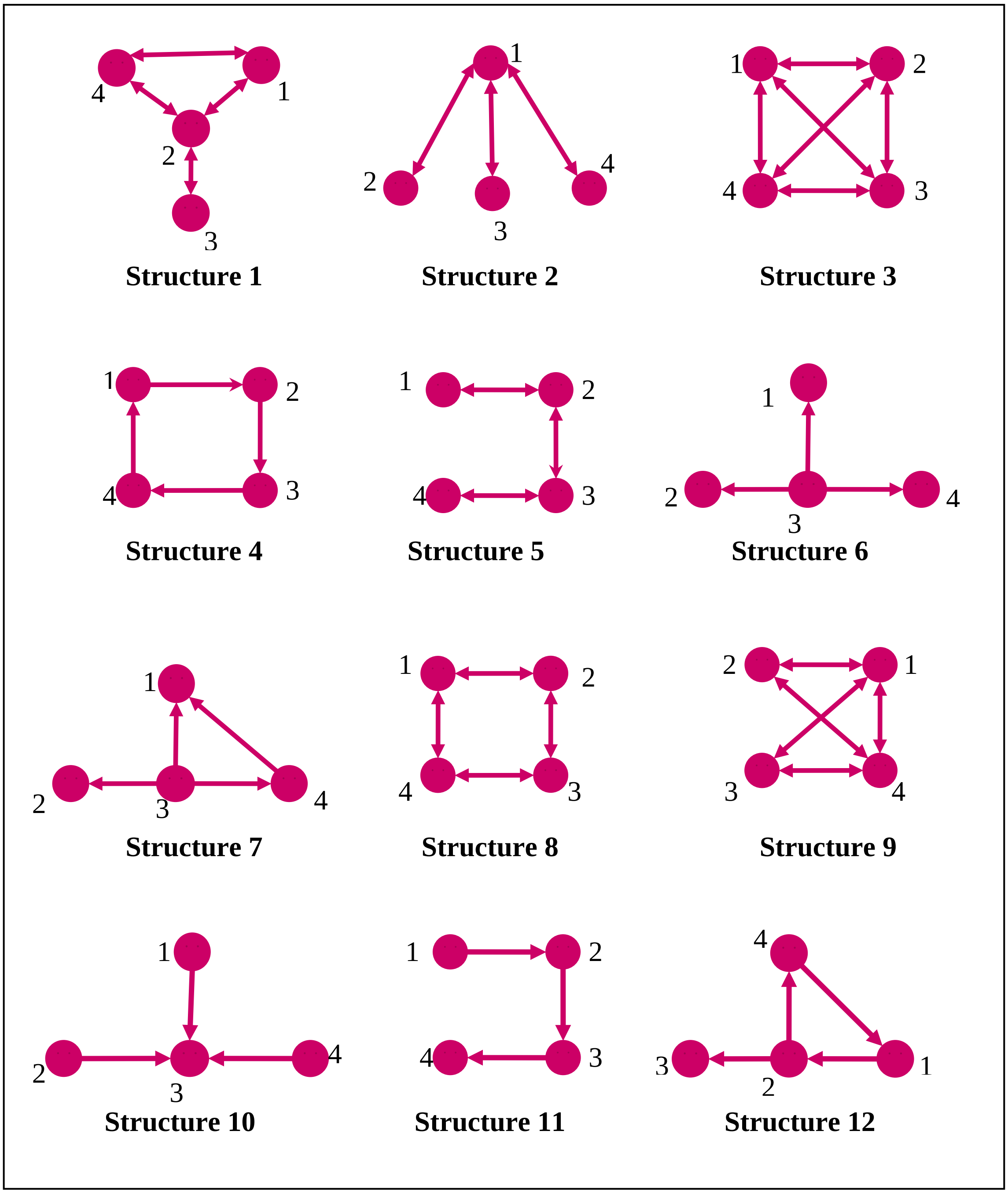


Figure 6.3: ROCCI Interaction Structures

In Figure 6.3, a circle is a person and each line represents an interaction link, this could be written, verbal or a visual. The arrowhead represents the direction of the flow of communication.

6.1.3.1 Direction of Interaction

In general, there is an interaction in both directions, hence an arrowhead at both ends of the interaction line. Each person in Interaction Structures 1, 2, 3, 4, 5, 7, 8 and 9 have bi-directional interaction.

In some cases, for example on a conveyor belt, where there is no direct feedback of information, there is only a one-way flow. If a product is transferred from person A to person B, person B can affect person A's work. But person A cannot affect person B's work. Persons A's work is only dependent on person A. This is an example of restricted communication, as there is no opportunity for feedback. Interaction Structures 6, 10, 11 and 12 represent one-way interaction.

6.1.3.2 Number of Interaction Links

Within a team there may be some people that interact with more people than other members of the team do. Alternatively, the team may be such that all members can interact with each other. The ROCCI interaction Structures represent the various combinations of number of interactions.

Structures 3, 4 and 8 represent an equal number of interactions links between all members of the team.

Structures 2, 6, 10 and 11 have one person in the team that has more interaction links than the other people do in the team.

Structures 5 and 9 represent a linear interaction flow. The two people in the middle of the interaction flow have an equal number of interaction links to each other, but a greater number of links that those at the end of the interaction flow.

Structures 1, 7 and 12 each consist of a team of people that have a varied number of interaction links.

6.1.4 Summary of Interaction Structures

The ROCCI Interaction Structures were designed to ensure that ROCCI could represent all possible formations of team interactions. This has been done by producing twelve interaction structures, each have different number of interaction links with the structure, between the people in the team and containing a variety on one-way and bi-directional interaction. These Interactions Structures will be used to test the algorithms used in ROCCI. The different structures will highlight the sensitivity of the algorithms and the effect that the different structures can have on team reliability.

6.2 Sensitivity Analysis

The ROCCI algorithms for Interaction Probability of Error P(I) and Team Probability of Error P(T) (Figure 6.3). are a fundamental aspect of the ROCCI 'proof of concept'. The ability for these algorithms to pick up on changes in individual reliability or team interaction will enable the designer / engineer to predict which combination of team members, interaction links or product to use. To test the ability of ROCCI to handle different inputted data and to predict P(I) and P(T) a sensitivity analysis was performed.

For the purposes of the sensitivity analysis:

- P(E) Probability of individual error
- CTS Communication-Trust Score
- P(I) Probability of interactive error between each role (e.g. between A and B)
- $P(I_n)$ Probability of interaction error for a role (e.g. between A and B & C)
- P(T) Probability of team error.

Each of the twelve interaction structures contains four positions 1, 2, 3 and 4. So in a team there are four people A, B, C and D. For each structure, the algorithms were tested for each person in every position, e.g. 1-A, 2-B, 3-C, 4-D, and then 1-B, 2-C, 3-D, 4-A. There are twenty-four possible combinations of people and positions for every structure. So for each structure the algorithms are tested twenty-four times.

The data needed for the interaction algorithm is P(E) and CTS for each person in the interaction. The sensitivity analysis tested the algorithms with various values for individual P(E) and CTS.

There were six combinations of values that were used to test the algorithms. The first three combinations were to test the basic logic of the algorithms. The first test had P(E) = 0 and CTS = 0 (Section 6.2.1) The second test had P(E) = 1 and CTS = 1 (Section 6.2.2). The third test had P(E) = 0.1 and CTs = 0.5 (Section 6.2.3).

The next three combinations changed either the P(E) or CTS. The fourth test had a P(E) = 0.1 but a variable CTS, 0.5<CTS<1.2 (Section 6.2.4), this produced a consistent P(I) for each person e.g. $P(I_{AB})$ = 0.05, $P(I_{AC})$=0.05. The fifth test had a variable P(E), 0.1<P(E)<0.6 and a constant CTS = 0.9 (Section 6.2.5). The sixth test had a constant P(E)=0.1 and a variable CTS, 0.5<CTS<1.2 (Section 6.2.6), this varies from the fourth test as the P(I) for each person varied, e.g. $P(I_{AB})$ = 0.07, $P(I_{AC})$=0.09.

The algorithms that being tested are:

$$P(I_A) = \frac{(P(E_A)CTS_{AB}) + (P(E_A)CTS_{AC}) + \cdots (P(E_A)CTS_{AN})}{n}$$

$$P(T) = \frac{1 - \left(1 - P(I_A)\right)\left(1 - P(I_B)\right) \dots \left(1 - P(I_N)\right)}{n}$$

Sections 6.2.1 to 6.2.7 are a sequence to demonstrate the variety of interaction and their impact on reliability. The results will show the effect that P(E), CTS and team structure have on the overall reliability of the team. Therefore, the P(T) results will be displayed graphically and will be discussed further in the test.

6.2.1 Constant Individual P(E) = 0.0, Constant CTS = 0

The first combination of values was a consistent P(E) and CTS across all people in the team, P(E)=0.00, CTS=0. This results in P(I) for each interaction of 0 (Table 6.1). For all twelve team structures there was a consistent result P(T)=0.00.

Person	P(E)		CTS A	CTS B	CTS C	CTS D		P(I) A	P(I) B	P(I) C	P(I) D
A	0.0	x		0	0	0	=		0	0	0
B	0.0	x	0		0	0	=	0		0	0
C	0.0	x	0	0		0	=	0	0		0
D	0.0	x	0	0	0		=	0	0	0	

Table 6.1: Interactions for P(E) = 0, CTS = 0

The use of the value zero (0) for the baseline figure is also a basic test of the algorithms and the possible team structures and formations. There are no variables, as 0 x 0 = 0. The probability of an individual making an error was negligible (P(E) =0). There was no effect of interaction, $P(I_R) = 0$. As such, the team could not decrease their probability of error, nor is there a mathematical opportunity for an increase in probability of error, results of P(T)= 0.00. This is again as would be predicted by the mathematics, showing that the algorithms, team structures and formations are logical or suitable.

6.2.2 Constant Individual P(E) =1.0, Constant CTS = 1

The second combination of values was a consistent P(E) and CTS across all people in the team, P(E)=1.00, CTS=1. This results in P(I) for each interaction of 1 (Table 6.2).

Person	P(E)		CTS A	CTS B	CTS C	CTS D		P(I) A	P(I) B	P(I) C	P(I) D
A	1.0	x		1	1	1	=		1	1	1
B	1.0	x	1		1	1	=	1		1	1
C	1.0	x	1	1		1	=	1	1		1
D	1.0	x	1	1	1		=	1	1	1	

Table 6.2: Interactions for P(E) = 1.0, CTS = 1

For all twelve team structures there was a consistent result P(T)=0.25. Figure 6.4 graphically demonstrates the P(T) produced for possible people and role combinations in each structure. Where all people and role combinations produced the same P(T) only one mark is displayed for that structure. It was shown that the people and role combinations created different values when the P(E) and CTS combinations become more varied, see later Sections.

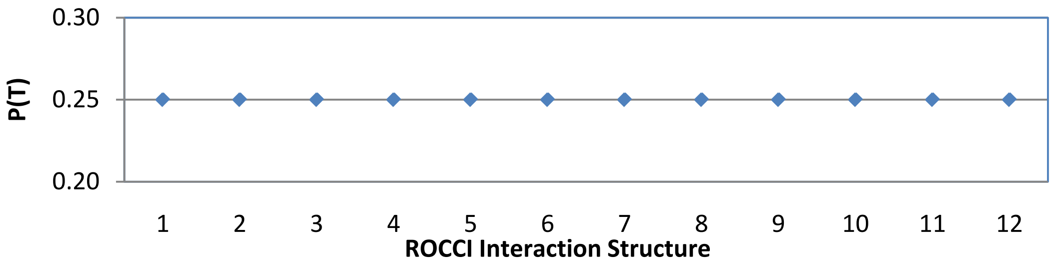


Figure 6.4: P(E) = 1, CTS = 1, P(I) = 1

The use of the value, one, 1, for the baseline figure is a basic test of the algorithms and the possible team structures and formations. As 1 X 1 = 1, and 1 / 1 = 1, 1 is a special number. There were no other variables in the data.

The probability of an individual making an error was certain (P(E) = 1). The interactions each person makes with other people does not affect their individual probability of error (P(I) = 1). However, when they work together as a team, the sensitivity analysis presents a decrease in probability of error (P(T)= 0.25). The algorithms work as predicted. The overall team error is ¼ of each person P(E). The analysis showed that the algorithms passed the test.

6.2.3 Constant Individual P(E)=0.10, Constant CTS = 0.5

The third combination of values was a consistent P(E) and CTS across all people in the team, P(E)=0.10, CTS=0.5. This results in P(I) for each interaction of 0.05 (Table 6.3).

Person	P(E)		CTS A	CTS B	CTS C	CTS D		$P(I_R$ A	$P(I_R$ B	$P(I_R$ C	$P(I_R$ D
A	0.10	x		0.5	0.5	0.5	=		0.050	0.050	0.050
B	0.10	x	0.5		0.5	0.5	=	0.050		0.050	0.050
C	0.10	x	0.5	0.5		0.5	=	0.050	0.050		0.050
D	0.10	x	0.5	0.5	0.5		=	0.050	0.050	0.050	

Table 6.3: Interactions for P(E) = 0.1, CTS = 0.5

The results of P(T) for this combination is not consistent across all team structures (Figure 6.5). When the interaction was bi-directional (Structures 1, 2, 3, 5, 8 and 9), or all team members had equal influence on the team (Structure 4) there was a consistent result P(T) = 0.0464, which shows a marginal decrease in probability of error. For structures that had one-way interaction the reliability of the team appeared to decrease, (Structures 7, 10, 11 and 12 P(T) = 0.57) and (Structure 6 P(T) = 0.67).

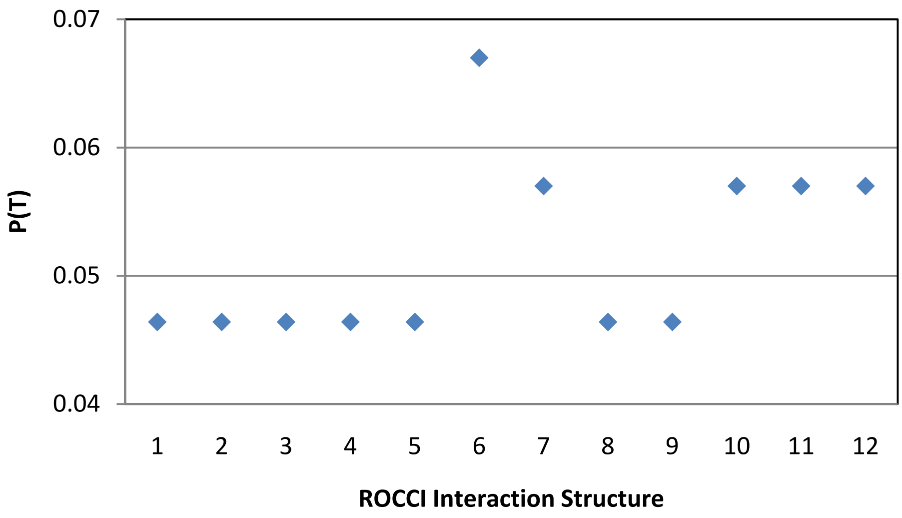


Figure 6.5: P(E) = 0.1, CTS = 0.5

This shows that the algorithms are sensitive to the slight changes in the structures. The P(I) for those three people that have least interactive influence on the team had least influence on the P(T). And as this circumstance P(I = 0.05) decreased the probability of error of the team, there will be less of a decrease, and so P(T) will be higher. The opposite would occur if there is a high CTS and therefore and increase in P(I).

6.2.4 Constant Individual P(E) = 0.1, Variable CTS, Constant P(I) for Each Person

The fourth combination of values was a consistent P(E)=0.1 for all members of the team and a varied CTS score, 0.5<CTS<1.2. This resulted in a variation of interaction probabilities, 0.05<P(I)<0.12 (Table 6.4) across the people in the team, but constant for each person, e.g. $P(I_{AB}) = P(I_{AC}) = 0.05$.

Person	P(E)		CTS					P(I)			
			A	B	C	D		A	B	C	D
A	0.1	x		0.5	0.5	0.5	=		0.05	0.05	0.05
B	0.1	x	0.7		0.7	0.7	=	0.07		0.07	0.07
C	0.1	x	0.9	0.9		0.9	=	0.09	0.09		0.09
d	0.1	x	1.2	1.2	1.2		=	0.12	0.12	0.12	

Table 6.4: Interaction for P(E) = 0.1, Variable CTS, Constant P(I)

Figure 6.6 shows that when all interactions were bi-directional P(T) = 0.0731 (Structures 1, 2, 3, 4, 5, 8 and 9). This is because the interaction probabilities for each person are constant e.g. a = 0.05, b = 0.07, so the team reliability scores are made from the same values. However, when the interaction is one-way the location of the people in the team and the influence that they have on interactions will affect the P(T) even if the structure of the team does not change (Structures 6, 7, 10, 11 and 12).

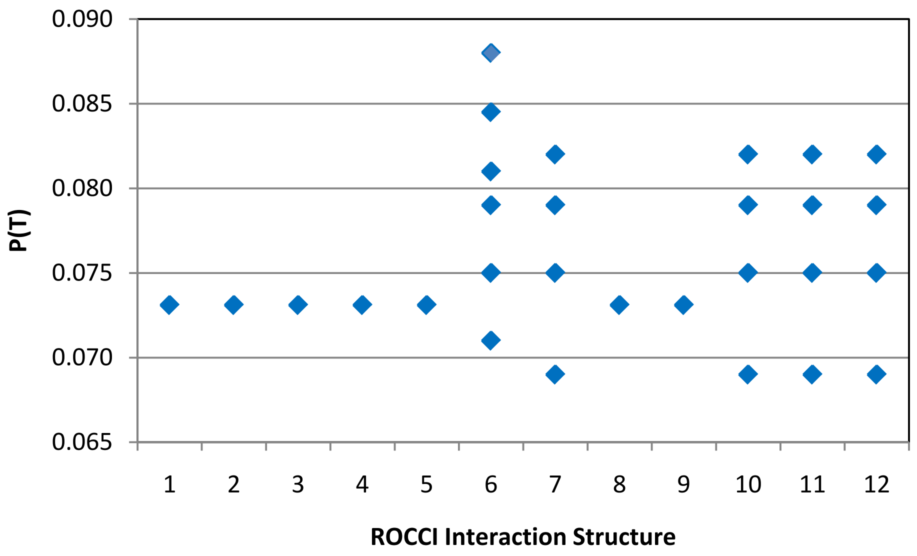


Figure 6.6: P(E) = 0.1, Variable CTS, Constant P(I)

The structures where there are multiple P(T) were investigated to further understand affect the values have on the algorithms. In Structure 6 (Figure 6.8), where two positions (2 and 4) have no effect on the other positions in the team. When the most people with the lowest CTS are in these positions the P(T) will be higher as these people have no opportunity to increase the reliability of the team. Figure 6.8 shows that when A (P(I)=0.5) and B (P(I)=0.7) are in positions 2 and 4 the P(T)=0.088. However when C (P(I)=0.9) and D (P(I)=1.2) and in positions 2 and 4 P(T) = 0.071.

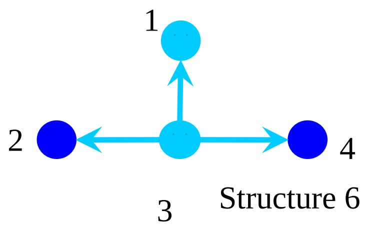


Figure 6.7: Interaction Structure 6 with non-influencing positions highlighted

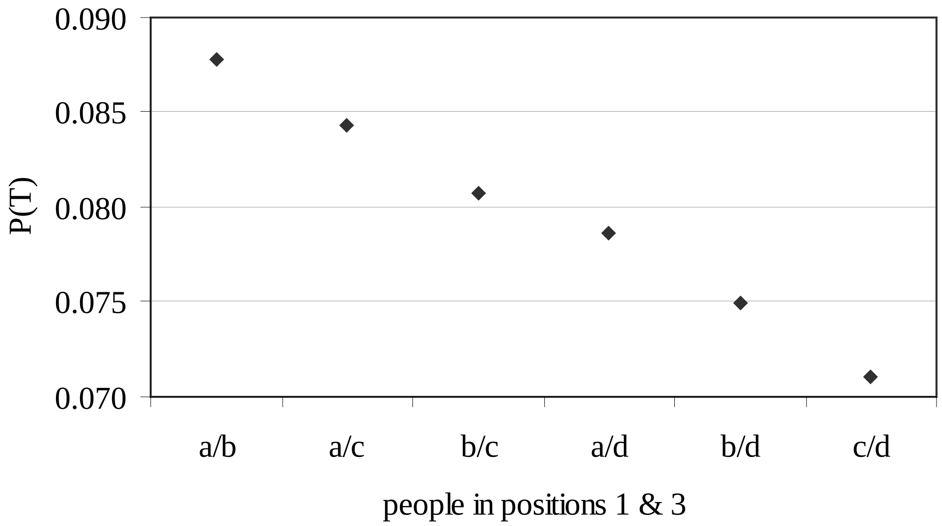


Figure 6.8: P(E) = 0.1, Variable CTS, Constant P(I), Structure 6

This same effect is seen in Structures 7, 11 and 12. For these structures there are four alternative P(T) values (Figure 6.9). For these structures there is only one influencing position. For Structure 7 it is position 2, for Structure 1 it is position 4 and for Structure 12 it is position 3. When the person with the lowest CTS is in these positions the P(T) will be its highest as these people will have least influence on the working of the team.

