Author:
Dester, W. S

Title:
The development of a structure for the design of hazard audits.

THE DEVELOPMENT OF A STRUCTURE

FOR THE

DESIGN OF HAZARD AUDITS

by

W. S. Dester

A thesis submitted to the University of Bristol
in accordance with the requirements of the degree of
Doctor of Philosophy in the Faculty of Engineering.

Department of Civil Engineering

November 1992

ABSTRACT.

Hazard auditing, which is a formal, systematic, critical examination of a situation or set of circumstances to identify hazards, is fundamental to hazard management. Auditing is facilitated by "an audit" that details activities, procedures, systems and artefacts, where hazards might be identified. This thesis describes the development of a structure, in the form of a hierarchy, that can be used in the design of hazard audits. An examination of systems such as manufacturing and process plants, for hazards, is usually undertaken by examining the subsystems, (i.e. activities, systems, and procedures). Existing audits therefore, tend to be specific, as for example, audits of unsafe acts, unsafe conditions, technical functioning of materials and machinery, management. This type of audit restricts the examination to a closed system within observable and well described physical and organisational boundaries. It is argued in this thesis that examinations for hazards should go beyond this closed system and also look for hazards within the larger systems of society and industry. An examination of hazards can be seen as a search for evidence of proneness to failure.

The hierarchy developed in this research focuses on hazard auditing for a construction project. Construction, which is associated with the construction industry, is only one phase in a larger system, the project, which encompasses development, use, and withdrawal from use. It is argued that evidence of proneness to failure of a construction project may be found in these systems, (project and industry), in the larger system of a social environment, and in the subsystems that are part of a construction project. These hazards are described in terms of concepts, and presented in the form of a hierarchy that indicates inter-dependencies between concepts. This hierarchy is a basic structure to be used in the design of hazard audits.

The concepts incorporated into the hierarchy are discussed and described in terms of their potential to provide evidence of proneness to failure. Sections of hierarchy are built up and presented at appropriate positions in the thesis.

It is proposed that this approach to hazard auditing will allow for flexibility in dealing with specific situations, yet provide for the identification of hazards that can exist and develop outside of those situations. It is suggested that such an approach should be regarded as a specialist activity of hazard management. Further, it is argued that the activity of hazard engineering should be recognised as a separate discipline within its own right.

DEDICATION

To my Mother

ACKNOWLEDGEMENTS

I wish to express my thanks to all those who have made this work possible, and in particular the following:

Professor D. I. Blockley for his guidance and encouragement,

members of the civil engineering systems group,

the people who agreed to be interviewed for this research,

the Science and Engineering Research Council for the award of a studentship.

DECLARATION

The work on which this thesis is based was carried out between October 1989 and November 1992 under the supervision of Professor D. I. Blockley of the Department of Civil Engineering, University of Bristol.

It is entirely due to the author except where acknowledged in the text, and has not previously been submitted for a degree or diploma of this or any other University or examining body.

Signed..........

Date....13/11/92

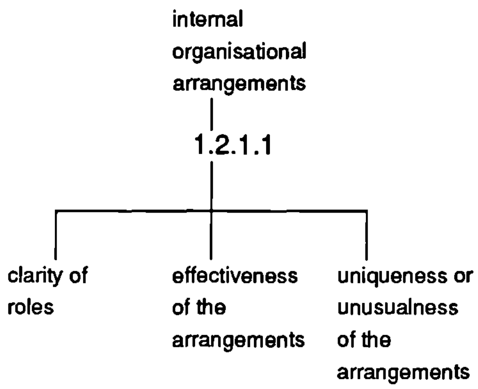
CONTENTS

LIST OF FIGURES

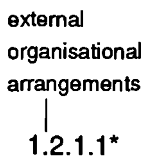
LIST OF TABLES

NOTATION

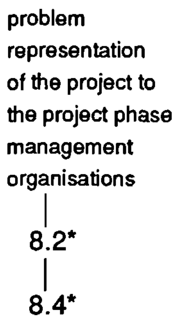
Specific examples are used here to illustrate the reference system for hierarchical expansions that are included in this thesis.



The reference number, (e.g. 1.2.1.1), will be used to represent the hierarchical development shown below 1.2.1.1, irrespective of context.



The hierarchical expansion of the concept above 1.2.1.1* develops in terms of the concepts shown below 1.2.1.1



The hierarchical expansion of the concept above 8.2* develops in terms of the concepts below 8.2.

The hierarchical expansions of each of the concepts represented by 8.2* develop in terms of the concepts shown below 8.4.

WOL	World Outside the Laboratory.
WIL	World Inside the Laboratory.
Use	Uncontrolled tests in the WOL.
Prototype tests	Controlled prototype tests in the WOL.
Proof tests	Controlled proof tests in the WOL.
Laboratory tests	Controlled laboratory tests in the WIL.

Chapter 1.

Introduction.

1.1 Objectives of thesis.

1. To describe critically, hazard auditing and its significance to hazard engineering.

2. To identify and examine factors, (concepts), that provide evidence of proneness to failure of a construction project.

3. To discuss, describe, and explain concepts that are incorporated into a structure for the design of hazard audits.

4. To present a hierarchy of concepts as a structure for the design of hazard audits.

1.2 Definitions.

Some basic definitions are given here. Some, such as for "proneness to failure", "state of the art", "dependability", and "safety culture", are expanded upon within the thesis. Other terms are defined as they arise.

Failure of an artefact: Lack of correspondence between a required state of the world and an actual state of the world, (Blockley, 1992).

Hazard: A set of preconditions for failure. A hazard exists in many forms including physical, behavioural, abstract, social, and natural. Examples of physical hazards are restricted headroom, faulty materials or equipment, and potentially unsafe structures. Behavioural hazards involve unsafe behaviour. A persons state of mind, such as concern or intentionality, is an abstract hazard. A poor communications system is a social hazard. Areas susceptible to earthquake or hurricanes are natural hazards.

Hazard content: The extent to which there is a precise clear set of preconditions for failure. This definition has been used in preference to that given by Blockley, (1992), which defines hazard content of an artefact as the extent to which an artefact has a precise clear failure content, because a hazard may not necessarily be perceived as failure.

Proneness to failure: The susceptibility to failure, as indicated by the hazard content. The greater the hazard content, the higher the proneness to failure.

Culture: A set of beliefs, norms, attitudes, roles, and practices. For a group, this is a shared set of beliefs, norms, attitudes, roles and practices.

Safety culture: The set of beliefs, norms, attitudes, roles, and social and technical practices which are concerned with minimising the exposure of individuals, within and beyond an organisation, to conditions considered dangerous or injurious. (Pidgeon, Turner, Blockley, Toft, 1991).

Society: The system of interrelationships which connects together the individuals who share a common culture, (Giddens, 1989). It includes the effects of political, religious, environmental, scientific, and technical characteristics and yet has unique characteristics of its own.

Technology: The practice, description and terminology of any or all of the applied sciences which have practical value and/or industrial use. (Chambers English Dictionary, 1988).

Socio-technical system: A system involving inter-dependencies between; individuals, groups and their social arrangements, and technical knowledge, products and processes. Technology is a socio-technical system.

Dependability: The extent to which there can be confidence about knowledge products or processes.

State of the art: The range, quality, and dependability of knowledge products and processes.

Industry: The collection of individuals and organisations, and the knowledge, products, and processes associated with a particular technology. For example; agriculture, medicine, aerospace, construction.

Construction Industry: The collection of individuals and organisations, and the knowledge, products, and processes associated with civil/structural engineering and building.

Project: A planned undertaking to achieve a clearly defined objective. For example; to sail around the world, to construct a bridge, to go to Mars. Aims such as to be wise, which cannot be precisely defined, will not, in this thesis, be interpreted as projects.

Expert: A person who has detailed knowledge and experience of a topic, situation, or activity.

Specialist or specialist activity: Relates to topics, situations, and activities for which there are relatively few experts. Suspension bridge design and thatching are both specialist activities.

1.3 Overview of thesis.

Safety is typically defined as "freedom from danger". Hazards represent danger, and the elimination of hazards improves safety. The objective of a hazard audit is to identify hazards. A hazard is evidence of proneness to failure. An assessment of the proneness to failure of a project is based on the interpretation of the total evidence gained from an audit of the project. The underlying theme of this research, in the context of project construction, is to present a set of concepts which it is thought can represent, and therefore help to identify, potentially hazardous conditions. These concepts, whose common characteristic is that they can provide evidence of proneness to failure, are classified and presented in the form of a hierarchy.

The processes that comprise a project can be classified into the following phases: feasibility and planning; conceptual design; design; construction, including commissioning; operation, (i.e. use), including repairs, renovation, and modification; decommissioning and demolition; post decommissioning and demolition. Each phase is influenced by the industries and societies with which it is associated. Societies and industries do not themselves exist in isolation, but are inter-dependent. Any phase of a project is therefore subject to influence and in turn influences all other phases, industries and societies with which it has any link, no matter how tenuous.

The safety record of the construction industry is outlined in chapter 2. Proneness to failure and the significance of the society/industry/project/project phase relationship is explained. There is a brief account of safety auditing, and a discussion about the context of hazard auditing. The relevance of a "proneness to failure" hierarchy as a structure for the design of hazard audits is outlined.

The research method is described in chapter 3. The interaction of the development of the hierarchy and knowledge acquisition from literature, interviews with experts, and personal experience is explained. The use of interviewing, to elicit knowledge, and of grounded theory for interview analysis is described and discussed.

Although relevant literature is discussed in the thesis where appropriate, some of the features arising out of an initial literature review are described in chapter 4. Other literature sources, where relevant to the initial review, are also included.

Certain sections of the hierarchy are repeated. The most fundamental of these relate to: policy implementation; state of the art of knowledge, products and process; hazard engineering. The hierarchical developments of these are discussed in chapters 5 to 7.

In chapter 5, the relevance of policy and its implementation is explained. A "management framework" is described in terms of organisational, information and planning arrangements. The relevance of these arrangements is explained, and the characteristics for their evaluation are described. There is a discussion about culture, and its significance to the implementation of policy and the operation of a management framework.

The state of the art of technology and its influence on proneness to failure is discussed in chapter 6. The characteristics that influence "the state of the art", in the context of technical engineering, (clauses 6.3 and 6.5), are described and discussed. The significance of the need to understand and consider engineering as a socio-technical system is outlined.

In Chapter 7, it is proposed that hazard engineering be considered as a separate activity in much the same way as other engineering disciplines such as aerospace, civil, and mechanical. This activity, which deals with the management of hazards is multi-disciplinary. It is proposed that hazard auditing, as an element of hazard engineering, needs to be developed as a specialist activity.

Chapter 8 provides an overview of the interaction between society and technology. The influences that a social environment has on the proneness to failure of a project are described. The difficulties presented in an assessment of these influences are outlined.

In chapter 9, the factors existing in or developing from the activities of an industry, that can influence proneness to failure of a project, are described. With reference to the construction industry, there is a discussion about the significance of the industry to safety. The role of representative organisations within an industry is discussed.

The characteristics of an evaluation of "overall project management" for evidence of proneness to failure are described in chapter 10. These involve the inter-dependencies amongst project phases, (i.e. feasibility and planning, conceptual design, design, construction, operation, decommissioning and demolition, and post decommissioning and demolition).

Evidence of proneness to failure in the "project history" is considered in Chapter 11.

The hierarchical development of concepts that are thought to provide evidence of proneness to failure during the construction phase or subsequent phases are described.

Chapter 12 contains the conclusions drawn from this research and in chapter 13 there are suggestions of further areas of research.

Chapter 2.

Hazard auditing.

2.1 Objectives.

1. To outline briefly, the safety record of the construction industry.

2. To explain the concept of proneness to failure.

3. To introduce the concept of hazard auditing within the context of existing audit procedures.

4. To introduce the idéa of a "proneness to failure" hierarchy as a structure for the design of hazard audits.

2.2 Safety in the construction industry.

The consequences of disasters and major incidents associated with technology can be severe in both human suffering and financial cost. Over recent years, disasters such as Piper Alpha, the Space Shuttle, and the Zeebrugge Ferry have received wide publicity. Examples from the construction industry include the Abbeystead pumping station explosion in 1984, the box girder bridge collapses in the late 1960's and early 1970's, and the Ronan Point collapse 1968. These incidents may appear infrequent, and their immediate consequences, compared to disasters of other industries, less severe. Infrequency, or non occurrence, is no guarantee against occurrence in the future. If, for instance the Zeebrugge disaster had been averted, the conditions under which cross channel ferries were known to operate may have remained unchanged to this day. Auditing is important both to identify hazards and to concentrate the mind on their existence.

The perception that there are few major incidents in the construction industry may, in part, be due to the relatively low severity of consequences. There are in fact numerous significant failures. Kaminetzky, (1991), and Piésold, (1991), give many examples of building and civil engineering failures of varying degrees of severity. In terms of occupational safety performance, the construction industry has a very poor record. It has a fatality rate of approximately five times, and a major injury rate of about twice, that in the manufacturing industry. Statistics shown in table 2.1 have been taken from the Health and Safety Commission annual report (HSC, 1989/90).

	1981	1982	1983	1984	1985	1986/7	1987/8	1988/9	1989/90
Fatal injury									
Construction	9.7	9.7	11.6	9.8	10.5	10.2	10.3	9.9	9.2
Manufacturing	2	2.4	2.2	2.7	2.4	2.1	1.9	1.8	2
Major injury									
Construction	155.6	188.5	213.2	225.2	225.8	282.7	276.5	285.9	306.9
Manufacturing	68.8	72.3	79.6	89.6	92.3	145	142	143.7	141.1

The 1989/90 figures are provisional.

In 1986, the system of reporting covered by RIDDOR, (1985) was introduced. This widened the coverage of the major injury category.

Table 2.1 Fatal and major injury rates per 100,000 employees

In outlining the Health and Safety Commission, (HSC), annual report for 1990/91, the HSC Newsletter, (February 1992), implies that there is little sign of improvement, stating:

> The report also shows that the construction industry remains top of the league table for deaths and serious injuries, with on average, one worker killed every three days, 59 reported injured daily and one member of the public killed by construction activities every month.

Some of the reasons given by Davies and Tomasin, (1990), for such a poor safety record are: the short term and transitory nature of the industry, the lack of a controlled working environment, and the complexity and diversity of size of organisations within the industry. Similar views were elicited from the author's interviews with safety practitioners in industry. For example, the following answers were given to questions about the differences between the construction industry and other industries with regard to their safety records:

> Also the question of the size of the unit has an important influence. A lot of the construction industry is small companies and its the small companies that have the worst record. Whereas the accident rate in the country as a whole may seem very high with something like over a hundred people killed every year in construction accidents, in any particular company, a serious accident is a rare event, and therefore it is difficult to convince the owner or manager of the company that safety is a serious matter.
> (Interview A).

> The transience, the transitory nature of a lot of the tasks.
> (Interview E)

> Obviously the main difficulty is movement of labour between sites, and the fact that people tend to be on sites for days, or at the most months and then onto another site, different location, perhaps different supervisory staff, management, and they don't get a fixed work location. ....we've certainly got a record that doesn't compare favourably with other industries, but the reason I've just given, probably not an excuse, but the reason, is because we haven't got a set work place, if you like, a settled work place.
> (Interview L).

It could be argued that such views are excuses. They are perhaps symptomatic of a need to justify what has become acceptable. Every industry has its particular difficulties, and a move towards a safer construction industry may be accelerated by an acceptance that its "special" difficulties are problems that can be overcome.

Proposals from the Health and Safety Commission (HSC consultative document, 1989 and 1992) and in the European Communities Commission Council Directives, (1989 and 1992), appear to be positive moves towards improving safety in construction. These directives are due to be adopted by member states, by the end of 1992 and 1993 respectively. However, the introduction of regulation is not an indication of improved attitudes, or a guarantee of improvement in safety. It will only be effective in so far as it can be properly policed and used to motivate safety improvements. Regulation is discussed further in later chapters with respect to its possible effects, (chapter 7, clause 7.4.3; chapter 8, clause 8.11.6), implications, (chapter 13, clause 13.4), and assessment, (chapter 8, clause

8.8).

To summarise, the construction industry has a poor safety performance record. This is reflected in safety performance statistics and in the incidence of failure, although perhaps not in terms of major disasters. If this situation is to be improved, action requiring effort and commitment is needed. Failures are the manifestations of hazards. Actively seeking to identify hazards is the first step in the mitigation of failure.

2.3 Proneness to failure.

An audit to identify hazards provides a means for the formal, systematic, gathering of evidence to indicate how prone a project is to failure. This thesis, in the context of the construction of a project, discusses the development of a set of concepts that are believed to have the potential to provide evidence of "proneness to failure". The concepts are set out in the form of a hierarchy that provides a structure that can be used in the design of hazard audits.

A project, unless specifically described otherwise, (e.g. construction project), should be considered to cover development, use, and withdrawal from use. This can be conveniently divided into phases, which are defined as follows:

Feasibility and planning describes the conception and initial investigation into the feasibility of, and a possible course of action for, the development, use, and withdrawal from use of a project.

Conceptual design describes the development of the concept into a firm proposal, that comprises a more detailed course of action or alternative courses of action.

Design is the process that transforms the conceptual design into a form which can be directly developed into an artefact.

The **construction** phase is the implementation of the design to create an artefact that is fit for its intended use. This includes commissioning.

The **operation** phase encompasses all activities, systems, and procedures that are necessary for the use of an artefact or, if unused, its maintenance in a safe form. This includes maintenance, repairs and modifications.

Decommissioning and demolition covers the activities, systems, and procedures that are necessary for the removal of an artefact.

The **post decommissioning and demolition** phase continues for as long as there are likely to be any effects arising out of the history of a project.

A project phase, such as construction, can be associated with a specific industrial context, (i.e. the construction industry), in that it is part of that industry. Both phase and industry exist within a social environment. In its simplest form the project phase/industry/society relationship can be represented as shown in fig. 2.1.

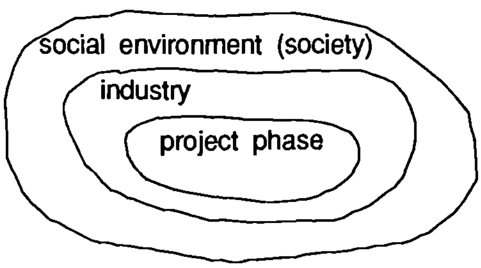


Fig. 2.1 Society/industry/project phase relationship

Project phases, industries and social environments are interactive. For example, the design phase and construction phase of a project represent two separate but interacting processes. Each of these systems can be associated with an industry, (design and construction respectively). These industries have common content, and in combination they form what is generally referred to as the construction industry. In turn, each industry may be associated with a different social environment; but again social environments interact. Fig. 2.2 illustrates the inter-dependency of design and construction phases, their associated industries and social environments.

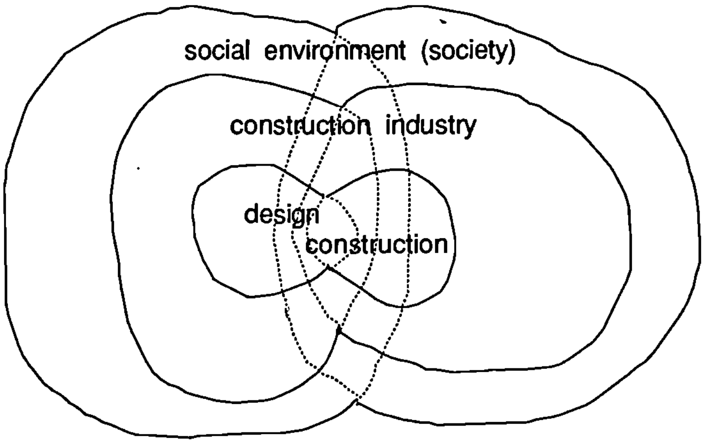
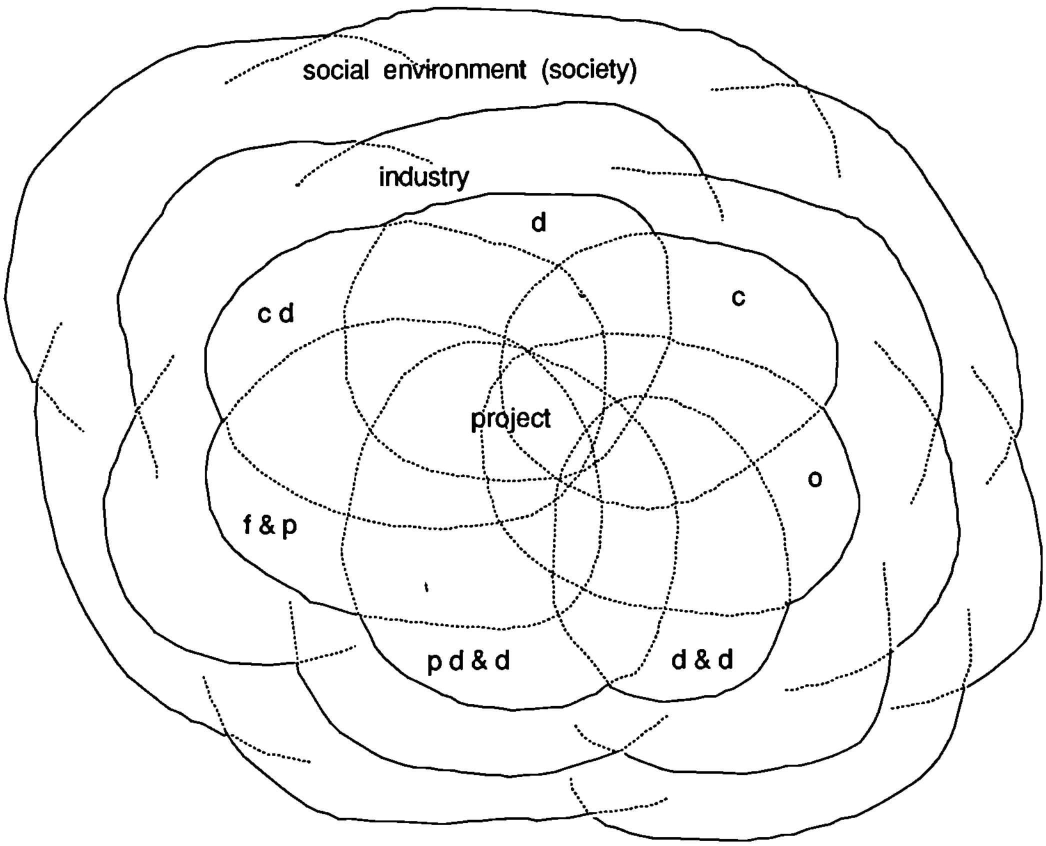


Fig. 2.2 Society/construction industry/design-construction phase reationship

Fig. 2.3 represents the system containing the overall project. It incorporates the seven phases and associated industries and societies. Each separate phase is influenced by and influences every other phase, industry and society.

In a particular social environment there is interaction amongst different projects and industries, such as construction, aerospace, and medicine. Because, as shown in fig. 2.4, different social environments interact, there will be dependencies between industries and projects of different societies.



f & p - feasibility and planning

c d - conceptual design

d - design

c - construction

o - operation

d & d - decommissioning and demolition

p d & d - post decommissioning and demolition

Fig. 2.3 Model of the society/industry/project/project phase relationship

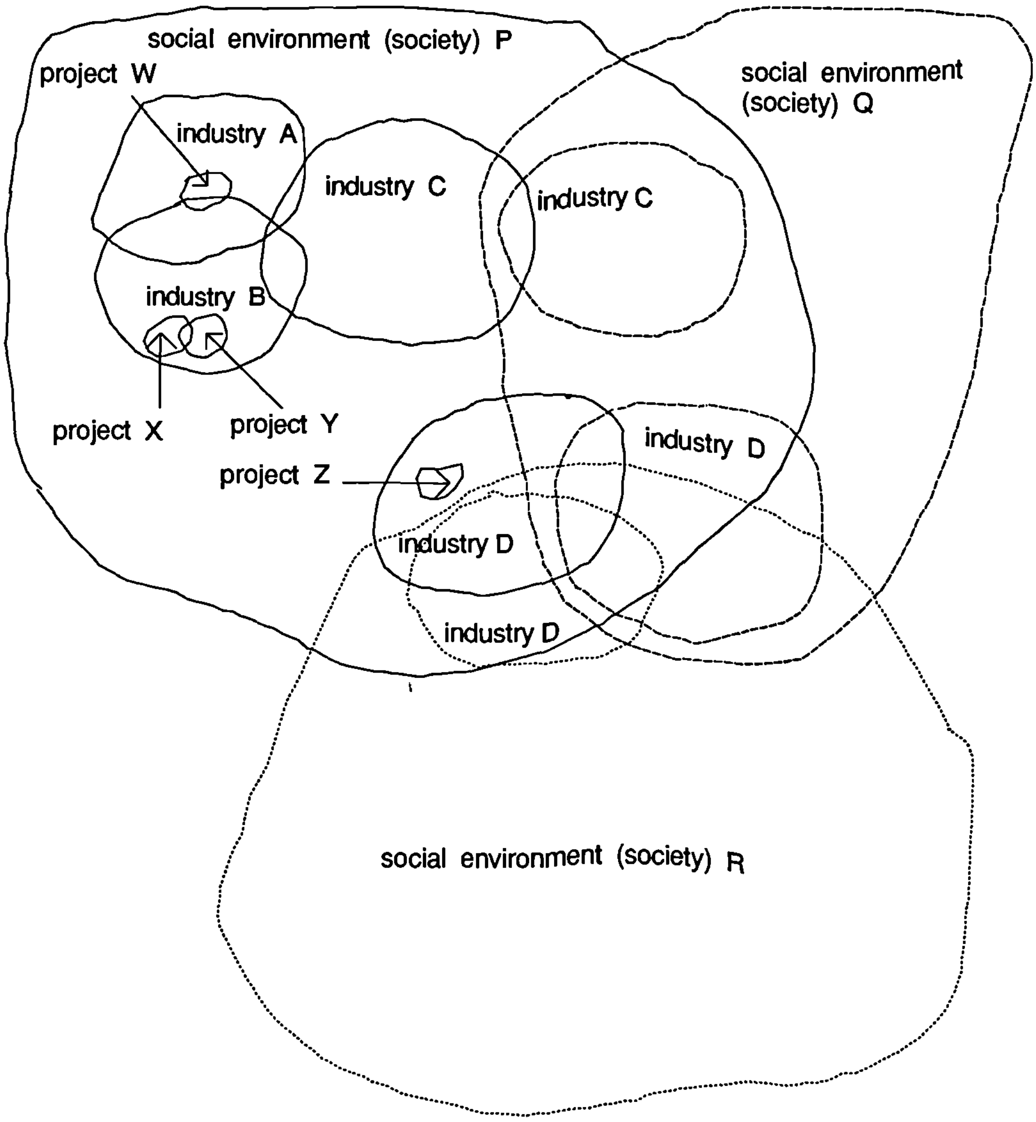


Fig. 2.4 Relationship between different societies, industries, and projects

An examination of safety, at any stage of the development, use and withdrawal from use of a project, needs to accommodate the interactions of society, industry, project, and project phase. Fig. 2.5 illustrates how these interdependencies are represented in hierarchical form.

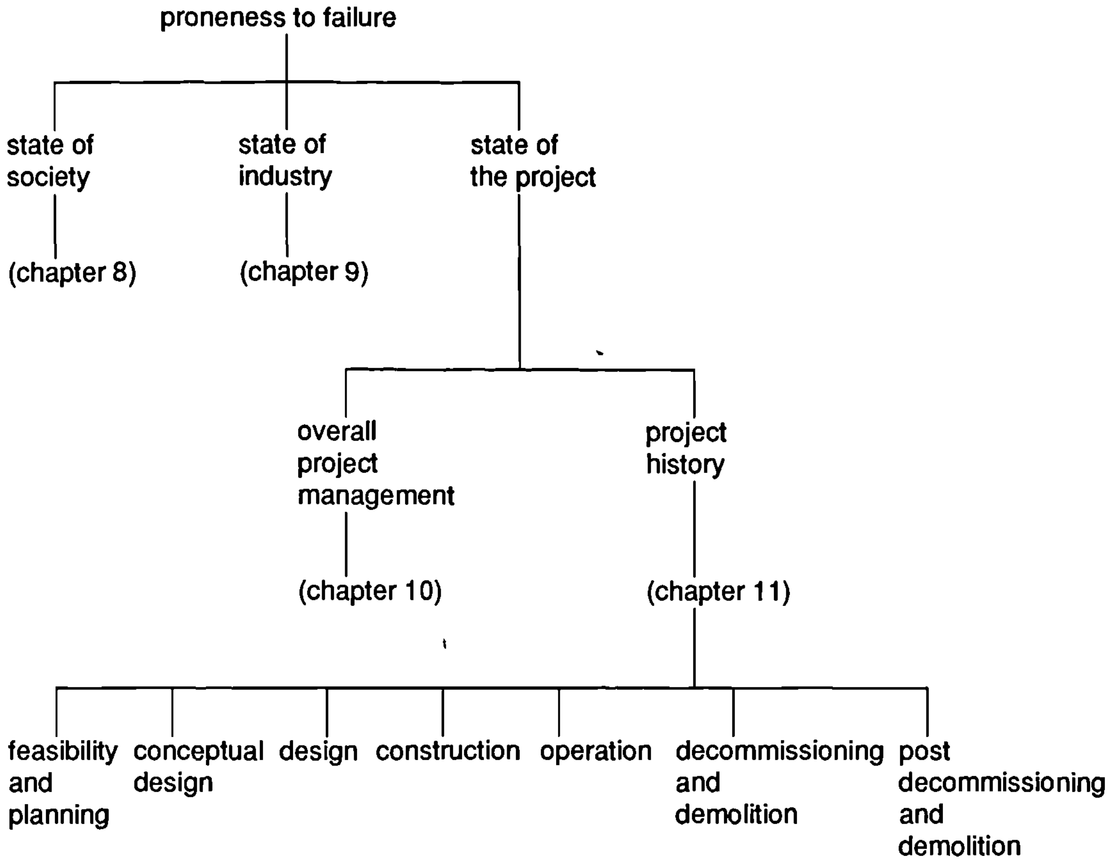


Fig. 2.5 Top levels of the "proneness to failure" hierarchy.

Each concept in fig. 2.5 has the potential to provide evidence of proneness to failure. The evidence exists if the concept exhibits a particular characteristic, or attribute. For example, poor overall project management may be evidence of proneness to failure. This attribute is a measure for the evidence of proneness to failure. For every concept shown in fig. 2.5, it happens to be "poor". Other attributes such as high or low may be relevant to other concepts. For example a low number of tests may be evidence of low dependability, (see chapter 6, clause 6.6.3.3). Using the concepts in fig. 2.5 as an illustration, the relationship between concepts is interpreted as follows:

There may be evidence of **proneness to failure** if there is evidence of: **a poor state of society**, and/or **a poor state of the industry**, and/or **a poor state of the project**. There may be evidence of **a poor state of the project** if there is evidence of: **poor overall project management**, and/or **poor project history**. There may be evidence of **poor project history**, if there is evidence of: **poor feasibility and planning**, and/or **poor conceptual design**, and/or **poor design**, etc.