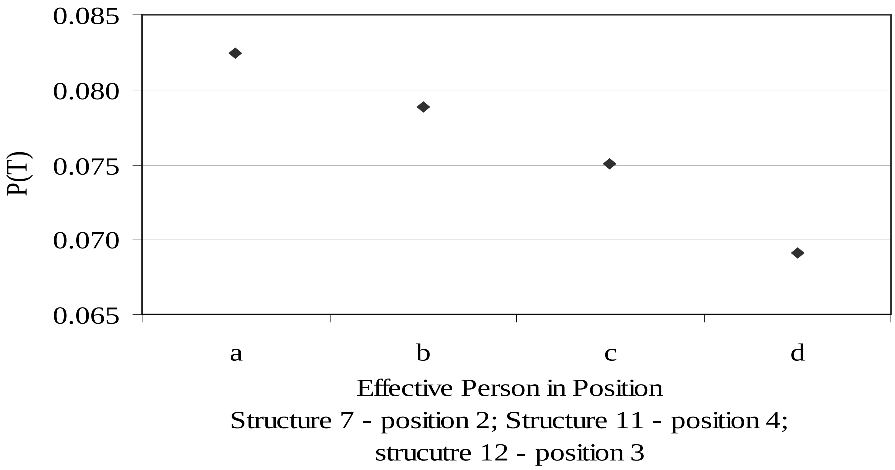


Figure 6.9: P(E) = 0.1, Variable CTS, Constant P(I), Structure 7, 11, 12

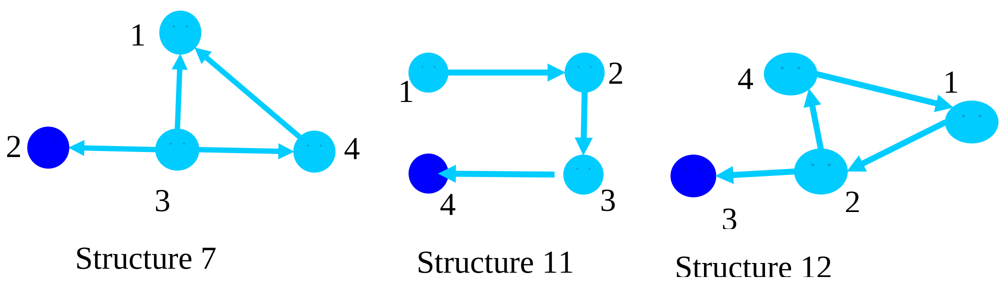


Figure 6.10: Structures 7, 11 and 12 non-influencing positions highlighted

Having a constant P(E)=0.1 and a variable CTS shows that the location of the people within the team can have an affect on the overall reliability of the team. When an engineer / designer is using ROCCI it is important for them to remember that if there is one person that is highly trusted and capable they cannot have a positive influence on the team if they cannot interact with the team.

6.2.5 Variable P(E), Constant CTS = 0.9

The fifth combination of values was a variable P(E), 0.1<P(E)<0.6 and a consistent CTS=0.9 for all members of the team. This resulted in a variation of interaction probabilities, 0.09<P(I)<0.54 across the people in the team, but constant for each person, e.g. $P(I_{AB}) = P(I_{AC}) = 0.54$ (Table 6.5: Interactions for P(E) Variable, CTS = 0.9).

Person	P(E)		CTS A	CTS B	CTS C	CTS D		P(I) A	P(I) B	P(I) C	P(I) D
A	0.6	x		0.9	0.9	0.9	=		0.54	0.54	0.54
B	0.5	x	0.9		0.9	0.9	=	0.45		0.45	0.45
C	0.2	x	0.9	0.9		0.9	=	0.18	0.18		0.18
D	0.1	x	0.9	0.9	0.9		=	0.09	0.09	0.09	

Table 6.5: Interactions for P(E) Variable, CTS = 0.9

Figure 6.11: Various P(E) , CTS = 0.9Figure 6.11 shows that when all interactions were bi-directional P(T) = 0.0203 (Structures 1, 2, 3, 4, 5, 8 and 9). This is similar to the results of the Fourth Combination.

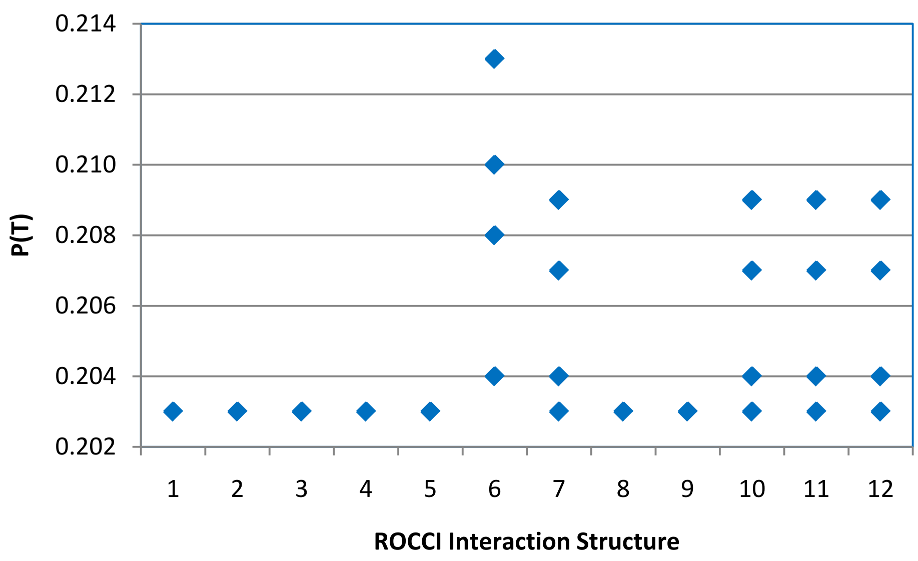


Figure 6.11: Various P(E) , CTS = 0.9

When there was a single one-way interaction, that individual has least influence on the P(T). Figure 6.12 shows the effect of the outlying Individual on the overall P(T).

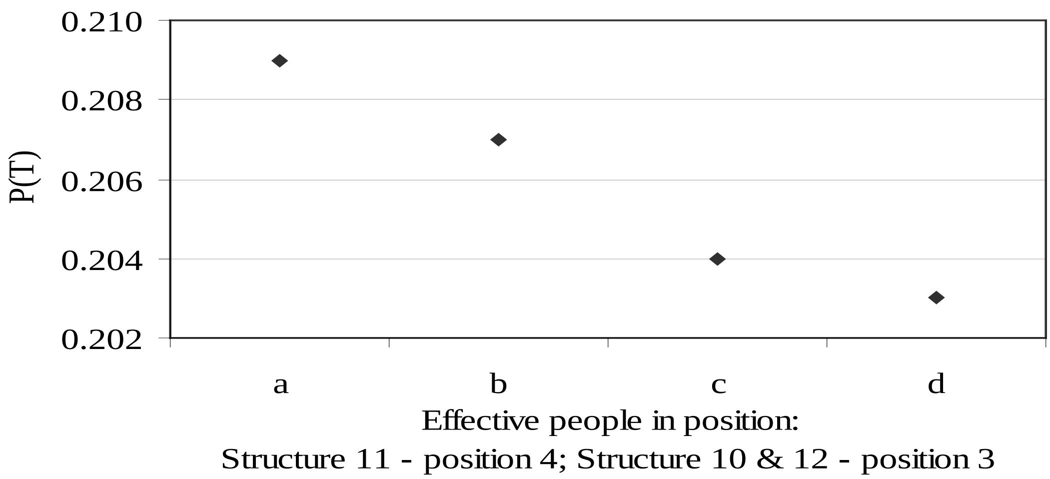


Figure 6.12: Effective positions for structures 10, 11 & 12

When two individuals have one-way interaction, e.g. Structure 6, then both people will effect P(T) (Figure 6.13).

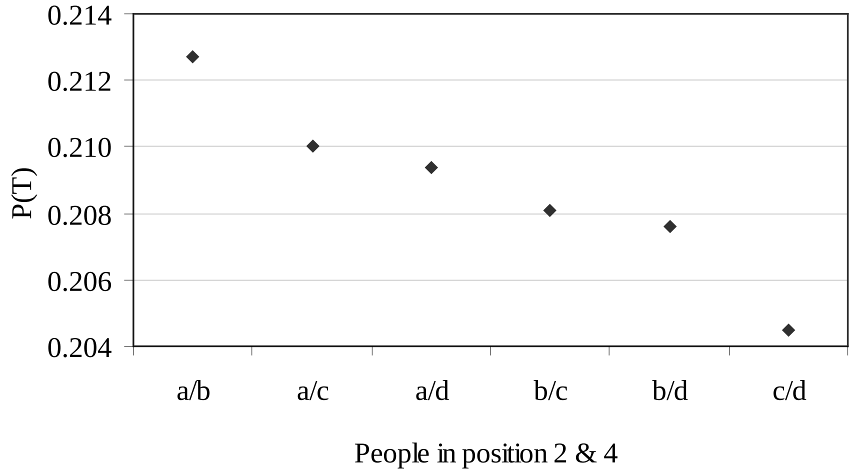


Figure 6.13: Effect of Two One-Way Interactions when P(E) = Variable, CTS = 0.9, Structure 6

When only two-way interaction structures (Structures 1, 2, 3, 5, 8 and 9), or all team members had equal influence on the team (Structures, 3, 4 and 8) there was a consistent result P(T) = 0.203. In structure 6 (Figure 6.4) only 1 and 3 have an effect on another person, 2 and 4 do not affect another person. The lower P(T) shown in the graph occur when the highest P(E) are in positions 1 and 3, as their P(I) is lower than their P(E), so their contribution to the P(T) is lower. In structure 10, person 3 has no interaction links. There is a positive relationship between the P(E) of person 3 and P(T). This is because P(E) is used in the P(T) calculation for person 3, rather than P(I), and P(E) is higher than P(I). If CTS was 1.2, then P(I) would be higher than P(E) and a negative relationship would be seen. Structures 7, 11 and 12, supported this pattern.

The algorithms mathematically show how teams can improve the reliability of an individual and that this affects the reliability of the team.

6.2.6 Constant Individual P(E) = 0.1, Variable CTS Score, Variable $P(I_R)$ for each person

The fifth combination of values was a consistent P(E) = 0.1, for all members of the team and a variable $0.5<CTS<1.2$. This resulted in a variation of interaction probabilities, $0.05<P(I)<0.12$ across each person, e.g. $P(I_{AB}) = 0.07$ $P(I_{AC}) = 0.09$ (Table 6.6).

Person	P(E)		CTS A	CTS B	CTS C	CTS D		P(I) A	P(I) B	P(I) C	P(I) D
A	0.1	x		0.7	0.9	1.2	=		0.07	0.09	0.12
B	0.1	x	0.5		0.9	1.2	=	0.05		0.09	0.12
C	0.1	x	0.5	0.7		1.2	=	0.05	0.07		0.12
D	0.1	x	0.5	0.7	0.9		=	0.05	0.07	0.09	

Table 6.6: Interactions for P(E) = 0.1, Variable CTS, Variable P(I)

Due to the variability of P(I) the values for P(T) are more varied than the previous combinations. Figure 6.14 shows that when there is an equal level of interaction between all team members the P(T) is constant (Structures 3, 4 and 8). This knowledge can be applied, so that when a team has equal communication links with all the other members of the team, the P(T) will not change as each person is having an equal effect on the team.

Structures 1, 2, 5 and 9 no longer have a single value for P(T). Structures 10 and 11 still have four values, this implies that there is one position in the team that has a greater or lesser effect on the P(T) than the other positions (as discussed in previous sections). For this combination Structure 2 has four values for P(T) (Figure 6.15). The person in position 1 has the most effect on the team, when the person is A with whom other people have a low CTS then the overall P(T) is also low.

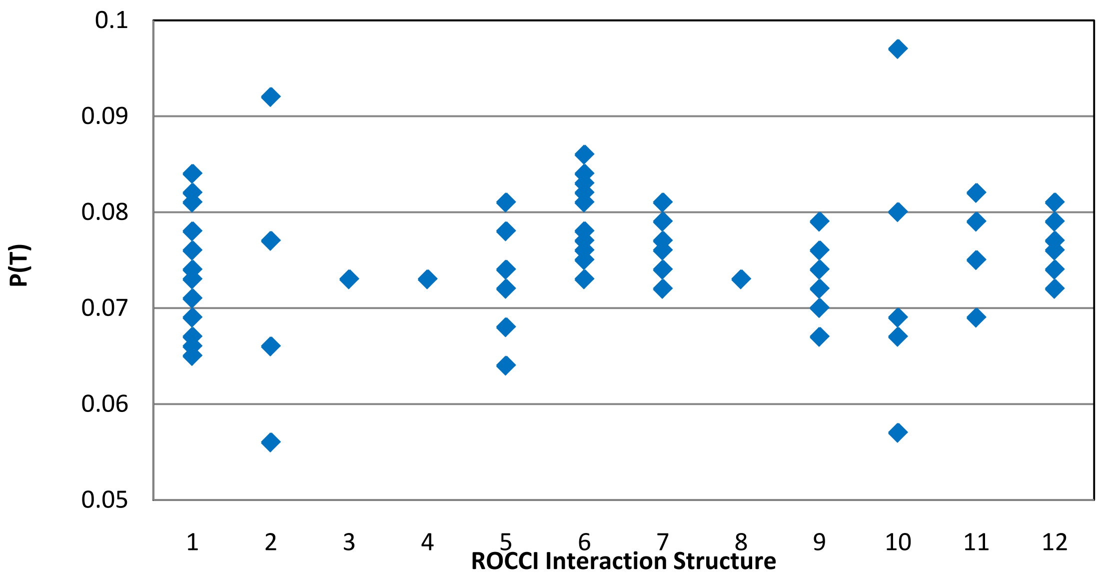


Figure 6.14: P(E) = 0.1, CTS = (0.5, 0.7, 0.9, 1.2, P(I) varied across Person

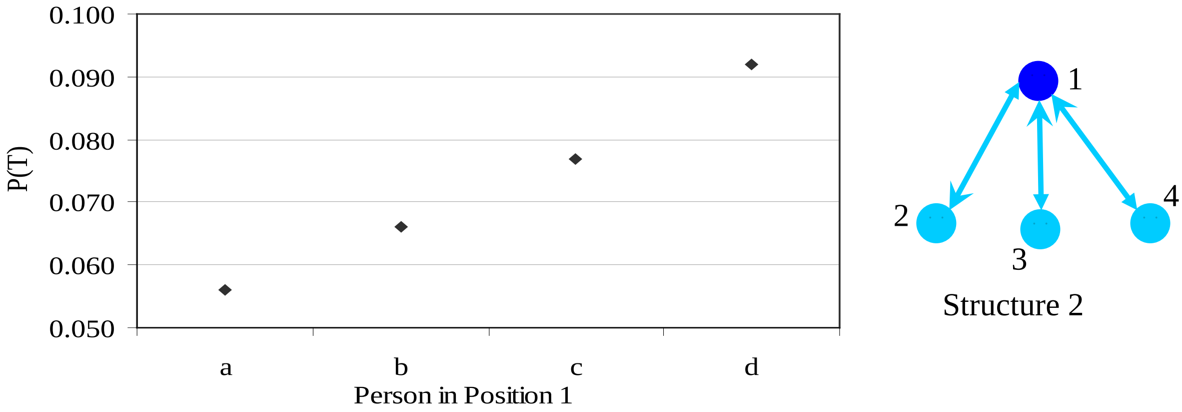


Figure 6.15: P(E) = 0.1 CTS varied across people: Structure 2

Structures 5 and 9 have a similar shape, they are a line of four people, where the end people cannot interact with each other. The two people in the middle of the line have a greater impact of the P(T) than the two people at the end of the line. When the lowest P(I) are in these positions the P(T) is lower, e.g. when A and B are in these positions P(T) = 0.066 (Figure 6.16)

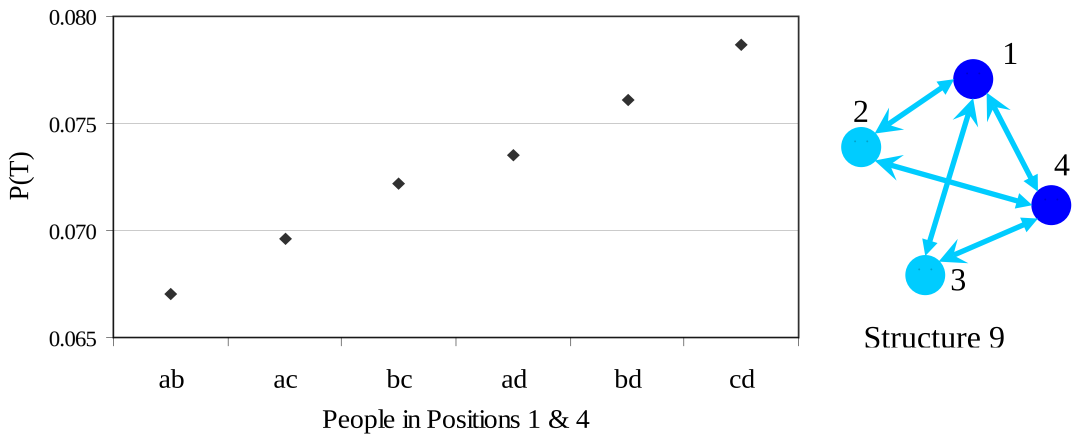


Figure 6.16: P(E) = 0.1, Variable CTS and P(I_R), Structure 9

The sixth combination of P(E) and CTS values has shown that the algorithms are sensitive to the different structures that have been applied and to the data inputted into the calculations. The structures that have bi-directional interaction produce a more consistent P(T) when the people rotate positions around the structure. This suggests that bi-directional interaction is better for team work as it produces a more consistent team work.

6.3 Conclusions

The algorithms for P(I) and P(T) were tested against four team members in twelve interaction structures. When constant basic values (0, 1) were used the algorithms behaved in a predictable manner. When variable P(E), CTS or P(I) were used the significance of the team structures and outlying team members became apparent. This theoretically showed that team structure affected the reliability of the team.

If an unreliable or non-team player were a central person in the teams configuration the reliability of the whole team would be more negatively affected than if this person was an outlier to the team, or if the central person was reliable and had good team skills.

The Sensitivity analysis produced the results that the algorithms can show the importance of individual members of the team, whether that is based on their placement in the team or their ability to perform a task. This sensitivity analysis showed that the algorithms, structures and formation can cope with the variety of input and is sensitive to the data.

6.3.1 Use in Safety Cases

It has been shown that, in theory, the ROCCI algorithms can account for variations in team structure, P(E) and CTS. Engineers and designers who will use ROCCI throughout the design process of a piece of equipment or capability can use this information. This can be done in a number of ways.

Changing the number of interaction links in the team

If the team is dispersed the method and bandwidth of communication available may affect the number of interaction links possible. Inputting different team configurations into ROCCI can investigate how communication and structure affects the communication scores.

Changing the person in each position

When deciding which member of the team should perform which function the level of experience can be used to inform the structure. The algorithms will assist in determining the effect of P(E), how well the person will perform the task, and team structure on the overall reliability of the team. The engineer/designer may advise to ensure that an experienced member of the team is responsible for performing a complex task, whilst an inexperienced member should perform fewer and more simple tasks, as each team member will be less likely to perform an error in the suggested role.

Comparing Different Products

The Engineer/Designer may have the opportunity to compare several possible products to purchase. These are likely to have different configurations of team members, methods of communications and skills required to perform a task. Using the ROCCI algorithms will help the engineer to decide which product will enable the team to perform most reliably.

6.3.2 Modification to ROCCI

6.3.2.1 Inclusion of Decision Making Power Distance (PD)

After performing the sensitivity analysis the level of responsibility within the team and the influence one person may have over the other **became important**. The solution that the researcher identified and applied was the use of PD (decision making Power Distance). Hofstede's (1984) definition of high power distance is a dependence of subordinates on superiors with little inclination to question decisions (a dictatorship). Low power distance is preference for consultation.

In ROCCI decision making power distance (PD) is a weighting factor from (low) 1 to 5 (high). The higher the PD score, the more that team member will influence the person. This is important as information and instructions received from a person that is more senior are more likely to be followed than information and instructions received from a person, who is more junior. Thus, the senior team member's interaction will have more of an effect on the individual than that of the junior team member's.

In any team, there is a decision hierarchy and ultimately somebody will take responsibility for the decision made. This person is at the top of the hierarchy. Those that do not have this responsibility are lower in the hierarchy. The **difference** in PD level is the primary interest.

6.3.2.2 Measuring PD

To calculate decision hierarchy, the sum PD score for each pair of team members that interact will equal 6. If they are at an equal level in the hierarchy, each PD score will be

3. A large PD will exist if there is little or no discussion of instructions and decisions, the PD scores will be 1 and 5. A small PD exists if decisions and instructions are made, but the other team member can discuss these, the PD scores will be 2 and 4.

If people have equal power over decisions in the group, then they are level on the hierarchy. If there are two people that take responsibility for all decisions and the success of the team, then these two people are at an equal level.

PD is **not** the number of levels between one person in a team and another.

6.3.3 Summary

Chapter Six has examined in depth the sensitivity analysis of team reliability in a range of team structures. Chapter Seven will be a full review of the contribution, the potential for development and current limitations of ROCCI.

Chapter Seven: Discussion

Chapter Six on Sensitivity Analysis has fully explained the way ROCCI has been applied to test the team reliability of the alternative team structures. The graphs associated with the test of each structure have been explained and presented in a way that permits easy comparison between structures.

This Chapter Seven, Discussion, is a fuller review of ROCCI. This review provides the detail of the different contributions that ROCCI might make, including its use in relation to Safety Cases. It provides a critical review of ROCCI that describes its potential and also discusses its present limitations.

The Chapter uses a worked example to illustrate the Seven Step Process of ROCCI, and the contribution that ROCCI might make. The example is that of a sailing crew in action consisting of the captain, a deckhand and a helmsman. Whenever the worked example is used it is placed within a green box (Figure 7.1).

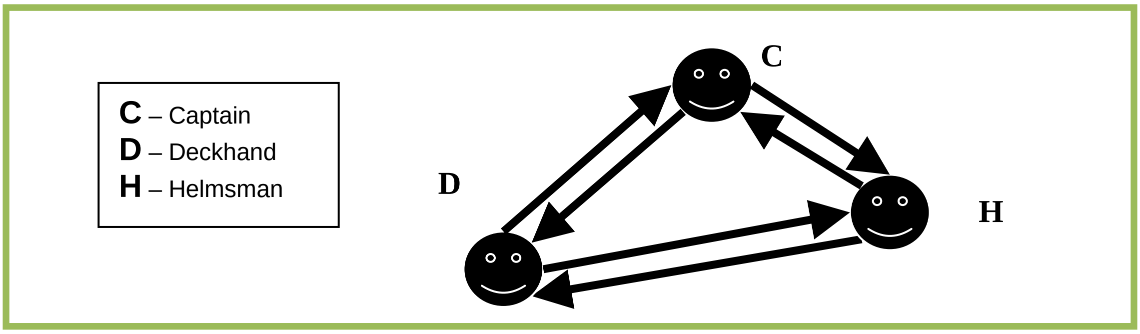


Figure 7.1: A Worked Example of a Sailing Crew

7.1 Performing ROCCI

7.1.1 Introduction

The effect of the interaction factors are found by applying ROCCI to the individuals. The interaction multiplier, CTS, is applied to each individual's probability of error P(E), producing P(I). These are combined to provide the team error probability P(T).

Using Kirwan's (1994) '10 HRA Stages' (Figure 7.2), the shaded areas represent which parts of the HRA process are covered by ROCCI.

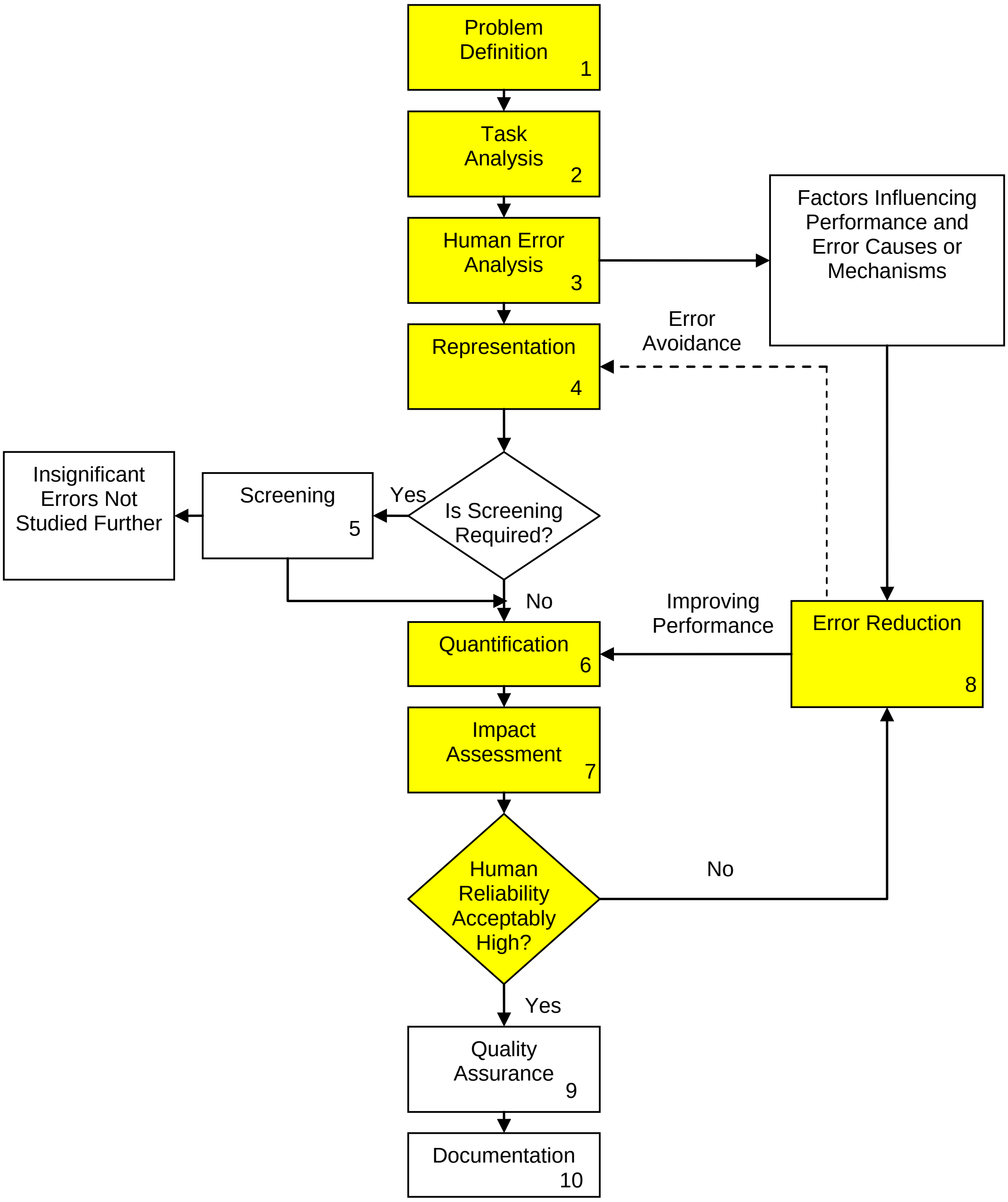


Figure 7.2:The 10 HRA Stages (Kirwan, 1994)

The first steps in ROCCI are to define the process and allocate roles to team members. These are necessary for the individual HRA as well as ROCCI. ROCCI consists of seven steps, the first three are needed for the individual HRA. Steps five and six are used to calculate the interactive probability of error. Steps six and seven assess the overall team reliability.

This provides three sets of data to help assess the team:

1. Individual probability of error: P(E) (Steps 1-3)
2. Interactive probability of error: P(I) (Steps 4-6)
3. Team probability of error: P(T) (Steps 6-7).

Definitions of annotation for ROCCI are provided:

$P(E_A)$	Probability of individual error for A
$P(I_A)$	Probability of interactive error for A
PD_{AB}	Decision making Power Distance between A and B
ΣPD_A	Total number of PD for A
CTS_{AB}	Communication Trust Score between A and B
P(T)	Probability of team error
Σt	Number of people in the team

7.1.2 Overview of ROCCI Process

ROCCI is a seven step process, as can be seen in Figure 7.3. If there is already a HRA process in place, then ROCCI can be used as an 'add – on' to that current work, as many of the steps will already be covered in the existing HRA process.

Step 1: Define the team and task (Section 7.2.1)

Determine the boundaries of the task and the team that is being assessed. Identify the equipment that is used for communication and sharing information.

Step 2: Produce task analysis for each role (Section 7.2.2)

Define the tasks that each person performs. This will help confirm the identity of the equipment that the team members use to communicate and with whom they are interacting.

Step 3: Perform HRA for each role (Section 7.2.3)

The task analysis can be used to perform the HRA for each person. Any method that provides a quantitative probability of error can be used. The individual HRA assesses many of the attributes that affect the reliability of each person. This means that only a few additional attributes are needed to assess the reliability of the team.

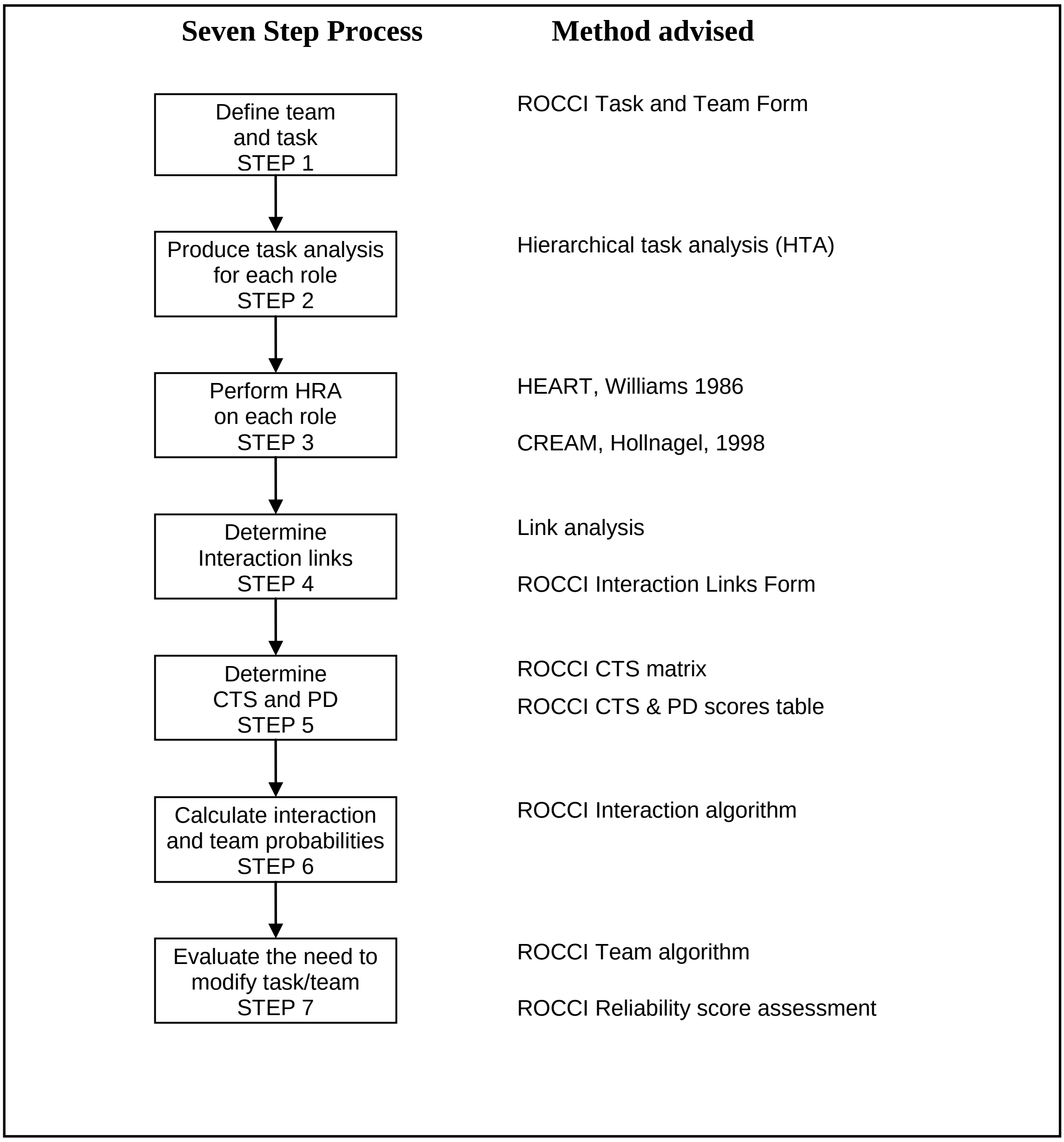


Figure 7.3: Advised Methods to be Used During the Seven Step Process of ROCCI

Step 4: Determine the interaction links (Section 7.2.4)

Clarify who interacts with whom in the team. This step is the key to ROCCI. It is these lines of interactions that the CTS and PD scores evaluate. This step produces a diagrammatic representation of the interactions.

Step 5: Determine the CTS and PD (Section 7.2.5)

Communication, Trust and Decision Making Power Distance are the three attributes that are used to assess the reliability of the team. Communication and trust combine to produce the CTS. CTS and PD scores for each interaction are used in the equations for interaction and team reliabilities.

Step 6: Calculate the interaction and team reliabilities (Section 7.2.6)

Use the CTS and PD scores for each interaction to calculate how a person interacting with their team mates affects their probability of error P(I). The P(I) scores are then used to calculate the overall team probability of error P(T).

Step 7: Evaluate the need to modify task/team (Section 7.2.7)

The suitability of P(T) can be assessed, on whether it is suitably low, or how it compares to other structures of the team. Modifications to the team structure and interactions can be made to improve P(T) if required.

7.2 Seven Steps to ROCCI

These seven steps will now be described in detail with worked examples (Sections 7.2.1 to 7.2.8).

7.2.1 Step 1: Define the Task and Team

The aim of the first step is to define the task that is to be studied and so focus the designer / engineer on the goal of the team and who is in the team.

A definition of a **team** is

> *'two or more individuals who must perform distinct, complementary or independent tasks in pursuit of a common, specified goal. Teams must communicate as well as share information and resources in order to meet their goal(s). (P.794, Salas et al., 2005)*

This definition is used to help define the boundaries around the task and team.
'*two or more individuals*' – there must be at least two individuals in the team. How many people are there in the team?
'*perform distinct, complementary or independent tasks*' – the tasks are those that each team member performs. These can be different from the other team members or the same. The location of the team does not matter. They can either be together or

separated by space and time. The tasks that each person performs must be capable of being defined with clarity.

Define Task and Team Form

The Goal:

To perform a gybe to change tack whilst sailing in waters where there may be submerged reefs. This is performed during the day, but the weather conditions are wet, making verbal communication at a distance difficult.

The tasks performed by each team member to complete the goal:

The Captain will decide when to perform the gybe, considering the sea conditions, submerged reefs and weather conditions. He will also instruct the deckhand and helmsman on the functions they must perform.

The helmsman will steer the boat into the wind at the correct time.

The Deckhand will furl and unfurl the jib, and main sail.

The number of people in the team:

There are three members in the team. Captain, Deckhand and helmsman, whom all interact with each other.

The methods used for communication/sharing information or resources:

Main form of communication is hand signals, which have been taught. Along with talking/shouting to each other along the deck of the boat or face-to-face communication in the cockpit area. Communication is sometimes passed down a line of team members along the length of the boat when visibility and audibility is difficult/low.

Figure 7.4: Defining Task and Team Form. With Example Answers Shown.

'*in pursuit of a common specified* goal' – this is what makes the team a team, all team members must have a common goal. Once this has been determined the task and team may become more clear.

'*teams must communicate as well as share information and resources*' – communication and sharing of information is critical to deciding who is in the team. It is these links that creates the team structure. A person who does not communicate or share information with another person in the team is not part of that team. Therefore they should not be included in the analysis. It may be found that some people in the team may only communicate with one other team member, whereas other team members will interact with a majority of the team. An unevenness in interaction does not matter. It is the interaction links that are studied, not the team as a whole, and so this will be accounted for later on in the tool.

In a military setting there is a very hierarchical working structure. The team could include many levels of the hierarchy, but that may have very little impact on the reliability of the team. It must be decided at this point, who should be included in the team. This should become more obvious when the goal that the team must reach is decided and defined.

A tool to aid the designer in defining the information about the team, the Task and Team Form (Figure 7.4), was produced.

7.2.2 Step 2: Produce a Task Analysis for Each Role

This further defines the tasks and team that is being assessed. Any method of task analysis can be used (e.g. HTA). The next step is to provide a link analysis of the interactions of the team members (e.g. TTA).

7.2.3 Step 3: Perform HRA on Each Role

When the task analysis has been created, it is possible to perform HRA on each team member to calculate the P(E) for each person. Any quantitative HRA method can be used (e.g. HEART (Williams, 1986), CREAM (Hollnagel, 1998)). If a person performs many actions in the defined task a fault tree should be created.

7.2.4 Step 4: Determine the Interaction Links

The tasks that each team member performs (Steps 2 & 3) show that team members interact with each other. Step 4 represents the interaction links in a diagram to aid visualisation of the team, and show factors that would not normally be seen, e.g. one person interacts with many people, yet has very poor lines of communication. Each team structure is drawn individually; implying that any team structure can be represented using the same method and algorithms (Figure 7.5).

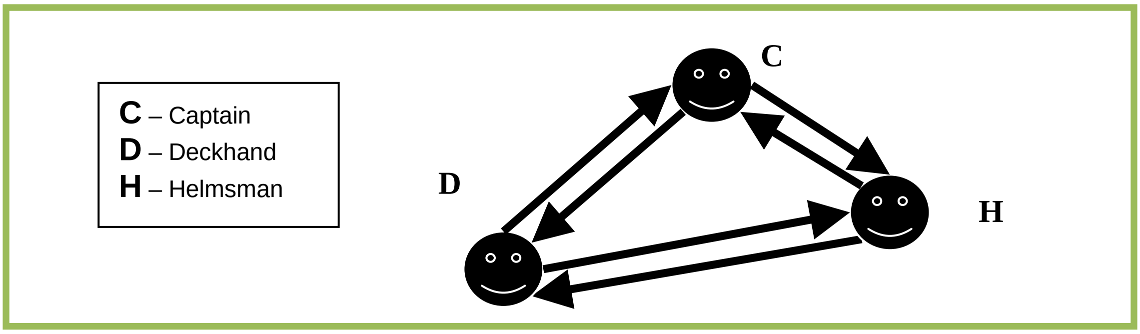


Figure 7.5: Interaction Diagram of Three Crew Members from Case Study 2

7.2.5 Step 5: Determine CTS and PD

The three main factors that can affect the reliability of a team are communication, trust and decision making power distance (PD). These are defined below:

Communication: the efficiency and effectiveness of the communication.

Trust: the amount of trust there is between team members to perform the work to their best ability; and the trust that is there for team members to check each other's work and receive criticism on their work.

Decision Making Power Distance (PD): PD is a weighting factor, the higher the PD score the more the person will be influenced by that team member. This is important as information and instructions received from a more senior person are more likely to be followed than information and instruction received from a person that is more junior, thus the senior team member's interaction will have more effect on individuals.

Communication and Trust are interdependent factors and so their scores combine to produce the Communication Trust Score (CTS).

7.2.5.1 ROCCI Assessment Form

For each interaction link, the scores for CTS and PD need to be identified. The 'ROCCI Assessment Form' (Figure 7.6) is completed for each person by selecting the correct score for each interaction link.

Question A relates to the PD (scored 1-5); Question B relates to the amount of trust score for the work to be performed (scored 1-4); Question C relates to the trust in the value of the interaction (scored 1-4). Questions B and C represent the two aspects of trust; a simple matrix is used to combine these scores to provide a single score for trust

(Table 7.1). Question D relates to the quality and efficiency of the communication (scored 1-4).