The hierarchical development of the concepts in fig. 2.5, is described in later chapters. A method for presenting concepts (with definitions and descriptions) is outlined in clause 2.7.

2.4 "Proneness to failure" model.

Proneness to failure of an artefact, or project, is a measure of its hazard content. Fig. 2.6 illustrates the concept of proneness to failure, which can be conceptualized as follows, (Blockley, Turner, Pidgeon, 1991):

A project can be modelled as a "state point" in a multi-dimensional space, (three dimensions are shown in fig. 2.6), within which there is a hypervolume bounded by constraints. The constraints, not necessarily clearly defined, represent the limits for the "state point", outside of which there is failure. The potential for passing through a limit state boundary is a hazard. The "distance" between the "state point" and any constraint boundary is a measure of the degree of hazard, and the totality of these measures is a measure of the hazard content or proneness to failure of an artefact. The axes of this multidimensional space can represent both quantitative and qualitative "measures", thus allowing for inclusion of features such as human error. If one of the axes of the multi-dimensional space is time, the "state point" will run through time from conception of a project through design, construction, and use, until some stage after decommissioning and demolition.

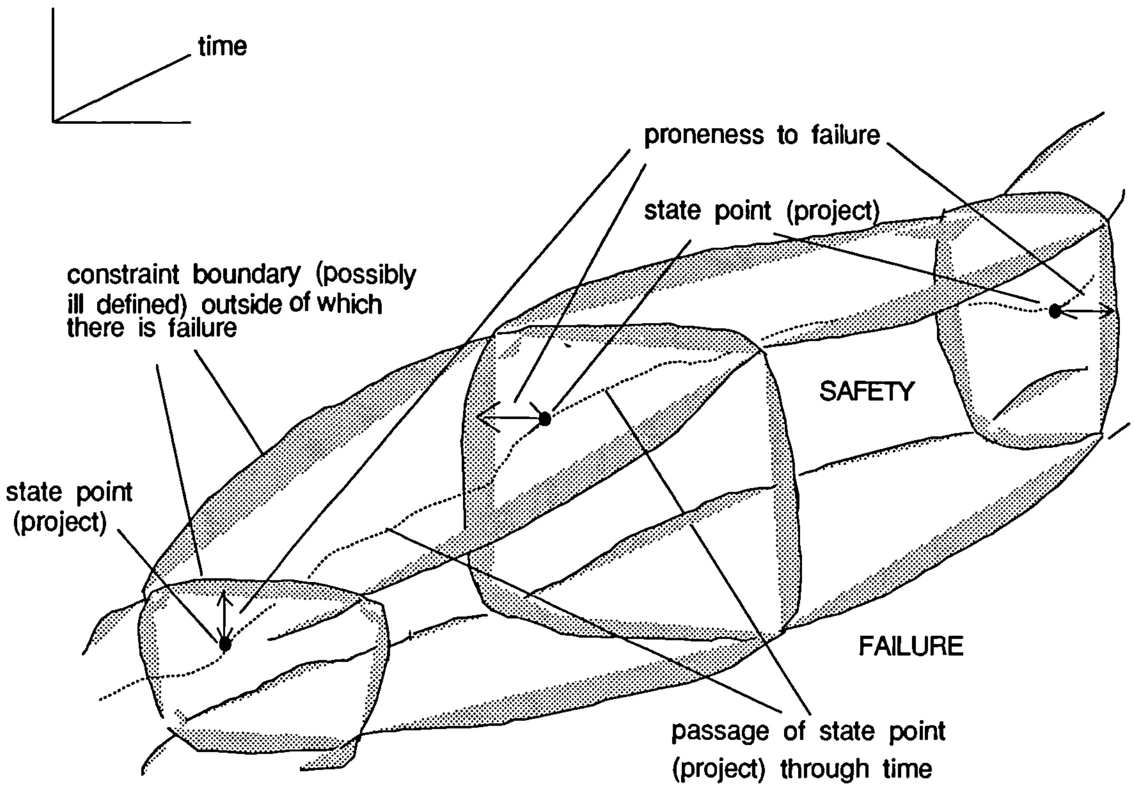


Fig. 2.6 Representation of proneness to failure within a 3 dimensional hypervolume, one dimension being time.

For this research, proneness to failure is taken to apply to physical integrity, whether limit state or serviceability, and the safety of people. Other forms of failure such as economic or aesthetic are of secondary concern but they may provide evidence of proneness to failure in the context stated above.

An assessment, or interpretation, of the proneness to failure of a project is based on judgement of the accumulated evidence arising out of an audit.

2.5 Auditing for safety.

Kletz, (1990), records that in 1910, what would now be called audits of fire hazards and plant conditions were carried out, by outside experts, for Solvay, a U.S. company. Systematic checking to mitigate failure is probably as old as "mankind", but over recent years the term "safety audit", has increasingly been used to describe such procedures. There is broad interpretation of what constitutes a safety audit, including audits of unsafe acts or conditions, audits of the management of safety, and safety inspections. The important point is that an audit is a formal, systematic, critical examination.

The chemical industry has a well established record in the use of safety audits. The impetus to improve safety performance in the U.K. chemical industry seems to have resulted, to a large degree, from a report called, "Safe and Sound", (British Chemical Industry Safety Council, 1969), which describes an investigation of safety practices in five large U.S. chemical companies, their U.K. subsidiaries, and four small U.S. chemical companies. The report concluded that the safety performance of the U.S. companies, specifically chosen for their good safety records, was better than all but a few of the British chemical companies. This report "did much to introduce safety auditing into the U.K.", (Kletz, 1990, page 31), and in 1973, the British Chemical Industry Safety Council, (1973), produced a guide to safety auditing in the chemical industry. In this publication, safety audits are advocated as a means of assessing the quality of safety effort which, it is stated, is not necessarily indicated by quantitative measurements of losses. This point is echoed by the Health and Safety Executive, (1976), who state that accident frequency or incidence rates are not a reliable guide to safety performance and suggest the use of systematic inspection and auditing to provide an assessment of "efforts to control reasonably foreseeable risks". The 1973 guide, lists (page 7) five main elements to be addressed by an audit. These are:

1. *Identification* of possible loss-producing situations.
2. *Assessment* of potential losses associated with these risks.
3. *Selection* of measure to minimise losses.
4. *Implementation* of these measures within the organisation.
5. *Monitoring* of the changes.

In this publication, therefore, auditing is seen as a procedure for the identification and assessment of hazards, as part of the management process, (selection and implementation of measures, and monitoring of changes), for the control of hazards.

The Chemical Industries Association, (1991), has revised the safety audits guide of 1973, to include safety, occupational health, and environmental protection. This publication allows that the scope of an audit can vary; from a supervisors inspection to a corporate site review; to cover any combination of safety, occupational health and environmental protection; to include any activity, systems of work, and conditions. The statement, (Page 5), that "Auditing is the most effective way of ensuring that standards are maintained and improved," has the authority of years of experience of safety auditing. Guidance is given on such matters as auditing frequency, auditing teams, procedures, the scope of the audit, and the need for an audit plan.

Another hazard management technique used in the chemical industries is Hazard and Operability studies, (HAZOP). This is a systematic critical procedure for hazard identification. It is an audit of the design intention, applied at various stages in the development of a new process or plant or in a major alteration to an existing one. A detailed description can be found in Kletz, (1986). Hazard Analysis, (HAZAN), usually referred to with HAZOP, (i.e. HAZOP and HAZAN), is the quantitative assessments of hazards. Also described by Kletz, (1986), it is a numerical method of assessing selected hazards, based on an estimation of how often an incident will occur and the estimated consequences.

The International Atomic Energy Agency, (1980), produced a **safety guide**, setting out requirements and recommendations for establishing a system of audits of a quality assurance programme. It applies to the design, manufacture, construction, commissioning and operation of nuclear power plants. The following requirements of auditors are listed: qualification of audit personnel in specialist knowledge and experience of areas audited; knowledge and experience of audit techniques; knowledge of codes, procedures, and industrial processes; training, and maintenance of proficiency in quality assurance principles and techniques, and in the application of codes and practices. These requirements suggest that auditing needs to be regarded as a specialist activity. Other requirements indicate a need for effort and commitment. These include: audits have to be planned and well organised; auditors should have access to specialists, to all levels of management, and to information and facilities as required; the responsibilities and authority of auditors should be clearly defined; recommendations for action should be followed up.

Du Pont, a United States chemical company, which has an outstandingly good safety record, (Kletz, 1990), is an advocate of auditing. Monk, (1988), describes a safety audit procedure used by Du Pont. This entails regular inspections of a work-place, which although not neglecting unsafe conditions, is orientated towards people's behaviour in terms of unsafe acts. It is not stated that the audit need follow a documented procedure, but it is a formal systematic process. It is advised that written records of observations and recommendations be made to help monitor corrective action. An interesting proposal is that audits be carried out jointly by personnel from different levels of management and work-force, and that the combinations of personnel be varied in successive audits. This, it is suggested, as well as making everyone in the plant an auditor, enhances the climate for safety.

The audits described so far take the form of guidance, but there are more formal auditing methods that document specific activities, procedures and systems that need to be examined. Possibly the most well known of these is the International Star Rating System, (ISRS) audit, produced by the International Loss Control Institute, (1988). Described as a guide, it sets out twenty major elements or categories. For each category there is a detailed questionnaire. Scores are awarded for each answer, producing a rating for each category. The accumulated rating is a "measure" of an organisation's safety effort. The categories are:

Leadership and administration.

Management training.

Planned inspections.

Task analysis and procedures.

Accident/incident investigation.

Task observation.

Emergency preparedness.

Organisational rules.

Accident/incident analysis.

Employee training.

Personal protective equipment.

Health control.

Programme evaluation system.

Engineering controls.

Personal communications.

Group meetings.

General promotion.

Hiring and placement.

Purchasing controls.

Off the job safety.

The ISRS audit has been introduced in the U.K., most notably on the Channel Tunnel project, (Construction Weekly, 1990), and on the London Underground (New Civil Engineer, 1990a). The ISRS provides for an audit of the management of safety within an organisation, as part of a programme of safety auditing. For example, under item 13, (pages 136 - 149) there is a requirement to evaluate compliance with standards of: the ISRS audit itself, technical audits, fire prevention and control audits, and occupational health audits. Individually, each of these elements involves comprehensive examinations of systems, procedures, equipment, and inspections, requiring a great deal of time effort and resources. Gaunt, (89-2), produced a report, funded by the International Loss Control Institute, of a study of the effect that the ISRS has on organisational performance. The study reported on 173 organisations who had used an ISRS audit. The report concluded that the positive effects from use of the audit were:

Improved management skills.

Improved accident frequency and reduced severity.

Improved investigation.

Improved safety inspection and emergency procedures.

Improved safety awareness.

Improved safety programme development and documentation.

Improved communication and participation.

The negative effects were:

Too much paperwork.

Increased workload and time in supervision.

Major effort and time for implementation.

Interesting features of the ISRS audit are:

- The audit is focussed on an organisation, (company), or company operation.
- The audit tries to set a standard for safety, and attempts, by using ratings, to assess to what extent the standard has been achieved.

If the basis for an examination is an organisation, inter-dependencies, for example between organisations, may be overlooked An alternative approach would be to examine operations, (e.g. a project). This would force considerations of the interdependencies that are outlined in clause 2.3. Although the use of ratings facilitates comparisons between audits, it may not necessarily be appropriate. In using a rating system for safety auditing, there is a presumption about standards of safety and the relative importance of factors that are thought to influence safety, but the effects of different factors and their interactions change with circumstances. This means that predetermined quantitative relationships may not be appropriate to different situations, and in some circumstances may create an unjustifiable sense of security. Judgements as to the overall and relative effects that different factors have on safety should be made during both auditing and analysis of results. There is also the possibility that improvement of ratings, rather than of safety, becomes the priority. This may result in safety improvements, but perhaps not the levels of improvements that might be achieved if safety were the priority.

The hierarchy developed in this research, for the design of audits, allows for a different approach, in that:

- The focus of the audit is a project. This explicitly provides for an examination of inter-dependencies amongst organisations, industries, and social environments. These dependencies could be overlooked in an examination that focuses on an organisation.
- No predetermined standards of safety are set. Hazards are searched out as evidence of proneness to failure. The extent of the proneness to failure is evaluated on the basis of the accumulated evidence in the particular circumstances of the situation under examination
- The use of ratings is avoided. It is proposed that by concentrating on identifying proneness to failure the objective of mitigating failure is not lost or compromised by other objectives such as improving ratings. Qualitative evaluation should be facilitated if it is carried out by specialists, trained to make such evaluations, (see chapter 7, clause 7.2).

"Construction Chase", produced by the Building Advisory Service and Health and Safety Technology and Management Ltd, (1990), is an another formal audit that uses ratings, and therefore tries to set standards. It is an audit at two levels of contractor's (construction) organisations. At company level, to check the adequacy of project planning procedures, it is completed by a director, senior manager, or manager responsible for project planning. At site level, as an aid to the management of health and safety, it is completed by a site manager or someone having responsibility for day to day site operations. Because it involves a "self examination", there must be doubts about impartiality. It is questionable whether safety culture, (Chapter 7, clause 7.4.3), in the construction industry is strong enough to ensure impartiality or remove doubts. Poor attitudes or culture are likely to reduce rigour in auditing and may lead to abuse of the rating system, where improvement of ratings takes precedence over improvement of safety.

In some respects, the Construction Chase audit does not appear to take assessments far enough. Consider for example the following extracts:

A3.4 Personnel: Recruitment and induction.

In Project Planning, is consideration given to:

A3.4a The use of bonus systems which allow for full compliance with health and safety rules?
A3.4b Recruitment of personnel with special fitness needs (e.g., for work in confined spaces)?
Etc.
(Page 22)

A3.5 Personnel: Supervision.

In Project Planning, are appropriate arrangements, including training, made to ensure:

A3.5a That managers and supervisors **accept** and **understand** their general and specific responsibilities for health and safety?
A3.5b Adequate supervision of the work of employees?
Etc.
(Page 23)

These questions provide for an assessment of policy and organisation, but there is no means of directly determining whether "considerations" have been actioned, or arrangements implemented. Such deficiencies are similar to those referred to by Cullen, (1990), in the inquiry into the Piper Alpha disaster: Page 224, para. 14.10.

> I do not fault Occidental's policy or organisation in relation to matters of safety. However, in previous chapters I have had to consider a number of shortcomings in what existed or took place on Piper. This calls in question the quality of Occidental's management of safety, and in particular whether the systems they had for implementing the company policy on safety were being operated in an effective manner.

Perhaps a more obvious example of such a deficiency is in the assessment of excavations (including shoring), under management of tasks and operations 1. (Page 49). The full list of questions is as follows:

Where work involves excavations:

B3.2a Have you selected excavation plant carefully as suitable for the work to be carried out?
B3.2b Is the operator competent to carry out the work required and has his training achievement been certificated by the CITB?
B3.2c Has a method statement been produced for the excavation work and for the support of the excavation and all associated protection?
B3.2d Have you identified all Regulations, Codes of Practice and Guidance which

apply to excavation work?

B3.2e Have the statutory "competent persons" been appointed to carry out regular inspections and examinations and have they been properly trained to carry out their tasks?

B3.2f Do you carry out inspections and examinations at appropriate intervals and enter the results in the prescribed register?

B3.2g Do you have a system for monitoring the frequency of inspections and examinations and for taking action on any faults discovered?

B3.2h Do you have an audit procedure for checking the effectiveness of the inspection, examination and recording programme?

Each question could be answered as "yes", giving a maximum rating, but there is no provision for assessment of whether the systems or procedures for inspections or auditing are actually being carried out. This would appear to be an omission in an audit designed for site operations.

It seems clear that both the ISRS and Construction Chase audits deal with aspects of safety in specific contexts, with respect to particular organisations. They relate to quantitatively fixed relationships between factors, (activities, procedures systems) that are believed to influence safety, irrespective of circumstances. The hazard audit, represented by the hierarchy of concepts proposed by this thesis, looks at safety in a wider context that covers society, industry, project and project phase. Although linked to an examination of a construction project, it can be applied to an organisation. It looks for evidence of proneness to failure which is not prejudged by the allocation of predetermined levels of significance. The evidence needs to be evaluated at the time of an audit and judged in the subsequent analysis. Audits designed from the hierarchy are intended to establish a qualitative assessment of proneness to failure. This assessment, and the evaluations that produce it, can be used to decide what action, if any, is required to alleviate any problems.

2.6 Classification of hazard audits.

In looking at the context of an audit, it is useful to consider the model of disaster proposed by Turner, (1978). The development of disaster, its occurrence and aftermath are described as follows, (page 85):

Stage I; represents the normal culturally accepted beliefs of the world and its hazards, with the precautionary laws, codes of practices, and traditions, that exist to deal with the world and its hazards.

Stage II; is the incubation period. There is an accumulation of unnoticed events, which are contrary to the accepted beliefs about hazards and the norms for their avoidance.

Stage III; is the precipitating event, whose characteristics and consequences reveal the previously unnoticed events of the incubation period in their true form.

Stage IV; is the onset of the direct and unanticipated consequences of the failure.

Stage V; is the rescue and salvage.

Stage VI; is the cultural readjustment.

The event immediately preceding the precipitating event, which is sometimes interpreted as the cause, can be referred to as the trigger. The trigger is likely to be at the end of a chain of events or a number of chains which can stretch back to the pre-incubation period. The conditions that exist and develop from the pre-incubation period, through incubation, to culminate in an incident, are common. This commonality is an important feature of Turner's model. It means that no project is immune from disaster, and importantly, that lessons can be learned from disaster, that are applicable to all situations. The precipitating event may be unique, but the conditions that existed in industries or projects that have suffered major incidents are just as likely to exist in others.

It is possible to associate different audits with stages or parts of stages of the "disaster" sequence. For example, a "management of safety" audit covers part of the incubation period. If it includes emergency precautions and incident investigation, it can also be associated with the rescue and salvage, and cultural readjustment. In diagrammatic form the association between disaster sequence and audit type is illustrated in fig. 2.7. Because audits in current use have recognizable labels, the audit associated with this research will be referred to as the hazard audit.

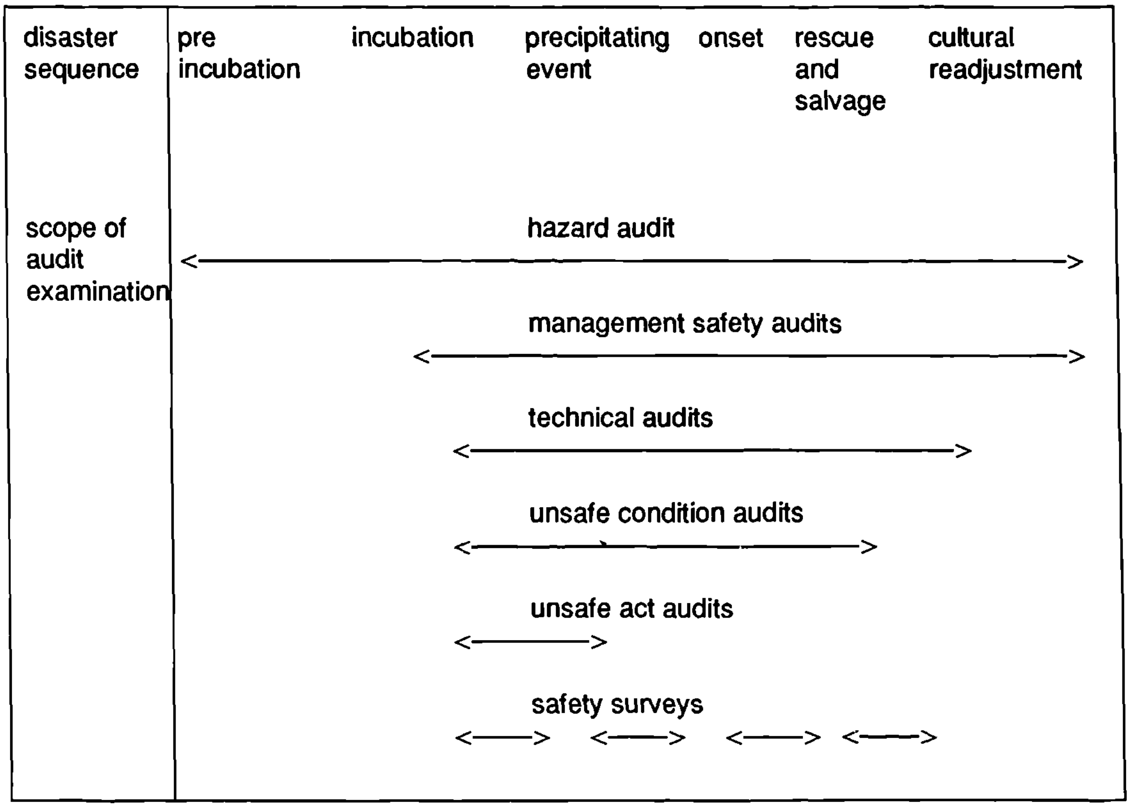


Fig. 2.7 Association between the scope of an audit and the disaster sequence.

This association can be used to describe an audit in terms of "levels" that relate to the scope of the disaster sequence covered by the audit. Fig. 2.8 illustrates the comparative levels of different types of audit.

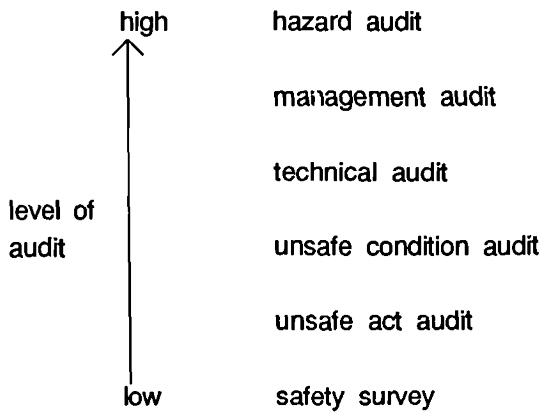


Fig. 2.8 Levels of audit

There is a dependency between higher level and lower level audits, which can be incorporated in a programme of auditing. In higher level audits there should be a provision for the examination of lower level auditing. For example, the ISRS audit looks at how well technical aspects are evaluated through separate audits, and how well there is compliance with appropriate standards (Clause 13.2, pages 138 - 141). There are separate evaluations of the auditing, and of compliance with the standards of; fire prevention and control, (clause 13.3, pages 142 - 144) and occupational health, (clause 13.4, pages 144 - 147). For rigour, audits should include a self examination of how well they are being conducted and acted upon. In general, the lower the level of audit, the greater the frequency of auditing. Lower level audits, such as of unsafe acts, can be carried out internally by an organisation, but there is increasing desirability for external audits as the level increases. At the highest level, they should be conducted by independent specialist auditors.

Although there is benefit in a one-off examination of proneness to failure, the greatest benefit will come from a continuing programme of auditing at all levels. Audits through the life of a project, which incorporate the wider context of both industry and society, provide opportunities for improving control of subsequent events. For example, early project audits, with accurate assessments of the probable predominant societal and industrial influences can provide useful information for the production of designs, systems and procedures, to make them amenable to the state of the art, culture, and circumstances under which the project is to be constructed. Monitoring and feedback from a programme of auditing allows for planning and control which are central to management.

As well as looking for common features that are thought to fuel the conditions for failure, audits need to be flexible enough to deal with changing circumstances. A hierarchy, of concepts that have the potential to provide evidence of proneness to failure, allows for this in providing a structure for the design of audits.

2.7 Representation of hierarchy concepts.

To be presentable in hierarchical form, concept labels are inevitably shortened versions of definitions and descriptions. Because it is not practicable to convey a precise meaning and explanation of relevance in such a shortened form, each concept needs to be fully described and explained elsewhere. A full description can be incorporated into a data base, to be used in conjunction with the hierarchy. Fig. 2.9 illustrates an "object form" description of the "state of the project".

Name: State of the project.
Reference: 1.3
Project and audit Nos:
Short definition: The capacity within a project to provide for its safe development, use, and withdrawal from use, as intended.
Long definition:
Attribute: Poor.
Assessment:
Higher concept: Proneness to failure.
Lower concepts: Overall project management; project history.
Other dependent concepts: State of society; state of the industry.
Questions: What evidence is there of a poor state of the project? To what extent does this evidence indicate a poor state of the project?
Guide: For evidence of a poor state of the project examine:
The arrangements for the overall management of the project.
The project history. This covers the phases of; conceptual design, design, construction, operation, decommissioning and demolition, and post decommissioning and demolition. The most relevant phase is the current phase.

Fig. 2.9 Object form description of the "state of the project".

Reference to fig. 2.5 is assumed in the following explanation of the object form representation shown in fig. 2.9.

The concept **reference** system is illustrated in fig. 2.10.

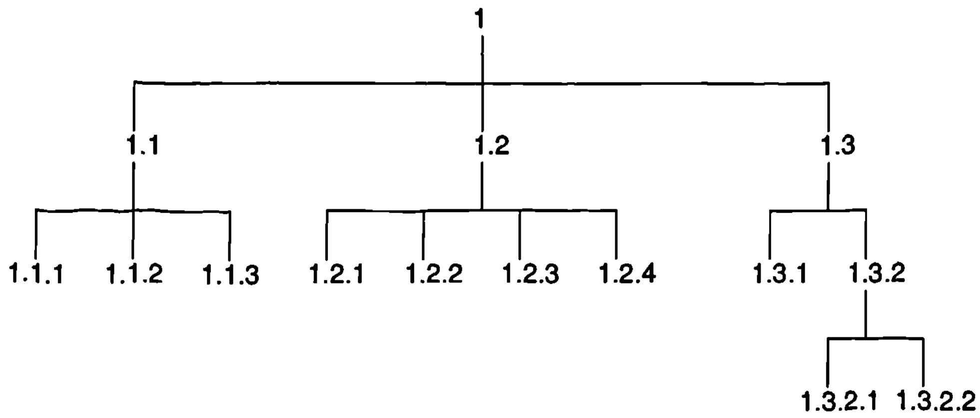


Fig. 2.10 Illustration of the concept reference system.

The **project number and audit number** allow for referencing project and audits.

Each concept has a **short definition.** A **long definition** is included if further explanation is thought necessary.

The **attribute** is the measure of the concept as an indicator of proneness to failure. It will be in linguistic form, such as; poor, high, low. It could be yes or no, (i.e. there is, or there is not).

There may be a tendency to qualify assessments in terms of; quite poor, very high, to some extent yes. Depending upon the confidence in the evidence, there will be degrees of uncertainty about the assessment. To cater for these features, the use of interval probabilities might be considered in further developments of the application of the hierarchy. (Cui and Blockley, 1990).

Direct dependencies between concepts at successive hierarchical levels are described by a **higher level concept** and **lower level concepts. Other dependent concepts** that have been generated from the same higher level are describe separately.

The **questions** to be answered for an assessment will usually be of the form: What evidence is there of.........? To what extent does this evidence indicate.........? The second of these questions implies the need to consider evidence in relation to any mitigating circumstances.

Guidance on what needs to be considered in an evaluation usually relates to lower level concepts.

2.8 The hierarchy as a systems approach.

The hierarchy can be thought of in terms of a systems approach such as examined by Churchman (1968), who discusses systems thinking with respect to five minimal considerations:

1 System objectives including performance measures of the overall system.

2 Environment, or the fixed constraints. The environment influences the system but cannot be controlled by it.

3 Resources that are available to the system. These are used to shape the activities of the system.

4 Components and their activities, goals and performance measures. These are the subsystems that use the resources.

5 Management of the system.

An objective of the elimination of failure is not real because there are influences, some known, such as human behaviour, and some unknown, that cannot be controlled. Nor is it legitimate because there are other goals such as financial gain, pleasure, and comfort, that will not be sacrificed. The real objective will always be qualified. Whether admitted or not, the objective may be as vague as minimising the occurrence of failure. The performance measure is the incidence of failure. Given particular resources and constraints it is probable that there is some level of incidence of failure beyond which improvement is not possible. This point is made by Adams, J. (1985), in the context of road safety. He argues that a world of zero risk is unattainable and undesired, and observes that: (Page 169).

> If risk taking is an inescapable human attribute, then the safety campaigner's pursuit of a state of zero risk will be as futile as the physician's pursuit of immortality.

This makes an objective of the elimination of failure unrealizable, and according to Adams, undesirable because it recognises no limits to the resources available for its achievement. Rather, the limiting level of incidence of failure is analogous to the "norm" described by Vickers (1983). At this level of failure the objective would be that of "norm holding". However, because of the interactions between, and the changing nature of, environment, resources, and components, the norm can change. The system and subsystem objectives, the environment, resources, and components need to be defined.

Aspects of management are distributed throughout the hierarchy.

The hierarchy is a conceptual model of hazards to be compared to a specific situation such as a civil engineering project. It therefore represents the starting point in a systems approach to hazard auditing. Comparisons of the hierarchy, (the conceptual model), with a project will involve thinking within the constraints imposed by the larger systems of project, industry and society. This exemplifies "the law of conceptualization" as stated by Checkland, (1981), page 237.

> A system which serves another cannot be defined and modelled until a definition and a model of the system served are available.

The definition and model of a larger system, (project, industry, society), will dictate the constraints, resources, and the components that apply to the system, (the provision of safety), and its subsystems that include the "proneness to failure hierarchy" and hazard auditing. If the conceptual model, (the hierarchy), is rich enough, comparisons with a construction project may mean that some concepts are thought of as part of the system environment to account for the constraints applied by the system being served, (a construction project). The resultant model is likely to be more accurate and complete than if concepts are built up from scratch to match a specific situation.

The hierarchy is not complete. There will be missing concepts because there are always unknowns in problems associated with safety, (chapter 3, clause 3.3). The complex inter-relationships between the different concepts continually change depending on circumstances. The hierarchy, though, does provide the basis for a systems approach.

2.9 Summary and conclusions.

The construction industry has a poor safety performance record. It is an appropriate context for an investigation into the mitigation of failure.

A project should be considered to encompass its full life of development, use, and withdrawal from use. This can be classified into phases of: feasibility and planning; conceptual design; design; construction; operation; decommissioning and demolition; post decommissioning and demolition.

Improving safety is synonymous with reducing proneness to failure. The essential first step in addressing the problem of failure is the identification of hazards. Hazards that provide evidence of proneness to failure in a particular situation may have developed independently of that situation. Specifically, hazards that manifest themselves in a construction project, may have developed from; other phases of a the overall project, the overall project management, other projects, industry, or social environment, that are in any way linked to the construction project.

Some hazards are peculiar to particular industries, but the conditions that allow for the incubation of incidents are common to all projects and industries. Such conditions, therefore, are significant to hazard control, irrespective of type of project, industry, or sector of society.

Hazard auditing provides a procedure for the identification and assessment of hazards. It is a management tool for the control of hazards.

There is a need to develop hazard audits that examine all conditions that can influence failure. This includes the conditions that allow for the incubation of hazards which can often go unnoticed until they manifest themselves in a form which cannot be ignored, such as the occurrence of an incident.

The development of a hierarchy of concepts that have the potential to provide evidence of proneness to failure, can provide a structure to be used in the design of hazard audits. It deals with the commonality of hazards, but allows for flexibility in the design of audits for different situations.