ROCCI Assessment Form

A Assess the difference in hierarchical decision making between each team member.

1 Inferior, instructions will be given and will rarely be questioned or overridden.

2 Inferior, advice/instructions will be given, these and decisions will be discussed.

3 Equal, advice/instructions are given between team members, and they do not have to be followed.

4 Superior, advice/instructions will be received, these and decisions will be discussed

5 Superior, instructions will be received and will be rarely questioned or over-ridden.

B Assess each team member on how much they should be trusted to complete the work that was set for them to do.

1 The work will probably not be done

2 The work will be of low quality or incomplete or late

3 The work will be done on time, but would not be of good quality

4 The work will be done on time, and would be of good quality

C Assess each team member on the value of their views on aspects relating to the task.

1 Their views could be inappropriate and irrelevant

2 They will not have many views on the task

3 Their views will be a mixture of inappropriate and valuable

4 Their views will usually be well justified and were valuable

D Assess how the efficiency and effectiveness of communication and transferring information between team members.

1 The communication will be insufficient, it will be hard to pass documents and facts or have discussions between each other.

2 The communication was insufficient, either documents and facts could be sent OR discussions were sufficiently supported, but not both.

3 The communication was sufficient, documents and facts could be sent, and discussions, but some problems occurred.

4 The communication was sufficient; if information was needed at any point it was easily shared, and discussed, with very few problems.

Interaction Link	Quest. A	Quest. B	Quest. C	Quest. D

Figure 7.6: One Page ROCCI Assessment

Table 7.1: Trust Matrix

		Question B			
		1	**2**	**3**	**4**
Question C	**1**	1	1	2	3
	2	1	2	3	3
	3	2	3	3	4
	4	3	3	4	4

Communication-Trust Score (CTS)

Communication and trust are attributes that are interdependent. For example if there is good trust between the team members, the effect of communication may be less important. Equally, if there is bad trust between the team members, there may be a greater need for good communication and if it is not provided there may be severe consequences on the team success. For this reason, communication and trust are combined to give the CTS. CTS is a multiplying factor to the individual probability of error P(E). Figure 7.7 shows the CTS for each interaction (Communication - Trust). These scores are then used in the CTS matrix (Table 7.2) to provide the final CTS in the CTS and PD scores table (Table 7.3).

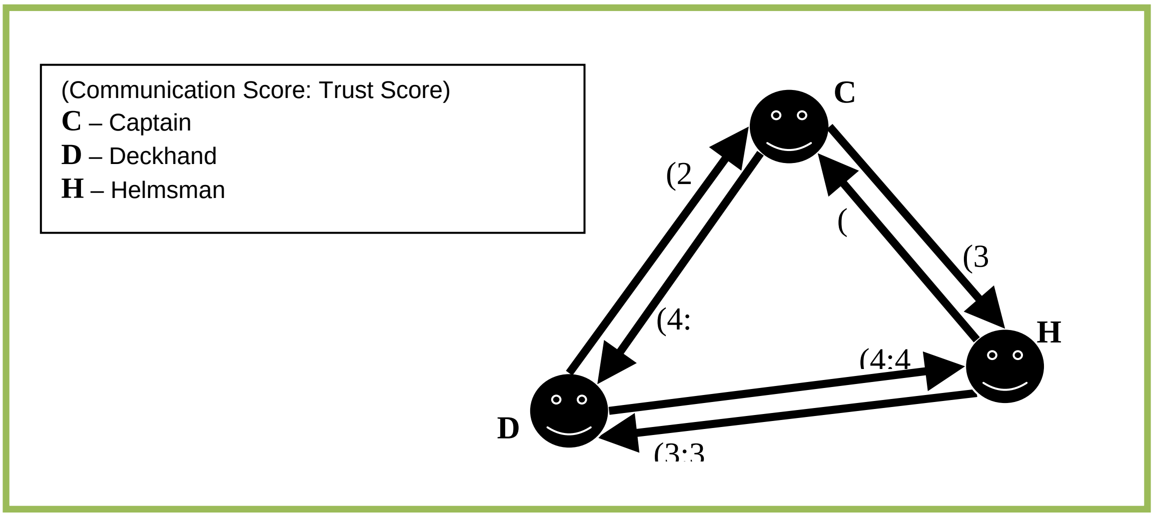


Figure 7.7: Interaction Diagram Showing Communication Score and Trust Score

Table 7.2: CTS Matrix

Trust \ Communication	1	2	3	4
1	2	1.9	1.8	1.7
2	1.9	1.8	1.7	1.2
3	1.8	1.7	1.2	0.7
4	1.7	1.2	0.7	0.5

Table 7.3: CTS and PD for Each Interaction

	Comms	Trust	CTS	PD
CD	4	2	1.2	1
CH	3	2	1.7	2
DC	2	3	1.7	5
DH	4	4	0.5	3
HC	2	4	1.2	4
HD	3	3	1.2	3

The final CTS and PD should now be placed on the interaction diagram (CTS:PD) (Figure 7.8).

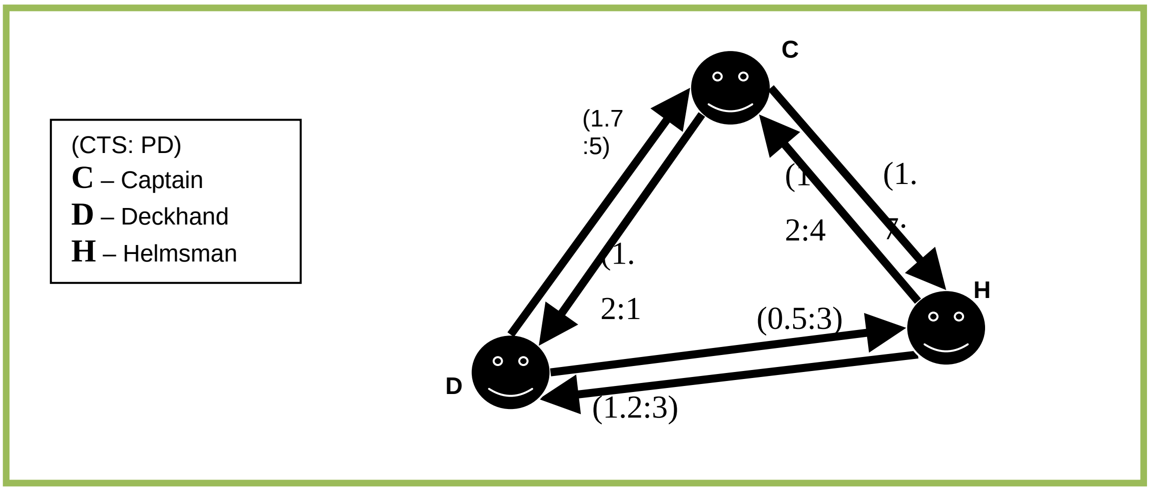


Figure 7.8: CTS and PD Score on Interaction Diagram

7.2.6 Step 6: Calculate Interaction and Team Probabilities

To perform the interaction calculations the information needed is:

1. P(E) for each person
2. CTS for each interaction
3. PD for each interaction.

7.2.6.1 Interaction Algorithm

The individual probability of error (P(E)) found from the HRA (Step 3) remains the basis for the interaction reliability for each person. The CTS is a multiplying factor to the P(E) as it is believed that these are the main attributes of team work that strongly effect reliability. Probability of Interactive error (P(I)) is calculated using the Algorithm for interactive Reliability (Figure 7.9).

$$P(I_A) = \frac{(P(E_A)CTS_{AB}PD_{AB}) + (P(E_A)CTS_{AC}PD_{AC}) + \cdots (P(E_A)CTS_{AN}PD_{AN})}{\Sigma \mathrm{PD_A}}$$

Figure 7.9: Algorithm for Interactive Reliability for Each Person

The worked example of the sailing crew (Figure 7.10) demonstrates the Algorithm for interaction. The probability of error for each team member is shown in . The interaction Algorithm will be used to calculate P(I) for the Captain, Deckhand and Helmsman, presented in

Table 7.5.

Table 7.4: Table of Probabilities of Error for Each Sailing Crew

Team Members		Probabilities of Error	
C	Captain	$P(E_C)$	0.5
D	Deckhand	$P(E_D)$	0.3
H	Helmsman	$P(E_H)$	0.2

Calculation of P(I) for Captain, Deckhand and Helmsman using the Interaction Algorithm

P(I) for **Captain**

$$P(I_C) = \frac{(P(E_C)CTS_{CD}PD_{CD}) + (P(E_C)CTS_{CH}PD_{CH})}{\Sigma \mathrm{PD_C}}$$

$$P(I_C) = \frac{(0.5 \times 1.2 \times 1) + (0.5 \times 1.7 \times 2)}{3}$$

$$P(I_C) = 0.76$$

P(I) for **Deckhand**

$$P(I_D) = \frac{(P(E_D)CTS_{DC}PD_{DC}) + (P(E_D)CTS_{DH}PD_{DH})}{\Sigma \mathrm{PD_D}}$$

$$P(I_D) = \frac{(0.\times 1.7 \times 5) + (0.3 \times 0.5 \times 3)}{8}$$

$$P(I_D) = 0.38$$

P(I) for **Helmsman**

$$P(I_H) = \frac{(P(E_H)CTS_{HC}PD_{HC}) + (P(E_H)CTS_{HD}PD_{HD})}{\Sigma \mathrm{PD_H}}$$

$$P(I_C) = \frac{(0.52 \times 1.2 \times 3) + (0.2 \times 1.2 \times 4)}{7}$$

$$P(I_C) = 0.24$$

Figure 7.10: Calculation in Interaction Algorithms

Table 7.5: Table of Probabilities of Interaction for Each Sailing Crew

Team Member		Probabilities of Interaction	
C	Captain	$P(I_C)$ =	0.76
D	Deckhand	$P(D_D)$ =	0.38
H	Helmsman	$P(H_H)$ =	0.24

7.2.6.2 Team Algorithm

For the team to be successful in attaining the goal, everyone in the team must be successful. The P(I) scores are probability that an error is made – the probability of failure. The probability of success = 1-probability of failure, = 1-P(I). As everyone must be successful the success scores are multiplied together, and then divided by the number of people in the team (Figure 7.11). This is only performed once, and must include all active members of the team.

$$P(T) = \frac{1 - \left(1 - P(I_C)\right)\left(1 - P(I_D)\right)\left(1 - P(I_H)\right)}{\Sigma \mathrm{t}}$$

Figure 7.11: Algorithm for Team Reliability

Demonstration to calculate Team Algorithm. The P(I) for each member of the team are shown in Table 7.5. Figure 7.12is a demonstration of the team algorithm .

$$P(T) = \frac{1 - \left(1 - P(I_C)\right)\left(1 - P(I_D)\right)\left(1 - P(I_H)\right)}{\Sigma \mathrm{t}}$$

$$P(T) = \frac{1 - (1 - 0.76)(1 - 0.38)(1 - 0.24)}{3}$$

$$P(T) = 0.30$$

Figure 7.12: Calculation of Team Reliability

By comparing these values to the P(I) values for each person, it can be seen that working in a team has reduced the probability of error for most of the members of the team. An overall probability of error for the team is 0.30, this is less than the reliability of the captain or the deckhand, therefore, in this case, working as a team is beneficial.

7.2.7 Step 7: Assessment of the Reliability Score

There are several ways in which to use the score for the reliability of the team

It can be used to see if the team is suitably reliable for the safety case

- If this is a redevelopment of a product that is already available and in use, then the new product or system can be compared against the original to ensure that the team does not decrease its reliability.

- Modifying the number of people in the team, the methods of interaction, the hierarchy level and the training of the team may affect the reliability of the product or system and so some experimentation of different inputs can be used to work out the most suitable set up of the team.

- The product or system can be compared against other similar products that are already available, but made by competitors, to show buyers which is the better product.
- It can also be used to see how a team's reliability will be affected if a team member leaves unexpectedly, e.g. if they are injured. This is particularly useful in a military environment and also in the non-military, where a key decision maker or executor of tasks is unavailable.

The engineer or designer can use ROCCI as they see fit. Changing the CTS and PD scores will not take much resource and so experimentation is feasible.

7.2.8 Summary

This section describes the final prototype of ROCCI. It uses all the previous information. ROCCI is a seven step process, with the ability to produce a quantitative value for P(E), P(I), P(T). Qualitatively the tool can focus designers and engineers on possible areas of improvements that would benefit team reliability.

7.3 Stakeholder Review of ROCCI

This chapter describes the final prototype of ROCCI. It uses all the previous information.

7.3.1 Aims

The stakeholder review aimed to:

1. Get SMEs to use and assess ROCCI
2. Gain opinions on the interaction factors trust, communication, PD
3. Gain opinions on the interaction multipliers matrix
4. Gain opinions on interaction algorithms used in ROCCI.

7.3.2 Participants

Six human factors experts were interviewed in three separate interviews; interview one was with ID1, interview two was with ID2, ID3, ID4, interview three was with ID5, ID6 (Table 7.6). The aim of the interviews was to explore different opinions on the matrix values. Having a single group meeting could have resulted in a common agreement in the matrix values, but individual thoughts and conclusions would have been missed. The purpose at this stage was to collect as many opinions as possible. Table 7.6 shows each participants experience with HRA and roles as human factors experts.

Table 7.6: Participant Information Showing HRA Experience

Int.	ID	Job Title	Job Description	HRA Experience
1	**ID1**	Technologist advisor of HFI	Direct and carry out research on current and future projects	Developed method of HRA use on nimrod and typhoon
2	**ID2**	Graduate systems engineer	Graduate training scheme	Knowledge but no experience
2	**ID3**	TNA and manning manager	Defines manning solutions and training requirements	Knowledge and some experience
2	**ID4**	HFI coordinator	Responsible for HFI on submarine	Used HEART, have used HRA and developed a process.
3	**ID5**	Senior Principal Scientist	HF research and consultancy	Little experience,
3	**ID6**	Senior principal scientist	Design and analyse data, HF design, team assessment	Worked with Williams and HEART and other methods.

7.3.3 Methodology

The interview consisted of five sections:

1. An introduction and description of the ROCCI tool and its parts (Section 0)
2. Exercise 1: Determining basic values in the CTS matrix (Section 7.3.3.2)
3. Exercise 2: Scenario examples (Section 7.3.3.3)
4. Exercise 3: Group discussion (Section 7.3.3.4)
5. Confidence and feedback forms (Section 7.3.3.5).

Table 7.7: Example of Matrices presented in Exercise One

Please fill in THIS matrix

		Communication			
		1	**2**	**3**	**4**
Trust	**1**	**2**			**1.7**
	2				
	3				
	4	**1.7**			**0.5**

		Communication			
		1	**2**	**3**	**4**
Trust	**1**				
	2				
	3				
	4				

Throughout the interview the researcher was available to answer any questions relating to the use or wording of ROCCI. Discussion during the exercises was discouraged, however notation on the sheets was encouraged, and there would be an opportunity for discussion after each exercise.

7.3.3.1 Introduction and Description of ROCCI

The interviewees were given information sheets about the data collection and consent forms (Appendix 3).

The interview began with a PowerPoint© presentation of the ROCCI tool, including who would use it, the stage in the design process it would be used, and how it was performed with a worked example of ROCCI. Handouts were given to each interviewee with definitions of Trust, Communication and Power Distance, as referred to in ROCCI (Appendix 4). It was important to ensure that the workings of ROCCI and all its parts were fully understood.

7.3.3.2 Exercise One: Determining Basic Values in the CTS Matrix

The aim of Exercise One was to insert multiplication factors into each box of the CTS matrix. This began with a clarification of the terminology of Trust and Communication in the ROCCI tool. The sheet provided consisted of two matrices (Table 7.7), the first with the four corner values of the matrix filled in. This was designed to give a starting point of the interviews.

> *"Based on your experience, please assess the appropriateness of the extreme corner multiplication factors, whilst considering the definitions of communication and trust, and the statements that are used to assign the 1-4 scores.*
>
> *Based on your experience and judgement, please write the values you would use for the extreme corner multiplication factors in the matrix on the right.*
>
> *Please write an explanation for your values, e.g. are there any examples that you are basing the values on."*

Figure 7.13: Exercise One Instructions

The exercise was divided into three parts.

1. Part A to fill in the corner values,
2. Part B to fill in the edge values,
3. Part C to fill in the central values.

The directions for each part is based on the information given below (Figure 7.13).

Once all parts had been completed everyone in the interview discussed the suggested values.

7.3.3.3 Exercise Two: Scenario Examples

The aim of Exercise Two was to get the experts to use ROCCI, to test its usability and the credibility of the process and also to see the range of values assigned to each scenario.

Scenario 1 – Sailing Crew

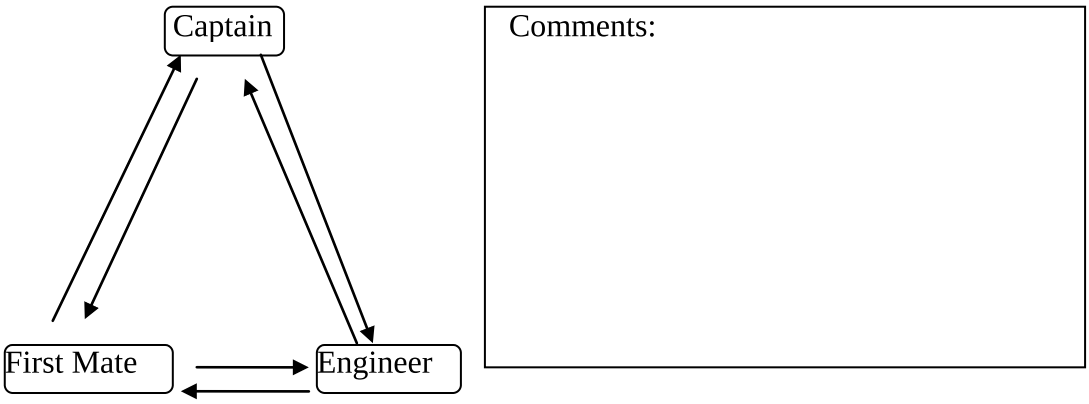


Figure 7.14: Example of Interaction Diagram Case Study Two

The three scenarios were a sailing crew, air traffic control / pilot team and London Underground station team. The interaction diagrams (Figure 7.14) for each team were provided. Each scenario was described on an A4 sheet of paper (Appendix 4). This provided a description of the piece of equipment or system with which the team were interacting; the role of the three or four members in each team; the team attributes; the communication method and its suitability; the trust between each team member; the experience of each team member; and the power distance of the team. This was followed by the specific scenario to be assessed.

Each interviewee then completed the interaction diagram, giving the communication, trust and power distance scores for each team member.

7.3.3.4 Exercise Three: Group Discussion

When everyone had finished the three scenarios, the experts discussed the values for communication, trust and PD and the justifications for these choices. Also comments on problems with the use of ROCCI, were noted by the researcher.

7.3.3.5 Confidence and Feedback Form

The interviews were concluded with each person filling in a feedback form (Appendix 4). This requested information on each person's experience with HRA and human factors. To guide the researcher, each person assessed their confidence that they had in the CTS values they provided. There are also areas provided to write comments on the matrix, multiplication factors, and general ROCCI tool.

7.3.4 Results

7.3.4.1 Exercise One

ID1

Table 7.8: ID1 CTS Matrix Values

		Communication			
		1	**2**	**3**	**4**
Trust	**1**	5.0	4.0	2.5	2.0
	2	4.0	3.0	2.0	1.75
	3	3.5	2.5	1.75	1.25
	4	3.0	2.0	1.5	1.0

Table 7.8 shows ID1 values for the CTS matrix. ID1 suggested that the best team is base line, i.e. (4,4) – 1.0. There should be a bigger distance between (4,4) and (1,1). The middle numbers were chosen by looking vertically and horizontally at the matrix, then by skewing the numbers slightly. So lowest multiplication factor is 1. Bad team work will affect reliability strongly so the high multiplication factor is large at 5.

ID2

Table 7.9 shows ID2 suggested matrix values. ID2 believes that there is no need for the separate values in each box as they don't add much. Bad communication would have more impact on reliability than trust.

Table 7.9: ID2 CTS Matrix Values

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Communication</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td rowspan="4">Trust</td><td>1</td><td colspan="2" rowspan="2">1.75</td><td colspan="2" rowspan="2">1.4</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td><td colspan="2" rowspan="2">1.75</td><td colspan="2" rowspan="2">0.5</td></tr>
<tr><td>4</td></tr>
</table>

ID4

Table 7.10: ID4 CTS Matrix Values

		Communication			
		1	**2**	**3**	**4**
Trust	**1**	1.7	1.6	1.4	1.2
	2	1.8	1.6	1.2	0.8
	3	1.9	1.5	1.0	0.5
	4	2.0	1.5	0.8	0.3

Table 7.10 shows ID4 CTS matrix values. ID4 believes that the best situation is good trust and good communication. If there is insufficient communication then the level of trust is unimportant, but lack of trust can be counteracted by good communication. If there is bad communication ((1,1)(1,2)(1,3)(1,4)) then trust will increase in multiplication factor. If communication is difficult there are assumptions on what other people in the team will be doing. If there is low trust in the other person, there will be an increase in checking and mitigation factors. If there is high trust it will be assumed that the other team members are performing their tasks correctly so there may be little attempt at checking and mitigation, this could mean that errors are missed. ID4 believed that (4,4) is too low in the original matrix, and so increased the value to 0.3.

ID5

Table 7.11 shows ID5 CTS matrix values. ID 5 believes that there should be a normal distribution curve of how CTS affects reliability. With the diagonal ((1,1)(2,2)(3,3)(4,4)) values of 1.0 being the most common. The most reliable team would have high trust and high communication. A team with perfect communication will "trap" errors. ID5 was not sure how trust mitigates errors but low trust could increase errors. High trust and low communication could lead to an unreliable team, hence the high multiplication factor.

Table 7.11: ID5 CTS Matrix Values

		Communication			
		1	2	3	4
Trust	1	1.0	0.8	0.6	0.4
	2	1.3	1.0	1.0	0.6
	3	1.7	1.6	1.0	0.8
	4	2.0	1.7	1.3	1.0

ID6

Table 7.12 shows ID6 CTS matrix values. ID 6 believes that the values in the original matrix were not extreme enough. The type of team will vary depending on the task, e.g. operating theatre or airline cockpit, and maybe different matrices are required for different scenarios. ID6 correctly assumed that the tasks are performed generally in parallel, as there would be a different method of calculating reliability for serial tasks.

Table 7.12: ID6 CTS Matrix Values

		Communication			
		1	2	3	4
Trust	1	3.0	2.75	2.25	2.0
	2	2.5	2.1	1.8	1.3
	3	2.0	1.8	1.2	1.0
	4	1.0	0.8	0.5	0.2

7.3.4.2 Exercise Two

All interviewees reported that they did not have any problems when using ROCCI to apply the communication, trust and the power distance scores. There was some confusion about the direction of the interaction, but this was understood after a re-explanation by the researcher. The diagrams produced were very similar, showing that ROCCI is repeatable.

ID1: Scenario two, air crew – there may be prejudices, due to a conflict of nationality between the pilot crew and ATC crew. This may result in a communication and/or trust issue.

When comparing PD and trust. Sometimes the person with higher power distance may not be the most experienced. In the RAF / Navy, there may be members of the Royal Family in the flight crew with less experience, but their decisions may not be questioned by other flight crew. There is implicit trust from PNF to EC.

7.3.4.3 Discussion Exercise

Two interviewees provided specific feedback to ROCCI.

ID1:

- Trust is related to autonomy, there will be less trust if there is less autonomy.
- From his experience when looking at a team, if both people are reliable to 10^{x-3} then the most reliable would be a P(E) 10^{x-5}, but if both people have the same environment and training then P(E) $10x^{-4}$.
- It may be better to have several equations that will suit different situations.
- There should be a greater difference between the best and worst multiplication factors.
- Communication is more important than trust.
- When using a HRA reliabilities are normally discussed between a couple of people. This would produce more reliable figures.
- Use ROCCI on a series of snap shots throughout the task, rather than looking at the task as a whole.
- Trust could change frequently.
- Statements – B3 – variable quality, not good quality, B1 – work not done or not done as I would. C1/2 other way around. D1 – incorrect as well as insufficient.

ID4:

- If operator doesn't trust supervision and there is bad communication what is the result?
- DIF analysis would be useful for communication, difficulty , importance, frequency.

7.3.4.4 Feedback Exercise

The results from the confidence forms are displayed in Table 7.13, showing a large range in confidence of the matrix values.

Table 7.13: Stakeholder Review Interviewees Feedback and Answer Confidence

ID	Confidence Value	Values of Aspects Particularly confident in	Suggestions for the Matrix, Statements, or ROCCI
ID1	70%	Least confident in Rail scenario	Easier to use with 2 than 1.
ID2	70%	None	No suggestions
ID3	65%	None	Steering board to provide advice and guidance on matrix values approx to team scenario
ID4	60%	Not sure about the 4,4 value whether it should be higher or lower. Generally more confident in relationship of values than absolute score	Nothing extra
ID5	40%	Communication key factor, breaks into passive v's active comms. Trust needs more thought	A "graphics equalizer" like GUI for sensitivity / trade off analysis. Probably need to rethink the 2 factors in the matrix.
ID6	30%	None	Definitions of trust and comms need to be clear, and note what they exclude. Real data from a small tasks could be useful.

7.3.5 Conclusions

ROCCI is a seven step process, with the ability to produce a quantitative value for P(E), P(I), P(T). Qualitatively the tool can focus designers and engineers on possible areas of improvements that would benefit team reliability.

The aims of the stakeholder review were:

1. Get SMEs to use and assess ROCCI
2. Gain opinions on the interaction factors trust, communication, PD
3. Gain opinions on the interaction multipliers matrix
4. Gain opinions on interaction algorithms used in ROCCI.

Each of these aims were met in the exercises. The main outcome from the interviews was to get opinions from the stakeholders on ROCCI. From the interviews the following key points were made

- Communication is very important, and in some instance it is more important than trust
- There was little agreement on the values for the matrix
- The statements used need better wording to be more easily understood
- ROCCI was a valuable tool.

No further adaptations were made to ROCCI at this stage. This research has showed that a proof of concept THRA tool would be beneficial to the design process. Advantages and limitations of ROCCI that were discussed in the Stakeholder Review should be taken forward in any further development of a THRA too. These future modifications and validation methods are described in Section 7.5.1.

7.4 Discussion

The previous six chapters have provided the reader with a complete account of the elements of the research. They have shown how the background from which BAE Systems commissioned this research led them to identify a gap in the suite of HRA tools for a quantitative technique for teams. The existence of such a gap was confirmed by the literature review (Chapter Two). The subsequent stages of the research confirmed that the stakeholders could articulate their requirements sufficiently clearly (Chapter Four) for the researcher to develop the model, matrix and algorithms of the requested quantitative tool, now known as ROCCI (Chapter Five).

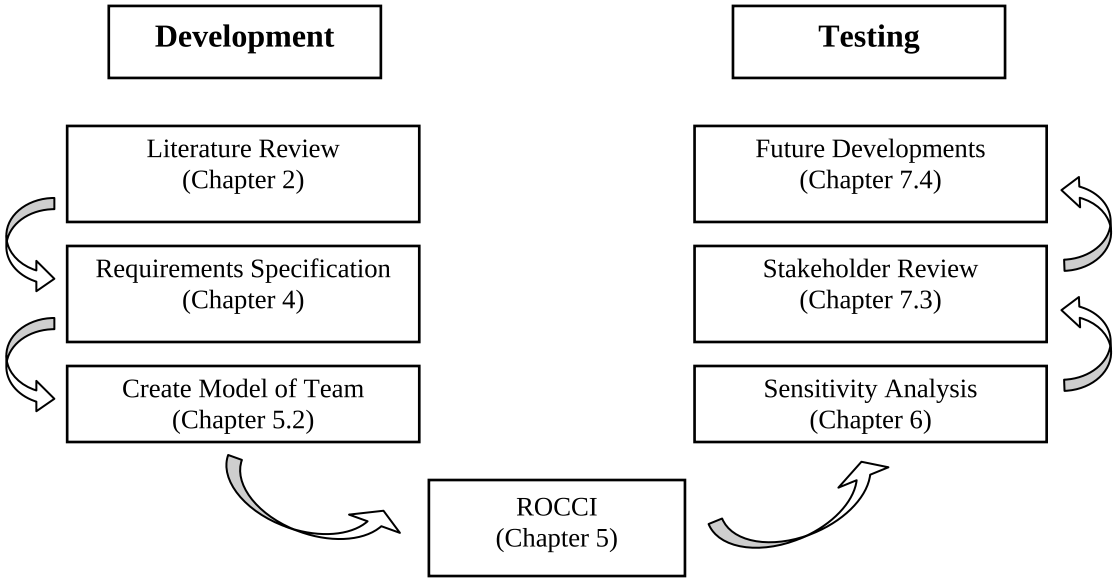


Figure 7.15: Model of Research Stages: Development and Testing

Section 7.4 reflects on the integrity and value of this research project as a whole. The first task is to appraise the methodology of the research structure (Section 7.4.1), in its development and the testing stages. The next section highlights the benefits of ROCCI (Section 7.4.2) both as a tool and in its applications. This clarifies how the tool provides a solution that fills the gap about team assessments that had been identified earlier as missing from the range of HRA tools (Section 7.4.3). The researcher then explores some of the limitations of ROCCI and suggests how these might be addressed (Section 7.4.4) The thesis concludes with a general summary of the research project (Section 7.5), which brings the chapter to a close with ideas about the potential for future research and development of ROCCI.

7.4.1 The Research Structure

The research has two stages. The development stage leads to the formulation of the HRA Tool ROCCI. The testing stage validates its benefits in applications (Figure 7.15).

7.4.1.1 Methodology of the Development Stage

This section reviews the strengths of the research methodology applied to the development stage. The development stage prepared the groundwork for the formulation of the HRA tool ROCCI. In general, there was confirmation that it is normal to use HRA in the design process. There was also agreement that including a team HRA would be a benefit, since it would address the team issues, which are not currently included in the normal HRA assessment. The development stage process went on to identify that the different business units would require different outcomes from a team HRA tool. For example: the aeronautical business unit required not only a quantitative technique but also a qualitative technique that would be straightforward to use by those that are not experts in HF. Another example: naval BU suggested that the best size for this tool would be one or two sides of A4 that could be laminated. This is supported by Kariuki and Löwe's (2007) procedure to identify the benefit of human factors in process hazard analysis. Their HF assessment was a simple one side of paper document with simple tick boxes.

In summary, the development stage produced the requirements specifications which shaped the Tool Vision (Smith et al., 2006, Smith et al., 2007) and provided the framework from which to formulate the team HRA tool ROCCI.

Literature Review

The literature review (Chapter Two) successfully showed that there were HRA's available, but highlighted that there was no method for assessing team reliability. The literature review also highlighted areas of team working that should be considered. However there was not a large amount of literature on this topic, so other methods of developing information for ROCCI was required.

Requirements Specification

The development of the Requirements Specification (Chapter Four) through stakeholder semi-structured interviews revealed that the gap found in the literature for a team HRA was also felt by SME's. The interviewees drew the researcher's attention to team attributes and issues with HRA that had not previously been known.

The Requirements Specification and House of Quality were useful tools in the development of ROCCI as they guided how the tool should be used and how it should be presented. The Requirements Specification was referred to frequently throughout the design process. The model of team reliability, matrix and algorithms came as a result of the researcher's work with the interviewees.

7.4.1.2 Methodology of the Testing Stage

This section evaluates the strengths of the methodology of the final stage of the research process, the testing stage. Just prior to the testing stage, the researcher had incorporated the specification requirements into the HRA tool, ROCCI. The formulation of these specification requirements was the final step in the development stage. The testing stage assessed how practical it was to include all the requirements in arriving at a Proof of the Concept for the tool. The validation process scrutinises the specific aspects of the tool that need to be used in an operational application and so test the logic for their inclusion. The testing stage included sensitivity analysis, two case studies and the stakeholder reviews.

Sensitivity Analysis

This process assessed the sensitivity of the algorithms (Chapter Six) used in ROCCI. It demonstrated that they were suitable to be developed and used further. It enabled the researcher to identify the different types of team structures that exist in theory and practice. The process provided a mechanism to measure the impact that these team structures had on the overall reliability of the team. It established that different team structures create different results, even when the input data was identical.

Stakeholder Reviews

These reviews with the stakeholders took place as the ROCCI prototype was nearing completion. It was at that almost final stage when there is a benefit in exposing it to expert users. The objective was to get their opinions on the matrix values and the application of the ROCCI tool. The technique applied was based on the spiral development method. The individuals assessed the tool independently and then came together as a group to share their assessments. Changes were then made in the light of the feedback. This method was very useful. It provided different perspectives and opinions on the matrix values. An excellent benefit was that the interview process included time for discussion with the researcher, who was then able provide further explanation of ROCCI. It also gave the experts the chance to provide constructive criticism of the technique. One of the limitations was the lack of availability of the interviewees for a second round of reviews. Ideally, there would have been a benefit in visiting all the interviewees with an adapted version of the matrix and ROCCI that had emerged from the first round of interviews.

7.4.1.3 Summary

During the testing stage of ROCCI a variety of methods were used. Each exercise assessed different aspects of ROCCI: the sensitivity analysis tested the logic of the algorithms and structures; case study one tested the evaluated the usefulness of the tool; case study two assessed the repeatability and sensitivity required of the inputted data, and use of statements; the stakeholder reviews appraised the use of ROCCI by expert users, suggesting intra-analyst reliability.

Throughout the time of research ROCCI was presented to stakeholders and experts in the form of presentation at conferences or internal meetings. This presented the opportunity for the researcher to defend ROCCI whilst the experts critically assessed and questioned it. Generally ROCCI was well received, with no major concerns. This provided a greater strength in the knowledge of the need and validity of a THRA tool.

7.4.2 Potential of Team HRA Tool ROCCI

As stated earlier, the methodology of the development stage of the research process (Section 7.4.1) included a round of interviews with the potential stakeholders of ROCCI. The outcome of the development stage was the formulation of the requirements specification for the team HRA tool ROCCI. The previous section examined the final stage of the research process, the methodology of the testing stage.

The development and the testing stages lead up to and away from the prototype of the core product THRA tool ROCCI. The benefits of this THRA tool can now be reviewed further. The review begins (Section7.4.2), with a summary of the requirements, which the researcher incorporated into the HRA tool ROCCI (Figure 7.16). This is at the central point of the research program. There then follows an assessment of the benefits for the practical application of ROCCI in a variety of operational scenarios (7.5.1).

7.4.2.1 Proof of Concept: ROCCI

The proof of concept tool, ROCCI, is the outcome of the development stage of the research process. It incorporates the requirements, which were identified by the potential stakeholders (Chapter Four), who would be using the application in real life operations. Of the requirements listed in the Requirements Matrix (Figure 4.2) 24 of the 30 requirements were met. One of the requirements that is not met is the production of a computerise HRA tool. A programming expert could transform ROCCI as it currently stands relatively easily into a computerised tool.

The full description is provided in Section 7.1, which includes the steps needed to complete the ROCCI process (Figure 7.3). This process was published by the author in an earlier paper and is reproduced here (Figure 7.16).

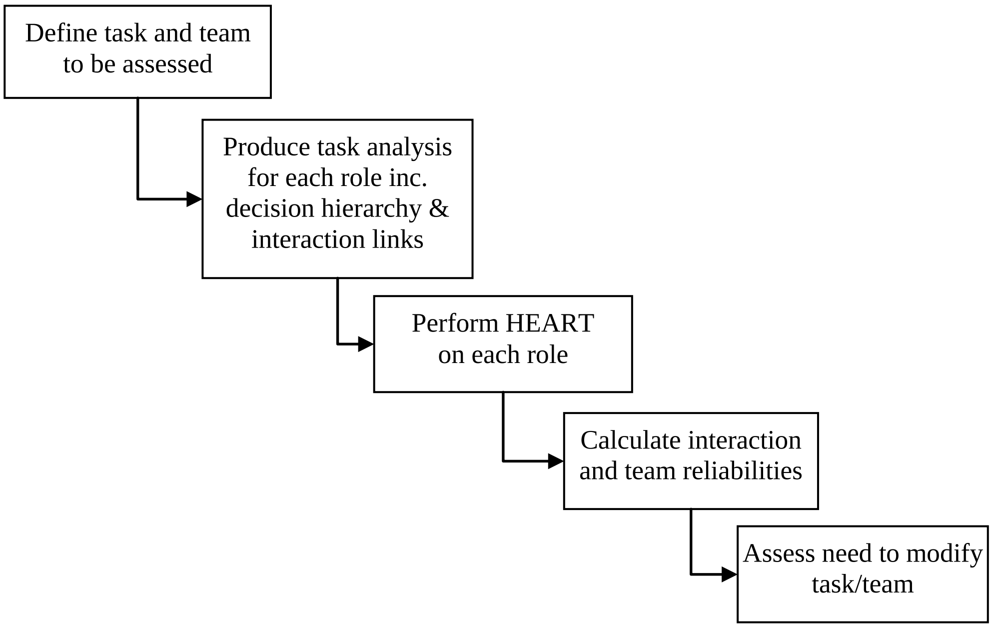


Figure 7.16: Process for Evaluating Team Reliability (Smith et al 2007)

A general benefit of the Team HRA tool ROCCI is that it is designed to fit into existing design processes. Any quantitative HRA and any task analysis can be used with ROCCI, without being time consuming. The next section provides some examples of applications of ROCCI.

7.4.2.2 ROCCI Team Attributes

This section looks at recent research that has been produced on the attributes of ROCCI. There are many aspects to communication interaction (Cushings, 1994, Gibson et al., 2006, Rognin and Blanquart, 2001). This includes the language used, content of the communication and the background level of noise. Svensson and Andersson (2006) found that the warnings inside a cockpit can interfere with general communication within a cockpit.

A recent review of the literature on the team attributes show that a high level of trust is not always best (Burt et al., 2009). If there is a lower amount of trust, there will be more monitoring, leading to more errors being detected. However there is not an inverse relationship between trust and reliability. Trust between team members is needed for the team to function sufficiently and safely. From this research and the findings from the stakeholder review (Chapter 7.2) the relationship between trust and reliability should be further investigated.

7.4.2.3 Contributions of ROCCI to Safety Cases

The Sensitivity Analysis illustrated that ROCCI algorithms could determine between the different aspects of a team, such as number of interaction links, different levels of trust and communication skills. This knowledge can influence a decision on the potential reliability and safety of the system designed and can be used in Safety Case arguments. There THRA tool can be applied with to a variety of situations where reliability and safety will change: the development of a new product; comparing Commercial off the Shelf (COTS) products on the market; refitting systems; reducing manning of a system and man-down situations. A review of these applications follows.

Developing a new product

ROCCI can be applied to test how reliable a new product will be when used by a team. Areas of bad communication, interaction links, trust and PD would be highlighted by ROCCI and so indicate if adaptations to these are required. This would result in changes to: the extent of the training; number of people in the team; configuration of the team; altering the tasks the team performs; variations in the communication methods used.

Comparing COTS products

This comparison can take place prior to the time of purchase, to identify the degree of team reliability of the different products. ROCCI will reveal the different manning levels, the number of tasks required, the communication methods used and evaluate whether more equipment or extra training is needed for each product, so informed decisions can be made about their selection.

Refitting Systems

When a product is being developed further, there is a benefit in testing the new version of the product against the previous version of the product. The ROCCI results from the previous version will show areas that could be improved when designing the new version. Mock models can then be compared at an early stage in the design process, when the cost of change is lower than the cost of change later in the design LCM.

Reducing manning in a system

There may be circumstances that make it necessary to reduce the number of people on a team. An example was the number of men on a submarine. ROCCI could evaluate the impact of reducing the number of people in the team. Along with workload information, it was possible to assess how roles could be combined without reducing the reliability of the team, whilst taking into account the interaction links, the communication methods and trust.

Man-down situations

Equipment is designed for operation by a certain number of people. Occasionally someone in that team may become incapacitated. This reduces the number of active people in the team and may change the PD. When there are products where this is a high possibility, it would be useful to run ROCCI in a 'man-down' scenario. This examines the effect on the team reliability. It can aid in the formulation of standard operating procedures for these circumstances.

7.4.3 ROCCI and Individual HRAs

The researcher reviewed the current list of HRA methods available (Section 2.2.2 and Section 2.2.3). Some were new to the researcher, as described below.