The hierarchy is a conceptual model that can serve as a starting point in a systems approach to the identification of hazards. The model can be compared to a construction project and an audit can be designed which allows for the constraints applied by society, industry, or project.

Audits can be classified in terms of their scope and content by reference to the model of a disaster sequence. A disaster sequence, (Turner, 1978), covers the conditions and events that influence the occurrence of a disaster and its aftermath. This covers all states between the "normal situation" before and the "normalised situation" after, a disaster. Audits that cover the full extent of this sequence are high level. Those that deal with elements within the sequence are low level. Those nearer the completion of the sequence are of the lowest level.

Hazard auditing should be regarded as the programmed implementation of audits of different levels. The use of low level audits should be examined in higher level audits. Audits should include a self examination of their own use.

The functioning of systems, procedures and activities needs to be examined if an audit is to be more than a checklist to ensure that systems and procedures are in place.

Chapter 3.

Research method.

3.1 Objectives.

1 To outline the research procedure.

2 To outline the philosophy of the method used to develop the "proneness to failure" hierarchy.

3 To describe the elicitation of knowledge through interviews, and the use of grounded theory for the analysis of interviews.

3.2 Introduction.

The first step in this research was familiarisation with safety and safety auditing. This, and the process of information gathering was achieved initially through a literature survey, which is outlined in chapter 4. As the research progressed, the context, as described in chapter 2, became clearer, and the procedure evolved in more detail.

3.3 Procedure.

Although the procedure is outlined below as distinct activities, in practice, there was considerable overlap.

1 Literature survey for familiarisation with the topic of safety, and for gathering information for inclusion in the "proneness to failure hierarchy".

2 Interviews with practitioners from industry. Analysis of interviews using "grounded theory" to generate concepts for comparison with, and inclusion in the hierarchy.

3 Development of a hierarchy of concepts, with descriptions and definitions.

4 Comparison of hierarchy concepts with those obtained from; interview analyses, literature survey, and any other source. Modification of the concept hierarchy as appropriate.

Although literature was a continuing source of information; for the first five months of the research, a literature survey was the principal activity.

After this initial period, interviews of safety practitioners in industry were begun. These, and their analyses, were carried out intermittently over a period of about eight months.

Shortly after beginning the interviews, preliminary work started on the development of the "proneness to failure" hierarchy. After formal interviewing, this became the main activity. Development and modification of the hierarchy continued throughout the research. This activity was independent from the process of knowledge acquisition through interviews in that there was no formal explicit input into the hierarchy, of knowledge gained in the interviews. Obviously though, there was an implicit input. The process of developing the hierarchy was itself a valuable tool of the research, in that building up and linking concepts allowed for a systematic method of working.

Grounded theory analysis of interviews, was used to generate categories, (concepts), relevant to the prevention of failure. These were compared to the independently produced hierarchy concepts. Because it was felt important to try and identify as many concepts as possible, other check-lists of factors relevant to safety, (or proneness to failure), were also produced. One list came from the initial literature survey. (See chapter 4, and appendix A). A second list, arose out of the ongoing research; from literature, discussions, thoughts, and ideas, as and when they occurred. The formal comparison of concepts generated from interviews, the initial literature survey, and ideas that occurred throughout the research, with those in the hierarchy began when it was felt that the hierarchy was as complete as it could be. Where necessary the hierarchy was modified.

It is clear from discussions in chapter 2 that problems associated with safety are full of ambiguities, inconsistencies, uncertainties, and unknowns. These can be described as "open world problems", (Blockley, 1989), where all possibilities have not been identified, as distinct to "closed world problems", in which all possibilities have been identified, although sometimes not very clearly. Knowledge about such problems needs to be gained from any source which is able to contribute relevant information. People have different worldviews, or ways of looking at the world, (Wilson, 1990). One effect of acquiring this knowledge, is that different perceptions, based on other's worldviews, are incorporated into the problem solving cycle. In developing the hierarchy, my own worldview will determine my perceptions. Other's perceptions will be interpreted in the context of my own worldview, but my own worldview and hence perceptions will be influenced by other's perceptions. This process, because of the open world nature of the problem can produce an even messier problem. This should not be considered undesirable, since problems such as the provision of safety have, so far, not been solved by reduction to more manageable proportions. There is a requirement to address such problems in their messy form.

The research procedure could be modelled by the usual characterisation of the problem solving loop of: (Blockley, 1992).

problem——>collect information——>find alternative solutions——>evaluate alternatives——>select an alternative——>implement solution——>follow up consequences——>review situation——>new problem.

However, as suggested by Blockley, (1992), this model does not capture the importance of perception and worldview, and the integration of perception, reflection and action is missed. The method of this research is more appropriately represented by the model of reflective practice proposed by Blockley, (1992), and reproduced in fig 3.1. This model, illustrates the integration of perception, reflection and action, and the recursive nature, (of loops within loops), of the process used in the research method. It models the concurrent interactive activities of hierarchy development and knowledge acquisition that is central to the research method.

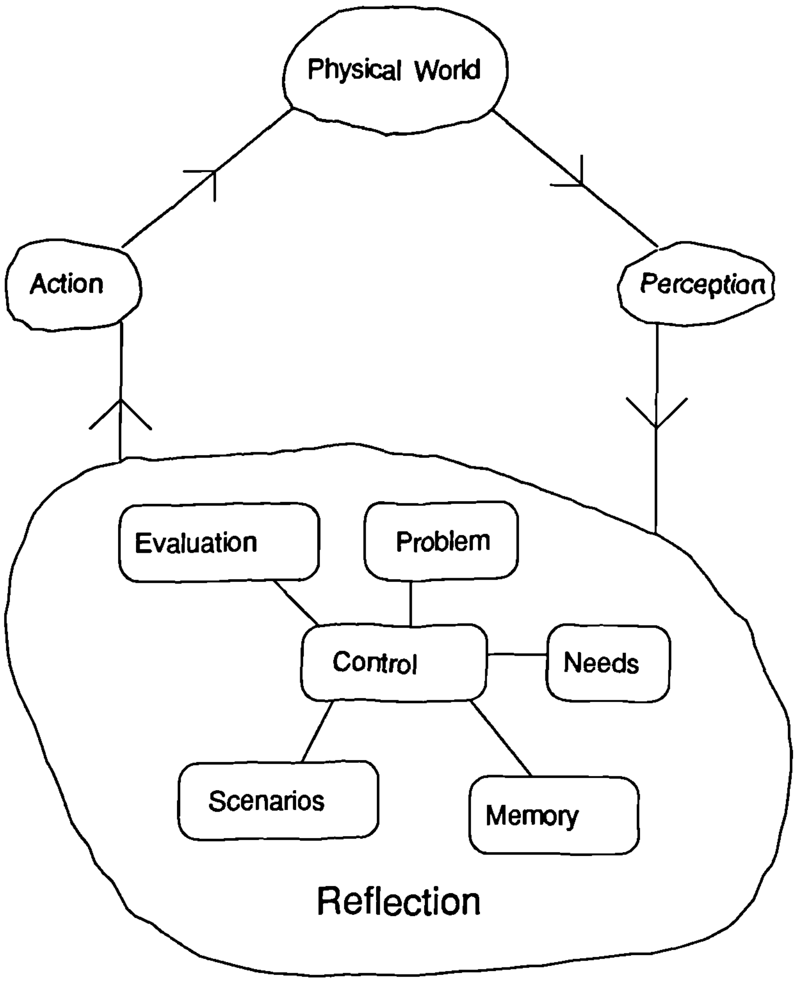


Fig. 3.1 The reflective practice loop

3.4 Knowledge elicitation.

One source of knowledge is in practitioners whose interest or work lies in the field of safety. The topic of safety is so open ended and wide ranging in content, that systematic methods of eliciting information from this source are largely inappropriate. Methods such as the repertory grid, (Gaines and Shaw, 1980), protocol analysis, (Ericsson and Simon, 1984), and concept sorting, (Gammack and Young, 1985) are too restrictive, requiring the problem to be well defined. Processes for probability encoding such as described by Merkhoffer, (1987), are used to quantify uncertainties in already well established models of problems. Interviews were judged to be the most appropriate way to identify basic concepts, (Gammack and Young, 1985). The interviews were analysed using a procedure outlined by Pidgeon, Turner and Blockley, (1991), based on a technique known as Grounded Theory. This technique was developed by Glaser and Strauss, (1967) for social science research.

3.4.1 Interviews.

A semi-structured style of interviewing was adopted. This style provides a framework within which an interviewee feels free to elaborate his, or her, ideas. The interviewer uses an aide-mémoire of themes or topics which it is felt are relevant to the knowledge domain. The degree of structure of the interview depends upon the topic, the response of the interviewee, and the personal style of the interviewer. Guidance on this method of interviewing can be found in Burgess, (1984), and Gorden, (1975).

The initial contact, to arrange interviews, was by telephone; to either a known individual or the safety department of an organisation. If requested by the prospective interviewee, this was followed up with a letter, briefly outlining the research. Interviews were arranged with all but one person/organisation approached in this way.

At the beginning of the research, one organisation was approached by letter, but there was no response.

If acceptable to an interviewee, the interview was tape recorded. Of the thirteen interviews, seven involved tape recording. Notes were taken during interviews, whether taped or not. These were written up, and recordings transcribed as soon as possible. Once transcribed, taped interviews were erased, as promised. Unless otherwise stated there was one interviewee per interview. Twelve interviews involved people who's main role was in the management of safety. These "safety practitioners" possessed varying degrees of experience, having held, or being in, management positions at various levels up to top company level. The other interview was with a practising consultant civil engineer. The interviews have been labelled from A to M, in the order in which they were carried out. The author's background is in construction, (contracting), and to obtain a different perspective, it was decided to begin the interview programme with safety practitioners from outside the construction industry. Of the first four interviews, three were with practitioners from the chemical and process industries, (interviews A, B, which were taped, and D, which was not.) Interview D involved three different personnel. The organisation represented in interview C had a more general background that covered primarily, safety in petrochemical, industrial, and offshore industries. For interview C, there was input from four different personnel of which three were tape recorded. Six of the remaining interviews were with safety practitioners from three large major UK based construction companies. (Interviews: E-taped, F-taped, H-not taped, I-not taped, J-not taped, and L-taped). Four of these (F, H, I, and J) were with personnel from four different "companies" within the same group, including the main controlling company. Interview G, (untaped), obtained input from three different personnel from an organisation with an interest in safety throughout industry. The background for Interview K, (taped), was in civil engineering consulting. Interview M, (untaped) related to the mining industry.

I feel that the atmosphere of the interviews was friendly and open. Information appeared to be freely given. This was probably aided by the semi-structured nature of interviews. It appeared, to me, that interviewees held views that had been given previous thought, and generally speaking, responses did not appear to be off the cuff affirmations of company philosophy, or views that they thought I wanted to hear.

3.4.2 Grounded Theory.

Pidgeon, Turner and Blockley, (1991), suggest that the problems of knowledge elicitation and qualitative social science studies are similar. Table 3.1 reproduces their comparison of characteristics common to qualitative social science research and knowledge elicitation.

	Characteristics of qualitative research	Characteristics of knowledge elicitation
1	Qualitative data	Qualitative knowledge sources
2	Behaviour can only be understood in context	Expertise is not readily divorced from task domain
3	Subject orientated methods	Expertise is required from individual expert(s)
4	Complexity of phenomenon	Expert knowledge is complex
5	Critical role of tacit knowledge	Expertise incorporates strong tacit components
6	Emphasis upon the discovery of theory	Absence of strong a priori models emphasises learning through discovery
7	Grounded approaches: data drives theory	Models are generated from the expert testimony
8	Analysis is interpretive	Knowledge elicitation is a process of interpretation
9	The role of researcher as a "research tool" is critical	The role of the knowledge engineer as an interpreter of testimony is critical
10	Closeness of fit between theory data is a prerequisite	Closeness of fit between model and expert testimony is a prerequisite
11	Outcome should reflect the participants' social reality	Outcomes should reflect the experts' understanding of the problem

Table 3.1 Comparison between characteristics of qualitative research and knowledge elicitation.

Because of the similarities described in table 3.1, Pidgeon, et al, suggest that grounded theory which is used in social science studies to generate theory from qualitative data, can be applied to knowledge elicitation from qualitative knowledge sources. Developed by Glaser and Strauss, (1967), grounded theory is a methodology that generates theory that is grounded in qualitative data. This, though, does not guarantee dependability. For example, views expressed, even by experts, are not independent, if they simply reiterate "fashionable" theories that have become accepted on the basis of the reputation of the expert proposing the theory. In fact, this concern is not especially significant to the development of the hierarchy, where the main objective is to identify as many concepts as possible that have the potential to provide evidence of proneness to failure. Testing comes later, through use the hierarchy and the audits produced from it. (This is discussed in chapter 7, clause 7.7.2). For this research, interviewing and analysis to elicit knowledge serves two purposes.

1 As a check of independently produced hierarchy concepts.

2 To add, if new concepts arise, to the hierarchy.

Theory developed from interview data, in the form of concepts, is used to complement and supplement part of a wider theory, (the hierarchy). The concepts of the hierarchy are parts of the theory, but they are also theories in themselves. They are holons, a term first used by Koestler, (1967), to describe the idea of something which is both a whole and a part.

Two important features of the grounded theory approach, emphasised by Glaser and Strauss, (1967), are that the generation of theory from data should not be compromised by a desire to test the generated theory, and that the theory should not be "forced" to fit preconceived theories. The aim to produce as extensive a hierarchy as possible was a natural control on any desire to test generated theory. Not formally linking the hierarchy development to the interview programme was a precaution against letting preconceived ideas influence the generation of theory. However, "forcing a fit", needed to be consciously avoided in comparisons between hierarchy concepts and generated, grounded, theory.

The procedure used for this research is based on that described by Pidgeon, Turner and Blockley, (1991). Fig 3.2 reproduces their representation of the process.

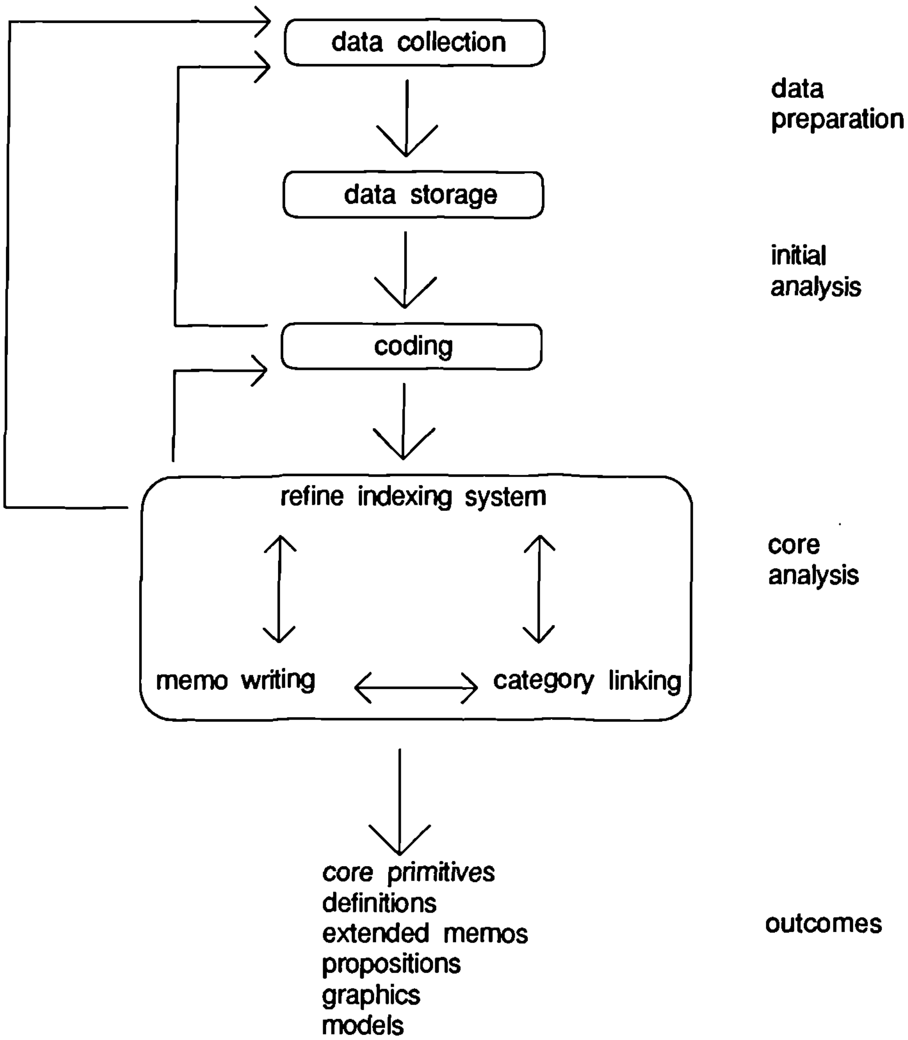


Fig 3.2 Steps in Grounded Theory analysis

Data collection, (the interviews), has been outlined in clause 3.4.1.

The first step in data storage is to organise interview data. Notes are written up, and interviews transcribed. To facilitate analysis, the interview is referenced to the interviewee, and each paragraph, (or question and answer), is numbered. The following extract from Interview L illustrates this: This example will be followed through in the description of the interview analysis.

INTERVIEW L.

Q. The construction industry has a bad reputation in safety. What do you think makes the construction industry different to other industries? Are there any particular difficulties?

Para 1. A. Obviously the main difficulty is movement of labour between sites, and the fact that people tend to be on sites for days, or at the most months and then onto another site, different location, perhaps different supervisory staff, management, and they don't get a fixed work location. Within the construction industry, as you're probably well aware, almost half of all fatalities occur within one week of arriving on a site anyway. That is an HSE figure. So we can see, the more frequent a person moves, the more critical a learning path they have on their next site. So as far as you saying we've got a bad record, we've certainly got a record that doesn't compare favourably with other industries, but the reason I've just given, probably not an excuse, but the reason, is because we haven't got a set work place, if you like, a settled work place. There is a certain amount of movement, plus the fact, obviously, that people are taken on, by contractors, who aren't properly trained or competent people; and those people that are taken on in the short term are at a disadvantage in the work place from day one, because not only are they unaware of what they might be doing and what hazards there are with their particular process; they're on a new site, they're in a new site location, so they've got added problems that they've got to look after. If the supervision isn't spot on within the site, and if the induction training isn't spot on at an early stage, then one can see the pitfalls that are likely to occur.

Q. That's induction in safety?

Para 2 A. Yes, for a particular site, which is what we try to encourage on all our sites, so that as soon as somebody arrives, within a reasonable amount of time, certainly within the first week, which is the critical learning curve, we encourage induction training which could be of the form of a short talk. We've got lecture notes to our site managers, which tell them the points to bring up; and the site manager will do it himself, or nominate another person to do the induction. In it's best situation we're looking at maybe a talk accompanied by a video as well. We've produced our own videos, so it can be a general safety video, if it's a road, motorway job, we've got a motorway video that we show them; or if it's a refurbishment building, modernisation programme, contract housing, we've got a video. We've got three separate programmes that we can show them, depending on the work that they're going to do. So what we show them in that video, hopefully they'll remember what's in it, and if they reappear on one of our sites in the months afterwards, all they need say is. "Well I've seen your video," but they'll still need a talk as to the specific hazards of that site. So it won't be, "well I've seen your video and had your talk. I've seen your leaflets." They've got to be inducted again, again and again; to a lesser extent obviously.

Coding, which is the next step, involves detailed analysis of the interview data. The purpose is to identify concepts which it is felt have a bearing on the knowledge domain under consideration, (i.e. safety). Concepts are numbered as they are identified. The following concepts were identified in paragraph 1 of Interview L:

277 THE TRANSITORY NATURE OF THE CONSTRUCTION INDUSTRY.

407 THE INCREASED INCIDENCE OF INCIDENTS AMONG "NEWCOMERS" TO A SITE.

382 RELATIONSHIP BETWEEN "TURNOVER" AND SAFETY.

179 SAFETY VARIES BETWEEN INDUSTRIES.

242 RELATIONSHIP BETWEEN JOB TRAINING AND SAFETY.

408 THE INFLUENCE OF SITE SUPERVISION.

152 THE IMPORTANCE OF INDOCTRINATION, INDUCTION INTO SAFETY.

Concept numbers 407 and 408, were new concepts identified in this interview. The others, identified in previous interviews, have been recognised again in paragraph 1 of Interview L.

Concepts are recorded on a card or a sheet of paper. The support data, from the text, that provides the evidence of the concept, is recorded. It is referenced by its interview and paragraph number. The documentation for concept 277 - THE TRANSITORY NATURE OF THE CONSTRUCTION INDUSTRY, is shown in fig. 3.3.

277 THE TRANSITORY NATURE OF THE CONSTRUCTION INDUSTRY.

Int F. Para 26. The description of the ....Project, where Mr ..... estimated the labour force at 100, but, which would probably be 150 - 200 in six months time.

Int F. Para 28. The answer to the question as to whether the changing face of labour causes difficulty is acceptance that there is a changing face of labour.

Int G. Par 17. The view that the construction industry is of a changing nature and has its own difficulties.

Int H. Para 7. The view that the casual nature of the work-force in the construction industry makes safety more difficult to deal with in the construction industry, than in other industries.

Int H. Para 14. The view that the casual nature of the construction industry influenced the safety culture.

Int I. Para 6. The view that the transitory nature of the labour force may cause companies to feel that there is limited benefit to them of training and induction.

Int J. Para 1. The opinion that the construction industry is of a continually changing nature.

Int. K. Para 36. When asked why safety in construction does not compare with other industries, Mr .... states that it was "because its not a production line process".

Int K. Para 38. In describing the need to weld and burn on site, Mr .... states; "It's a dynamic situation".

Int L. Para 1. "Obviously the main difficulty is the movement of labour between sites, ... and they don't get a fixed work location".

Int L. Para 28. The description of how the construction industry is not a production line.

Note 1. Linked to category 247. - THE CONSTRUCTION INDUSTRY COMPRISES TASKS OF A TRANSITORY NATURE.

Note 2. Linked to category 233. - THE BENEFITS OF TRAINING MAY BE CONSIDERED WASTED TO A PARTICULAR COMPANY.

Note 3. Linked to category 415. - THE EFFECT OF THE SIMULTANEOUS WORKING OF DIFFERENT DISCIPLINES.

Fig. 3.3 An example of the recording of concepts.

As illustrated by fig. 3.3, support data that "reinforces" the concept can be found within the same or different interviews.

Coding is time consuming, but it becomes easier with practice. In this respect, I was fortunate to have the opportunity to attend a number of seminars on coding. As suggested by Strauss, (1987), this was of considerable benefit. The seminars, involved people intending to use a grounded theory approach, and were chaired by a person experienced in the technique. Participants brought sections of their own data, to be analysed by the group. This allowed for a critical appraisal of ones own attempts at coding and an appreciation of different interpretations that can be applied to data.

While concepts are being developed, links between them will become apparent. Such dependencies are noted, (NOTES at the bottom of fig. 3.3). Memos are produced concurrently with coding and category linking. The memos are explanations, thoughts, or ideas that arise throughout the analysis and have relevance to specific categories or to the knowledge domain in general. Fig. 3.4 is an example of a memo relating to category 277.

CATEGORY 247 - THE CONSTRUCTION INDUSTRY COMPRISES TASKS OF A TRANSITORY NATURE. and:

CATEGORY 277 - THE TRANSITORY NATURE OF THE CONSTRUCTION INDUSTRY.

The construction industry can be considered as transitory in several respects:

1 The tasks are continually changing.

2 The numbers of the labour force are continually changing.

3 The type of work is continually changing.

Note. Tasks refers to the tasks within a specific type of work.

Fig. 3.4 An example of memo writing.

Coding, memo writing and category linking may indicate that the indexing system, (concept labels, and support data), needs refining. This can entail gathering together separate concepts under one heading, splitting other concepts into different headings, or relabelling concept headings to relate more closely to support data.

Definitions of the concept are produced, as soon as they become clear. For example the definition of concept 277 - The transitory nature of the construction industry, is:

> The transitory nature of the construction industry, in terms of the types of work, the tasks involved in different types of work, and the numbers of people involved in the particular tasks and types of work, is a particular characteristic of the construction industry that adversely influences proneness to failure.

A concept can be said to have been saturated with data, (Strauss, 1987), when it is felt that further data adds nothing new to the concept or its definition.

Comparison of "grounded theory concepts" and "hierarchy concepts" is by comparison of definitions. On comparing the definition for category 277 - The transitory nature of the construction industry, with the hierarchy concepts, the characteristic relating to "numbers of people" is covered by the hierarchy concept, "labour turnover". Such a comparison is not forcing a fit. However, there was no hierarchy concept that could be said to represent the transitory nature of type of work, or task within a type of work. To cater for these characteristics, the following concepts were added to the hierarchy:

- Variety and changeability of types of work.
- Variety and changeability of tasks.

The grounded theory technique is not the central methodology of the research. As outlined earlier in this chapter, (clause 3.3), it is part of a problem solving process, involving a systems approach, that can be described by a reflective practice model, (Blockley, 1992). It was not felt necessary to adopt the rigour that would be required in fully grounding generated theory. This meant neglecting the process of axial coding, (Strauss, 1987), which requires intense analysis to be carried out around one code at a time to accumulate information about relationships between categories. Core categories, (Strauss, 1987), to which other categories can be related, thus integrating theory around such categories, were not developed.

Selective coding that entails coding systematically around core categories was therefore also neglected. The reason for these omissions was that it was felt that any such integrated theory would inevitably be under developed because of the relatively small amount of data, (Strauss, 1987), that covered such a large subject area as safety. Many more interviews would have been required to deal with the full extent of the knowledge domain. If, however, interviews were focussed on specific issues of safety, the data would be richer, and a rigourous analysis would be appropriate. This would apply to investigations of particular incidents, as in the development of a knowledge base of case histories, (chapter 13, clause 13.3).

One aim of the overall research method was to produce as many concepts as possible. Therefore, concepts such as; 173 - THE RELATIONSHIP BETWEEN SAFETY AND HOUSEKEEPING, that are only supported by one piece of data, (Interview B. Para 17. "If you have ongoing bad housekeeping you have ongoing bad safety".), are not discarded. They are relevant for comparison with hierarchy concepts.

3.5 Summary and conclusions.

The research method involves knowledge acquisition and the development of a theory in the form of a concept hierarchy as the structure for the design of hazard audits. The procedure can be described in terms of a process of reflective practice, described by Blockley, (1992). This model of the problem solving process is particularly relevant to open world problems that are characterised by ambiguities, inconsistencies, uncertainties, and unknowns.

Knowledge acquisition from experts is an important feature in dealing with open world problems such as the "provision of safety". For this research, knowledge to complement and supplement that of the author's was gleaned mainly from literature and interviews with safety practitioners. The chosen method of analysis of interview data was the grounded theory approach. This technique, developed for social science research, was considered appropriate for dealing with the elicitation of qualitative knowledge. Knowledge acquired in this way was used to support and supplement knowledge that was incorporated into the independently produced knowledge base, (the hierarchy).

The aim of this research was to build as extensive a structure as possible, comprising concepts that have the potential to provide evidence of proneness to failure. Because of the extensive nature of this knowledge domain, is it was felt that the grounded theory approach could be modified. In this respect, the development of core categories was not pursued, and the rigour of axial and selective coding was not necessary.

In relation to safety, the grounded theory technique might be more appropriately applied to the investigation of incidents or specific problems such as influence of management on proneness to failure in the construction industry. Having produced a substantive theory, a more formal theory could then be developed by considering the influence of management on proneness to failure in other industries.

The coding process, used to ground theory in data, improves with experience. The difficulties of coding are not always apparent to the inexperienced analyst. The use of seminars to provide practice in coding is particularly helpful.

Chapter 4.

Literature survey.

4.1 Objectives.

1 To discuss some of the issues raised in an initial literature survey, that are relevant to the development of a structure for the design of hazard audits for the construction of a project.

4.2 Introduction.

Although the context of the research was hazard auditing for project construction, no boundaries were placed on the context or characteristics of safety included in the survey. The discussion in this chapter is a selective account of some of the important points arising out of the initial literature survey, but later references are included if appropriate to the discussion. Appropriate literature is also referred to throughout the thesis.

A list of factors to be considered for inclusion in the concept hierarchy was produced during the initial literature survey. This is given in appendix A. Another separate list that was continually updated throughout the research included factors that presented themselves from any available source, (chapter 3, clause 3.3), including literature other than the initial review. Because of its extensiveness, (several hundred items), this list is not included. However, its purpose was as a check on concepts included in the hierarchy. The completed hierarchy, therefore, incorporates these factors in some form. The items on the various lists were compared to concepts included in the separate hierarchical development. Concepts were amended and added to as appropriate, (see chapter 3, clause 3.3).

4.3 Literature survey.

Magyar, (1983), described conditions considered to be conducive to successful auditing. (Safety auditing has been discussed in chapter 2, clause 2.5). These are:

- Management participation such that they are comfortable with the audit.
- Consistent criteria of evaluation that can provide assessment in terms of ratings.
- An easily communicated and understood audit programme.
- The facility for the establishment of objectives and the measurement of progress.
- The production of safety award and bonus schemes.
- The generation of observable improvements in the way people work.

In outlining the implementation of an auditing system, (the ISRS audit, described in chapter 2), Ashburn and MacDonald, (1987), emphasised the importance of commitment and effort. They concluded that the audit required to be adapted to the needs of the coal mining industry.

References that outline requirements for successful safety programmes, as distinct to auditing programmes, include Cohen, (1977), who analysed eight studies of safety programmes in the work-place. This analysis indicated that successful safety programmes exhibited the following distinguishing characteristics:

- Strong management commitment to active support and involvement in safety.
- Communication, interaction, and contact between workers, supervision, and management, on safety related issues.
- Low turnover of work-force and a large core of married older workers with significant length of service.

- Good housekeeping, work-place conditions, and environmental quality control of the work-place.
- Well developed job selection, placement, advancement procedures, and employee support services.
- Continuing training and indoctrination in safety procedures.
- Additional features or variations to enhance conventional safety practices.

Mendez, (1987), in relation to the photovoltaics industry, proposed that the following features should be considered for inclusion in a safety programme:

- Division of facilities into safety areas, each area being treated separately in terms of its safety performance.
- A safety committee of managers and directors, who establish policy and ensure that the safety programme is implemented.
- An equipment safety review group.
- A chemical disposal team to dispose of hazardous waste and continually review disposal procedures.
- A trained emergency response team.
- An effective safety and health programme of medical checks, and treatment facilities.

According to Varadarajan, (1986), factors that influence levels of safety on chemical plants include:

- Site layout and location.
- Construction materials.
- Design practices.

- Storage conditions.
- Instrumentation reliability and maintenance.
- Control of operations.
- Maintenance.
- Safety management.
- Analysis of loss prevention techniques.
- Public relations.
- Transportation of materials and their use.
- Quality.
- Environmental impact.

Bayley, (1986), suggested that formal policy statements, putting policy into practice, design considerations, and accident investigation procedures are all conducive to successful safety programmes.

Of the characteristics listed in the preceding references, some are proposed as necessary conditions for successful auditing or for successful safety programmes, others as measures to improve safety. In fact, there should be no distinction. They represent perceived hazards, and should be identified and examined as such.