7.4.3.1 General List

An overview of HRA methods reviewed qualitative and quantitative methods. These were: the qualitative methods CRS, MDTA, and CESA (Reer, (2008a, 2008b)); and quantitative methods; MERMOS (Reer, 2008b); a generic Human Error template (HET; Marshall et al, as cited in Stanton et al (2009)); and application for a power plant environment DEPEND-HRA (Cepin, 2008); and an Analytic Hierarchy Process – Success Likelihood Index Method (AHP–SLIM ((Park and Lee, 2008)). These methods have general applicability, but they are not sufficiently specific to be a foundation of ROCCI.

7.4.3.2 HRA relevant to ROCCI

The most relevant HRAs to the development and support of the ROCCI tool were the HEPI and HEAR methods. These methods and their relevance to ROCCI are explained below.

HEPI (Khan et al, 2006)

Human error probability index (HEPI) (Khan et al., 2006) is a new quantitative tool for calculating error probability for offshore operations and has been designed during the period of this research. HEPI is based on SLIM. HEPI provides recommendations for training, procedures, management systems and equipment. An individual can perform many of the steps of HEPI. But HEPI must be assessed by an experienced team for the final three steps. If ROCCI is to be developed for us in many industrial sectors, an experienced team can produce the matrix values, so that any single person can use ROCCI in the design process.

HEAR (Kim eta l, 2010)

Human Error Analyses and Reduction (HEAR) (Kim et al., 2010) is a model of accident causation. It defines that an unsafe situation is caused by human failure, technical failure or an external intrusion. The unsafe situation can be intervened by human responses to mitigate the effects. ROCCI's team interactions would partially be involved in this intervention,. Since team members 'catching' another person errors would reduce the probability of human error.

7.4.3.3 ROCCI and HRA Summary

The literature review confirmed that HRAs continue to need to be refined (e.g. HEPI was based on SLIM) and developed (e.g. HEAR) as gaps in their application tools are identified. The main focus of HRAs was on quantitative assessments of the individual. This demonstrated that there was still a gap for quantitative assessment of groups of individuals or teams. This gap is precisely where the work of ROCCI, as a quantitative tool for teams, fitted into the HRA market.

7.4.4 Limitations of ROCCI Assumptions

To set the boundaries for ROCCI assumptions were made: the team must be stable; the equipment has 100% reliability; communication is not solely through a computer. The limitations of these boundaries are described below (Section 7.4.4.1 – 7.4.4.3). Also described are other fields of interest that are related to, but not covered by ROCCI including: situational awareness (7.4.4.4) and fuzzy theory (7.4.4.5).

7.4.4.1 Stability

One of the assumptions of ROCCI is that the team must be stable: by either working as that team for a long period of time, or at least working with the same people, or with the same roles for a period of time (Littlepage et al., 2007). This is because there is an increase in probability of incidents occurring when there is a high employee turnover (Burt et al., 2009).

7.4.4.2 Equipment Reliability

It is assumed that the equipment used is 100% reliable. ROCCI has not been tested with varying reliability of equipment. Equipment is often used to support human actions and to increase safety of systems (Hoc & Carlier, 2002; Hollnagel & Bye, 2000). So the equipment could be thought of as another team member (Kim, 2001). Each piece of equipment can have varying probability of error, communication ability and perceived trust levels (Bonini & Kirwan, 2003).

7.4.4.3 Virtual teams

One area where there has been a large amount of research is in exploring the potential for much wider scope of interaction and trust for virtual teams (Introna, 2001, Jarvenpaa and Lediner, 1999, Kanawattanachai and Yoo, 2002, Wilson et al., 2006). This is where the members of the teams are distributed and interact through computer links

However, this would have required the researcher to become involved in BUs which had, or were exploring the possibilities of, virtual teams. However they were not available for access by the researcher. This not being possible, this topic could not be included within the focus of ROCCI. From a technical perspective, the team HRA tool ROCCI could be adapted easily and used to assess the trust, communication and PD within virtual teams. This would be and exciting project to test and explore further.

7.4.4.4 Situation Awareness

ROCCI has not considered specifically the aspect of situation awareness (Endsley, 2000, Riley et al., 2006) or distributed situation awareness (Stanton et al., 2005). Although good situation awareness within a team is a key part to working as a team (Artman, 2000, Patrick et al., 2006). ROCCI uses the attributes of good communication and good trust to ensure that the best sharing of information for good situation awareness is possible (Stanton and Baber, 2006, Stanton et al., 2005).

7.4.4.5 Fuzzy theory

ROCCI is designed to be a transparent tool, which uses three selected core team attributes, with two clear algorithms of interaction. Fuzzy Theory would enable the tool to be developed for more complex team interactions. Another strength of using fuzzy theory is that it is capable of including many more attributes about the team.

The final prototype team HRA tool ROCCI is intended to be straightforward, transparent and easy to use, by those who were not experts in HF. The researcher had initially examined the feasibility of applying Fuzzy Theory in the research. However, it became apparent from the stakeholder interviews, that they had an immediate need for a '*simple*' practical tool to provide a solution for a gap that had been identified as part of the original research specifications from BAE Systems.

7.4.5 Present Limitations of ROCCI

ROCCI developed as a prototype shows that there is potential for future development into a real tool. SMEs have shown interest in the use of the tool (Section 7.2) and that the tool is usable and potentially helpful for designers, engineers and ergonomists. However as ROCCI is a prototype there are areas of the tool that are not fully developed. These include:

- **The development of the values that are in the matrix.** The interaction multipliers need developing, e.g. what is the dependency of trust and communication, how much does the does trust effect individual reliability.
- **Rigorous testing and validation of the algorithms and ROCCI tool**. HRAs generally have little validation, and as such, are not fully accepted by all

ergonomists. Validation of the tool will indicate the usefulness and impact of Safety Cases that HRAs can have.

- **Development of ROCCI into a computerised tool**. Computerisation was indicated as a requirement early in the research. It would be useful in cases where there are a large number of team members and the interactions are complex, or where many combinations of the interaction are to be tested.
- **Further research into the attributes that effect team reliability**. ROCCI has focused on 3 aspects of team reliability. There has been little research that proves that these 3 aspects are those that most effect team reliability. Further research into this development would be advisable and potentially fruitful.

7.4.6 Summary of Limitations for ROCCI

ROCCI is a good tool and it is well developed. Most of the seven steps of ROCCI are performed during LCM, e.g. the TA and HRA. The assessment of the team interactions can be fitted onto a single piece of paper that can be stuck onto a display board. Stakeholders agree that the use of communication, trust and PD are key attributes to teams. This is a innovative tool. There are no other tools available that address THRA quantitatively. It is possible to vary the values in the matrix to adapt ROCCI for different industrial sectors. The limitations of ROCCI are that the statements have not been fully elaborated and matrix values have not been fully tested and validated. This needs to be performed before the tool can be used commercially (Table 7.14).

Table 7.14: Strengths and Limitations of ROCCI

Strengths	Limitations
Steps performed already in LCM	Matrix values need validation
Change matrix values to suit different industrial sectors	Statements need validation
Innovative	
Stakeholder agreement that trust, communication and PD are important	
Short and simple to use	

7.5 Conclusion

The aim of this research had two components. The first and primary component was to develop a proof of concept prototype of a quantitative team HRA (THRA) tool. This

THRA tool was called ROCCI (Reliability of Collaborative Crew Interaction). The second component was to evaluate whether the process could be implemented further.

To achieve these aim the work consisted of a number of objectives:

1. To explore, using interviews with stakeholders, requirements based on current experience and future expectations
2. To develop a model for team reliability using information from Objective One and produce team structures and algorithms for use in sensitivity analysis
3. To carry out sensitivity analysis on ROCCI algorithms
4. To further develop and validate ROCCI through stakeholder reviews.

The **first objective** was progressed through semi-structured interviews with nine stakeholders at BAE Systems. These produced a detailed Requirements Specification for the tool, which in turn developed the House of Quality and Tool Vision on which the Proof of Concept was based.

The key requirements were:

1. two sides of A4 with seven questions
2. qualitative and quantitative
3. fits in with current LCM
4. usable by all.

The **second objective** delivered a model of team reliability (Figure 5.1) based on the team structures of Leavitt and Eason. Twelve team interaction structures were developed. These structures meant that all team structures could be accounted for in a sensitivity analysis. Two algorithms were produced, one to encompass P(E), CTS and PD to create P(I) and one to evaluate P(T) overall).

The **third objective** involved a sensitivity analysis on the two algorithms using the twelve structures of a team of four people. The sensitivity analysis showed that the algorithms were logical and suitable to be used further.

The **fourth objective**, was to develop ROCCI to a further level and present this Final Prototype of a THRA to stakeholders. They had the opportunity to assess the Matrix

Values, Questionnaire Statements and general ROCCI tool, by using the Delphi Method and Case Study examples. This was another test of repeatability of ROCCI and the interviewees all produced similar CTS and PD scores for the case study examples. Adaptations suggested by the reviews were noted and are a good basis for future research.

7.5.1 Future Research

Salas et al (2008) performed a review of current work in the field of teams, teamwork and team performance. Salas et al (2008) stressed the importance of the field keeping pace with the changing demands in the workplace. In particular, one of the areas to focus on is the need for better measurement of team work. They also identified the importance of communication structure on team performance. A fully developed and validated ROCCI would produce a robust tool that fulfils these requirements.

7.5.1.1 Future Validations of ROCCI

One method for validating ROCCI would be to test it against other similar methods to see if similar results are produced (Stanton et al., 2009). Another method for validating ROCCI would be to get several analysts to use ROCCI on the same situation to test the inter-analyst reliability (Stanton et al., 2009).

Validation of AHP – SLIM is by comparing the results of two groups of expert assessors when they use AHP – SLIM to assess ten driving errors (Park and Lee, 2008). This is quite a simple method of validation, and is a possible method for ROCCI.

7.5.1.2 Laboratory Based Experiments

Laboratory experiments assessing the definition of trust; the important factors for communication and team work; and the relationship between trust and communication can be used to validate ROCCI.

7.5.1.3 Computerisation of ROCCI

A recent development of HRA is a probabilistic cognitive simulator (PROCOS) that provides simulation of human error (Trucco and Leva, 2007). A computerised tool that can vary the values of P(E), CTS, and PD automatically, would be a version of ROCCI that could assess a large variety of situations relatively quickly.

Human error databases such as CORE-DATA (Gibson and Kirwan, 2004, Kirwan et al., n.d.) and OPERA (Park and Jung, 2007) are useful to accurately predict human error. Linking ROCCI to one of these could increase the reliability of the P(E) values in ROCCI, and therefore the P(T) values would also be more accurate.

CAS-HEAR (Kim et al., 2010) is a computer-aided tool. More HRAs are becoming computer aided. A more complex version of ROCCI could be produced as a computer program. This could increase the possible number of team attributes accounted for in ROCCI, and very large teams, such as combined military forces, could be assessed.

Kirwan et al (2008)is producing a method for collecting human error data in ATM real time simulations. This is a method of collecting data errors with a high validity to realistic situations. Mentioned in the paper was the need to allow and account for recovery after an error has occurred, this is is also mentioned in CAS-HEAR (Kim et al., 2010). Safety cases for European ATM required quantified risk and safety assessments (Kirwan et al., 2008). ROCCI could be used for this and it shows that quantification is still required by governing authorities.

7.5.1.4 Extending the Scope of Application for ROCCI

There is an opportunity to provide a more developed version of ROCCI, which can be used in the tool kits of all ergonomists as a core element in the design process, even if this requires it to become compulsory

Create different ROCCI matrices for different sectors, e.g. nuclear, military, civilian academics the scope of ROCCI and its internal reliability of its matrices and probabilities. This would be done by adjusting the statements of trust (Bonini & Kirwan, 2003) communication and PD to be task specific. The matrix values could also be adjusted as the relationship between trust and communication varies between different industrial sectors.

7.5.2 Summary

This draws the thesis to a close. The final chapter has summarised the aims and the objectives of the thesis. A proof of concept for a team HRA tool, ROCCI, has been put forth for further development.

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Appendix

List of Appendices

Appendix 1: Conference Papers presented by the Author

Appendix 1A: Paper Presented at Ergonomics Conference 2006

DEVELOPMENT FOR A TOOL TESTING TEAM RELIABILITY

I.H. Smith[1], C.E. Siemieniuch[2] & M.A. Sinclair[1]

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Human reliability assessment techniques (HRAs) have been in existence since the 1960's. Following Dougherty's (1990) comments, a second generation of more complex HRAs were created, all measuring the reliability of individuals. However, often a team of people interact with a system, not an individual. This can increase or decrease the individual's reliability. A new generation of HRAs is needed to assess the effects of teamwork on reliability. During the development of a new tool, the model of team reliability needs to be validated. This is to be partially accomplish at a workshop at the Annual Conference of the Ergonomics Society, where HRA experts and other interested parties can critique the model. These opinions will then be utilised to enhance the model.

Introduction

A human interacting with a system can be analysed to determine the errors that could occur, what factors could help mitigate these errors, and the probability of these errors occurring. This is done by using human reliability assessments (HRA). HRAs are qualitative and quantitative measurements of the risks and errors that can occur in a system because of human actions, not by a fault of the system. HRA have been developed for designers and users to understand the technical difficulties of using a product or system. As, no matter how good the product is, it is impossible to make the product error proof: humans are inevitably fallible.

As a field of research HRA has been around since 1960s. Predicting the probability of error can be a controversial topic because probabilities are based on random behaviour and humans are not random; some factors that can affect them that are consistent (Redmill, 2002). HRA techniques have accounted for factors that influence the error probability in the form of "performance shaping factors" (PSFs). The task, the individual and the environment define the performance shaping factors. There are three main approaches to HRA (Kirwan, 2002):

1. Human error identification – what can go wrong?
2. Human error quantification – how often will a human error occur?
3. Human error reduction – how can human error be prevented from occurring or its impact on the system reduced?

The first generation of HRA techniques began in the 1970s, e.g. THERP (Swain & Guttmann, 1980) and HEART (Williams, 1986). Criticism by Dougherty (1990) triggered a new generation of techniques that included the most recent knowledge of error and human behaviour (Redmill, 2002). Second-generation techniques such as, CREAM (Hollnagel, 1998) have improved the reliability of the HRA for individuals.

However, often a team of people interacts with a system, not just an individual. There is now a call for a new generation of HRA techniques to account for team interaction with a product or system. The interactions between the team members can increase and decrease the reliability of each individual and hence the overall reliability of the team. Some of the PSFs of team reliability are communication, trust and resource management (Sasou & Reason, 1999).

CHLOE (Miguel, Wright, & Harrison, 2002) has been developed to take into account the effect of teams on reliability. Miguel *et al* (2002), wrote ‘collaborative errors may be caused by factors such as a lack of [situational awareness (SA)], misunderstandings between participants, conflicts and failures of co-ordination’ (p. 4). CHLOE is a qualitative method, and in a time when corporate manslaughter is becoming more prominent and system reliability is measured in probabilities, human reliability also needs to be quantitative.

Aim

Therefore the aim of the workshop is to validate, using expert judgements, a model of team reliability and tool that will quantitatively measure team reliability.

Definition of a team

The tool being validated will be looking at a team of people that are either interacting with the same system or piece of equipment, and whose procedures are all critical in achieving the same overall goal. The tool does not look into how an organisation works, and so it will not go into details of the command structure. However, the communication structure, and decision structure are important to team reliability. Several group topologies that should be considered are shown in Figure 1.

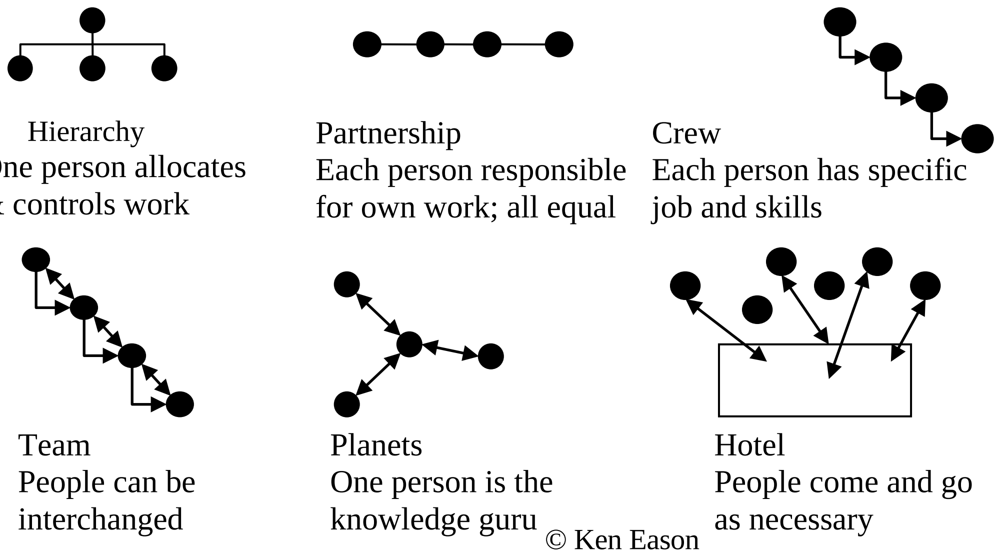

Figure 1. Group Topologies need to switch planets and teams

Error classifications

Before team reliability can be measured, how and why humans perform errors must be understood. There are three main aspects that can cause error; the task, the environment and the individual. There are several types of errors that humans can perform, such as execution errors, or errors of cognition. There are also, many causes of error, e.g. bad design, or cognitive overload. Below are some of the main classification of errors.

Kletz (1999) presented four classifications of errors.

1. *Mistakes* are errors that are made because the correct procedure is not known and the intention of the action is wrong.

2. *Violations* are actions that are known to be wrong but are thought of as being the most suitable action at the time given the information known; again the correct procedure is not followed.
3. A *mismatch* is where the task and the cognition of the operator are not compatible, for example the operator could be overloaded or may have established a habit and cannot change their viewpoint when new information is offered.
4. A *slip* is where the intention is correct but that action is wrong, for example, pressing the wrong knob on a control panel. A lapse is where an action is missed.

Rasmussen (1982) presented error classifications based on the cognitive functions,

1. *Skill based errors* are errors related to variability of force, space or time.
2. *Rule based errors* are errors that are related to cognitive mechanisms, such as classification, recognition or recall.
3. *Knowledge based errors* are errors in planning, prediction and evaluation.

These definitions of errors are for individuals, not teams. Errors of execution, such as slips, or skill based errors, are affected less by team reliability. Cognitive errors are affected by team reliability, as cognitive overload, can be augmented by the presence of other team members. Taxonomies of team error should also be used, such as Sasou & Reason's (1999) individual and shared errors.

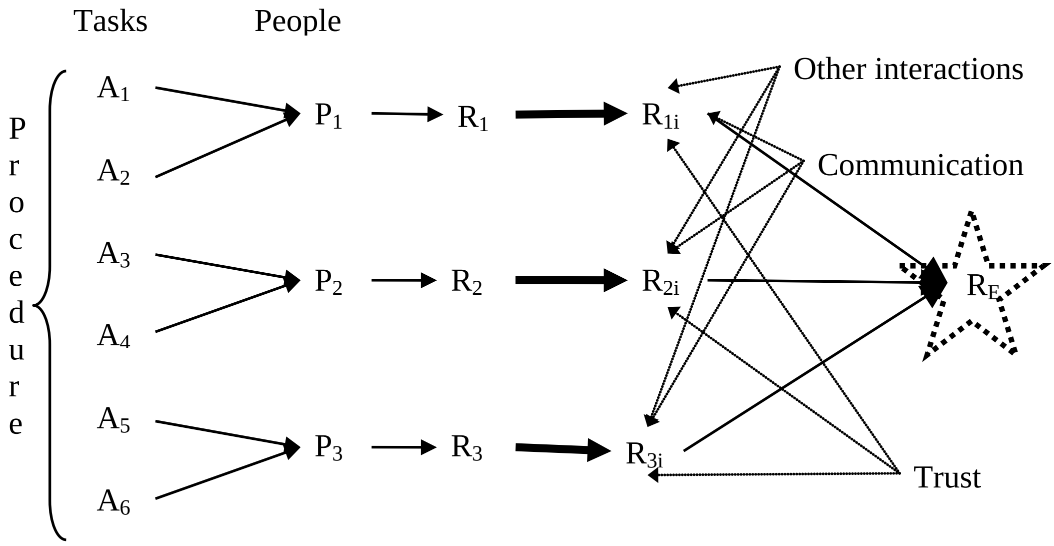

Figure 2. Model of Team Reliability

Model of team reliability

Before the tool can be developed a model of how the individuals in a team interact should be produced. One viewpoint of team reliability is represented in Figure 2. A procedure is performed by a team of people. Each person has an individual reliability score (R_n), as measured using a 1st or 2nd generation HRA technique. The interactions between team members, such as communication and trust create the PSFs for the team. But as each individual, their task and their environment is unique, effects of the interaction should be calculated separately, creating new 'interaction reliability' scores R_{ni}. These are then combined together to produce the overall team reliability score, R_E.