An obvious source for the identification of hazards is the investigation and analysis of incidents. Howard, (1988), considered a number of disasters from the process industry, such as Flixborough in 1974, Seveso in 1976, and Bhopal in 1984. He suggested that there were common technical factors that contributed to these failures and that they might be dealt with by changing procedures or further research. This implies that the state of the art was not all it should have been. That such failings are not restricted to the process industry, is borne out by Sibley and Walker, (1977), who described four structural accidents from the past: Dee Bridge, Tay Bridge, Quebec Bridge, and Tacoma Narrows Suspension Bridge. Their suggestion that there were common identifiable, design related problems, in the circumstances leading to the four accidents, demonstrates deficiencies in the state of the art. These two references, (Howard 1988; Sibley and Walker, 1976), indicate that collective analysis of incidents may identify common features that are perhaps not apparent from individual investigations. For example, the association of technical faults with fundamental deficiencies in the state of the art. Deficiencies in the state of the art signifies a requirement to examine knowledge, to ensure that it can justifiably be applied to particular situations. The Tacoma Narrows Bridge, for instance, was much more flexible, both longitudinally and torsionally, than existing bridges up to that time, (Blockley, 1980). The Tacoma Narrows Bridge design in its use of span/width and span/depth ratios that greatly exceeded those of comparable bridges up to that time was not justified.

Turner, (1978), has analysed a number of disasters in various industries. He argued that disaster is rarely the result of a single factor, and that the actual disaster is triggered at the end of an "incubation period" during which time a potential for failure has built up. The conditions that exist and develop during the incubation period are created by a combination of individual and organisational influences. Within this socio-technical context of disaster, Turner suggested that there are repeating or common factors that are part of a chain of events that eventually lead to failure.

The following synopsis of an account of the Love Canal disaster, by Kharbanda and Stallworthy, (1986), illustrates the Turner model of disaster incubation. Love Canal is situated near Niagara Falls, USA. Development of the canal for the transport of goods was commenced at the end of the 19th century. It was never completed and in 1910 the project was abandoned. It lay fallow until 1941, after which it was used for the disposal of industrial wastes. It appeared suitable for such use because of the impermeable clay lining that had been used on the bottom and sides of the canal. After ten years of disposal operations, the waste was also covered with a layer of impermeable clay. Following this, over a period of many years, despite knowledge about the history of the area and warnings, there were occasions when parts of the waste disposal site were graded, excavated, and removed. In 1976, there were reports of chemicals seeping into basements in the area. In 1978, there was a temporary closure of a local school, and pregnant women and children were evacuated. Remedial work on the canal was carried out and there was further evacuation of families, and purchase of their homes. In 1979 there was a very high rate of birth defects and miscarriages observed in the locality of Love Canal. The US President declared a state of emergency, and the ensuing lawsuits resulted in settlements of many millions of dollars. This is an example of the socio-technical nature of disaster, involving mismanagement at several points in the project's history. This included a failure to recognise the consequences of actions. It might, perhaps, have been due to the absence of a culture to actively search for and identify potential for failure, and take corrective action.

Blockley, (1980), also argued that it is necessary to look beyond the technical aspects of engineering and include the effects of social influences. Based on analyses of several civil engineering failures, he proposed a set of questions that might be used to recognise the potential for failure. These questions include socio-technical characteristics of engineering such as the general climate, (financial, industrial, political and professional), surrounding the design and construction process.

The socio-technical nature of failure is also a feature of an analyses by Kletz, (1988; 1985a; 1985b; 1985c;), of incidents that have occurred primarily, but not exclusively, in the chemical and process industry. He emphasised the significance of failures of management systems in creating the conditions for the occurrence of incidents.

The "immediate causes" of failure, though, have to be dealt with. Piésold, (1991), in describing various civil engineering failures, focused on the technical features. Similarly Kaminetzky, (1991) in an analysis of a number of civil engineering failures, describes the technical causes of failure. Such publications provide valuable information for use in lower level audits, (see chapter 2).

The importance of low level auditing, of for example, unsafe acts, is indicated by Heinrich, Peterson and Roos, (1980), who suggest that about 90% of incidents involve unsafe acts. Low level audits should be integral to high level audits, (chapter 2). They are selective and frequent, but resources are limited and guidance on what to look for is invaluable. For example, Ramsey, Burford, and Beshir, (1986), outlined a classification of unsafe acts to provide a measure of safety performance. Based on a study in a metal products manufacturing plant, involving over 1700 unsafe acts; 73% were related to worker, (e.g. improper use of body, failure to dress properly or use protective clothing), 22% were related to unsafe use of tools and materials, and 5% were related to materials handling equipment. Such information is significant in that it can indicate where best to take corrective action and where best to look when auditing unsafe acts.

Adams, E. (1985), considered it impracticable to investigate every injury related accident in detail, and suggested a method to establish which accidents, and to what extent they should be investigated. Briefly, this requires evaluating each accident in terms of five criteria: Severity of injury; status of the injured personnel, whether manager, key employee or other employee; level of energy; type of equipment, such as electrical, moving, hand tools; type of material, whether hazardous or non hazardous. In the event of an accident, each criterion is rated on a scale of 1 to 10. The total score indicates the extent to which an investigation should be taken. In practical terms, this type of scheme may help to optimise the use of limited resources for accident investigation.

The following references deal specifically with safety in the construction industry.

Levitt and Parker, (1976), in an account of a study of top level management in U.S. construction companies, proposed the following guide-lines for improving safety:

- Managers should be informed about the accident rates on each project.
- Salary increases and promotions for field managers should be based on their contribution to safety as well as production and costs.

- Managers should consider safety in the same way as costs and schedules. Field personnel should be made aware of accident costs.

- Managers should adopt a cost reporting system that reflects the costs of accidents. Consideration should be given to charging accident costs against projects, and possibly charging part or the whole of safety equipment costs to company overheads.

- Newly hired workers should be trained in safe work methods and job hazards.

- Detailed work planning, including materials, equipment, manpower, safety requirements, should be carried out before beginning the work.

- Incentives based on accident records should be used with caution.

Hinze and Parker, (1978), described an investigation to determine how work practices and job policies of field supervisors affected the safety performance of U.S. construction workers. They suggested that good safety performance and high productivity are compatible and linked to management styles. An interesting conclusion was that excessive pressures by company head offices on superintendents, and by superintendents on the labour force was likely to increase injury frequency and reduce productivity.

Hinze, (1978), looked into the influence of worker turnover on safety performance in the U.S. construction industry. This study concluded that safety performance was improved by reduced work-force turnover. This applied to turnover of workers with a particular company, and turnover of workers with a particular field supervisor. Because relatively high work-force turnover is a feature of the construction industry, it would appear prudent for management to try and ease the problem of new workers introduced into new situations by training, induction, and if possible, balanced integration into an existing work-force.

Hinze and Harrison, (1981), outlined an investigation, of large U.S. construction firms, to determine whether there was any consistency in the character of safety programmes, and whether safety performance was affected by specific aspects of the programme. They concluded that the largest firms had better safety performances. Characteristics common to larger companies thought to contribute to this were: the use of more formal safety programmes involving accident reporting, formal training, incentives, clear requirements for safety.

A survey, by questionnaire, of 75 construction companies in Washington State, U.S.A., by Reed and Hinze, (1986), indicated that safe companies were characterised as follows: geographically, they were relatively non diverse in their operations; there was a high supervisor to employee ratio; there was a shallow hierarchy containing relatively few levels of management; a relatively high proportion of work was obtained in a non competitive environment.

Samelson and Levitt, (1982), investigated practical means of reducing construction costs by improving safety performance levels. As this related to U.S. practices, detailed cost considerations, particularly insurance costs, may be irrelevant to the U.K. More generally, it was stated that there were potential savings to be made from managing and controlling safety, and that a client could benefit by selecting "safe" contractors. Laufer, (1987), suggested that the greatest motivation for the introduction of accident prevention measures in construction, is economic. However, according to Leopold and Leonard, (1987), reduction of insurance costs, through improved safety performance, would appear to have a limited effect in the U.K. They concluded that only the largest firms can hope to influence insurance costs though safety performance. If, as they stated, "hidden" costs, compared to insurance premiums, are not sufficient to act as an incentive for improved accident prevention, the economic advantages of increasing the safety effort in construction may be limited.

Gross, (1986), summarised an Engineering Foundation Conference, held in 1983, to examine whether there had been an increase in structural failures and to look at causes of failure. Generally, the conclusions were as follows:

- There was no evidence of increased frequency but the magnitude, (loss of life per incident), appeared to have increased.

- Instances of failure could usually be attributed to a number of, (rather than single), contributing factors, within both the design and construction processes.

Recommendations based on a consensus of 90% - 100% of the conference were as follows:

- Improved and better understood design methods were needed, particularly for non-redundant structures. Codes and standards required amendments to provide higher safety factors for non-redundant structures.
- Designers should be required to certify that the structure is safe for occupation.
- For buildings above a certain threshold, there should be a structural design review by suitably qualified independent engineers.
- Design and construction responsibilities should be clearly defined.
- Risk insurance needed to be developed to cover, under one policy, designers, contractors, and clients, to encourage closer cooperation between design, construction and occupancy.

Many of the points raised in the preceding references, relating to safety in construction, could be regarded as good management practice. The management of safety should be integral to management. There is a requirement to look for reasons, if efforts to improve safety appear deficient in an otherwise efficient and effective management system. One reason is increasingly being recognised as the existence of a poor "safety culture". As defined in chapter 1, safety culture is "the set of beliefs, norms, attitudes, roles, and social and technical practices which are concerned with minimising the exposure of individuals, within and beyond an organisation, to conditions considered dangerous or injurious". This covers factors such as management commitment, communication, training, and planning.

The CBI, (1990) describes safety culture as "the ideas and beliefs that all members of an organisation share about risk, accidents and ill health". The manifestation of a culture, as outlined in this publication, can be seen in the numerous activities that are part of "the way in which things are done".

Butler, (1989), proposes that there is a need for a fundamental change in corporate culture with regard to safety. This, he states, is the responsibility of management, who have to give a lead. This point is echoed by Heiermann, (1988), who suggests that employers need to actively develop safety consciousness, which he defines as "the preparedness and capability of recognising danger, estimating the likelihood of an accident happening, and its extent, and acting correspondingly". Management, it is suggested, can take the initiative through: ongoing training and persuasion to develop safe working practices; fostering safety, by example and encouragement, using a minimum of regulation; promotion of safety, by praise and if necessary reprimand; openness, to allow for interchange of ideas and views amongst and between management and work-force; commitment to safety, demonstrated by the allocation of resources; viewing safety and production as compatible.

Steiner, (1987), outlines a survey designed to assess the safety climate which she defines as "the intangible safety attitudes and perceptions", that exist in a plant. The survey, developed by Safety Services of Du Pont Co., attempts to evaluate safety attitudes and practices among the work-force and management. Questioning of the work-force, therefore, requires them to give their perceptions of both management and co-workers attitudes.

Peoples attitudes and behaviour towards safety is influenced by their perception of risk. The Royal Society, (1983), defines risk perception as "the combined evaluation that is made by an individual of the likelihood of an adverse event occurring in the future and its likely consequences". Slovic, (1987), discusses the lay persons perception of risk in comparison with quantitative risk assessment, (which is also based on an estimated likelihood of occurrence and estimated consequences). The conclusion is that people do sometimes lack information that leads to differences between perceived and calculated risks. However, it is stated that perceptions often reflect legitimate concerns that are omitted in "expert" risk assessment. This is summed up by Slovic, (1987), as follows:

> Perhaps the most important message from this research is that there is wisdom as well as error in public attitudes and perceptions. Lay people sometimes lack certain information about hazards. However, their basic conceptualization of risk is much richer than that of the experts and reflects legitimate concerns that are typically omitted from expert risk assessments. As a result risk communication and risk management efforts are destined to fail unless they are structured as a two-way process. Each side, expert and public has something to contribute. Each side must respect the insights and intelligence of the other.

This suggests that evaluations of hazards, particularly when expertise is involved should be approached with caution. It is conceivable that the perception of some risks, by experts or practitioners, may be acceptable to the extent that a hazard is not recognised as such. This eventuality could be mitigated by combined evaluation involving experts, lay people, and decision makers.

Slovic, Fischoff and Lichtenstein, (1982), describe some of the processes used by people to judge risk and the biases that may influence judgements. Briefly, these are as follows:

- The availability heuristic; where an event is judged as likely if it is easy to imagine or recall.
- Over-confidence; where people have great confidence in heuristic judgements using inferential rules based on experience and observation. "Experts" are particularly prone to over-confidence.
- Presentation; where the way in which risks are expressed influences perception and behaviour.
- Comparison between different risks; which may have little meaning, and can mislead. For example, there is, according to Slovic, et al, no particular conclusion to be drawn between comparing the risks of motorcycling and advanced age. Also, characteristics such as voluntariness and controllability are often neglected in statistical summaries used in comparisons of different risks.

If judgement about risk is biased, judgement about hazards may be biased, and as a result, their assessment may be biased. Auditors, responders, (i.e. those making evaluations), and decision makers need to be aware of, and attempt to guard against bias in perception of risks.

Similarly, attributional processes, which relate to the way in which people process information in determining the causality of an event, can influence auditing and associated decision making. Dejoy, (1985), discusses this with respect to: how workers perceive risk; how supervisors respond to incidents; how management influences the safety climate. Again, very briefly, the attributional processes outlined are:

- Self-other attributes; where those involved in an incident tend to explain it in terms of factors outside their control.
- Self protective attributes; where people tend to explain events in terms that do not reflect badly on themselves.
- The availability heuristic in which events are judged more likely or frequent if they are easy to imagine or recall.

In general terms, it is concluded that the safety climate can be adversely affected, particularly if work-force, supervisors and management are biased by self-other and self protective motives.

Quantitative Risk Assessment, (QRA), like hazard auditing is a tool of hazard management. Although the merits or otherwise of QRA are not part of this review, the perceived mistrust of QRA, (Slovic, et al, 1987), is of significance. Descriptions of the use and benefits of QRA can be found in various publications: (Gittus, 1986; Novegno and Asculai, 1987; Vinck, Gilby and Chicken, 1987; Russell and Gruber, 1987.) The claim by Freeman, (1985), that "it is a powerful tool for making choices between clearly defined alternatives in a specific problem," appears realistic. However, the technique may have been discredited for many people by apparent attempts to justify a particular risk. For example, Feynman, (1989), a member of the Presidential Commission's investigation into the

Challenger Space Shuttle disaster in 1986, observed that management sources were quoting figures of 1 in 10^5 chance of failure of the flight. On being questioned informally, some of the engineers involved in the project estimated the risk of failure of the main engines at nearer 1 in 200 - 300. Regardless of where the figures came from, there is ambiguity and perhaps a deliberate attempt to justify unacceptable risks. Openness and explanation of the risk and the criteria used in their assessments may help to create confidence in QRA, (Slovic, 1987; and Slovic et al, 1982). This same point is made by Moore, (1988) and Tusa, (1986). However, experts do fail to recognise legitimate concerns, (Slovic, 1987), and discussions involving experts and lay persons may be more appropriate than the "education" of lay people. Similarly if auditing is to be effective as a management tool, it should be explained for what it is. It is a procedure used for the identification of hazards. Importantly, the act of carrying out hazard audits should not be propounded as evidence that safety is being managed. Lack of commitment, effort and resources will undermine the effectiveness of auditing. If properly used, there should be increased confidence that the conditions in which major incidents may occur are less likely to develop.

Quality and safety are closely linked. If defined as such, safety is a characteristic of quality. Baker, (1986), defines quality assurance as, "the design and controlled application of a set of product and process verification procedures, both prior to completion of a structure and during service to ensure fitness for purpose with an appropriately high probability." This is deemed to apply to all phases of a structure's life from initial planning right through to decommissioning. This definition does encompass safety, certainly structural safety, and the absence, or malfunctioning, of quality systems may contribute towards evidence of proneness to failure.

Newell, (1987) argues that lack of design quality assurance results in inefficiencies in the provision of safety, rather than a reduction in safety. It is, I believe, wrong to think in this way. If there are inefficiencies in the provision of safety, there is evidence of proneness to failure. However, Newell suggests that design quality assurance needs to include the conditions that influence the process of design such as: human factors including experience, personalities, and character; social interactions in the work-place; designers' environment; economic planning of design procedures.

Definitions and descriptions of the various terms associated with quality can be found in British Standards publications, (BS 4778, 1987 and 1979; BS 5750, 1987; BSI handbook 22, 1990). Information and guidance on quality in the construction industry, is available in various publications of the Construction Industry Research and Information Association, (CIRIA); (Ashford, 1989: Oliver, 1990; Power, 1985; Technical Note 121, 1985; Special Publication 55, 1988;).

The proposed use of hazard auditing begs the question as to its likely effectiveness. The chemical industry, for example, based on many years of use, appears to have confidence about its benefits. Other industries including construction, can only test the benefits of auditing by proper application. However, the theory of risk homeostasis may be of relevance to the use of hazard audits. This is the theory that safety measures, (procedures), will not reduce accident loss unless they lower "target levels of risk", (Adams, 1988). A hazard audit is, after all, a safety procedure. The issue of risk homeostasis appears to have generated some debate, (Wilde, 1982; McKenna, 1987; Adams, J. 1985), as to whether the theory is supported by evidence, or even whether it is testable, (Adams, 1988). The debate is outside the scope of this thesis, but I feel that it probably has little significance to hazard auditing. I would argue that factors such as attitudes to safety, education, state of the art, and safety culture all relate to how risk is perceived. Lowering target levels of risk is integral to the concepts in the hierarchy and therefore to audits designed from it. The theory of risk homeostasis is dependent upon target risk levels remaining unchanged.

4.4 Summary and conclusions.

The initial literature survey served two purposes:

- Familiarisation with safety and safety auditing.

- As a source of information for possible inclusion in the "proneness to failure" hierarchy. A check-list was drawn up, of factors arising out of the literature survey, that appeared relevant for inclusion in the "proneness to failure hierarchy". This is given in appendix A.

The issues outlined in this chapter indicate that safety, in any context, is part of and subject to influences within a complex system of individual, social and technical inter-dependencies.

Chapter 5.

Policy implementation.

5.1 Objectives.

1. To describe the principal characteristics that provide for the implementation of policy. These are: policy, management framework, and culture.

2. To discuss and describe the hierarchical development of each of the above mentioned characteristics with respect to their potential as evidence of proneness to failure.

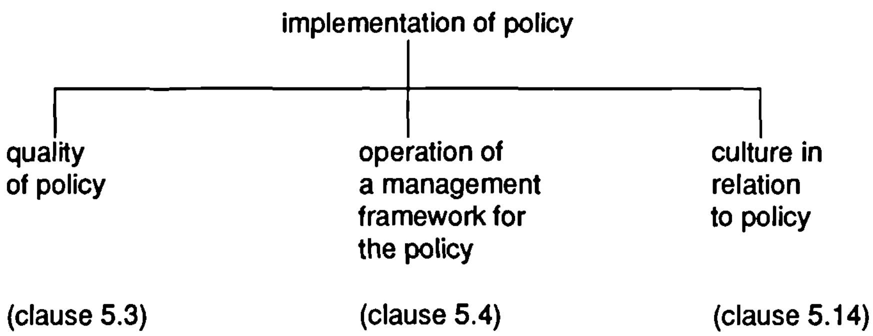
3. To present a hierarchy of concepts that can provide for an evaluation of policy implementation.

5.2 Introduction.

Setting objectives, including the maintenance of norms, implies intent. If intentions are to be realised, a course of action needs to be adopted. This involves monitoring and planning within a system of organisation and information arrangements. A framework of these activities and systems allows for the development and operation of other activities, systems, and procedures. The desire and motivation to set and achieve objectives is reflected in the culture relating to policy.

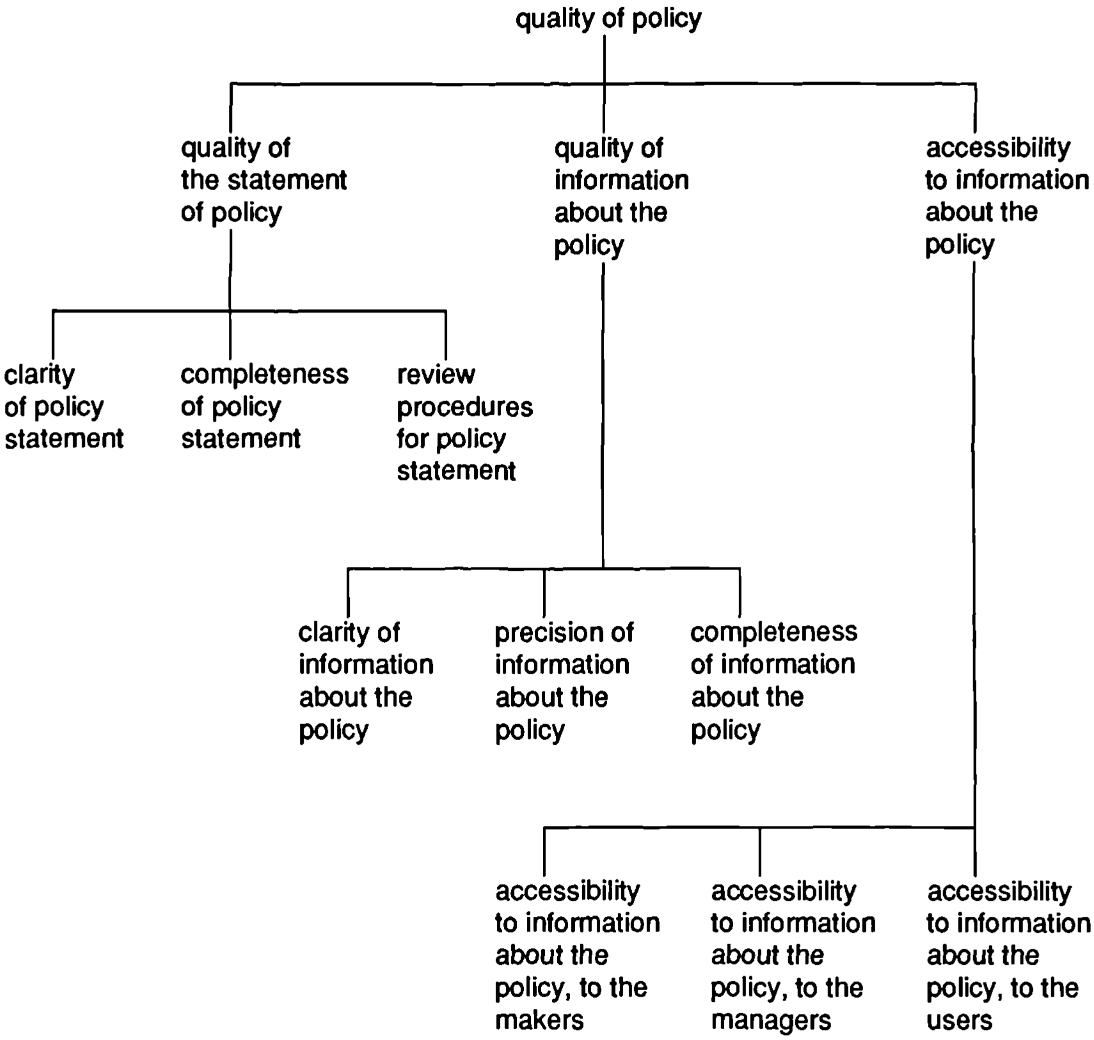
In narrow terms, a policy can be defined as a statement of intent. Organisational, information and planning arrangements can be thought of as a management framework. The context of a course of action can be almost anything, as for example, the government of a nation, or washing the dishes. Policies can be inter-related. A management framework may be common to separate policies but operate differently in different policy contexts. An examination of a management framework is therefore policy related. Similarly, culture needs to be evaluated in the context of a particular policy. For this research, contexts tend to be linked to both safety and the state of the art of engineering in: society, industry, project, and project phase. Deficiencies in the characteristics of policy implementation, (policy, management framework, culture), may be evidence of proneness to failure. This chapter describes the general principles of policy, management framework, and culture. The hierarchical expansion of the "implementation of policy", is built up and presented in fig. 5.6, at the end of the chapter. Specific details of context are dealt with in the thesis as they arise.

The implementation of policy is defined as the functioning of the arrangements that provide the basis for the implementation of policy. As indicated in the following hierarchical expansion, evidence of poor implementation of policy is evaluated in terms of quality of policy, the functioning, (operation), of a management framework, and the culture in relation to the policy context.



5.3 Policy.

Policy is a statement of objectives and an outline of a management framework for the control of activities, systems, and procedures that are necessary for the achievement of objectives. The concepts that provide for assessment are shown in the following diagram:



Assessment of the **quality of the statement of policy** is based on the **clarity** of the statement, its **completeness**, and **procedures for review**. Good clarity is a lack of ambiguity. Incompleteness is the extent to which the policy statement requires extrapolation, modification, or change of the information it contains. The statement may be clear but incomplete. The policy statement is of course information, and the distinction between clarity and completeness of information is illustrated further in clauses 5.11.2 and 5.11.4, with respect to information arrangements. Recommendations and advice on policy making, coupled with experience, can be used to define standards of clarity and completeness with which a policy can be compared. Because objectives and the means of achieving them can change, there is a need for review procedures, to monitor that a policy remains appropriate and to allow for revision if necessary.

Quality of information about the policy requires an evaluation of the **clarity,**

precision and **completeness** of information that is available to explain the policy, its development, management, and implementation. Precision is the extent to which possibilities are excluded. (See chapter 6, clause 6.6.3.4, which defines precision of specification). Information may be clear and complete, but can still be improved by making it more precise if, in certain circumstances, complementing pieces of information are given. The example given in clause 5.11.2 for reinforcement drawings and bending schedules illustrates this. Information about policy complements policy statements. It is often in the form of guidance, as for example in publications listed by the Health and Safety Executive, (BIANNUAL). (See chapter 8, clause 8.4.1). Assessment of quality requires comparison with standards, based on expertise and experience.

Accessibility of information about policy relates to the accessibility of the policy statement, and information about it, to all those who are involved in the making, management and implementation of policy, and to those who might be affected by it.

Information about policy is not necessarily produced by the **policy makers** who therefore need to be in a position to check that interpretations are as intended. It is particularly important to ensure that new information, relevant to the policy, yet unknown or unaccounted for when it was made, is included in review procedures.

Individuals or organisations involved in monitoring, feedback, recommendation and enforcement of policy are **policy managers**. The Health and Safety Executive, for example, who advise, research, monitor, and enforce, are managers for society's policy on health and safety in industry.

Policy users are those who; outside of roles for making and managing policy; are directly involved in, or could be affected by, the practices adopted for implementing policy. For example, aircraft passengers are not directly involved in organising a flight (take-off, flight and landing), from London to Paris, but they are affected by it.

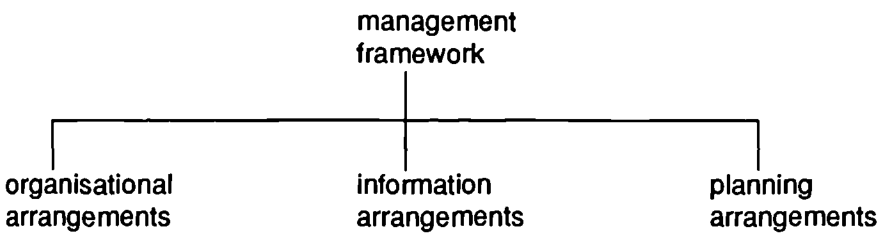
5.4 Management framework.

Control is fundamental to management. It necessitates:

- Being in a position to control a situation as far as is possible and exercise that control.

- Being in a position to control as far as is possible the consequences of failure to control a situation, and exercise that control.

A management framework is defined as the functioning of organisational, information and planning arrangements that provide for the implementation of policy and allow for control of the development and operation of activities, systems, and procedures to meet specified objectives.



As described in chapter 2, clause 2.5, the necessity to assess the <u>functioning</u> of a management framework is illustrated by Cullen, (1990), who, in the report of the Public Inquiry into the Piper Alpha disaster, expressed concern that although policy and organisation for safety existed, it was questionable whether the systems for implementing policy were being operated effectively.

5.5 Organisational arrangements.

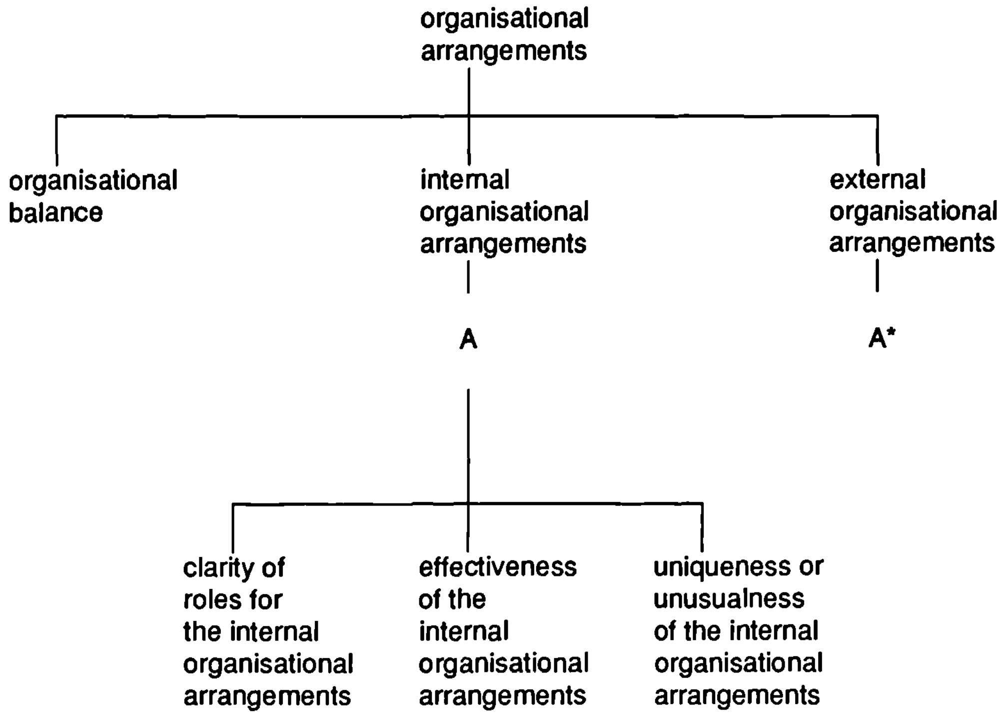
This is the functioning of an organisation, of groups and individuals, that in conjunction with information and planning arrangements provide for the implementation of policy and control of the development and operation of activities, systems and procedures to meet specified objectives. Organisational arrangements can be classified into two forms:

- "Internal" organisational arrangements relate to groups or individuals that have an active involvement in, and can be held accountable in some way for, the implementation of policy. In society, the Health and Safety Commission, (and Executive), operate internal organisational arrangements for promoting the objectives of the Health and Safety at Work etc. Act (1974), through research, putting forward proposals to Government, producing information, and enforcement of the act. On a construction project, contractors, client, and engineers, all operate internal organisational arrangements.

- "External" organisational arrangements relate to groups or individuals that have an active involvement in, but cannot be held accountable for, except to themselves, the implementation of policy. Institutions, organisations or even individuals who attempt to influence proposed regulations, but are not accountable for drawing them up, operate external organisational arrangements. Similarly, groups such as residents associations or environmentalists may act to exert pressure and influence on, say, a road construction project, but they are not accountable for the actual construction. Such groups will have internal arrangements associated with their own policies, and be accountable to society if their activities contravene the law.

The role of organisations such as The Institution of Civil Engineers, The Institution of Structural engineers, The Royal Institution of British Architects, and Trades Unions, who operate external organisational arrangements with respect to policy in industry, is discussed in Chapter 9.

Poor organisational arrangements may be evidenced in the concepts of the following hierarchical expansion.



A* repeats the hierarchical expansion under A in terms of the concept above A*.

5.5.1 Organisational balance.

This concept relates to "the way of life" that could be said to characterise the way in which a set of organisational arrangements function. The way of life is a viable combination of cultural bias and social relations closely tied together in a mutually supportive relationship, (Thompson, Ellis and Wildavsky, 1990). Cultural bias refers to shared values and beliefs. Social relations are patterns of interpersonal relations. In these terms, organisational balance is defined as:

The balance of the "ways of life" (viable combinations of cultural bias and social relations), of individuals and groupings operating within a set of organisational arrangements in relation to a principal policy objective.

The relevance of a principal policy objective will be explained after the following brief discussion relating to "balance".

If groupings or individuals within a set of organisational arrangements hold a single, or similar, set of values and beliefs there is a possibility that knowledge, relevant to decision making, will be missed. If the ways in which individuals or groups think and function are similar, reasoning and decision making may be blinkered or prejudiced. In either case there is evidence of proneness to failure. Impartiality and use of all available information will be facilitated if groups and individuals in a set of organisational arrangements collectively possess, and function with, a balanced "way of life".

Assessment requires comparison to a standard for "balance", which can be based on a classification, proposed by Thompson, Ellis and Wildavsky, (1990), for "ways of life". They state that cultural bias and social relations cannot be viably combined in just any way. Shared values and beliefs are tied to particular social relations to produce a limited number of ways of life. Their suggested classification, for which they provide a detailed explanation, is outlined below.

Five ways of life are classified: hierarchy, egalitarianism, fatalism, individualism and autonomy. These are described in terms of a grid-group typology proposed by Douglas, (1982), who suggests that two parameters of "grid" and "group" can be used to describe an individual's involvement in social life. Grid describes the extent to which a persons life is regulated by imposition. Group describes the extent to which an individual is incorporated into bounded units.

In the Thompson, Ellis and Wildavsky classification, autonomy represents a withdrawal from social involvement. If this is neglected, the classification can be adapted to evaluate the balance of organisational arrangements, using the following four criteria:

"Hierarchy" describes groups or individuals who are highly constrained in their roles and operate within larger and wider groups.

"Egalitarianism" applies to situations where there is little constraint or discipline on the roles of groups and individuals, who operate within larger and wider groups.

"Individualism" applies when groups or individuals have a great deal of freedom in their roles and tend to operate in isolation rather than as parts of larger and wider groups.

"Fatalism" refers to the situation where groups or individuals are highly constrained in their roles but as with individualism, they operate in relative isolation.

In practice it is likely that one characteristic will predominate within a particular set of organisational arrangements, but it is the balance within the set that needs to be evaluated.

An important element in the definition of organisational balance, is the significance of the principal objective of an overall policy. This means that separate organisations should be assessed for organisational balance in relation to the principal, or highest level, objective with which they can be associated. The significance of principal policy objective, can be seen in university education and research within the limits of available resources. If policy is set and managed jointly by society's representatives and the universities, a tendency towards egalitarianism and individualism within universities can be balanced against the cultural biases of other elements of society that make up the organisational arrangements for the management of higher education. However, if universities are expected to become more self dependent, and financially accountable, society has effectively abrogated part of its role in achieving the principal policy objective, by delegating it directly to the universities. It now becomes relevant, to assess the balance of separate university organisations with respect to that part of the principal objective that has been delegated to them. I would suggest that universities will tend to become more balanced, particularly with regard to financial accountability, not because previous arrangements were necessarily poor, but because the context of the principal policy objective has in part been delegated directly to them.

By its inclusion in the hierarchy, it is being proposed that poor balance may be evidence of proneness to failure. That it need not provide such evidence is illustrated by the army, which is basically a hierarchical type organisation and appears to operate successfully. It might be argued that although it has its own objectives, the army, (in UK society), is associated with the "higher level", principal objective of the defence of a social environment. The army or any other military service, in a democratic society, are separate elements of a set of organisational arrangements, (including Government), that decide objectives and manage the defence of a social environment. However, a more satisfactory explanation is that organisational balance is only one factor in a judgement of effectiveness, (or proneness to failure). Circumstances may determine that other characteristics have a disproportionate influence. For an army in a state of war, it may be the need for clarity of roles. In other situations, it may be that characteristics such as good information arrangements and "open mindedness", counter the effect of poorly balanced organisational arrangements. I would suggest, though, that unless there are special circumstances, organisational balance is an important element in an assessment of proneness to failure.

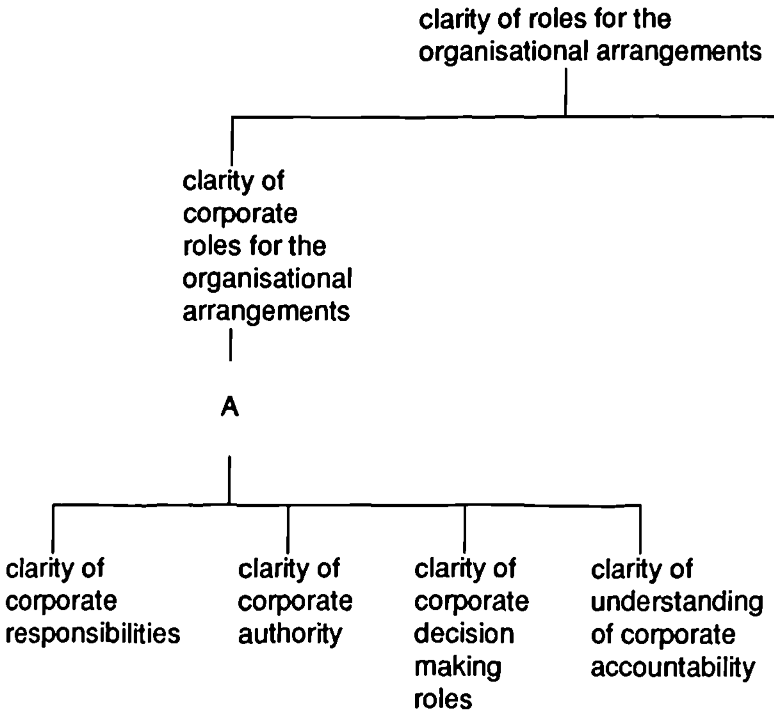
If, in the context of principal objectives of overall policy, an examination indicates that one characteristic of the Thompson, Ellis and Wildavsky classification seems to describe not only the overall set of organisational arrangements, but also the majority of the separate individuals and groupings, there is evidence of a poor balance. If the arrangements as a whole are comprised of individuals, groups, and organisations that could be described as an appropriate mixture of all four types, the balance is good.

Both internal and external organisational arrangements influence organisational balance. For example, on a construction project, the internal arrangements include the client, consultant, contractor, and sub contractors. Each can be characterised by type, although each, in themselves, may be balanced quite well. If each is clearly characterised as the same type, the balance of the overall project management is poor, but the effects of external organisational arrangements, such as pressure groups, professional bodies, and trades unions, exerting real influence, may improve the balance of the overall organisational arrangements.

5.5.2 Clarity of roles for the organisational arrangements.

This is the clarity with which the roles of responsibility, authority, decision making, and accountability are defined, understood, and enacted by individuals or groups within an organisation, and by organisations, operating independently or within a larger system of organisational arrangements.

Evidence of poor clarity of roles exists where there is potential for confusion, misunderstandings, and ambiguities in responsibility, authority, decision making, and accountability . Roles can be distinguished between corporate and individual. "Individual" applies to both individuals and groups that operate as a whole within an organisation. "Corporate" applies to organisations that operate within a larger system such as a consortium or construction project.



A* repeats the hierarchical expansion under A in terms of the concept above A*.

Responsibility is the state of being responsible; of being liable (apt or likely) to be called to account. The frame of reference for a definition of responsibility is based on one of three described by Hale and Glendon, (1987), (page 177). Two of the frames of reference relate to: persons being held responsible through requirements to conform to rules, and persons being responsible by virtue of their position or because it reassures others to assign them responsibility. These frames of reference are restrictive and could be perceived as relating to authority and accountability. The third frame of reference, which will be adopted here, relates to a person being responsible by virtue of their action or inaction. In other words, a person or organisation is responsible if their action or inaction can influence an outcome. This can be interpreted as meaning that individuals or organisations are either held or not held responsible. **Clarity of responsibility** is defined as:

The clarity with which the area of responsibility and its limits are defined, and the clarity of understanding, by the appropriate individuals or organisations, that they have or are affected by that responsibility.

People either have or do not have **authority**, but unlike responsibility, there are levels of authority in so far as one person can have authority over another. Authority is the capability to influence others by the use of legitimate power. Legitimate power is that which comes from a role or position in an organisation, (Handy, 1985). Authority implies accountability. It is distinct from the power to influence by, for example charisma, where there is no accountability within an organisation. The **clarity of authority** is defined as:

The clarity with which the area and extent of authority is defined; the clarity of understanding by the appropriate individuals, or organisations, that they have or are affected by that authority; and the clarity of the functioning of the roles of authority in accordance with their definition and understanding.

It is not sufficient that authority is clearly defined and understood. Importantly, it must be clearly exercised in accordance with definition and understanding of roles. The four criteria for evaluation are:

1 Clarity of definition of authority, which is based on documented evidence or statements from the highest management levels within an organisation, with regard to:

- Area of authority.
- Who has authority over whom.

2 Clarity of understanding of authority, which requires questioning of individuals, groups or representatives of an organisation, in relation to:

- Their area of authority.
- Over whom they have authority.
- Who has authority over them.

3 Clarity with which authority is exercised, is based on observations and questioning of personnel about their perceptions of relationships of authority, other than those in which they are involved, with respect to:

- Apparent area of authority.
- Who appears to have authority over whom.

4 Compatibility between definition, understanding and exercising of authority, involves comparisons between the definition, understanding and exercising of authority, in relation to:

- Area of authority.
- Who has authority over whom.

The definition of **decision making roles** is the clarity with which the roles of decision making are defined; the clarity of understanding by those making decisions, those requiring decisions, and those who may be affected by decisions; and the clarity of the functioning of decision making roles in accordance with their definition and understanding. These roles need not follow the same pattern as roles of authority, but the criteria for evaluation are the same.

- Clarity of definition of decision making roles.
- Clarity of understanding of decision making roles.
- Clarity with which decision making roles are exercised.

- Compatibility between definition, understanding, and exercising of decision making roles.

Assessment is also dependent upon the way in which decision making roles operate, which can be: distinct, parallel, or collective.

Distinct roles are those in which a single individual, or organisation makes decisions for particular situations. This does not preclude consultation or taking advice. Distinct roles need to be complemented by predetermined clear procedures for delegation if the principal decision maker is unavailable, coupled with efficient feedback, to principal and delegated decision makers, of the decisions that are taken. Distinct roles are desirable, but they can still be of poor clarity in terms of definition, understanding, functioning, and compatibility.

Parallel roles, which describes decision making by more than one individual or organisation about the same matter, is evidence of poor decision making roles. They create confusion. An evaluation of definition, understanding, functioning and compatibility will indicate the extent of "poorness".

Collective decisions are those arrived at by consensus by more than one individual or organisation. Time does not always permit such arrangements, and lack of consensus, or even majority, can result in continued argument and unhealthy disagreement. Collective decision making is usually evidence of poor clarity, the extent of which will be indicated in an evaluation of definition, understanding, functioning, and compatibility.

Accountability relates to the extent to which it is possible to exercise responsibility. It is a complex issue, and in the event of failure, accountability is often only established through legal proceedings. Despite the difficulties, an attempt should be made to establish a consistent understanding of accountability, which I suggest should follow the pattern of authority, modified accordingly to account for circumstances that include; availability of resources, intentionality, and decision making roles. Clarity of understanding of accountability is defined as follows:

The clarity of understanding of the area and extent of the accountability, and the *clarity of understanding* by appropriate individuals or organisations that they have or are affected by that accountability.

Evaluation relates to how clearly individuals or organisations understand their accountability. For example, individuals will be responsible, by virtue of their actions or inactions that can influence an outcome, for particular activities on a construction project. This includes, the project manager, foremen, engineers, and work-force. Their levels of authority will indicate "theoretical" levels of accountability. This can be modified in the light of decision making roles and circumstances, to establish an "expected" accountability. Individuals and organisations need to be questioned as to how they perceive their accountability. Non-compatibility between "expected" and perceived is evidence of poor understanding.

5.5.3 Effectiveness of the organisational arrangements.

Although factors such as management, motivation, and morale, that influence the effectiveness of organisational arrangements are distributed throughout the hierarchy, this concept allows for an overview in terms of characteristics that may produce, or be the consequence of, ineffectiveness. It is defined as the effectiveness of the organisational arrangements in providing for control, within a management framework, for the implementation of policy. Poor effectiveness may be evidenced by the following characteristics:

- The level of competence exhibited by the organisation.
- The extent to which there may be evidence of corruption within or by an organisation.
- The extent to which an organisation, or its parts, operate under a veil of secrecy, (i.e. with a lack of openness).
- The extent of evidence that the organisation may have divided interests that may

compromise policy objectives.

- The capacity of the organisation to use power, in relation to its policy objectives. Power in this context refers to any source, whether, physical, resource, position, expert, or personal. (Handy, 1985).

- The level of commitment of, and within, the organisation to its policy objectives.

These features are shown below in hierarchical form.

effectiveness of the organisational arrangements

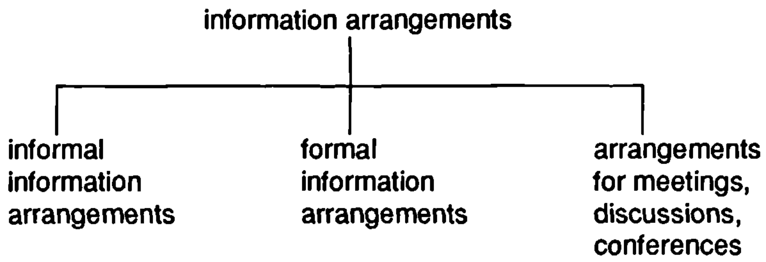
- competence of organisation
- evidence of corruption within organisation
- secrecy within organisation
- evidence of divided interests of organisation
- capacity of organisation to wield power
- commitment of organisation to policy

5.5.4 Uniqueness or unusualness of the organisational arrangements.

Within specific industries, the structure of organisational arrangements will be fairly standard, but there are likely to be noticeable differences between industries. **Uniqueness or unusualness of the organisational arrangements** has been included to allow for identification of organisational arrangements that are unusual with respect to the traditions of the industry *with which they are associated. Arrangements that develop by tradition are* usually tested, and departures must be regarded as added uncertainties. Tradition, however, should be regarded with caution, as it does not necessarily represent the safest approach to problem, (see chapter 10, clause 10.14.4.1). Eventually, having been tested, unique or unusual arrangements may become standard, but until then, the added uncertainty is evidence of proneness to failure.

5.6 Information arrangements.

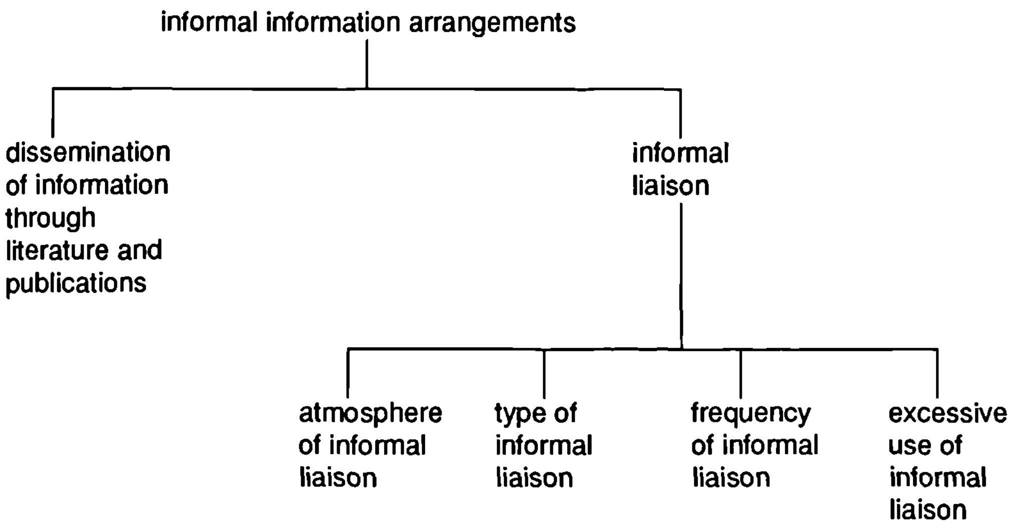
This is the functioning of arrangements for the dissemination of information, that in conjunction with organisation and planning arrangements, provide for the implementation of policy, and control of the development and operation of activities, systems, and procedures to meet specified objectives. Information arrangements are evaluated in terms of informal or formal arrangements, and the special case of meetings, discussions and conferences.



In the following discussion, "information" is interpreted as items of information.

5.7 Informal information arrangements.

This concept is defined as "the dissemination of information using arrangements that are not in accordance with established rules". The concepts requiring evaluation for evidence of proneness to failure are shown in the following section of hierarchy.



Evaluation of **dissemination of information through literature and publications** relates to policy context. Literature that is relevant to tunnelling for instance would include, tunnelling, mining, civil engineering, geology, and soil mechanics. Assessments are based on the quality of the publication, the relevance of content, and the extent of readership.

Evidence of poor **informal liaison** is judged through a combined evaluation of: atmosphere, type, frequency, and extent of use.

A poor **atmosphere of informal liaison** is evidenced by characteristics such as animosity, awkwardness, and indifference between participants. If conducted in a friendly cooperative atmosphere, informal liaison can help improve or maintain good working relationships.

The **type of informal liaison** refers to the way in which information is passed. For example, hurried conversations in passing, ambiguous memos, or unclear messages left on telephone answering machines may be evidence of poor type of informal liaison.

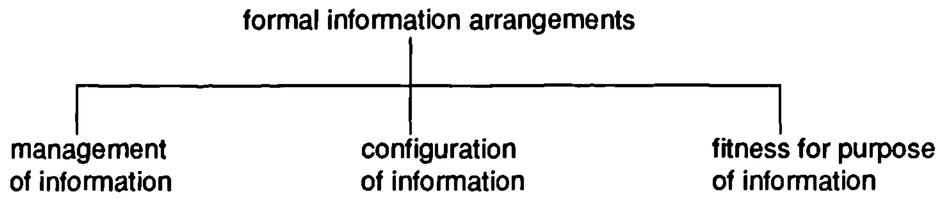
The **frequency of informal liaison** needs to be measured against what is considered ideal in the context of a situation and the positions, or status, of those involved. On a construction project, the resident engineer and site agent might be expected to have informal contact once or twice a week. There would be "poor" frequency if informal contact occurred say once every two or three months. Site resident engineers and site engineers, might be expected to have more frequent informal contact.

Informal liaison may be particularly useful in short cutting a system, but it can abused, (chapter 11, clause 11.4.4), or misused, mainly though excessive use. **Excessive use of informal liaison** can compromise the operation of a management framework, where formal information arrangements are intended to operate. The attribute that indicates evidence of excessive use, is yes, (i.e. there is). Symptoms of excessive use include:

- Informal liaison being the primary means of communication.
- Informal liaison being the main means of passing key, or important, information.
- Informal liaison, contrary to contractual requirements, being used to deal with contractual matters.

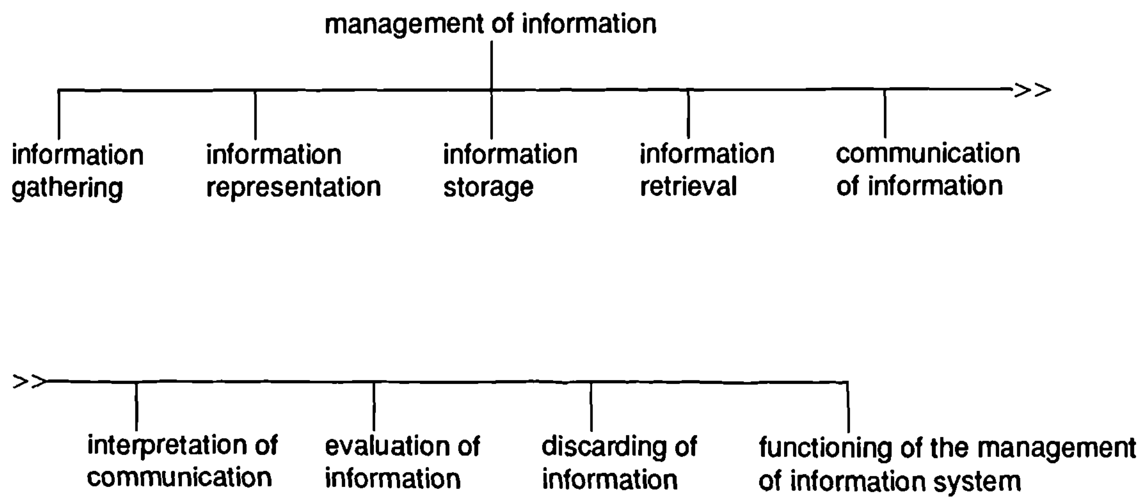
5.8 Formal Information arrangements.

Poor formal information arrangements, which is "the dissemination of information using arrangements that are in accordance with established rules", may be evidenced in poor: management, configuration, and fitness for purpose of information.



5.9 Management of Information.

This is the management, comprising; gathering, representation, storage, retrieval, communication, interpretation, evaluation, and discarding of information. The characteristics of management can be viewed as links in a chain. The chain can be of any length, with links recurring in various orders. The weakest link in the chain determines the "poorness" of the management of information. If making a strong link stronger, weakens a weaker link, it is counter productive. Even if separate links, (subsystems), operate effectively, the management of information system as a whole may still be poor. A separate evaluation of the functioning of the management system is therefore necessary. "Use of information" is omitted from the characteristics of management because it is implicitly assessed in concepts throughout the hierarchy.



Typical methods of information handling, employed in the design and construction of a project, will be used to illustrate points in the following discussion.

5.9.1 Information gathering.

This is "the operation of the arrangements for gathering information". During design and construction, for example, drawings and documents need to be gathered as they are produced or issued. Four methods of information gathering are outlined.

1 A monitored controlled central collection, illustrated in fig. 5.1, where information producers or providers send or deliver information to a collection point. There is a checking procedure at the collection point.

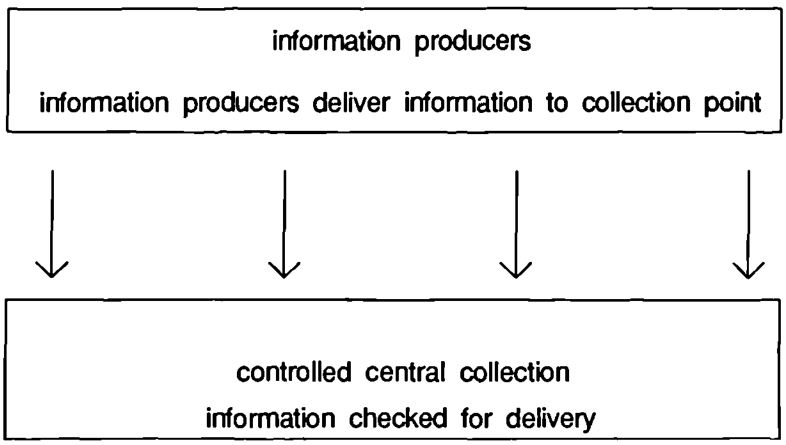


Fig. 5.1 Monitored controlled central collection of information

2 Unmonitored, uncontrolled central collection, illustrated in fig. 5.2, where producers or providers deliver information to a central collection point, but there is no check on what has been collected.

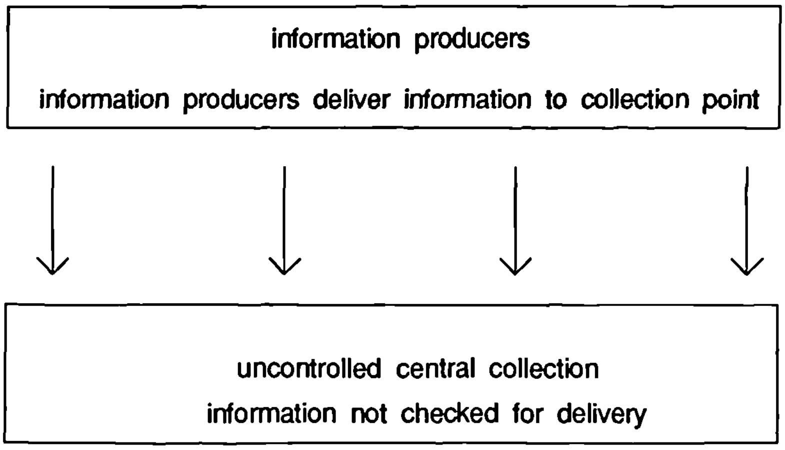


Fig. 5.2 Unmonitored uncontrolled central collection of information

3 Monitored, controlled collect and return, where information is collected but the producers or providers monitor that it has been collected. This is shown in fig. 5.3.

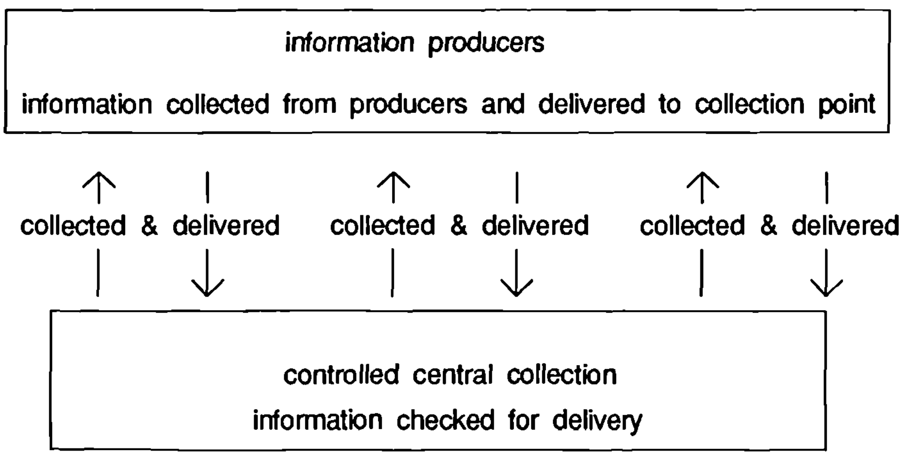


Fig. 5.3 Monitored controlled collection and delivery of information to central collection point

4 Unmonitored, uncontrolled collect and return, illustrated by fig 5.4. There is no check by the producers of information as to whether it has been collected.

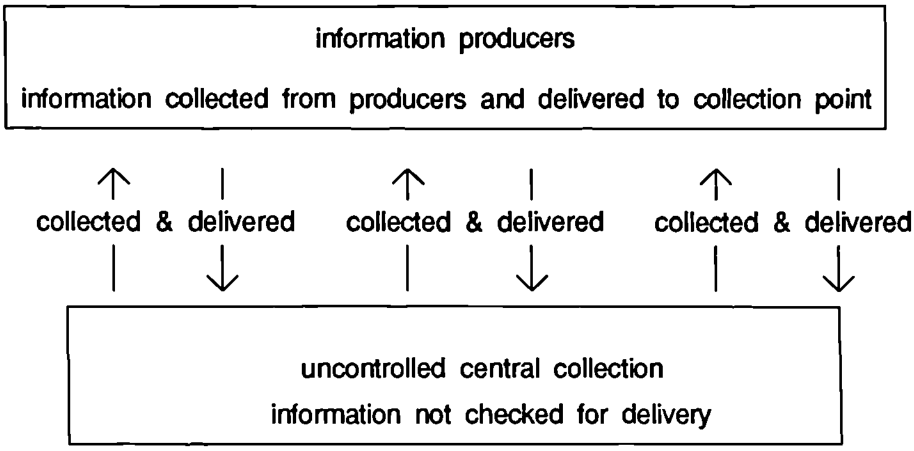


Fig. 5.4 Unmonitored uncontrolled collection and delivery of information to central collection point

In practice, gathering of information is likely to be a mixture of the four methods. An assessment should be based on how well a particular method or combination is operated. Systems in which checking is not included must be regarded as "poorer" than those in which it is.

5.9.2 Information representation.

This is defined as the form in which information is represented to facilitate its storage, retrieval, communication, interpretation, evaluation and discarding. Assessment therefore needs to check that the representation does not compromise the functioning of any of the other characteristics of information management.

5.9.3 Information storage.

The brain stores information, as does a traditional cabinet filing system, a computer data base, and a library. Whatever the system, records are required to ensure that what needs to be stored is being stored. For example, stored drawings should correspond to a current drawing list. A sophisticated data base provides the potential for failure if its contents are not clearly specified, or are out of date. An examination of information storage, which is "the operation of arrangements for the storage of information", should cover the keeping of records of current information, the correspondence between the records and what is being stored, and importantly, whether there is a proper back up storage system.

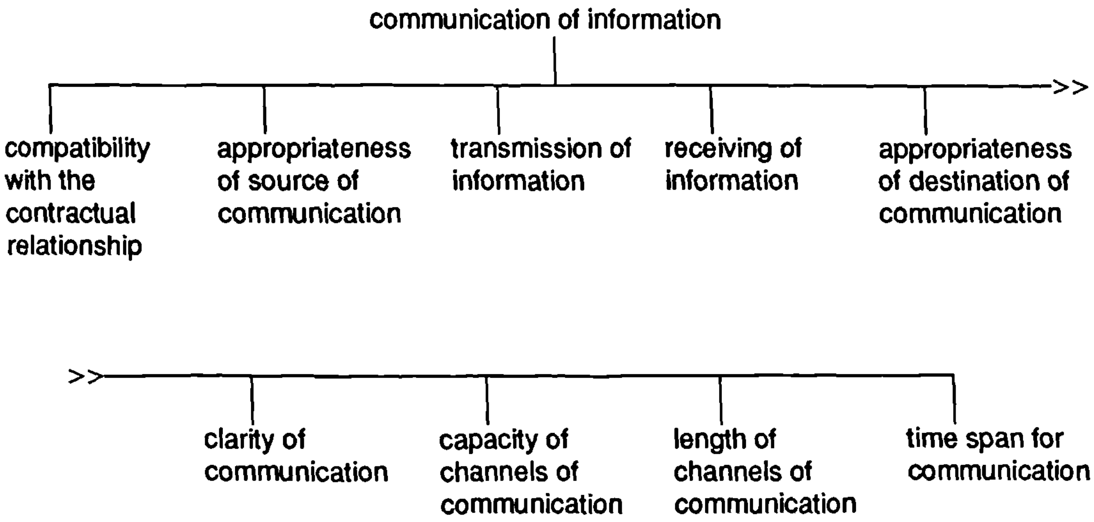
5.9.4 Information retrieval.