Tool vision

Following interviews with potential users of the tool (HRA and design experts in a defence systems integration company) a list of tool requirements was formed. These illustrated that it was necessary to develop a tool that can:

- quantitatively assess the reliability of a team.
- qualitatively predict areas of high risk
- be usable and accessible to non-human factors experts
- educate designers in the importance of the human factors to produce high usability and reliability.

Structure of the workshop

The workshop will consist of a brief introduction into the reasoning for collaborative HRA. The model that is used to represent team interactions will be described and explained. There will then be a discussion on some of the issues that may effect interactions within teams, and what errors may be produced from these interactions.

Subsequent work

Following the workshop the opinions expressed will be considered and further adaptations to the model and tool will be made.

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Appendix 1B: Paper presented at Ergonomics Conference 2007

Continued Development of a Tool for Predicting Team Reliability

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Human reliability assessments (HRA) have been developed so designers and users can understand how likely it is for a human to make an error when using a system, i.e. the reliability of the product. There are many tools that test reliability, but they only consider one person using a system. As human factors experts and engineers are getting more used to the role of individual human reliability in design and development, teams are becoming more prominent as an antecedent to errors and disasters. HEART (Williams, 1986), an individual HRA, is being expanded into one of the first tools that will quantitatively predict the reliability of a team. This paper is a continuation from a workshop presented at last year's Ergonomics Society Conference (Smith, Siemieniuch and Sinclair, 2006), where the tool was introduced.

Introduction

Human reliability assessments (HRA) have been developed so designers and users can understand how likely it is for a human to make an error when using a system, i.e. the reliability of the product. There are many tools that test reliability, but they only consider one person using a system. As human factors experts and engineers are getting more used to the role of individual human reliability in design and development, teams are becoming more prominent as an antecedent to errors and disasters, as interactions between team members can increase or decrease reliabilities.

A model of team reliability has been created. The main issue for consideration was how to best combine individual reliabilities to create a credible and realistic team reliability. Different hierarchy structures, decision systems, and the number of people at the 'sharp end' (those executing the actions of the team) all affect how the team is influenced by the individuals. A series of algorithms have been produced to ensure that the tool can manage various team structures, decision systems, and any number of people executing actions. The tool has been used by an external and independent source to determine the reliability of a helicopter crew that is potentially under missile attack, and on non-military operational crews. The function of the tool shall be described below.

HRA Background

As a field of research HRA has been around since 1960s. HRAs can be qualitative and/or quantitative measurements of the risks and errors that can occur in a system because of human actions, not by a fault of the system. A human interacting with a system can be analysed to determine the errors that could occur, what factors could help mitigate these errors, and the probability of these errors occurring. Predicting the probability of human error can be a controversial topic because probabilities are based on random behaviour and humans are not random; some factors that can affect them that are consistent (Redmill, 2002). There are three main approaches to HRA (Kirwan, 2002):

1. Human error identification – what can go wrong?
2. Human error quantification – how often will a human error occur?
3. Human error reduction – how can human error be prevented from occurring or its impact on the system reduced?

HRA have been developed for designers and users to understand the technical difficulties of using a product or system. As, no matter how good the product is, it is impossible to make the product error proof: humans are inevitably fallible.

The first generation of HRA techniques began in the 1970s, e.g. THERP (Swain & Guttmann, 1980) and HEART (Williams, 1986). Criticism by Dougherty (1990) triggered a new generation of techniques that included the most recent knowledge of error and human behaviour (Redmill, 2002). Second-generation techniques such as, CREAM (Hollnagel, 1998) have improved the reliability of the HRA for individuals.

As human factors experts and engineers are getting more used to the role of individual human reliability in design and development, teams are becoming more prominent as an antecedent to errors and disasters. There is now a call for a new generation of HRA techniques to account for team interaction with a product or system. The interactions between the team members can increase and decrease the reliability of each individual and hence the overall reliability of the team. There is a gap in the market for a new quantitative tool that combines the reliability of the people in a team and produce a realistic reliability of the whole team.

Tool Vision

The tool that is being developed assesses a group of individuals that are either interacting with the same system or piece of equipment, and whose procedures are all critical in achieving the same overall goal. It then uses their individual reliabilities, as found using an individual HRA, such as HEART; and the affect of performance shaping factors (PSFs) to produce an overall team reliability. It is envisioned that the tool will:

- quantitatively assess the reliability of a team.
- qualitatively predict areas of high risk
- be usable and accessible to non-human factors experts
- educate designers in the importance of the human factors to produce high usability and reliability.

It is important that the tool is usable by non-human factors experts. Therefore the tool should not contain human factors jargon, or require a interpretation from an ergonomist. The tool should be transparent so that designers and engineers can understand how the tool calculates team reliability. The calculations will be kept straightforward to use, and it will contain simple algorithms. To facilitate this simplicity some assumptions must be made.

- the process can be defined,
- a team/individuals can be allocated to roles
- the team has stability.

The process is to be defined by a form of task analysis (TA) which describes the tasks that need to be performed, the order in which they are to be performed, and the relative importance that the order has on the overall task. The team must be defined, and that tasks that are to be performed should be allocated to particular team members. This is necessary for the individual HRA to be performed. The PSFs require team members to have established relationships and personal perceptions of the other team members. Stability of the team is necessary for a representative reliability value, when a team is first brought together there is a period of introduction to each others skills, abilities and personalities. During this period relationships and personality differences are frequently changing, and so the reliability of the team may be inconsistent.

Tool Mechanics

Process Definition

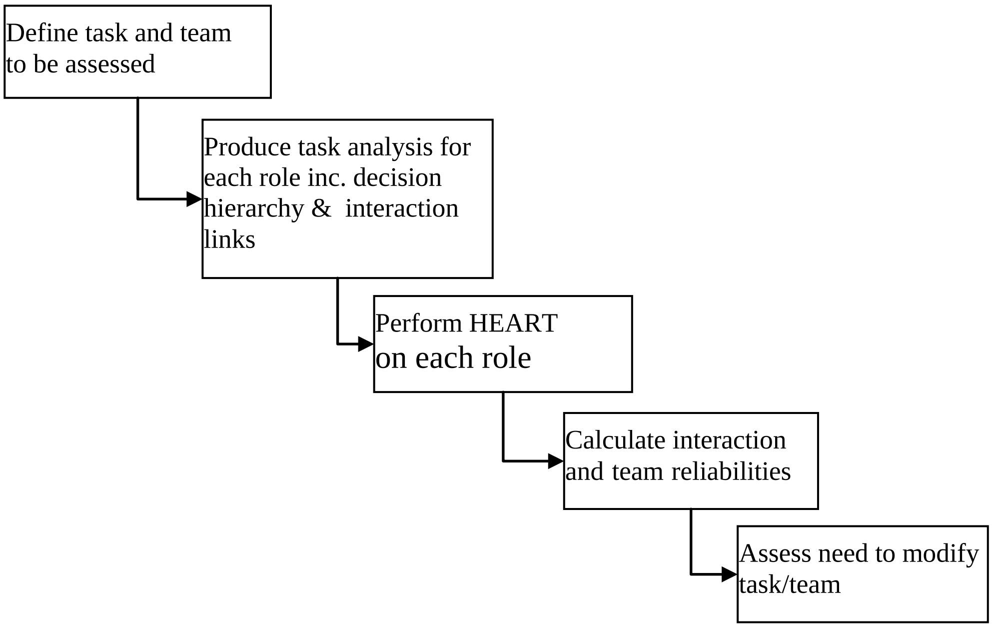

Figure 1. The process for evaluating team reliability

The process of using the tool is designed to have minimum increase in workload on the user of the tool, where an individual HRA is already performed (see Figure1). The initial step of the process is to define the task and team that are to be evaluated. The task can be defined by any form of TA, and the team can be defined using the role matrix technique (Callan, Siemieniuch and Sinclair, 2006). Alongside the TA interaction links between the team members must be illustrated, as it is these links where the calculations will be made. In addition, at this second stage, the decision hierarchy (power distance) within the team must be defined. Power distance is a PSF for this tool as it is a strong influencing factor on what actions are performed and when. It is presumed that the designer/engineer will have previously produced a TA and allocated roles for design purposes, and for completion of the HRA. Therefore little extra work has been created.

The third stage is to perform an individual HRA on each of the tasks. When a member of the team performs more than one task, then their reliabilities are to be averaged. Any HRA technique can be used, but it must be a quantitative technique, and during the design of the tool, HEART (Williams, 1986) has been consistently employed.

The fourth stage is to calculate the interaction reliabilities and the overall team reliability, this is a series of algorithms and tables and will be discussed in more detail below.

Once the overall team reliability has been found, the assessor uses this figure to determine whether this is an acceptable level of reliability, if it is then they can proceed through the design life cycle, and if appropriate the reliability score can be used in further validation assessments of the tool. If the reliability score is below acceptable levels, then the designer/engineer can reassess the tasks, system and team to evaluate how to adapt the either of these more effectively.

Interaction Algorithms

There are two algorithms used in the tool, the algorithm for interactive reliability (Figure 2) and the algorithm to calculate team reliability (Figure 3). These algorithms are representative of all teams, but in particular the team in Figure 4. The PSFs that are used in the tool are Team skills, how well people can give and receive instruction/criticism; trust, who well team members trust each other; and power distance (PD) a scale of 1-5 with 3 being no PD, and the extreme values being high PD. The first two are described as the Skills-Trust Score (STS), which is a multiplier to the P(e) on a scale of 0.5 (good STS score) – 2 (bad STS Score). The first algorithm should be performed for each team member. Then the algorithm for team reliability can be performed and this will provide the overall reliability for the team.

P(e) = Individual probability of error

P(i)= Individual interactive probability of error

P(T) = Team probability of error

STS = Skills-trust score

PD = Power distance multiplier

$$P(i_a) = \frac{(P(e_a) \times STS_{ab} \times PD_{ab}) + (P(e_a) \times STS_{ac} \times PD_{ac})}{PD_{ab}+PD_{ac}}$$

Figure 2. Algorithm for interactive reliability and abbreviations

$$P(T) = \frac{P(i_a) + P(i_b) + P(i_c)}{N}$$

Figure 3. Algorithm for team reliability

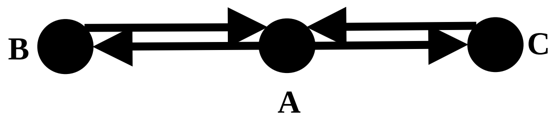

Figure 4. Interaction links between three team members

Validation methods

To date there have been several validations of the model and the tool at different stages of its development. There has been an independent evaluation of the tool when it was used by an external source to test the survivability of a helicopter sortie. The tool was used to assess two teams, one in the helicopter making the sortie, and the other a missile launching team on the ground, potentially attacking the helicopter. The team reliability was part of the over reliability and survivability score of the helicopter and its crew. The tool fitted well into the larger assessment that was being performed, and it was perceived that the methods of the tool were reasonable and easy to use.

More recently the model of team reliability, and the tool have been validated during an non-military operational exercise, onboard a sailing yacht. The crew were assessed on the PSFs and their overall team ability. This successfully confirmed the suitability of the tool and model for assessing team reliability.

Conclusions

Following the discovery of the gap in the market for a quantitative team reliability assessment this tool has developed significantly. The vision to keep the tool simple has been maintained and only a few PSF and algorithms are used. It should be understood that this tool is not complete, and final validations and assessments have not yet been performed. Validation of the tool hitherto has been positive, and has provided constructive development areas for the tool, which will be investigated presently.

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Williams, J. C. 1986, ***A Proposed Method for Assessing and Reducing Human Error (HEART),*** Paper presented at the 9th Advances in Reliability Technology Symposium

Appendix 1C: Paper presented at SEIC R&T 2007

THE PREDICTION OF TEAM RELIABILITY – A TECHNIQUE FOR USE IN DESIGN

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In a CASE studentship supported by BAe systems, a prototype has been developed to enable a designer to quantify and answer to the question, "If I allocate this team to execute that task in System X, how likely is it that they will succeed?" This technique should be useful to engineers in the earlier stages of the design process for a given capability; if successful, the prototype will be extended to operations; e.g. "can I reduce the manning for this task?"

There are 26 different techniques for assessing the reliability of individual humans in a process, and none for assessing team reliability; hence the CASE studentship. The prototype assumes that a process can be defined, in the form of a flow diagram, and that roles can be allocated to execute it. Then, using one of the 26 techniques (currently HEART), individual reliabilities are calculated. These are then modulated by considering team interactive effects; comprising at the present time Trust, Communication, and Power distance, to create 'interactive reliability' for each individual in the team. Then these reliabilities are combined, according to the team architecture for the process, to arrive at an overall team reliability. Mathematically, this amounts to an algorithm 2 lines long.

The paper will outline the technique, show its application to several scenarios (a helicopter mission; crewing a sailing yacht; managing a railway station), and will outline its interface to designers.

HRA Background

A human performing a task has a goal to perform, when this task involves interacting with a system, both the system, and the human can make errors. The number of errors made (the reciprocal of this being the reliability) of a system can be quite predictable, but the reliability of the human element of the task can vary. Human reliability assessments (HRA) are qualitative and quantitative analysis methods for measuring errors that can occur because of human actions, rather than by a system fault. These errors can be analysed in terms of; the causal factors, how to mitigate the errors, and the probability of these errors occurring (Kirwan 2002). Since the development of HRAs designers and users of a system can understand the human difficulties of using a product, and that human errors are always possible to occur, as, even for the most safe system, it is impossible to make it completely human error proof.

Technique for human error rate prediction (THERP; Swain & Guttmann, 1980) and Human error assessment and reduction technique (HEART; Williams, 1986) were amongst the first generation of HRA techniques which were developed between 1970's and 1990's. However, these were criticised by Dougherty (1990) triggering a second generation of techniques that included more recent knowledge of human error and behaviour (Redmill, 2002). Cognitive Reliability and Error Analysis Method (CREAM; Hollnagel, 1998) and other second generation techniques have increased the reliability and relevance of HRA for individuals.

Individual human reliability assessments are gradually becoming embedded into some design processes, and improvements in designs have been made and accepted. However teams are frequently used to operate a system and individual HRAs cannot account for how individuals affect each others ability. Consequently, there is now a call for a third generation of HRA techniques to account for team interaction. Some of the factors that can affect team reliability are communication, trust and resource management . Currently, there are no quantitative third generation techniques that combines the reliability of the people in a team to produce a realistic overall team reliability.

Tool Development

Tool Vision

A tool is being developed at Loughborough University that will predict the reliability of a team of people working together towards a given goal. It will take individual reliabilities and then combine to create an overall team reliability. During conception of the tool clear ideas of the general approach and vision of the tool were defined. It is envisioned that the tool will:

- quantitatively assess the reliability of a team
- qualitatively predict areas of high risk
- be usable and accessible to non-human factors experts
- educate designers in the importance of the human factors to produce high usability and reliability.

Nonhuman-factors-experts should be able to use the tool effortlessly and competently, without the aid of an ergonomist. Therefore, no human factors terminology will be used in the tool, and the algorithms used within the tool should be transparent. To facilitate this simplicity some assumptions must be made. The process must be definable, this can be done using a task analysis (TA), which illustrates the tasks that need to be performed, by whom, and in which order. The team must be definable, including the interaction structures, and the decision hierarchy. The team must be stable (i.e. exist for a period without a change in structure). At establishment of a team there is a period of ascertaining other team members abilities and personalities, during this period relationships can change, consequently, the reliability of the team may be inconsistent. This factor is not accounted for in this tool. If all assumptions are adhered to this tool should be representative of all teams.

Process Definition

As the tool is to be useable by a large range of people, the process only contains 5 steps (Figure 1) and two algorithms. The first and second steps of the process are to define the task, using any form of TA; and the team, using the role matrix technique (Callan, Siemieniuch and Sinclair, 2006), that are to be evaluated. Interaction links between the team members should be illustrated on the TA, as it is these links that will be evaluated by the tool. The decision hierarchy (power distance) of the team should also be identified at this stage. Power distance (PD) can be a strong influencing factor on which actions are performed.

The third stage is to calculate the individual HRA for each team member (P(e)). Any quantitative HRA technique can be used, during the development of this tool, HEART (Williams, 1986) has been predominantly employed.

The fourth stage is to use the P(e) and interaction factors to calculate the interactive reliabilities and subsequently the overall team reliability, this is a series of algorithms which are described below.

Finally, overall team reliabilities can be used in two ways. Firstly, to determine if the reliability is of an acceptable level, if the probability of error is too high, then the design changes can be made. Secondly, different scenarios can be compared, for example, varying the team hierarchical structures, or the methods of communication that are used.

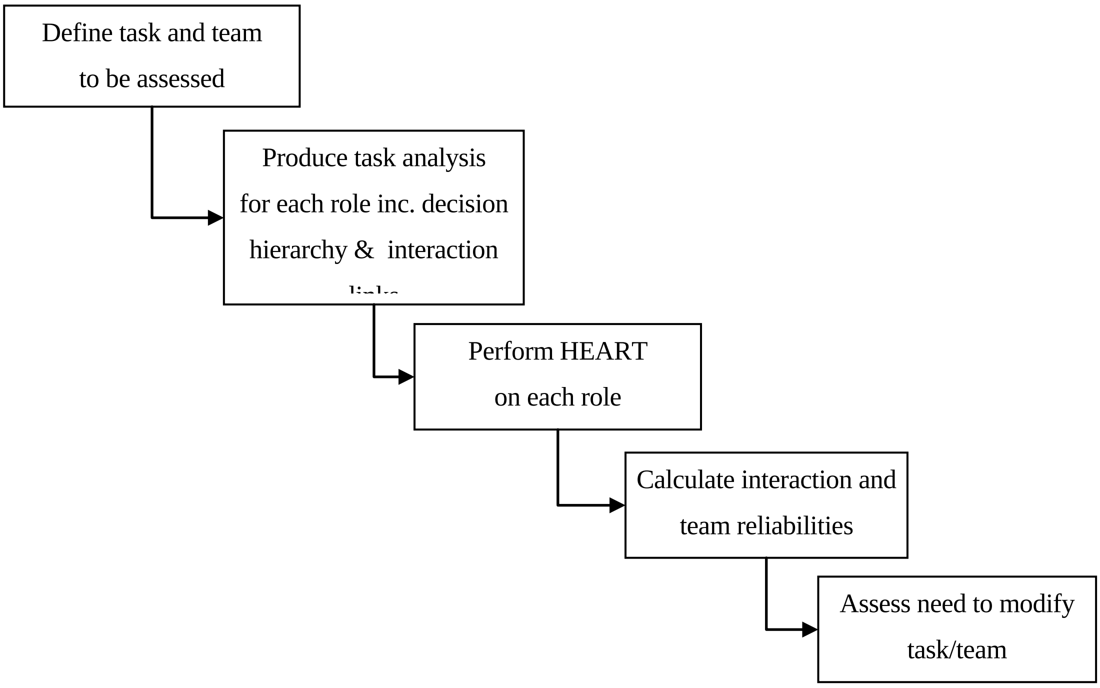

Figure 1. The process for evaluating team reliability (Smith, Sinclair, Siemieniuch , 2006)

Interaction Algorithms

Once the TA has been performed, a HRA can be executed for each task and individual, giving the individual reliability P(e). These reliabilities are then adjusted using the three interactive factors: communication, how efficiently and effectively information is passed between team members; trust, the amount of trust between team members; and power distance (PD), the decision and responsibility hierarchy between team members, a scale of 1-5 is used, with 3 being no PD, and the extreme values being high PD. The first two factors are described as the Communication-Trust Score (CTS), on a scale of 0.5 (good CTS score) to 2 (bad CTS Score) (Smith et al, 2006). The P(e), CTS and PD values are amalgamated for each individual using the interactive reliability algorithm (Figure 2). The team reliability algorithm (Figure 3) is then used to calculate the overall team reliability. These algorithms are suitable to represent all teams, but the team in Figure 4 can be used as an example of a simple team.