Defined as "the operation of the arrangements for the retrieval of information", information retrieval, together with information storage is essential for learning and for the practical application of knowledge. Assessment requires evaluation of the ease and efficiency with which information can be retrieved, whether for revision, communication, or use.

5.9.5 Communication of information.

Communication of information is the operation of arrangements for the communication of information between a human source and a human destination; by means of the transmission and receipt of information via appropriate channels. As well as being a separate system, communication is also inherent to the other characteristics of information management.

Information theory as described by Shannon and Weaver, (1963), and outlined by Krippendorff, (1975), may be used to help decide on corrective action, but first, the problems have to be identified. A qualitative evaluation is required of the whole process of communication. The following hierarchical expansion provides the structure for evaluation.



This hierarchy is comparable with Shannon and Weaver's (1963) model of communication, which is illustrated in fig. 5.5.

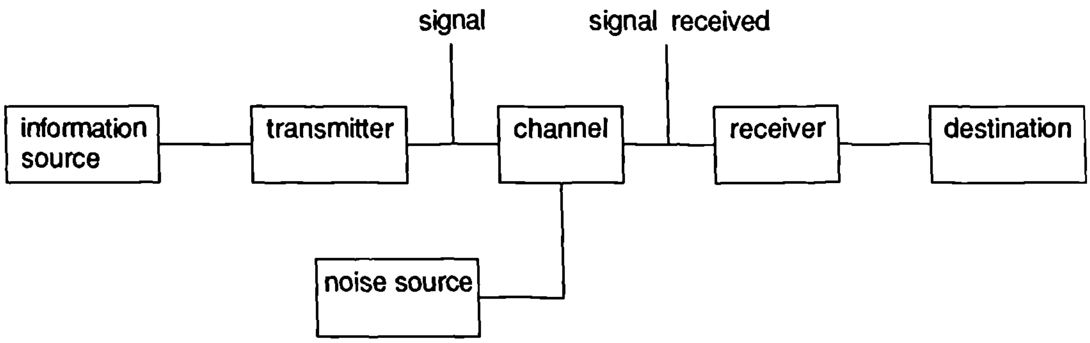


Fig. 5.5 Shannon and Weaver's model of communication

Channels will also exist between source and transmission, and receiving and destination respectively. Communication within the human body and the process of receiving, organising, storing, and using information at a personal level, are not considered here, although these features are relevant to information processing which is described in chapter 7, (clause 7.6).

Lines of communication should mirror the contractual relationships of a given situation. The methods of communication, relating to contractual matters, should be those that are most acceptable in law. These criteria are the basis for an examination of the

compatibility with contractual relationships which is defined as the compatibility of the lines of communication with contractual relationships, and the means of communication with contractual or legal requirements, such that the potential for ambiguities in law are minimised as far as is possible.

Assessments of compatibility of lines of communication with contractual relationships for client to sub-contractor communication on a construction project are illustrated in table 5.1.

	lines of communication (mirrors the contractual arrangements) client → consultant → contractor → sub-contractor			assessment
means of communication	written	written	written	acceptable
	verbal	written	written	poor
	written	written	verbal	poor

Table 5.1 Illustration of an assessment of the lines of communication on a construction project

By-passing the contracted parties, (an example of informal arrangements), as would be the case if the contractor were omitted from communications between consultant and sub-contractor, is also evidence of poor communication. The confusion and difficulties that can arise, will, generally, outweigh any apparent convenience. Sometimes, however, such shortcuts may be necessary, (chapter 11, clause 11.4.3).

The **appropriateness of source of communication** is the appropriateness of a particular human source to transmit information. Information may be available from various sources, but factors such as the ease of obtaining the information, or use of a familiar source, may result in the use of a source that is not appropriate to the situation or circumstances. The **appropriateness of destination of communication** is assessed in terms of the appropriateness of a particular human destination to receive information.

Tailoring information, including quantity, to suit communication methods may at times be necessary, but it is evidence of poor communication. Therefore, as well as the requirement for compatibility of a transmitter with receiver, source, and channels of communication; the means of **transmission of information** needs to be appropriate to the information. For example, if information that is well presented on an AO sized drawing is split into smaller elements and transmitted by fax machine, the overall view may be lost. Similarly, the means of **receiving information** should be appropriate to the information, and compatible with the transmitter, destination, and channels of communication.

Channels of communication are channels via which information is passed. These include sound waves through air or even water, radio waves, a postal system, and telephone lines. The **clarity of communication** which is "the correspondence between information as it is perceived, between any stages in a line of communication between source and destination", involves a qualitative assessment of clarity. It relates to noise, which is any disturbance in the channel that distorts or masks the information being communicated, (Shannon and Weaver, 1963). Interference between transmission and receiving over telephones and lack of correspondence between what is spoken into a telephone mouthpiece and what is transmitted are examples of the effects of noise.

The **capacity of channels of communication** is the capability of the separate channels of communication, between: source and transmission, transmission and receiving, and receiving and destination, to cope with the quantity of information needing to be passed in a given time. This relates to the rate of communication of information. (Littlejohn, 1983). Given time, any volume of information could be passed via a channel, (Krippendorff 1975), but in practice it usually needs to be to be passed in a specified time period.

If the **length of channels of communication**, defined as "the length, in terms of stages of communication, between a particular source and destination, (including secondary source to destination lines of communication)", is excessive, there is evidence of poor communication. For example, a piece of information may be passed via a number of different individuals, before it reaches it final destination. If intermediate recipients of the information have no need of it, nor add to the efficiency or effectiveness of the system, they are unnecessary and increase the potential for failure.

The **time span for communication** is defined as the period, and the consistency of the period, of time taken for the communication of information between source and destination. If the time span is inappropriate, information, relevant at transmission, may not be relevant at receipt. This is illustrated by remarks made in interview E, (chapter 3, clause 3.4.1). The interviewee, described the procedures used by visiting safety consultants, employed by some contractors to inspect site safety conditions. He stated:

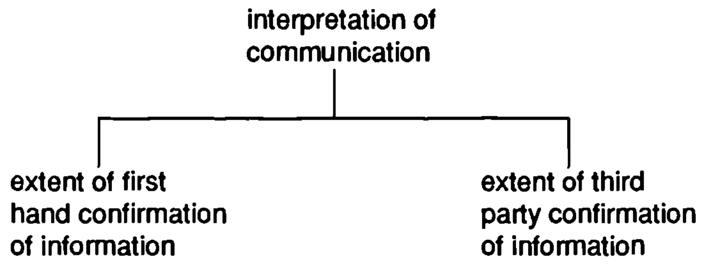
> What sometimes is very annoying, is that they go away and they perhaps write if there's something seriously wrong. They haven't had time for a meeting to end, or something, so they go away and write. By the time they've written, if they've seen something wrong this morning (Friday) the letter hits the table next Thursday or Friday, by which time we've done with section 4, and we're on section 7 and it's different again. So it becomes an irritation to try and find out what he was complaining about and have we gone past that bit yet?

Inconsistencies in the length of time for communication can lead to inefficiencies for those who have to use the information. It is, for instance, difficult to programme work if information comes in bulk at one time, interspersed with periods of inactivity when no information is forthcoming.

5.9.6 Interpretation of communication.

Since no two worldviews are identical from a particular worldview, it is inevitable that information is lost between source and destination. However, in order to give meaning to information, there must as far as is possible be correspondence between interpretation in the communication of information between producers and users, and sources and destinations. The interpretation of communication is assessed in terms of confirmation that received information corresponds to transmitted information.

First hand confirmation is where destinations or users confirm their interpretation of received information to sources or producers, respectively. For third party confirmation, where destinations or users confirm their interpretation with other destinations or users, it is preferable that the third party has received the information independently.



5.9.7 Evaluation of Information.

If information is to be managed, its significance must be understood. This requires that information be evaluated; that it be given worth. Evaluation is a prerequisite for determining significance and discriminating between information. Assessment of this concept requires an examination of whether information is being evaluated, and whether its evaluation is being carried out by properly qualified people. For example, on receipt of revised drawings on a construction project, it is expected that engineers and quantity surveyors examine the drawings to determine the consequences of amendments. There is evidence of poor "evaluation of information" if this is not being done. The facility to assess the actual worth of the information is provided for under fitness for purpose, which is discussed in clause 5.11.

5.9.8 Discarding of Information.

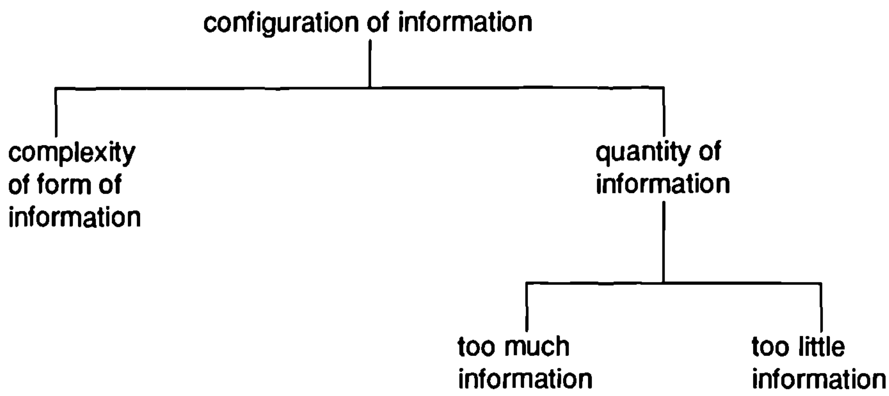
Obviously, information that is still required should not be discarded, but not discarding information when it is no longer required is also evidence of poor information management. It can put pressures on the other links in the chain, particularly storage and retrieval which can become overloaded. There is an obvious dilemma that future requirements are not always known, and decisions about whether or not to discard information need to account for this.

5.9.9 Functioning of the management of information system.

One objective of management is to be in control. Information is essential for control, but as a commodity, it requires control. The management of information is fundamental to management in all other contexts. The effective operation of every link, (subsystem), in an information management chain will not guarantee effective management. A separate evaluation of the system, as it functions as a whole, is necessary. It would be prudent, particularly if there is evidence of poor functioning of the management of information, to examine closely the culture in relation to both policy and the operation of its associated management framework.

5.10 Configuration of Information.

Configuration of information is "the complexity of form and quantity of information that is communicated, with regard to its facility to be understood by its recipients".



To some extent, understanding of information is dependent upon clarity, precision of presentation, and the abilities and experience of individuals. Apart from this, certain concepts or ideas are easier to grasp than others. **Complexity of form of information**, which is intended to elicit an assessment of this rather fuzzy concept, is defined as:

The feature that produces difficulty of understanding, in those people who possess what are thought to be appropriate qualifications and experience, of information that is presented as precisely and clearly as possible.

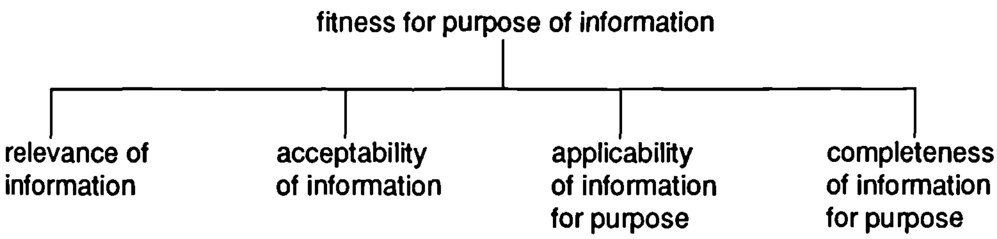
Assessment is based on the judgements of appropriately qualified and experienced people, (experts). Complexity is discussed further in chapter 10, (clause 10.4.1), in relation to problem difficulty.

An assessment of **quantity**, whether too much or too little, also requires expert judgement. **Too little information**, which is "a lack of information that is available for decision making", requires a balanced evaluation of the separate views of those involved in passing and receiving information. Disagreement between source and destination or uncertainties about whether sufficient information is being passed, is evidence of poor communication. **Too much information** exists if the quantity of information, which although relevant, cannot be dealt with by the recipient in the time available because of information overload.

Information processing, which describes the way in which people understand and deal with information is not included for evaluation under information arrangements. It is included under human factors engineering, (chapter 7, clause 7.6), as part of an examination of the state of the art of hazard engineering.

5.11 Fitness for purpose of information.

Fitness for purpose of information is defined as the characteristics that determine whether, in a particular context, information is relevant, acceptable, applicable, and complete, for inclusion within the information arrangements. The characteristics of evaluation are similar to those relating to acceptability, (chapter 6, clause 6.6.3), and fitness for purpose, (chapter 10, clause 10.5), of knowledge, products and processes. The emphasis, though, is different. This concept involves a more superficial, less detailed, evaluation than that for acceptability of the "state of the art". Knowledge that is "poor state of the art" may in fact be suitable for inclusion in information arrangements if, for example, it is to be used for study and research. Assessment requires evaluation of collective information as distinct to single pieces of information. However, hypothetical examples of pieces of information, (reinforcement drawings and schedules), will be used to illustrate the following discussion.

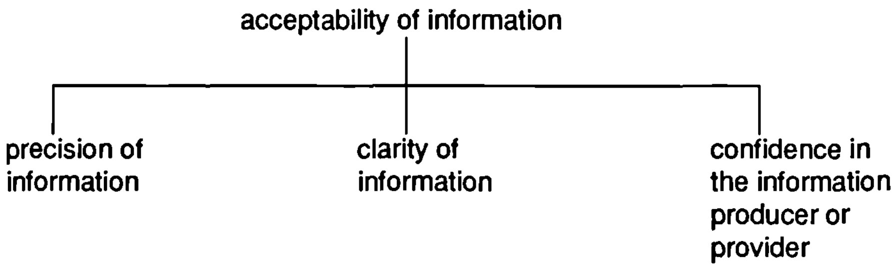


5.11.1 Relevance of Information.

This can be looked at in terms of semantical information, which by definition reduces uncertainty in a situation. The amount of semantical information passed is the difference between the uncertainty before a message was received and the uncertainty after a message was received, (Krippendorff, 1975). A message that does not reduce uncertainty conveys no information and is irrelevant.

5.11.2 Acceptability of Information.

Shown below in hierarchical form, this is defined as the acceptability of information with respect to its precision and clarity and the confidence that can justifiably be held in the producers and providers of the information.



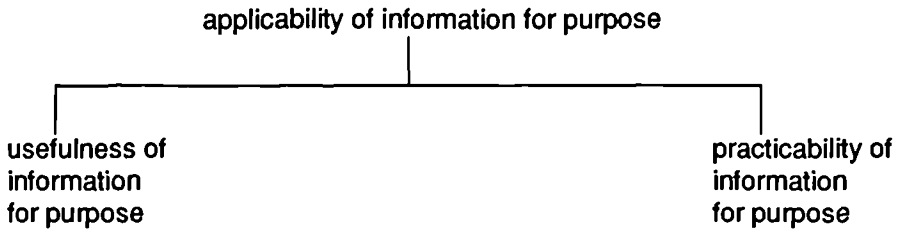
The **precision of information** is the accuracy with which information is presented. For a reinforcement drawing, if dimensions and bar diameters are given and the bars properly scheduled, the information is precise. If bars are simply shown as diameters and types, with no schedule, precision is poor.

The **clarity of information** is the lack of ambiguity of information. In the case of a reinforcement drawing and schedule, if the bar sizes, shapes, and types do not correspond between drawing and schedule, there is poor clarity. If the drawing is cluttered, yet complete, the clarity may be poor.

An assessment of **confidence in the information producer or provider** should not be confused with that of the "appropriateness of source of information", (clause 5.9.5). If, for a reinforcement and schedule, it is known that the information has been produced by someone not familiar with, or new to, the project, there is reason for lack of confidence. This is evidence of poor acceptability of the information for inclusion in the information arrangements. It is not a reflection upon the individual concerned.

5.11.3 Applicability of information for purpose.

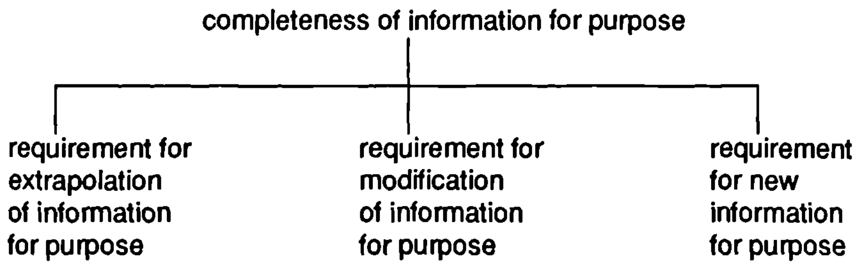
This is defined as the applicability of information; making the assumption that it is in accordance with fact or reality; for inclusion in the information arrangements, by virtue of its usefulness and practicability in a particular context.



Consider, for example, that 20mm reinforcement bars are detailed and supplementary information states that 16mm bars can be substituted to provide the same area of steel. If 16mm bars are not available, there is low usefulness of information. If, alternatively, 16mm bars are detailed but cannot be obtained, further information may state that 20mm bars can be substituted for 16mm bars, at the same spacing. Disregarding the contractual situation, a contractor, who would have to incur additional cost to make this substitution, may regard the information as impracticable.

5.11.4 Completeness of information for purpose.

This is the completeness of information; making the assumption that it is in accordance with fact or reality; for inclusion in the information arrangements, with respect to requirements for: extrapolation of, modification of, or new information, in a particular context.



Consider that the reinforcement drawing and schedule is for a chamber to be constructed with the roof at ground level.

If base and wall details only are given, and the information is relevant, and acceptable, there is a **requirement for extrapolation of information**, because roof details are required.

If all details, base, wall and roof are given, but openings are not detailed, there is a **requirement for modification of information.**

If the chamber is to be constructed in ground conditions that differ from those assumed in the design, there may be **a requirement for new information.**

5.12 Meetings, discussions, and conferences.

Meetings, discussions and conferences, as well as providing information, are particularly relevant to planning. An examination for evidence of poor arrangements will require the following evaluations:

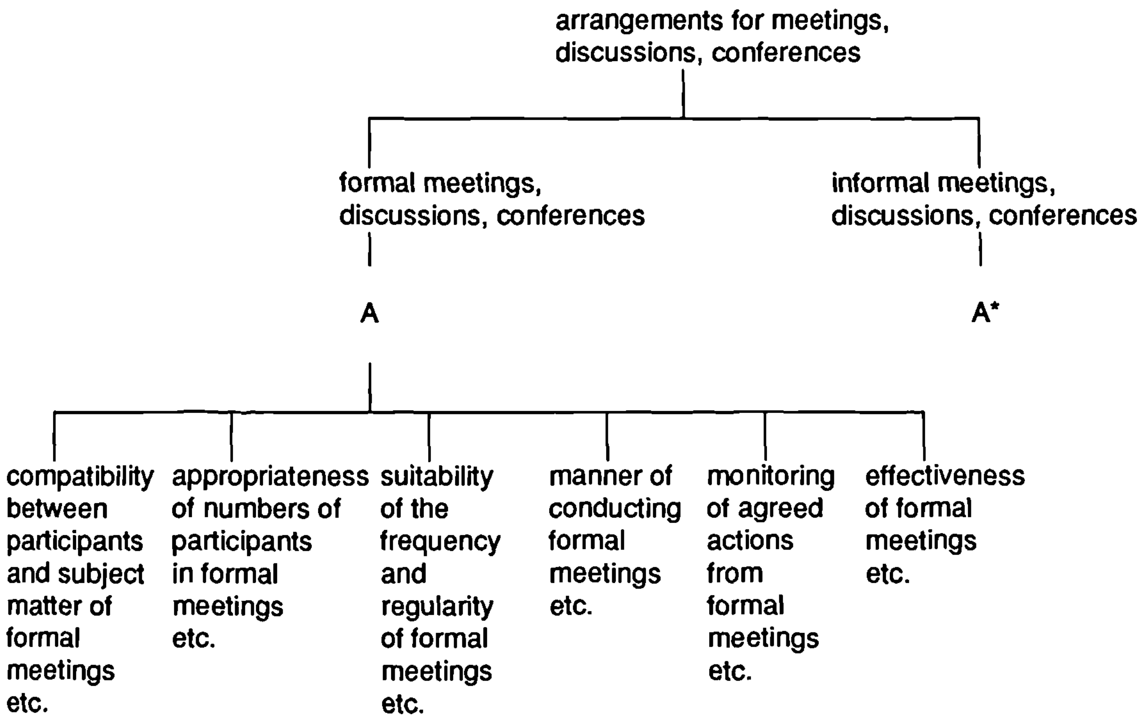
- The appropriateness of the numbers of participants.
- The appropriateness of the interests and roles of the participants to the subject matter.
- The frequency and regularity of meetings. This relates to the appropriateness of frequency and regularity of meetings for the participants. The arrangements are poor if the timing and frequency adversely affect other activities associated with a policy.
- The manner in which the meeting is conducted. This relates to: management of the

meeting, including the chairmanship; relevance of agenda; length of meeting, which if too long can produce disinterest and if too short doesn't deal properly with relevant matters; recording of meetings; distribution of records. Other relevant factors are the clarity of the objectives of the meeting, the availability of information to participants, and detailing planned actions.

- Monitoring of action agreed at previous meetings. Monitoring provides for continuity by checking that action agreed at previous meetings has been carried out. Poor monitoring is evidence of poor arrangements.

- The effectiveness of the meeting or programme of meetings. Assessment should be unprejudiced by assessments of other concepts such as frequency and regularity. If semantical information does not come from the meeting or action is not followed up, there is evidence of poor effectiveness.

Meetings, etc, can be classified as formal, (in accordance with rules), or informal. The hierarchical expansion is as follows:



A* repeats the hierarchical expansion under A in terms of the concept above A*.

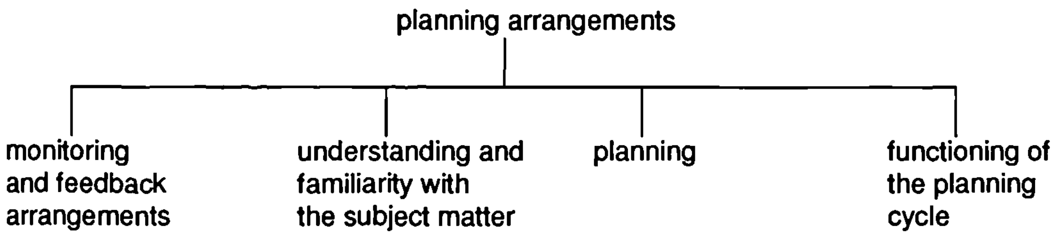
The main benefit of informal meetings is that they provide a forum for the exchange of ideas.

Formal meetings need not necessarily be regular, recorded, and specify follow up action. The criterion of this classification is "accordance with rules". This can include conferences, for example, where records can be made and distributed, but follow up action is usually at the discretion of the recipients of such records, who may not even have attended. Recording events, even for informal meetings, provides the opportunity for thought, reappraisal, or storage until it is felt that the information might be useful.

5.13 Planning arrangements.

This is defined as the functioning of arrangements that facilitate planning, and in conjunction with organisation and information arrangements, provide for the implementation of policy and the control of the development and operation of activities, systems, and procedures to meet specified objectives.

Planning arrangements involve a cycle of: planning - monitoring - feedback - planning. This cycle should not become the primary objective to the detriment of the objective of the subject of the planning arrangements. The concepts shown in the following section of hierarchy provide for an evaluation of the constituent parts of the cycle and the functioning of the planning cycle.



The **monitoring and feedback arrangements** are the arrangements for monitoring the implementation of planned activities, systems and procedures, and feedback of information about implementation. The purpose is to ensure that relevant information is made available for the continuing process of planning.

Understanding and familiarity with the subject matter is defined as the understanding and familiarity of the planners and/or their advisers with the requirements of a policy, the context of that policy, and with the state of the art of the discipline of planning. It is not always possible that those who are to carry out the work can be involved in planning. Time restrictions and the view that certain people are of greater value in the "doing", rather than the planning means that there can be a lack of coordination between planners and those who implement the plans. There should be familiarity and understanding on the part of the planners of how their plans are implemented; and those expected to put plans into practice should have input into the planning arrangements. Hence the value of meetings, discussions and conferences.

Planning is the planning of the activities, systems and procedures for the implementation of policy.

The separate elements of planning arrangements need to function as a system. The "**functioning of the planning cycle**", allows for an assessment of this.

An example of the value of planning is described by Lowery, Moore, and Thomas, (1988), in their outline of the planning arrangements for a period of intensive activities in the Ekofisk Area of offshore oil and gas production installations in the North Sea. Their account covered the planning of procedures and methods of work, as well as focusing upon safety aspects. It was concluded that:

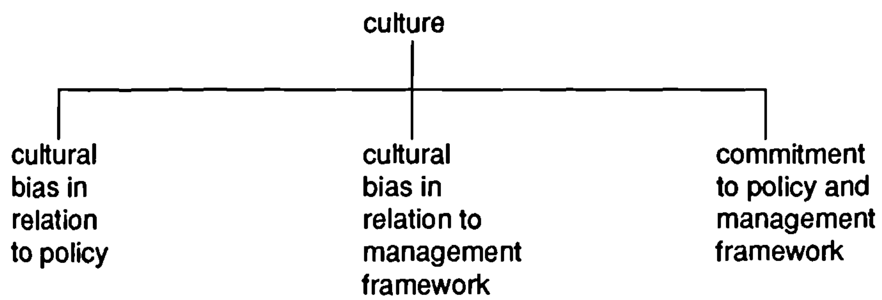
> An active, practical and sophisticated program for the prevention of accidents and property losses is proven to be a significant cost benefit investment. Such a program not only represents the protection of life and health, but also increases productivity in parallel with gains to the general work environment.

5.14 Culture.

Culture has been defined in chapter 1 as a set of beliefs, norms, attitudes, roles, and practices. These characteristics influence decisions about objectives and motivation to achieve objectives. This definition can be applied to any chosen context, such as safety, within any element of human society, from individuals to international communities.

Beliefs and attitudes are characteristics of open world problems, in that they can be ill-defined, fuzzy, and unknown or unidentified. Attitudes are particularly complex. They imply a way of looking at things that is influenced by personality and emotions, such as introversion, happiness, optimism, and fear. Assessment of these characteristics is difficult in individuals, and even more so in organisations. Because of these complexities, the term "attitudes", used in the definition of culture should be interpreted as a way of looking at things, without the influence of emotions. Assessment of emotional and personal characteristics is tacit in evaluations of qualifications for particular roles. For example, a requirement for particular types of personality are part of the qualifications for certain types of work, such as travel couriers or receptionists.

Culture is inherent to the activities and systems that are distributed throughout the concept hierarchy. Evaluation as a separate concept, as is required here, is an overview. The features that are used to provide for an overview are: cultural bias, (i.e. shared values and beliefs), (Thompson, Ellis and Wildavsky, 1990) and commitment. It is accepted that this is simplistic approach. Values and beliefs can be difficult to evaluate, but in combination with an evaluation of commitment which is linked to behaviour and the provision of resources, an assessment of culture should be possible.



5.14.1 Cultural bias.

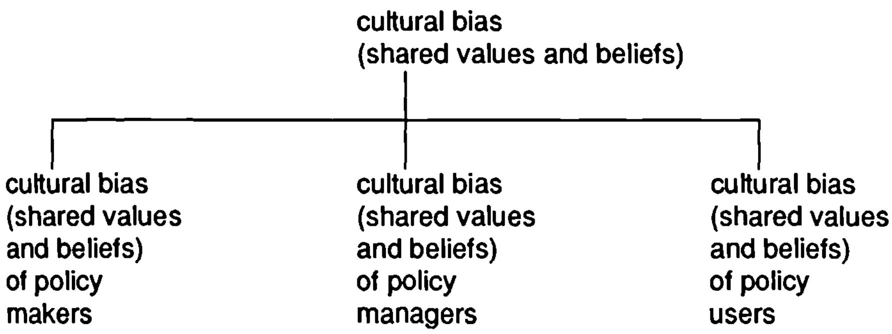
The term values and beliefs, used to describe cultural bias, is descriptive and can be evaluated as a single characteristic. Belief is reflected in the value, or importance, that is attributed to it. The definition of cultural bias is:

The comparative value of belief, in a set of concepts or ideas that have been formulated into a particular context, in relation to that in other sets of concepts or ideas that have similarly been formulated into different but comparable contexts.

For safety, shared values and beliefs can be compared with shared values and beliefs for other features such as environmental issues, profitability, and the development of technology. If safety is valued less than most of the other features in such a list, cultural bias in relation to safety is poor.

For management framework, comparisons are between values and beliefs in the functioning of management frameworks for different policy contexts. For example, a comparison of the shared values and beliefs about the need for and the functioning of management frameworks for: safety, production, profitability, and technical engineering.

A more detailed examination of cultural bias distinguishes between that for policy makers, policy managers, and policy users. These classifications are not mutually exclusive.



"Policy makers" includes those representing the interests of the policy makers. For example on a construction project, the highest levels of site management represent the policy makers, as well as being both managers and users.

The level of examination can be carried to lower levels in the policy and management framework hierarchies.

5.14.2 Commitment.

Commitment to policy and its management framework, as illustrated by the hierarchical expansion, is demonstrated by behaviour in relation to policy and its management framework and the allocation of resources for the implementation of policy.

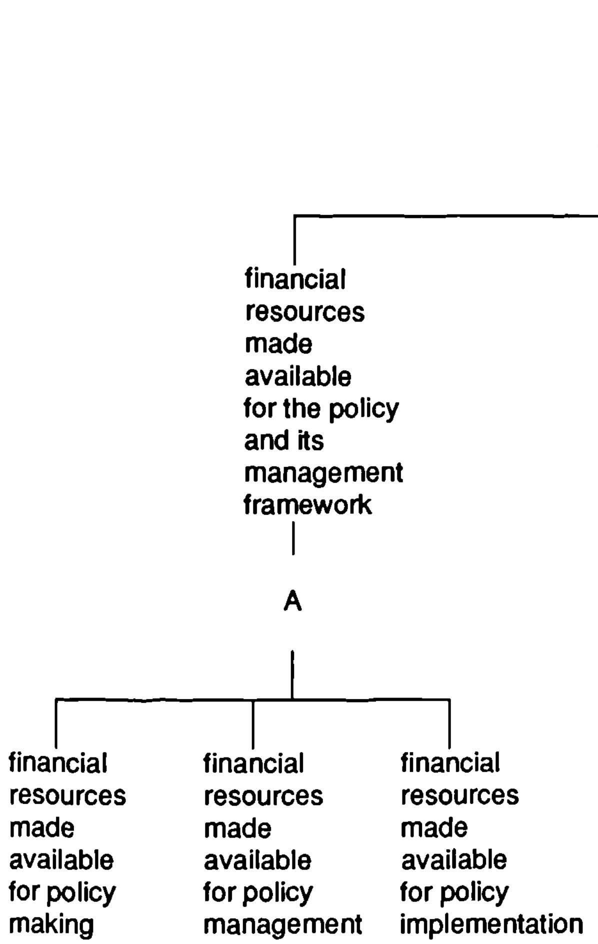
- commitment to policy and its management framework
  - behaviour in relation to policy
  - behaviour in relation to the operation of the management framework for policy
  - resources made available for policy and its management framework

Expected standards of behaviour and resource requirements need to be established by practitioners and experts. Auditors must be familiar with the standards.

Behaviour can be assessed separately for policy makers, policy managers, and policy users, and as for cultural bias, the level of examination can be carried to lower levels in the policy and management framework hierarchy.

There should be compatibility between assessments of cultural bias and behaviour. Apparent incompatibility may be due to deception or misrepresentation of shared values and beliefs or poor evaluation by the auditor.

As shown in the following hierarchical expansion, resources are classified into financial, human, and time, with respect to policy making, policy management, and policy implementation.



A* repeats the hierarchical expansion under A in terms of the concepts above A*.

Judgement is required as to whether a lack of resources is the consequence of their not being available or not being made available.

5.15 Summary and conclusions.

Policy, whether or not it is explicit, is fundamental to any undertaking. Working to achieve objectives necessitates the implementation of policy. For policy implementation, a management framework is necessary to control other activities, systems, and procedures. Culture in relation to policy is fundamental to setting objectives and motivating policy implementation.

The formulation of policy needs to set out objectives and outline the means by which it is proposed to achieve these objectives. The policy needs to be flexible enough to allow for amendment, if necessary.

A management framework is made up of the functioning of organisational, information and planning arrangements. These three elements are inter-dependent. Their functioning, independently and as a system, provides the basis for the development and operation of other activities, systems and procedures.

Culture, (beliefs, norms, attitudes, roles, and practices), provides the motivation to develop objectives and implement a policy for the achievement of those objectives.

Although culture is evidenced in all the activities, systems and procedures adopted for policy implementation, an indication of the nature of a culture in relation to particular policy can be judged in terms of cultural bias and commitment.

The hierarchical development of policy implementation, described in this chapter, is shown in fig. 5.6, at the end of the chapter.

Fig. 5.6. Hierarchical expansion of "implementation of policy". (Sheet 1 of 2).

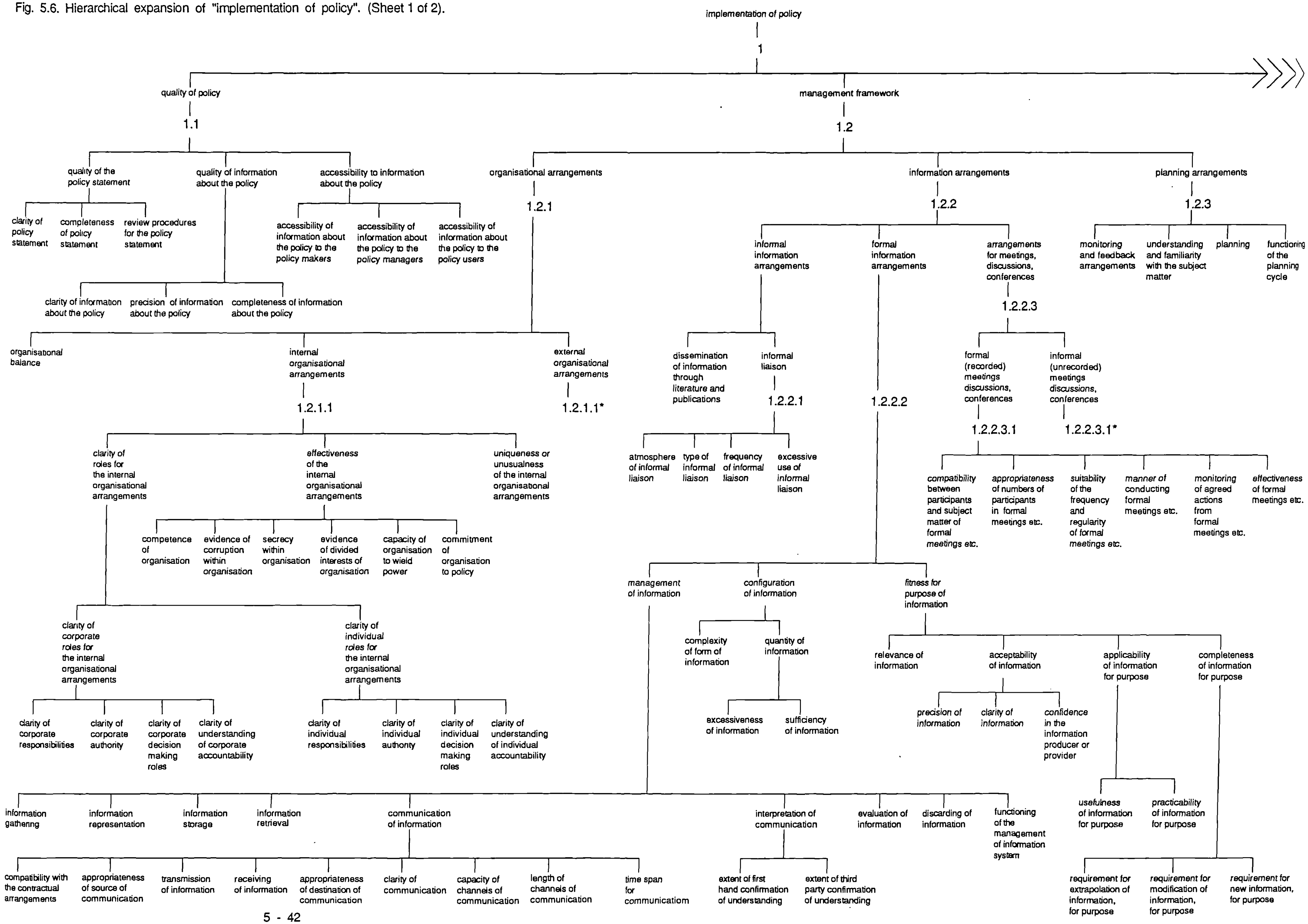
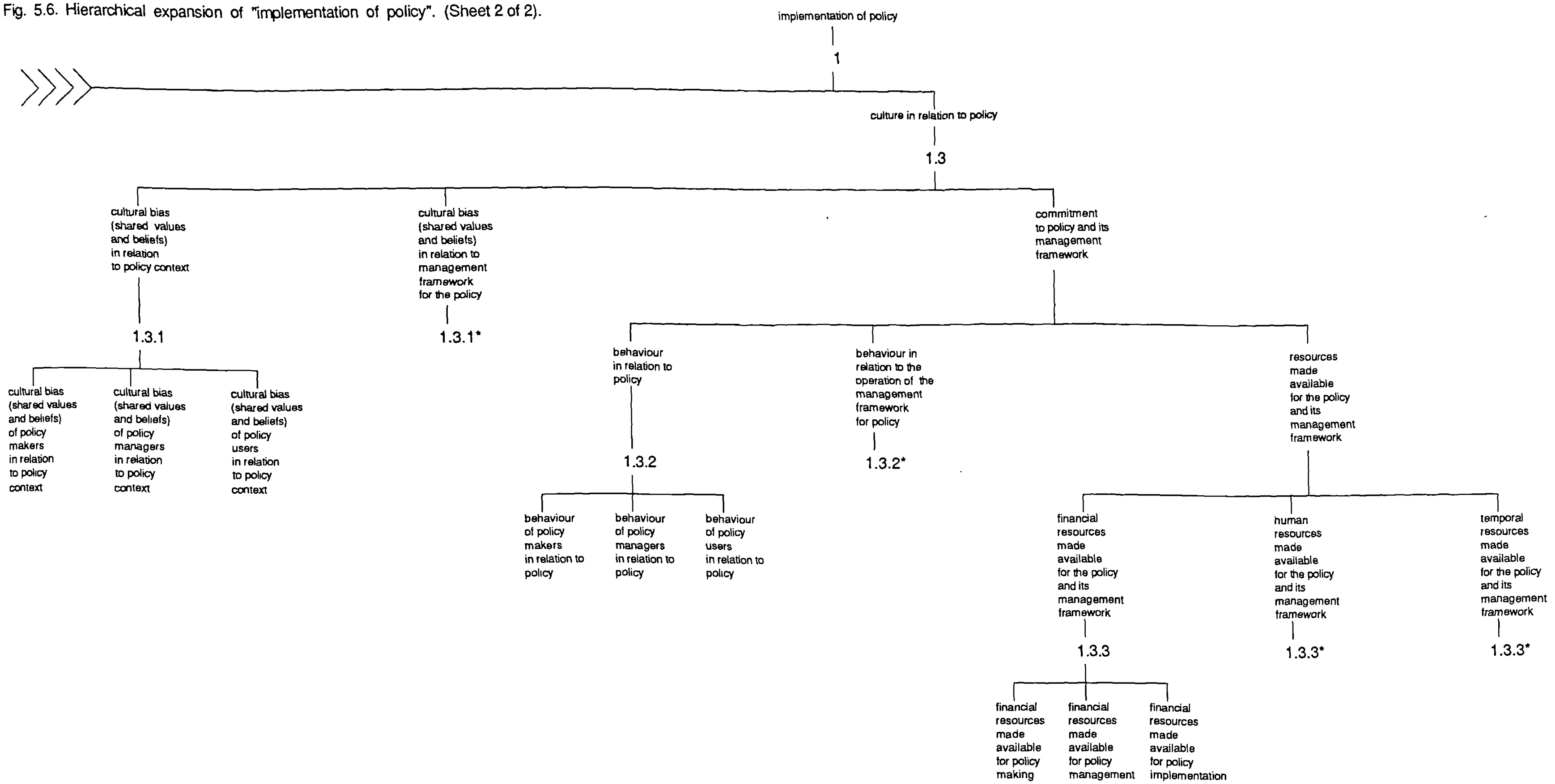


Fig. 5.6. Hierarchical expansion of "implementation of policy". (Sheet 2 of 2).



Chapter 6.

State of the art of technology.

6.1 Objectives.

1. To outline the state of the art of technology as a socio-technical system with regard to its influence on proneness to failure.

2. To develop and discuss critically, concepts that can provide evidence of proneness to failure in the state of the art of technology.

3. To present a hierarchy of concepts that can provide for an evaluation of the state of the art of technology for evidence of proneness to failure.

6.2 Introduction.

In chapter 4, it was suggested that analyses of failures have indicated that deficiencies in the state of the art of technology contribute to failure. A notable example, given in chapter 4, is the Tacoma Narrows Bridge collapse, in the USA, 1940, due to a mode of behaviour not understood by the technology of the period, (Blockley, 1980). For the West Gate Bridge, collapse in Australia, 1970, (Blockley, 1980), it could be argued that the use and development of the state of the art was adversely effected by poor inter-personal and inter-organisational relationships during construction. Perhaps, if there had been better relationships, the individuals and organisations involved in construction might have been more receptive to the problems of others? The chances of solving construction problems, and thereby improving the state of the art, might have been increased and disaster might have been avoided. In an analysis of the Aberfan coal tip disaster in the UK, 1966, Turner, (1978), reported that knowledge about procedures to stabilise coal tips had been available for many years. This knowledge was not generally appreciated because of poor functioning of organisational and information arrangements. This apparent non availability of knowledge to those having need of it represents deficiencies in the use state of the art, brought about by failures in what are primarily social systems.

These examples demonstrate that the "state of the art" can influence proneness to failure. They also indicate that the state of the art of technology can be subject to social influences which need to be incorporated into the hierarchical development. Engineering, which represents the activities associated with technology, needs to be understood as a socio-technical system.

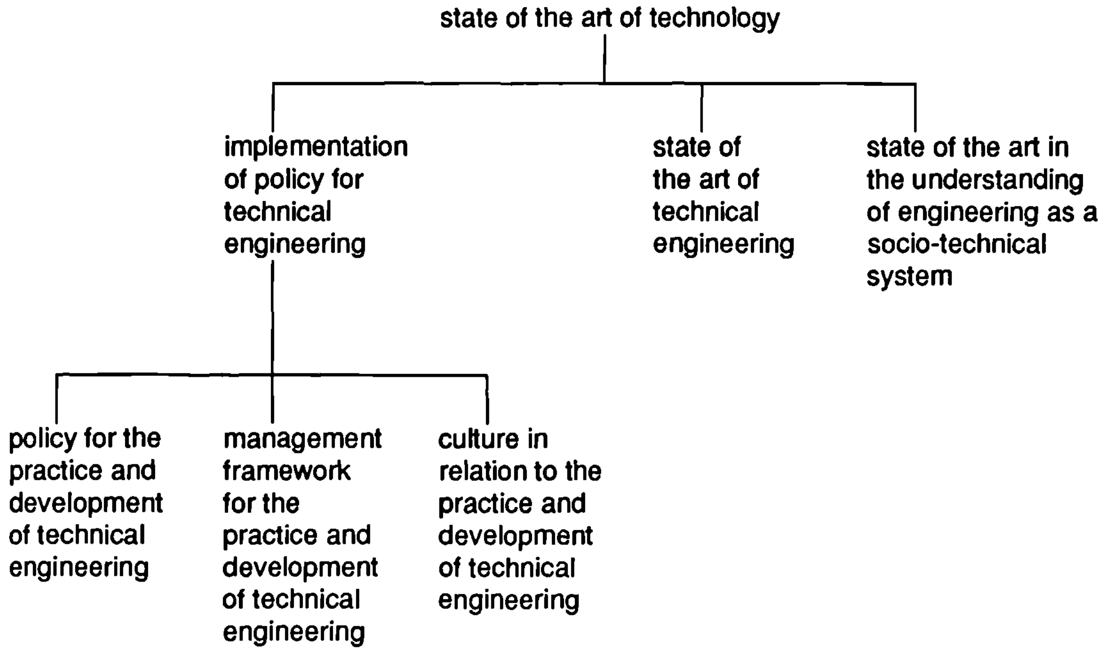
Inter-dependencies between society and technology are discussed further in chapter 8.

6.3 State of the art of technology.

This is defined as the range of knowledge, products, and processes that are relevant to and available for, the practice and development of any or all of the applied sciences, which have practical value and/or industrial use.

Concepts that provide for an evaluation of the state of the art of technology are shown in the following section of hierarchy. Factors that are relevant to an evaluation of these concepts for evidence of proneness to failure are discussed in this chapter. These factors are built up to form fig. 6.1, presented at the end of the chapter, which shows the hierarchical development of state of the art of technology.

The term "technical engineering" is used to distinguish it from hazard engineering, human factors engineering, and the socio-technical characteristics of engineering.



Implementation of policy is examined in terms of the hierarchical expansion outlined in chapter 5.

6.4 Testing.

Testing propositions is essential for the maintenance and development of a technology. A "successful" test enhances confidence in a theory; a "failed" test produces a new problem, requiring a new proposition.

Standard laboratory tests used in engineering science are closely controlled. Blockley, (1980), called these controlled tests in the World Inside the Laboratory, **(controlled tests in the WIL)**. Parameters can be controlled as closely as is possible, and the influence of parameters that are difficult to define, measure, or control can often be eliminated.

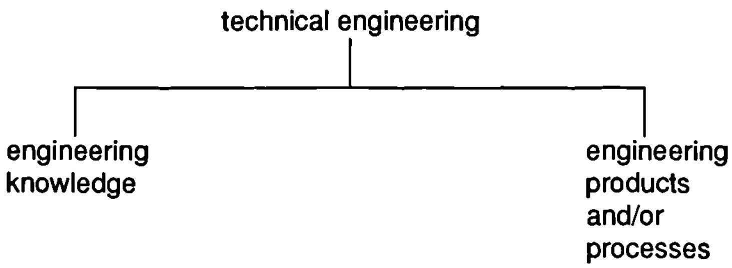
Use is the most common type of test. In civil engineering, design and build is the hypothesis; use of a structure is the test. A bridge, for example, is tested in use under uncontrolled naturally occurring conditions. Using the "Blockley" terminology, use can be defined as an uncontrolled test in the World Outside the Laboratory, **(uncontrolled test in the WOL)**.

Prototype tests are carried out in the "world outside the laboratory," under conditions that are controlled as closely as possible, to a state such that an artefact or component of an artefact may possibly not be fit for use after completion of the tests, (Blockley, 1980). These are described as **controlled prototype tests in the WOL**. They can be used to investigate the behaviour of an artefact by comparing performance with prediction, or by simulating service conditions, to examine the behaviour of the artefact as it is intended to be used. Prototype tests, rendering an artefact unserviceable, have a limited use in the "one off" projects that are typical of the construction industry. They can, of course, be used to test specific components that might be used extensively in the industry.

Proof tests, although controlled are also conducted outside a laboratory environment. They are used to demonstrate a certain minimum performance, to a state such that an artefact or component of an artefact can be used in service after completion of the tests. Described as **controlled proof tests in the WOL**, they reduce the total uncertainty, particularly with regard to minimum performance. They may yield useful information about system performance, especially in the serviceability limit state, (Blockley 1980).

6.5 Technical engineering.

Technical engineering is classified into engineering knowledge and engineering products and processes.



6.5.1 Engineering knowledge.

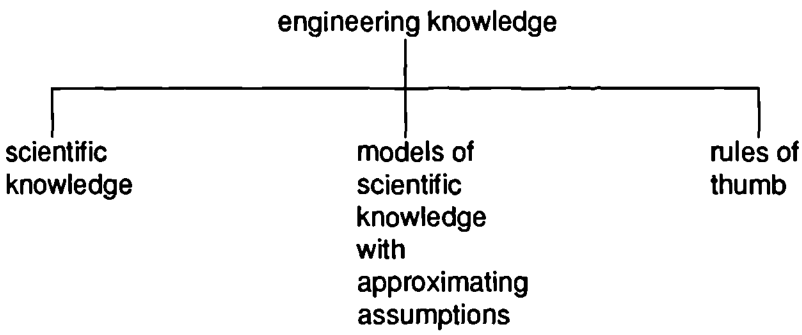
According to Blockley and Henderson, (1980), engineering knowledge consists of three components representing models of collective experience. These are:

- Scientific knowledge. This models scientific theory that has been tested in the precise confines of the laboratory. Newtonian mechanics is an example.

- Scientific knowledge with necessary approximating assumptions. Scientific knowledge, as tested in the laboratory, does not necessarily represent situations as they occur. Assumptions are made such that scientific knowledge can be considered to model actual situations. For example, in structural engineering design; joints may be assumed fixed or pinned, and loads may be assumed as uniformly distributed.

- Rules of thumb, such as those specifying edge distances to bolt holes in steelwork, are rules that appear to work. They often develop through trial and error, but experience indicates that they are applicable in certain circumstances. Another example, the Ministry of Agriculture, Fisheries and Food, (1977), guide for the design and construction of small earth reservoirs, embankments, and dams for irrigation, is essentially a set of rules of thumb.

In terms of these components, engineering knowledge, is defined as the accumulated scientific knowledge, scientific knowledge with necessary approximations, and rules of thumb; that model the collective experiences available to engineering or any of its disciplines.



The following equation for predictions of settlements in clay soils, (Tomlinson, 1986), illustrates the components of engineering knowledge, shown in the preceding diagram.

$S = qB(1-v^2)I_s/E$, where:

S is the vertical settlement of a loaded area on the horizontal surface of the material.

q is the increment of vertical stress causing the settlement.

B is the least dimension in plan of the loaded area.

v is Poisson's ratio.

I_s is an influence coefficient containing all the geometric proportions of the case under study.

E is the deformation modulus for the soil.

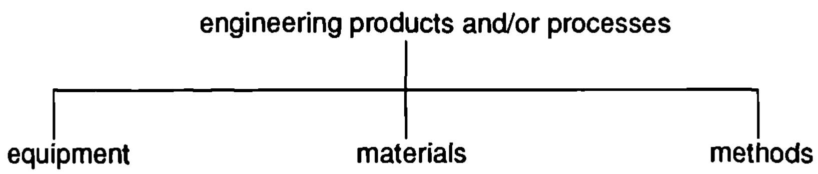
Elastic theory for an ideal isotropic elastic material is scientific knowledge.

The model of the scientific knowledge with the necessary approximating assumptions, includes assumptions of consistent soil properties over the loaded area.

Rules of thumb exist in the parameter I_s, for which values, based on the shape of the loaded area, (e.g. circular, rectangular, square), can be obtained from an empirically developed series of graphs.

6.5.2 Engineering products and/or processes.

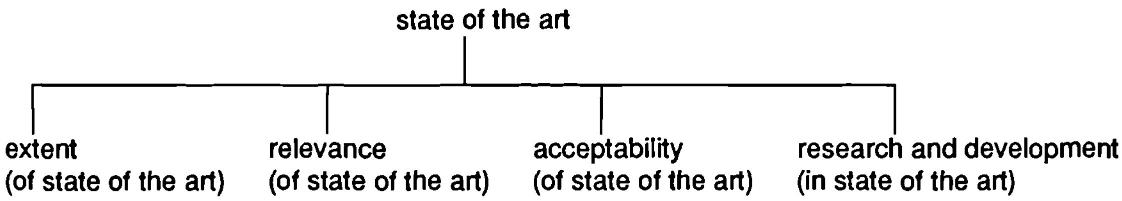
Engineering products and processes comprise equipment, materials, and methods that are available to engineering or any of its disciplines, as separate artefacts or "tools".



Although developed from engineering knowledge, certain pieces of equipment, (e.g. cranes), materials, (e.g. steel), and methods, (e.g. finite element packages), have become established as independent systems. To guard against complacency in taking such products and processes for granted, but to avoid repeated evaluations as engineering knowledge, they can be assessed separately. Expert judgement is required for evaluations. Expertise should include familiarity with the use the system, with the philosophy underlying their development, and with the bases of their development.

6.6 State of the art of technical engineering.

This is the range of engineering knowledge, products, and processes that are available for the practice and development of technical engineering. The characteristics that may provide evidence of a poor state of the art of technical engineering are shown below.



A fundamental characteristic of assessment is a standard with which to compare. The state of the art of technical engineering is continually changing and developing. Standards relating to concepts used for an evaluation will also change. If the state of the art is to improve, standards against which comparisons can be made might be expected to become more rigourous. Because of the changing nature of technical engineering and the standards that facilitate assessment of its state of the art, evaluations for an audit need to be carried out by persons currently expert in the appropriate knowledge domain.

6.6.1 Extent of the state of the art.

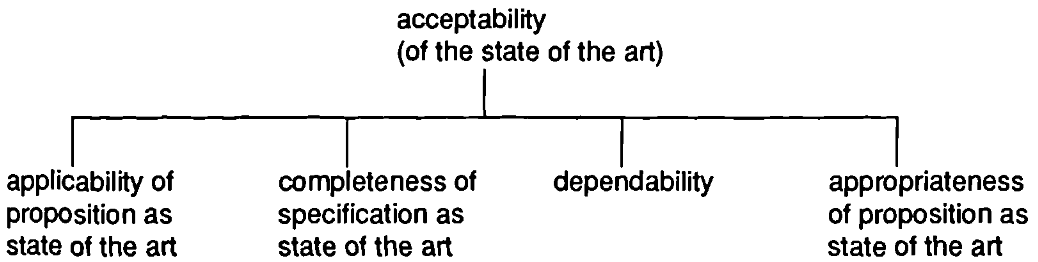
A poor extent equates to a limited range of engineering knowledge, products and processes. Assessment is context related to the industry or discipline associated with the subject of an audit, such as a construction project. For example, chemicals used as concrete additives or cleaning agents in the construction industry will probably have been developed by the chemical industry. For the chemical industry, the state of the art, in all respects, may be high. If, in the construction industry, there is a lack of knowledge about such products and processes, whether of their existence or properties, the extent of the state of the art, in the context of construction, would be assessed as "poor".

6.6.2 Relevance of the state of the art.

Relevance is the bearing on, or having reference to the matter in hand, which for an audit relates to the subject of the audit. On a construction project, for example, a concrete cleaning agent is assessed with respect to its relevance to construction, not in terms of its relevance to other industries or application.

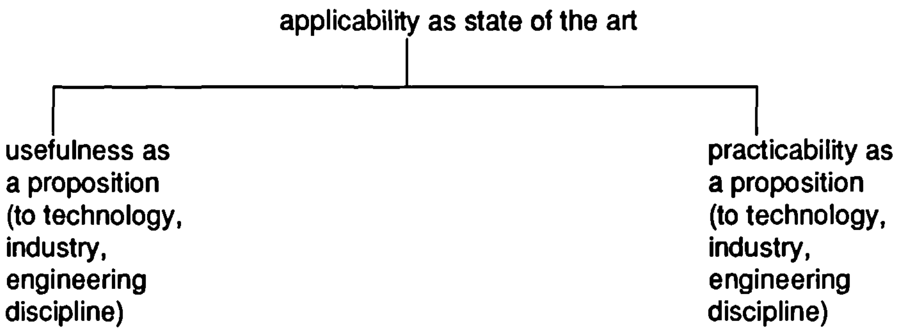
6.6.3 Acceptability of the state of the art.

This is the acceptability of a proposition, or set of propositions, as knowledge, products and processes, with respect to standards of acceptability, that have been established within a technology, industry, or engineering discipline. These standards will have been established by consensus among practitioners who have been judged by their peers as qualified to enunciate on such matters. Following a brief description of the characteristics of an evaluation of the "acceptability of the state of the art", which are shown in the following hierarchical expansion; hypothetical examples will be used, (clause 6.6.3.5), to illustrate evaluations.



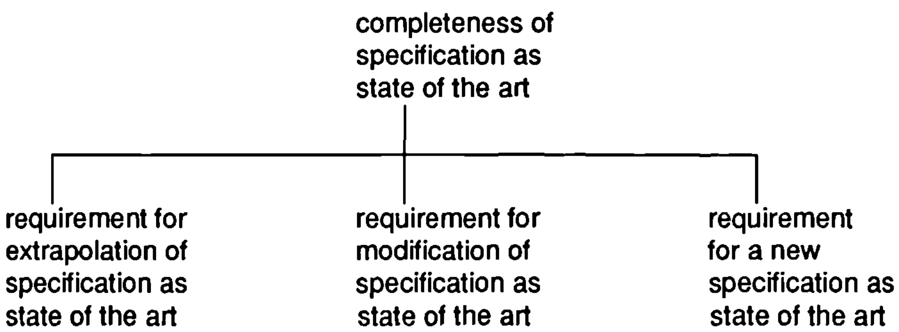
6.6.3.1 Applicability as state of the art.

There is a distinction between applicability defined here as "the applicability of a proposition as engineering knowledge, product or process", and applicability for a specific use, which is described in chapter 10, clause 10.5. For acceptability as state of the art, evaluations require comparison with standards, established or agreed by experts in the discipline associated with the proposition, (Clause 6.6.3). This is more difficult to assess than applicability for a specific application. Hence the requirement for expertise both for establishment of standards of applicability, and assessment by comparison with these standards. The criteria for evaluation are usefulness and practicability.



6.6.3.2 Completeness of specification as state of art.

This is defined as "the completeness of a specification with respect to requirements for: extrapolation of, modification of, or a new specification". Again, expert evaluation is necessary.



A requirement for extrapolation means that the original knowledge, product, or process remains essentially unchanged but, to be acceptable as technical engineering, the specification needs to be expanded or extended to incorporate additional parameters. (See clause 6.6.3.5).

A proposition requires modification if parameter descriptions remain unchanged, but the conditions attached to them need modification to conform to the standards required of technical engineering. (See clause 6.6.3.5).

A new proposition is required if, in the judgement experts in a discipline, parameters used in the specification need changing, to other, different parameters. (See clause 6.6.3.5).

6.6.3.3 Dependability.

Introduced by Blockley, (1980), as a characteristic of engineering theory, dependability relates to the confidence that can justifiably be held in a piece of engineering knowledge. The emphasis differs from the concept of testability, (Popper, 1972).

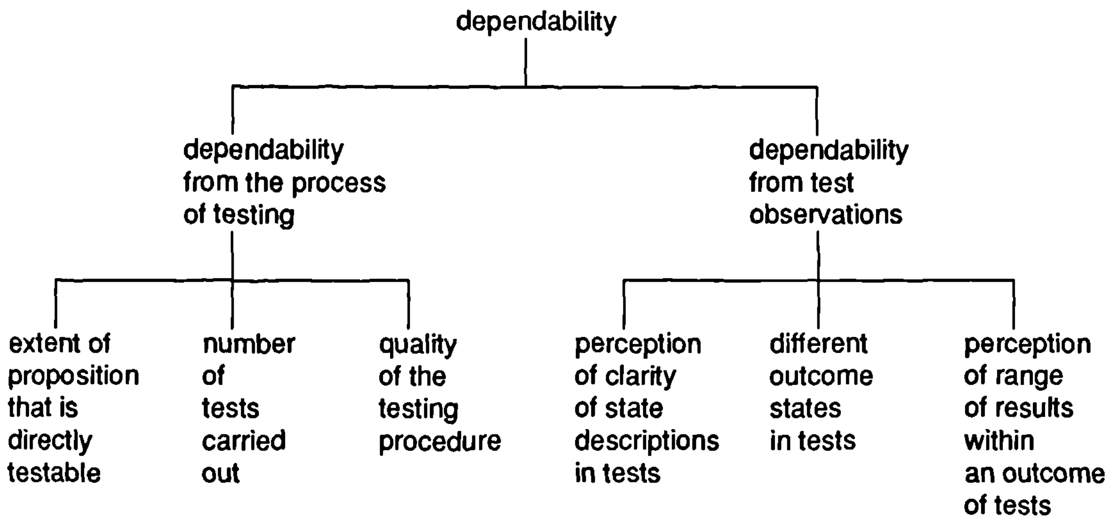
O'Hear, (1989), on page 38, states that:

> The testability of a theory is related to its capacity for yielding testable predictions and to its degree of empirical content. Roughly the idea of a high empirical content is that a theory which is simple, bold, and highly precise is very likely to be false and is thus more testable than a theory more hedged about with qualifications and exceptions.

Engineering requirements go beyond the development of theories, into application. Although testability is important, a theory needs to be dependable if it is to be used. Dependability comes through testing, (Comerford and Blockley, 1992).

The dependability of a proposition, whether engineering knowledge, product or process, can be thought of in the following terms. Assuming that a proposition has not been falsified through testing, its dependability is a measure of the extent to which there can be confidence in a proposition, based on the way in which tests have been conducted and perceptions of the states of a test process.

As indicated in the following hierarchical expansion, dependability can be differentiated between that evidenced by the test process, and that demonstrated by test observations.



Assessments of **dependability from the process of testing** involve examinations of propositions and test procedures. The **extent of the proposition that is directly testable,** (which is the definition), can be illustrated by considering the design and construction of a structure below ground or under water. The fact that the structure remains in use is a general test. Although more detailed tests can be carried out using instrumentation such as strain gauges, behaviour below ground level cannot be fully observed. Corrosion and cracking, for instance, go unnoticed. The design and construction cannot therefore be fully tested.

The **number of tests carried out** is the number of "successful" tests that have been conducted to attempt to falsify a proposition. The greater the number of "successful" tests, the greater the confidence in the proposition. Tests may be repetitions of the same test, or different tests, but like testability, the bolder the test, the greater the dependability from successful testing. Consider for example, a proposition that a particular element subject to repeated specified cyclic load will have an operating life of "x" cycles. Repeated tests at a constant frequency of cyclic loading may support the hypothesis, but confidence is increased if successful tests include different and varying frequencies of cyclic loading.