P(e) = Individual probability of error
P(i)= Individual interactive probability of error
P(T) = Team probability of error
CTS = Communication-trust score
PD = Power distance multiplier

$$P(i_a) = \frac{(P(e_a) \times CTS_{ab} \times PD_{ab}) + (P(e_a) \times CTS_{ac} \times PD_{ac})}{PD_{ab}+PD_{ac}}$$

Figure 2. Algorithm for interactive reliability and abbreviations

$$P(T) = \frac{P(i_a) + P(i_b) + P(i_c)}{n}$$

Figure 3. Algorithm for team reliability

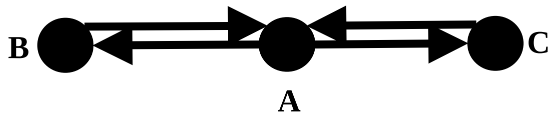

Figure 4. Interaction links between three team members

Scenario Application

Helicopter Sortie

During the tool's development, it has been used on several scenarios. An external source performed an independent evaluation of the tool using it to predict the best sortie route for a helicopter whilst it was potentially under attack from a ground missile launching team. The tool was used to assess the two teams, one, the helicopter crew making the sortie; and the second the ground missile launching team, potentially attacking the helicopter. The aim of the exercise was to create an overall reliability score for the equipment and the humans in the team when the helicopter took different sortie routes, and the missile launching team had varying aiming success. This tool was used in conjunction with other system reliability methods, and provided the human reliability of both teams. It was perceived that the methods involved in the tool, i.e. TA, HRA, did not result in a large increase in workload, or complexity. Furthermore, the tool fitted well into the larger exercise that was being performed. This tool could potentially be used to determine best plans for action in a military environment, depending on how well a team works together.

Sailing Yacht

During a journey of 3,000 nautical miles, a 3 person crew of a sailing yacht were assessed on their communication methods, trust levels, and the influence of power distance. Throughout the journey the crew performed a number of tasks repeatedly, for example, raising the mainsail, or performing a gybe. After each exercise was performed, the crew were asked to fill in a brief questionnaire on the thoughts of how the other crew members performed, and the success of the task. The crew members often changed their roles for each iteration of the task, therefore, the reliabilities of the team could be found whilst assessing the effect of individual HRA scores, communication abilities, trust and power distance. It was found that the team was a consistently reliable team, and the main factor that produced error was a malfunction in communication. The results supported the model of team reliability that is used, and demonstrated that the tool is suitable for assessing how the team factors could effect reliability of a future system.

Student Design Team

Presently, the tool will be used to assess a group of students that are designing a system. The students will be divided into design groups, the overall reliability will be the end of year assessment of how well their system performs. This experiment will further validate the team factors of communication, and trust (all students are equal so there is no PD). The students will self-assess their communication and trust levels with the other students in their groups. It is predicted that with an increase in effective communication there will be an decrease in the number of errors made by the team.

Railway Station Manning

Small suburban railway stations are being studied to see how different hierarchy and interaction structures effect the performance reliability of the station. The station crew, around 3-6 people, are distributed and function independently, but share information and a similar goal of ensuring the stations operates effectively. Communication methods, trust and power distance will be assessed, and the effect these have on reliability will be examined. This provides another application of the tool of distributed teams. Potentially, these stations will be compared to larger, busier train stations, with a crew of over 6 people, consequently the influence of team sizes can be investigated.

Each of these scenarios provide validation for the tool, and the model of team reliability that it is founded on. After each scenario testing the tool is adapted to account for the increase in knowledge of team interactions. Preceding validation of the tool has been positive, and has provided constructive development areas for the tool.

Conclusions

This BAE-Systems funded research is a result of a discovery of a gap in the market for a quantitative team reliability assessment tool. The tool is designed to be used by non-human factors experts, and to be transparent to the user. This is accomplish by founding the tool on other techniques that are already used by developers of systems. There are a limited number of interaction factors and algorithms employed. The tool is in the process of being validated for several scenario uses whilst current validations have proved positive and provided constructive areas of development , it should be understood that this tool has not completed its validation process.

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Appendix 2: Requirement Interview Information

7.6 Appendix 2A: Requirement Interview Information Sheet

<u>Information Sheet</u>

Isabel Smith, BSc, MSc

Designing a Human Reliability Assessment for Groups in the Military Domain

<u>Researcher</u>

My name is Isabel Smith. I am a PhD student at Loughborough University, with sponsorship from BAE Systems. My thesis is to design a tool that tests the reliability of group work in the military.

<u>Background of the thesis</u>

Previous work by Loughborough University investigated which Human Reliability Assessment (HRA) methods the different business units of BAE Systems used. A range of current techniques are in use:

- Human error assessment and reduction technique (HEART)
- Systematic human error reduction and prediction approach (SHEPRA)
- Hazard and operability study (HAZOPS)
- Technique for human error assessment (THEA)
- CHLOE

These techniques measure the reliability of individuals. It was discovered that there is a need to have an HRA tool to study the reliability of a team. CREAM (Hollnagel, 1998) was developed to test the reliability of a team, prototype called CREAM-T. This was tested for sufficiency at Eurocontrol over the summer, 2004. The test showed that there is plenty of scope for further development of a technique designed especially for teams.

<u>Purpose of the interview</u>

The aim of the current investigation is to increase the understanding of the current use of HRA in the different business units and future needs of HRA within the business unit. To obtain this information an investigator will interview you or your thoughts. The interview should last about an hour. The interview will be recorded. The tapes and any comments made during or in relation to the interview will be confidential.

The details of the investigation have been approved by the Loughborough University Ethical Advisory committee. You have the right to withdraw from the interview at any time without giving any reason.

If you have any questions pleas feel free to ask. You can contact me by:

Emailing: I.H.Smith2@lboro.ac.uk
Phoning: 01509 223942
Writing to: Department of Human Sciences, Loughborough University, Leicestershire, LE11 3TU.

Appendix 2B: Requirement Interview Consent Form

Consent Form

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that the information that I give will be treated as confidential. I understand that the information will be used in a way that will not allow me to be identified individually. I am aware that the data will be collected and stored in accordance with the Data Protection Act 1998 and will be disposed of in a secure manner. The data may be used for this and/or other studies and may be used in interim reports and/or the thesis.

I have read and understood this consent form.

I agree to participate in this study.

Your name ____

Your signature ____

Signature of investigator ____

Date ____

Appendix 3: Stakeholder Review Information

7.7 Appendix 3A: Stakeholder Review Information Sheet

Information Sheet

Isabel Smith, BSc, MSc

Designing a Human Reliability Assessment for Groups in the Military Domain

Researcher
My name is Isabel Smith. I am a PhD student at Loughborough University, with sponsorship from BAE Systems. My thesis is to design a tool that tests the reliability of group work in the military.

The aim of the current investigation is to review the matrix and statements that are used in the tool ROCCI. This will be done by a series of exercises and discussion. Your experience and opinion is very important to this investigation, and there are not right or wrong answers. The interview will be recorded, to ensure that the interviewer has a record of the interviews.

The details of the investigation have been approved by the Loughborough University Ethical Advisory committee. You have the right to withdraw from the interview at any time without giving any reason.

If you have any questions pleas feel free to ask. You can contact me by:
Emailing: **I.H.Smith2@lboro.ac.uk**
Phoning: 01509 223942
Writing to: Department of Human Sciences, Loughborough University, Leicestershire, LE11 3TU.

7.8 Appendix 3B: Stakeholder Review Consent Form

CONSENT FORM

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that the information that I give will be treated as confidential. I understand that the information will be used in a way that will not allow me to be identified individually. I am aware that the data will be collected and stored in accordance with the Data Protection Act 1998 and will be disposed of in a secure manner. The data may be used for this and/or other studies and may be used in interim reports and/or the thesis.

I have read and understood this consent form.

I agree to participate in this study.

Your name ____

Your signature ____

Signature of investigator ____

Date ____

Appendix 4: Stakeholder Review Exercises

Appendix 4A: Team Attributes of ROCCI

TEAM ATTRIBUTES OF ROCCI

The three main factors that can effect the reliability of a team are trust, communication and decision making power distance (PD). These are defined below:

Trust: there are several aspects of trust:

- Trust that team members perform actions as expected, successfully and on time.
- Trust that team members check, give and received advice/criticism on tasks they are performing and their ability to act on this information.

A person that is not skilled will either be given tasks that are easy, and so the level of trust that they will complete the task will be high; or they will be expected to perform a task that they are not sufficiently trained in, and so they will not be trusted to complete the task to the highest standard.

The ability to check each others work, and provide feedback on this is important, in the case that errors are made team members can be informed of their mistakes and correct them, or justify the work that they have done.

Communication: the effectiveness and efficiency of the communication and passing of information between team members. The method of communication or passing of information should be appropriate for the interaction.

In some cases hand gestures that are taught is all that is needed to communicate, so for effective communication the team members must be able to see each other at all times, and be trained sufficiently in the meaning of the hand gestures.

Another case would be the use of radio communication. If the radio is used to portray detailed information, vocabulary, environmental conditions at both ends of the radio need to be considered so that information is understood. Is there a specific technical language in which the radio operators should speak, if so are they trained sufficiently. Are there many users of the radio communication trying to speak at the same time resulting in disconnected communications and loss of information?

Decision making power distance (PD*)*: a weighting factor of the importance of the team members actions and decisions on other team members.

In any team there is a decision hierarchy and ultimately somebody will take responsibility for the decision made. This person is at the top of the hierarchy. Those that do not have this responsibility are lower in the hierarchy. The difference in PD level is the key interest.

To calculate decision hierarchy the sum PD score for each pair of team members that interact will equal 6. If they are at an equal level in the hierarchy, each PD score will be 3. A large PD will exist if there is little or no discussion of instructions and decisions, the PD scores will be 1 and 5. A small PD exists if decisions and instructions are made, but these can be discussed by the other team member, the PD scores will be 2 and 4. If people have equal power over decisions in the group, then they are level on the hierarchy. If there are two people they take responsibility for all decisions and the success of the team, they these two people are at an equal level.

PD is **not** the number of levels between one person in a team and another.

Appendix 4B: Exercise One

EXERCISE 1 - INSERT VALUES INTO MATRIX ON OWN EXPERIENCE

The purpose of this exercise is for you to assess the current multiplication factors in the matrix, and to assign the factors that you feel are appropriate. There are no right or wrong answers.

The matrix on the left is the Communication – Trust matrix that is currently being used.

Please fill in THIS matrix

		Communication			
		1	**2**	**3**	**4**
Trust	**1**	**2**			**1.7**
	2				
	3				
	4	**1.7**			**0.5**

		Communication			
		1	**2**	**3**	**4**
Trust	**1**				
	2				
	3				
	4				

Exercise 1 – Part A

Based on your experience, please assess the appropriateness of the extreme corner multiplication factors, whilst considering the definitions of communication and trust, and the statements that are used to assign the 1-4 scores.
Based on you experience and judgement, please write the values you would use for the extreme corner multiplication factors in the matrix on the right.
Please write an explanation for your values, e.g. are there any examples that you are basing the values on.

Exercise 1 – Part B

Now you have set the extreme corner values, based on your experience and judgement, please fill in the values you would use for the edge multiplication factors in the matrix on the right.
Please write an explanation for these values, e.g. are there any examples that you are basing the values on.

Exercise 1 – Part C

Now you have set all the outside values, based on you experience and judgement, please fill in the values you would use for the central multiplication factors in the matrix on the right.
Please write an explanation for these values, e.g. are there any examples that you are basing the values on.

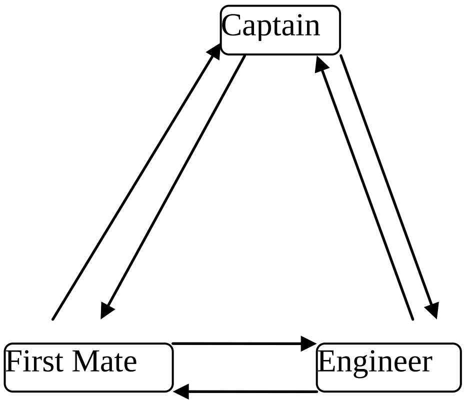
Appendix 4C: Exercise Two

EXERCISE 2 – SCENARIO EXAMPLES

Please read each of the following scenarios through. There are 3 or 4 members in each team, (diagrams of the interaction are shown below). The scenarios should provide enough information for you to assign Trust (1-4); Communication (1-4) and PD (1-5) score for each interaction.

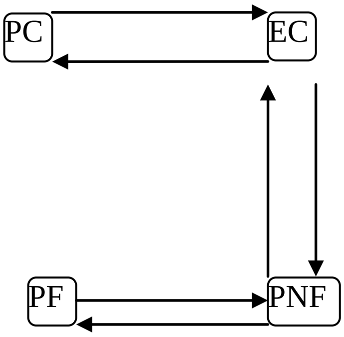
The Trust and Communication scores can then be used to find the multiplication factor to the probability of error from the matrix created by you. Please use the scenarios to ascertain whether the Communication and Trust scores correspond to the matrix values.

Scenario 1 – Sailing Crew



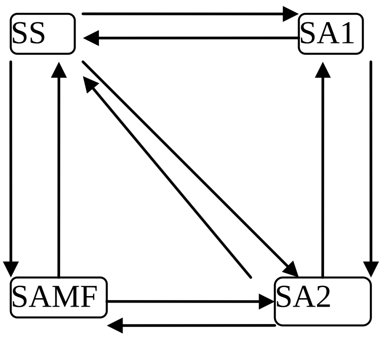
Comments:

Scenario 2 – Air Traffic Control



Comments:

Scenario 3 – London Underground Station



Comments:

Appendix 4D: Exercise Two, Scenario One

SCENARIO 1- SAILING CREW

The Boat: A large, 90ft, ocean going sailing yacht. The sails are too large to be moved manually so hydraulics aide the crew when they are furling or unfurling the sails. The sails are very large, and so they can have a lot of power, if a manoeuvre is performed incorrectly the rigging could fall down, causing upwards of £1million worth of damage, and also possible capsizing the boat, creating danger to the lives of those on board.

The three crew members:
Captain – is ultimately in charge of the survivability of the yacht. He decides the route of the boat, which sails are used and how much of the sail is unfurled. The captain gives instructions to the other members of the team, in order to maintain a smooth sailing trip.
First mate: assists the captain in ensuring the sails are in the correct position, and unfurled the correct amount. The first mate also contributes when deciding the route that the boat takes.
Engineer / crew: assists the captain and first mate in ensuring the sails are in the correct position, and unfurled the correct amount. The first mate also provides information to the captain on the state of the engineering, and all moving parts onboard the boat.

Team Attributes:
Communication: when performing a manoeuvre team members are located on different parts of the deck and it is often too noisy to use verbal communication, hand gestures are used instead, these are learnt through experience.
If a manoeuvre is not being performed communication is face – to face, with the use of charts / sailing rigging for reference.
Trust: the captain of the yacht is new; he is experienced at sailing many types of yacht in many environments and sea conditions, but has only been on this yacht a short period. The first mate and engineer have been on the boat for a year, under another captain. They are very capable at performing all tasks and manoeuvres under the old captain, and can predict each other's actions, so they can help each other quickly. They sometimes feel that the new captain will not always suggest the most effective solution to problems.
Power Distance: The captain informs the first mate and engineer what tasks they should perform on a manoeuvre. Before a manoeuvre is performed, the captain will ensure that team members know which tasks they are to perform.
When a manoeuvre is not being performed the captain will discuss specific aspects of the boat openly with the appropriate crew member.

Scenario
The crew are performing a Jibe, which requires all the members of the team to perform actions at the same time. It is raining, and with a strong wind, so team members cannot hear each other easily, but it is during the day time so hand signals can be used. To perform the manoeuvre the boat must change direction; the captain is at the helm, at the centre of the boat. The engineer and first mate are moving the main sail/boom, from one side of the boat to the other. They must work together to ensure the boom does not move abruptly or early, causing damage to the boat.

Appendix 4E: Exercise Two, Scenario Two

SCENARIO 2- AIR TRAFFIC CONTROL

The environment: A commercial aircraft on a long distance flight, with English speaking PF and PNF. Flying at high altitude through a sector, not preparing to land. The ATCs have control of a large very busy sector. If two aircraft become too close together they could collide meaning massive loss of life – a disaster.

The four crew members:
Pilot Flying (PF): flies the plan, receiving instruction from the PNF. The PF listens to all PNF communications with the EC, checking that all information is understood and inputted into the onboard computer correctly.
Pilot Non-Flying (PNF): receives communication and instruction from the EC on the correct heading and flight level of the aircraft. Inputs this information into the onboard computer. The PNF also passes on this information to the PF. The PNF performs other tasks in the cockpit not directly related to the heading and flight level of the aircraft.
Executive Air Traffic Controller (EC): watches aeroplane traffic on a screen in, reads information on the flight level, speed and destination of the aircrafts and determines the best route that each aircraft should take through the sector. The EC informs the PNF of each aircraft which heading and flight level they should be travelling. EC also gets information about future aircraft to enter the sector from the PC
Planning Air traffic Controller (PC): looks at the future aircraft that are entering the sector and foresees any problems that may occur. The PC then informs the EC of any situations that may arise. The PC will also listen to all the EC communications checking that they are all correct and understood.

Team Attributes:
Communication: the official language of ATC is English, with very precise language and terminology used. The communication is through a one-way radio that all crew on that frequency can hear, but only one person can use at a time. Very occasionally words can be misheard. Both the pilots and the ATC are trained in the correct terminology to use.
The communications within the cockpit is private, and face – to – face.
Trust: The ATC have worked together on the same sector for a long period of time, so they know the aircraft and the routes they will take well, and they also know how each other works. The PF has had many years experience, the PNF is recently trained.
Power Distance: The PF must follow the instructions of the EC, there is very rarely discussion of instructions but the PNF may ask the EC for a shorter route or higher flight level to decrease flying time and fuel consumption. The PNF provides information to the PF, but the PF has final say over decisions in the cockpit, it is encouraged that the PNF should question any decision or action that they seem is unsuitable.

Scenario
The PF has requested a change in heading from the planned route to reduce time and fuel consumption. The EC is aware that the airspace is very busy but gives permission for change in heading. However, another aircraft has changed flight level unexpectedly, and potentially a collision between the two aircraft could occur. The EC informs the PF to return to original heading, resulting in an increase in flight time.

Appendix 4F: Exercise Two, Scenario Three

SCENARIO 3 – LONDON UNDERGROUND

The environment: A central London Underground station, which consists of a ticket office, ticket hall, and platforms, each contains a team of people working together. Staff can move between teams depending upon where there are needed at the time. This is a busy central London location, where peak flow times are 7.30am – 9.00am and 4.30pm – 6.30pm.

The four platform team members:
Station Supervisor (SS): oversees the day-to-day accountability of the staff performance and events on the station, station safety and security inspections, deployment of staff and administration of takings, resources, records and the management of line and network wider information.

Station Assistant Multi-Functional (SAMF): duties include the selling of tickets, servicing the Passenger Operated Machines, account for all revenue taken and under degraded station operations the SAMF may also carry out gate line and platform duties as required.

Station Assistant 1 (SA1): perform gate line and platform duties, passing information to and taking reports from passengers, they communicate with the SS in order to reconfigure the station in the event of a station incident, or service is restricted.

Station Assistant 2 (SA2): Same as SA1.

Team Attributes:
Communication: the are many methods of communication that are used including radios, watching CCTV, fact – to face and transferring information to handheld personal computers (PDAs). There is no official technical language that is used, or taught.

Trust: The two SAs have differing approaches to controlling the passengers and train on the platform, and often come into conflict. The SAMF and SS understand this conflicting relationship, and knows each SAs strengths and weaknesses, although they do find the relationship frustrating and work is often compromised.

Power Distance: The SS has responsibility for all decisions that are made, and all other members of staff must follow the SS's instructions. The SAMF's and SAs's work separately in the station, and have equal power is decisions and actions that are made.

Scenario
It is rush hour, and all the staff are busy. An elderly lady has fallen from a train to the platform, causing the train to remain in the station, and causing confusion to the passengers on the platform. The SAMF is required to aid the SA1 and SA2 on the platform. First aid needs to be administered to the lady, and when possible she needs to be moved away from the door to the train. The passengers and other train stations need to be informed of the delay and the consequences of this delay on train times. Organisation of the different roles will be performed by the SS.

Appendix 4G: Feedback Form

FEEDBACK FORM

Name: ____

Job title: ____

Brief description of job: ____

____

Experience with human reliability assessments: ____________________________

____

____

Throughout this session you have been asked to suggest values in a Communication – Trust Score matrix. Generally, what is your confidence in the values that you have provided.

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Are there any values, or aspects of the matrix that you a particularly confident in, e.g. from occupational experience. Please state which values, and why.

Do you have any other suggestions for the matrix, statements or the ROCCI tool.