Successful tests are those deemed to support a proposition. There is an implicit assumption in an assessment of number that there is correspondence between the proposition and test outcomes. This equates to "truthlikeness or verisimilitude", (Popper, 1972), which is described in clause 6.6.3.4. If there is non correspondence which cannot be explained or accepted within the spirit of the proposition there is poor acceptability due to inappropriateness, (clause 6.6.3.4). In the light of an examination of truthlikeness, a proposition may have to be amended if assessment of dependability is to be relevant.

The **quality of the testing procedure** is defined as the quality of testing, relative to standards for: test procedures, qualifications and experience of those conducting the test, and any special requirements considered necessary for testing particular propositions. Standards need to be established by experts.

Assessments of the quality of uncontrolled tests in the WOL, (clause 6.4), require caution. Design often specifies minimum standards, whereas it will probably have used specific values. Often, during construction, minimum standards will be purposely exceeded to reduce uncertainties in meeting the specification. For example, concrete test strengths can greatly exceed specified minimum concrete strengths. Although construction may be in accordance with the specification, it may not, strictly speaking, comply with design intention. Quite apart from this, construction is unlikely to comply exactly with the design specification. Even if it did, it is unlikely that actual behaviour will accord to design assumptions, as for example in the design of structural steelwork connections. As a test of design, use needs to be considered very carefully. Construction needs to be closely monitored, and deviations from the design recorded and checked. "As built" information is essential for meaningful assessments of dependability from testing through use, (uncontrolled tests in the WOL).

Dependability, from test observations is based on characteristics described by Blockley, (1980). These are:

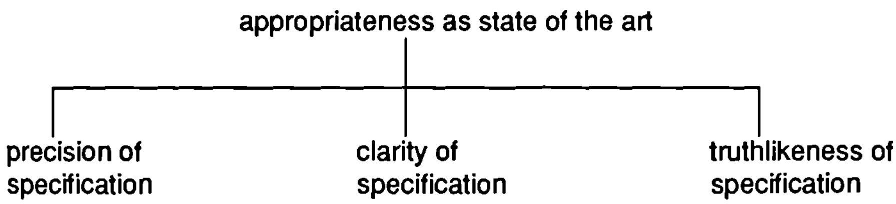
The **clarity of state descriptions** is the ease with which states can be identified. In a test of beam deflection, the loading state, the deflected state, the support conditions, the beam properties are all state descriptions. Ambiguity in the identification of these states detracts from dependability. State descriptions include the patterns of behaviour of parameter descriptions, such as loading conditions.

Different outcome states of a system applies to types or form of outcome state. For example, in tests of deflection of a steel beam, the resultant deflection could be: elastic; "collapse", if plastic behaviour occurs; or lateral torsional buckling. Different outcome states are not to be confused with variations in "values", which are described in the following paragraph. It is assumed that initial conditions are the same each time. If they are not, the tests are of different systems, unless of course the proposition specifies that the initial conditions are irrelevant.

The **range of results within an outcome** is the extent to which the quality or intensity of a particular state varies. For example, in fatigue tests on a piece of steel, there is likely to be a large variation in the results. If test observations indicate a large range of results in any intermediate stage, there is an inherent uncertainty about the behaviour, which reduces dependability.

6.6.3.4 Appropriateness as state of the art.

This is the appropriateness of a proposition, (knowledge, product or process), with respect to the precision, clarity and truthlikeness of the specification.



The **precision** of the specification is the extent to which possibilities are excluded. For example, the proposition that the deflection of a beam under certain loading conditions is $x \pm 10\%$ is more precise than that of $x \pm 20\%$.

The **clarity** of specification is the ease with which a state may be identified. It is the lack of ambiguity in a specification. Contradictory information represents poor clarity.

Truthlikeness, or verisimilitude, is used here in the context described by Popper, (1972), as correspondence to the facts. For assessment, the specification is compared to the facts as they are perceived. For example, if a beam deflection is specified as x ± 10%, and tests produce deflections of between 1.2x and 1.3x, there is poor truthlikeness.

Truthlikeness is likely to be low, if precision is high. In effect, precision relates to informative content. Although high informative content in a theory is likely to produce high falsifiability, or testability, (Popper, 1972), it is not necessarily appropriate to engineering applications. Precision and truthlikeness have to be balanced. A theory that has a high truthlikeness, yet is imprecise, may be appropriate as engineering knowledge. The balance between precision and requirement for truthlikeness should be determined by experts. The interpretation of truthlikeness relates to the type of proposition being tested and the type of test. For example, a prototype test of an earth retaining wall, will involve different standards of comparisons than a laboratory test of beam deflection.

6.6.3.5 Hypothetical examples of assessments of acceptability.

Two hypothetical examples, of assessments of acceptability of the state of the art, are described here.

EXAMPLE 1.

This compares evaluations of two similar propositions of scientific knowledge, assumed to be tested under controlled laboratory conditions. Both propositions are based on the hypothesis that the deflection of a simply supported beam subject to a point load at mid span is given by the equation: $d = WL^3/48EI$, where:

d	is the deflection.

W	is a point load, (a knife edge load).

L	is the span.

E	is the modulus of elasticity.

I	is the second moment of area.

Proposition A.

$d = WL^3/48EI$ For elastic behaviour.

Simple bearing at each support. Point load at mid span. Steel I section, of constant modulus of elasticity, and second moment of area. Low slenderness ratio, such that there is no lateral torsional buckling.

Proposition B.

$d = WL^3/48EI$ No limiting conditions on behaviour.

Simple bearing at each support. Point load at mid span. Steel I section, of constant modulus of elasticity, and second moment of area. High slenderness ratio, such that lateral torsional buckling can occur.

Evaluations are based on perceptions of what might be expected to occur in tests of the two propositions, assuming that they are being proposed as new scientific knowledge for engineering.

Applicability.

Because it is useful to be able to predict deflections, the usefulness of both propositions is high. Both propositions, as scientific knowledge, seem simple to use, easy to understand, requiring few resources for use. This indicates high practicability. The resultant applicabilities, as propositions, are high.

For presentation, each set of evaluations is summarised in the following form.

concept	assessments	
	proposition A	proposition B
usefulness as a proposition	high	high
practicability as a proposition	high	high
applicability as a proposition	high	high

Completeness.

Evaluations of the requirement for extrapolation of, modification of, or a new specification, are not linked to truthlikeness. Assessments require the input of expertise, to judge whether propositions conform to the standards expected of scientific knowledge, as a component of engineering knowledge. For both propositions, the requirements for extrapolation of, modification of, or a new specification, are low. Each, therefore, has a high level of completeness, as propositions of scientific knowledge.

requirement for extrapolation of specification	low	low
requirement for modification of specification	low	low
requirement for new specification	low	low
completeness of specification as a proposition	high	high

Dependability.

The extent that both propositions are directly testable is high. The number of tests and quality of tests are assumed to be high, and therefore dependability from the process of testing is high.

extent of proposition testable	high	high
number of tests (successful)	high (say)	high (say)
quality of testing	high (say	high (say)
dependability from the process of testing	high	high

For proposition A, the clarity of state descriptions is high, and the number of outcome states is low, (i.e. only elastic behaviour). Because the range would also be expected to be low, the dependability from test observations is high.

For proposition B, the clarity of state descriptions is assumed as low, because the descriptions of plastic behaviour and lateral torsional buckling may be unclear. The number of different outcome states is high, (i.e. three: elastic, plastic and lateral torsional buckling). The range of results for the outcome states may be low for elastic behaviour, but because, for plastic behaviour and lateral torsional buckling, the clarity of state descriptions is low, the range of results for these outcomes may be perceived as high. For proposition B, therefore, there is evidence of low dependability from test observations.

clarity of state descriptions	high (say)	low (say)
different outcome states	low (1)	high (3)
range of results	low	high
dependability from test observations	high	low

The resultant assessment of dependability for proposition A is high, and for B, low.

dependability as a proposition	high	low

Appropriateness.

For proposition A, the precision and the clarity of the specification are high. Truthlikeness would be expected to be high. Although the deflection is predicted precisely, test results would not be expected to comply exactly. Expertise is necessary to interpret correspondence to the facts. In terms of what could be reasonably expected in laboratory tests of beam deflection, the resultant appropriateness is taken to be high.

For proposition B, the precision and clarity of specification are high. The truthlikeness is low because plastic behaviour and lateral torsional buckling will result in deflections different to those predicted. Because of this, the appropriateness is low.

precision of specification	high	high
clarity of specification	high	high
truthlikeness of specification	high	low
appropriateness of specification as a proposition	high	low

Acceptability.

For proposition A, the acceptability of the proposition as scientific knowledge is high; because the proposition appears to be applicable, is complete, and is highly dependable and appropriate.

The acceptability of proposition B is low, because although it appears applicable and is complete, its appropriateness is low through lack of truthlikeness. Dependability which is also low, is not relevant.

Acceptability of proposition	high	low

EXAMPLE 2.

This compares evaluations of specifications for two pumps, for which prototype test results are the same.

	Pump Specification	Test results
Pump A.		
Head	x m	Between 0.8x m and 1.2x m
Constant pumping rate	y m^3	Between 0.7y m^3 and y m^3
Time to breakdown	z hr	Between z hr and 1.5z hr
Pump B		
Head	minimum 0.8x m	Between 0.8x m and 1.2x m
Constant pumping rate	minimum 0.7y m^3	Between 0.7y m^3 and y m^3
Time to breakdown	minimum 0.5z hr	Between z hr and 1.5z hr

Applicability.

For both pumps, usefulness is assumed to be high, as would be the case if the specified pumping rates were greater than those produced by existing pumps. If, however, the specifications were well below those for existing pumps, usefulness might be regarded as low. Assessments of practicability are not possible with the information given. Such things as cost, or physical size could render the pump specifications impracticable. For both pumps, the applicability as propositions based solely on usefulness, is high.

The format used to summarise each set of evaluations is the same as that used in the first example.

concept	assessments Pump A	Pump B
usefulness as a proposition	high (say)	high (say)
practicability as a proposition	not known	not known
applicability as a proposition	high	high

Completeness.

It is apparent that the specifications for both pumps is incomplete. They require extrapolation, to include parameters such as size, weight, and physical shape. In the case of pump A, there is a requirement for modification because limiting values of head, rate of pumping, and time to breakdown should be specified. Specifying time to breakdown means that users have to make their own judgements about the implications of this. New parameters specifying regular maintenance requirements would be better. The completeness of specification for pump A is low. That for pump B is a little better, and might be assessed as fairly low.

requirement for extrapolation of specification	high	high
requirement for modification of specification	high	low
requirement for new specification	high	high
completeness of specification as a proposition	low	fairly low

Dependability.

For both pumps, only the head, the pumping rate and the time to breakdown are specified. Each is testable, therefore, the extent of the propositions that are testable is high. Assumptions are made about the number of tests and quality. For pump A, they are assumed low, which results in low dependability from the process of testing. For pump B, they are assumed as high, which together with the high extent of the proposition that is testable, produces a high dependability from the process of testing.

extent of proposition testable	high	high
number of tests	low (say)	high (say)
quality of testing	low (say)	high (say)
dependability from the process of testing	low	high

Because the head, rate of pumping, and time to breakdown can all be clearly identified, the clarity of state descriptions, for both pumps, is high. There is assumed to be only a single outcome state for each parameter for each pump. If, in some tests, the pumping rate was constant yet in others it fluctuated, there would be two different outcome states for this particular parameter, and the assessment would have been high. At first glance, the range of results may appear high. However, if in the judgement of experts, such a range is within the standards required of pump tests, it could be judged as low, as is assumed here. The specification does not influence assessments of dependability from test observations. The test results for both pumps are identical. The assessments of dependability from test results should be identical. In both cases there is high dependability from test observations.

clarity of state descriptions	high (say)	high (say)
different outcome states	low	low
range of results	low (say)	low (say)
dependability from test observations	high	high

For pump A, the resulting assessment of dependability as a proposition is medium. For pump B, it is high.

dependability as a proposition	medium	high

Appropriateness.

Appropriateness is evaluated in the context of only the information provided in the proposition. For pump A the specification is precise and clear. The truthlikeness of the specification for pump A is low. The appropriateness of the specification, as a proposition is low because of the low truthlikeness.

For pump B, because limiting values are given, it is less precise. The clarity of specification high, and because limiting values are specified, the truthlikeness is high. The slight reduction in precision does not in this case detract from appropriateness. In fact the lack of precision, is what produces correspondence to the facts. Limiting values are appropriate to this particular specification. Precision and truthlikeness should always be considered together when evaluating appropriateness. The resultant appropriateness is high.

precision of specification	high	medium
clarity of specification	high	high
truthlikeness of specification	low	high
appropriateness as a proposition	low	high

Acceptability.

For pump A, the acceptability as a proposition is low. Lack of truthlikeness makes it inappropriate.

For pump B, although completeness is fairly low, dependability, applicability, and appropriateness are high. Acceptability as state of the art, could be judged as fairly high.

Pump B, which has the same test results as pump A has been judged acceptable, while pump A is unacceptable. This illustrates how amending a specification in the event of lack of truthlikeness, (see clause 6.6.3.3), changes the assessment of acceptability. The specification has been modified to make it more complete; and dependability, has, hypothetically, been improved through increased number of tests and better quality testing.

Acceptability of proposition	low	fairly high

6.6.4 Research and development.

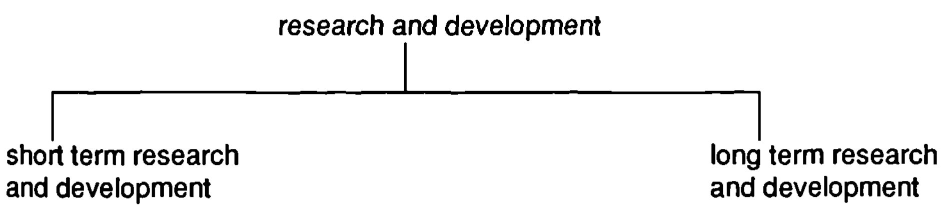
Knowledge does not remain static. It can be gained, built upon, or apparently lost. Good information arrangements go some way to mitigating losses of knowledge, and by disseminating knowledge to a wider population, the potential for its development is increased. The ability to build on knowledge is further enhanced if there is a policy to do so. Active research and development is the manifestation of such a policy. Research and development describes the activities, systems, and procedures that are adopted to search for new knowledge and develop that which already exists. The questions that need to be addressed in an evaluation of research and development are:

- Do arrangements for research and development meet the requirements of society, as enunciated by its representatives? One problem here is who represents society? This is discussed in more detail in chapter 8, clause 8.3.1. Establishing requirements will itself require extensive study and research into the consequences of the development of technology which, as discussed by Collingridge, (1980), needs to be controlled, if future failures are to mitigated. The availability of resources will influence the standards of requirement.

- Is research and development being conducted to required standards, as established or agreed, by experts in the appropriate field of study? This particular assessment should not be prejudiced by perceptions about the availability of resources.

The arrangements for research and development, and the standards to which it is carried out need to take account of the social implications of technology, and the socio-technical dependencies that influence technology. Assessment based on the opinions from one or two experts is not balanced. Evaluations need to be carried out by a representative body of experts, in the subject matter of the research and development, in the process of research and development, and in the socio-technical nature of technology and its consequences.

As indicated by its hierarchical form, research and development is classified into short and long term. Short term relates to immediate expectations and demands. Long term is more difficult to establish, because future needs may not have been identified, and the way in which scientific or engineering knowledge might develop is unpredictable, (Collingridge, 1980).

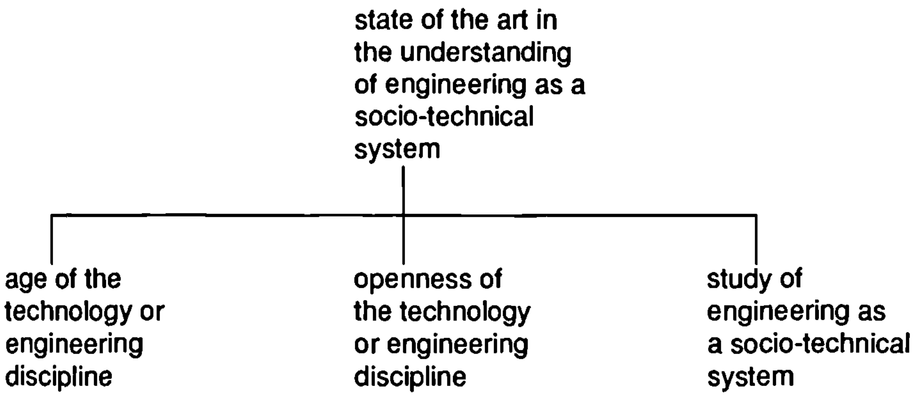


6.7 Understanding of engineering as a socio-technical system.

Based on the definition of a socio technical system given in chapter 1, this is the understanding that engineering is part of a system involving inter-dependencies amongst individuals and groups, their social arrangements, and technical engineering. This is particularly relevant to the development of technology, and for deciding upon the requirements, of society, for research and development.

The definition given in the previous paragraph expands on that provided by Abercrombie, Hill and Turner, (1984), which describes the socio-technical system in terms of the operation of an industry in relation to the social needs of employees. Inter-dependencies spread beyond a project, into other aspects of society and its environment. The interactions of social, individual and technological factors are represented in concepts such as culture in its various contexts, human behaviour, and management. These are included in concepts that are distributed throughout the hierarchy.

The section of hierarchy below provides for an assessment of the state of the art in the understanding of the socio-technical system as it affects a particular technology, industry, or project. Assessments are context related.



Socio-technical interactions are common to all industries, but the nature of relationships are peculiar to specific industries. For example, the relationship that society has with the nuclear industry differs from that with the construction industry. The **age of the technology, or engineering discipline**, affects the relationship, because little is known about new technologies. The **openness of the technology or engineering discipline** with society, also affects any relationship. Lack of openness and the reasons for it are characteristics of a socio-technical system. Perceived risks to society is another. These and other features such as culture, human behaviour, and management would feature in a **study of engineering as a socio-technical system.**

There appears to be a growing recognition of the social-individual-technical inter-dependencies, (Blockley, 1980; Pidgeon, Turner, Blockley, and Toft, 1991; Turner, 1978), associated with failure. A discussion about the functioning of a socio-technical system is beyond the scope of this thesis. Study and understanding would be facilitated if information that is available in different parts of society could be collected under one discipline such as hazard engineering, (chapter 7). Hazard auditing would be part of this discipline. The need to understand and coordinate audit assessments based on expert evaluation suggests a need for specialisation.

6.8 Summary and conclusions.

The state of the art of technical engineering influences proneness to failure. It requires examination in a search for hazards.

The socio-technical nature of engineering influences the use of technical engineering and the development of its state of the art. Assessment of the state of the art of technology needs to consider the consequences of engineering as a socio-technical system.

There is a requirement for evaluations of the concepts under the state of the art of technology to be carried out by experts. In some cases, evaluations are required from a representative cross section of expertise. This suggest a need for specialisation to understand and coordinate assessments based on evaluations from a variety of expert sources. This specialisation would be in hazard auditing.

There is a need to establish requirements for research and development in technology. This should include extensive study and research into the consequences of the development of technology. An understanding of the socio-technical nature of technology is central to this.

There is an indication that knowledge relating to the nature of technology as a socio-technical system, with respect to the identification of hazards, needs to be gathered under one discipline of hazard engineering.

The concepts discussed in this chapter provide the basis for the hierarchical development of the state of the art of technology as part of the structure for the design of hazard audits. The hierarchical expansion of the state of the art of technology is shown in fig. 6.1, at the end of this chapter.

Fig. 6.1. Hierarchical expansion of "state of the art of technology". (Sheet 1 of 2).

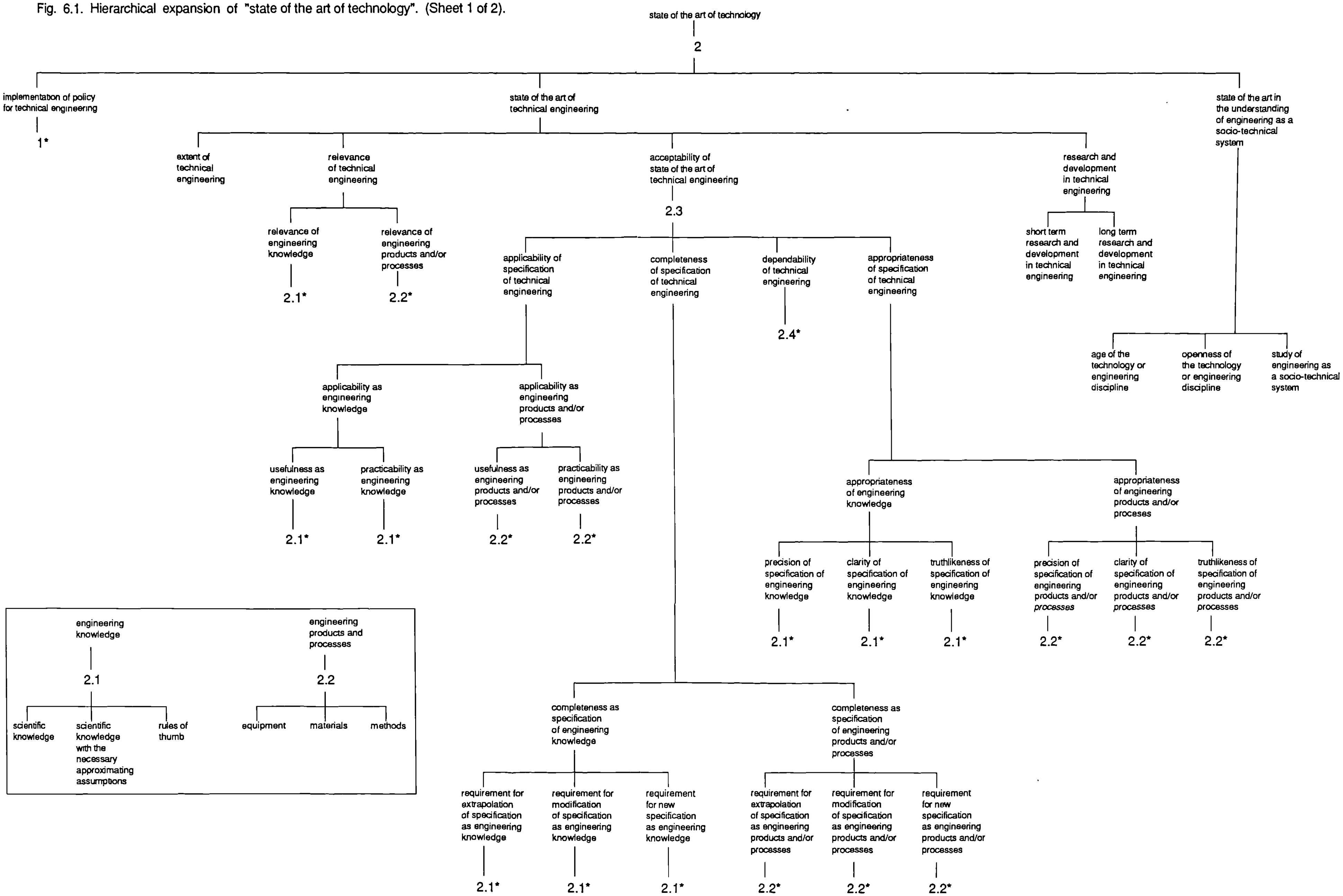
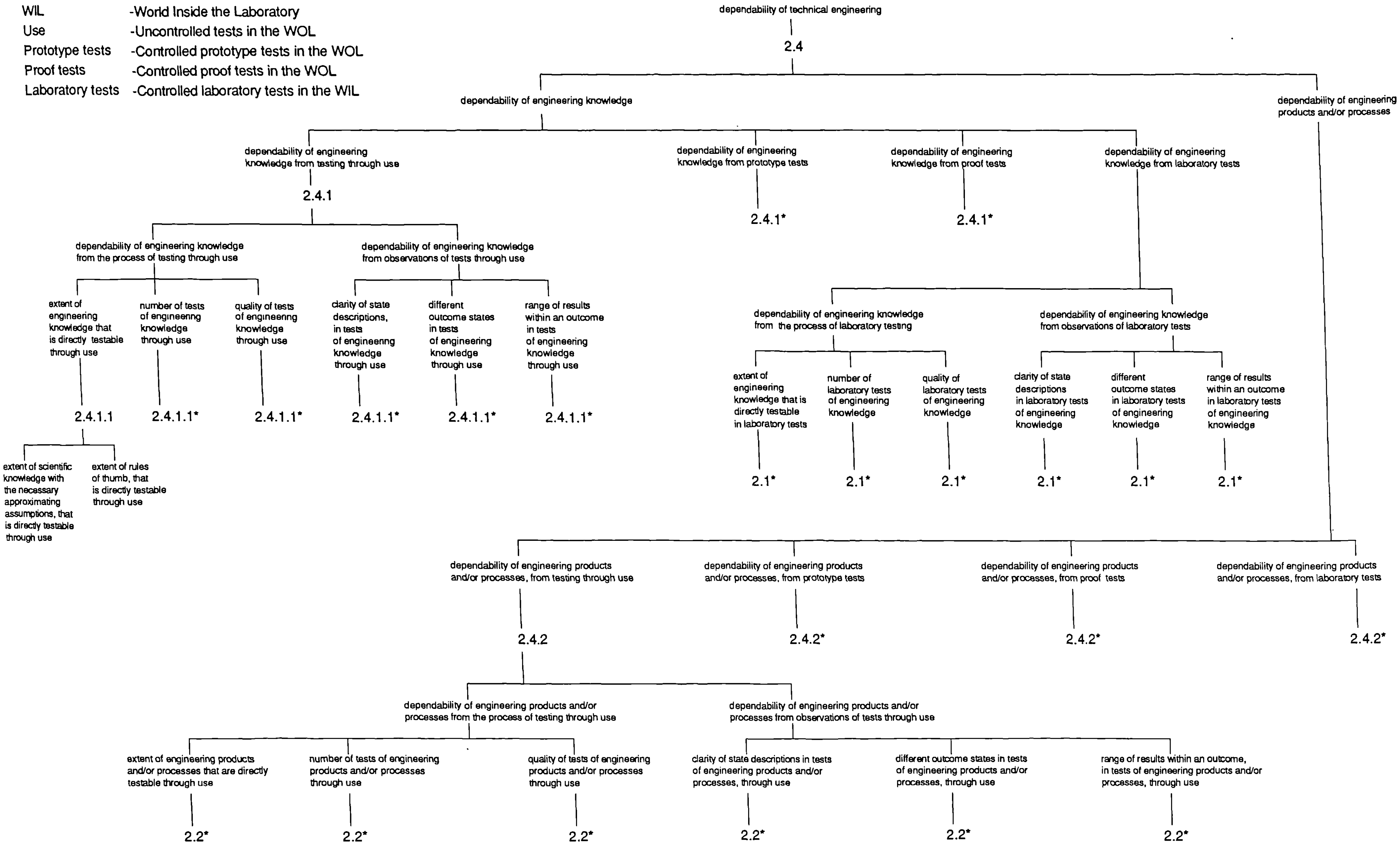


Fig. 6.1. Hierarchical expansion of "state of the art of technology". (Sheet 2 of 2).

NOTATION

WOL	-World Outside the Laboratory
WIL	-World Inside the Laboratory
Use	-Uncontrolled tests in the WOL
Prototype tests	-Controlled prototype tests in the WOL
Proof tests	-Controlled proof tests in the WOL
Laboratory tests	-Controlled laboratory tests in the WIL



Chapter 7.

Hazard engineering.

7.1 Objectives

1 To introduce hazard engineering.

2 To develop and critically discuss the concepts under the state of the art of hazard engineering, that have the potential to provide evidence of failure.

3 To present a hierarchy of concepts that can provide for an evaluation of the state of the art of hazard engineering, for evidence of proneness to failure.

7.2 Introduction.

According to Blockley, Turner, Pidgeon, (1991), there is increasing public concern about the incidence of disaster associated with technology. Together with a general recognition that quality, including safety, is good for business, (CBI, 1990), this they argue, is evidence of a need to define a new activity called hazard engineering which would be concerned with the identification and control of hazards. Further evidence comes from the requirement to unify the physical and social sciences of engineering to deal with the technical and human interactions that characterise disasters. At present, such an activity, (hazard engineering), seems to be viewed, primarily, as disparate parts of established disciplines. For example, structural safety is integral to structural design and occupational safety to particular occupations.

Discussions in previous chapters, and in the remainder of the thesis, indicate that evaluation of hazard audit concepts requires expert input from a variety of disciplines. This expertise needs to be coordinated, and the multi-disciplinary expert knowledge gained from an audit requires interpretation. Understanding is essential for interpretation. Understanding will be facilitated if the separate elements from different knowledge domains are gathered under a single discipline of hazard engineering. This discipline can be considered interactive with other disciplines of engineering, social science, and sciences, including psychology, rather than parts of them. This "new discipline" is applicable to particular contexts characterised by different industries, projects, or any other aspect of life, but will take on properties from the different contexts.

To summarise, the need to consider hazard engineering as a, "new discipline", is evidenced not only by the requirements of society and industry, but importantly, by the content and requirements of hazard engineering as a discipline.

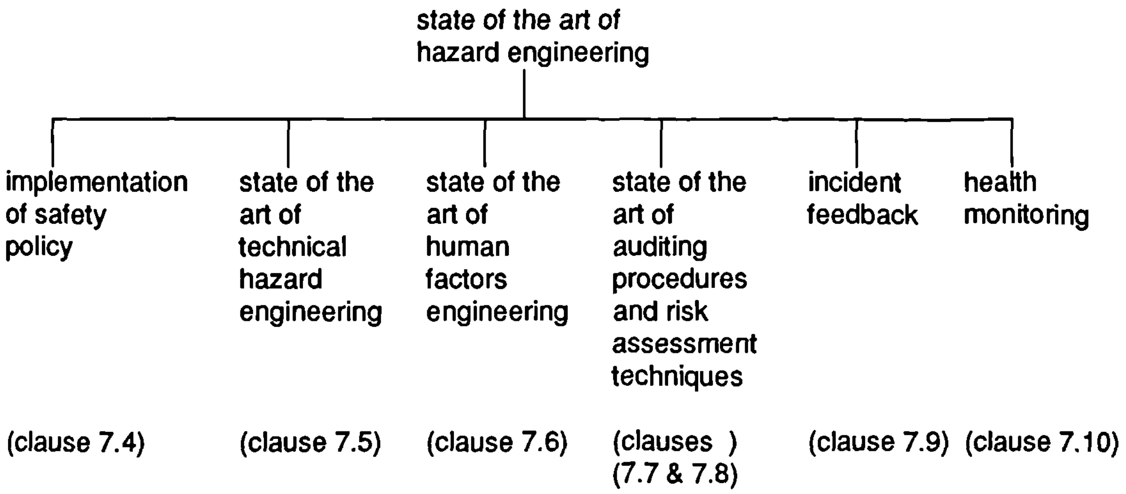
Quantitative audits in the form of rating systems can concentrate the mind in that tangible figures are produced as measurements of safety effort. Such rating systems do not necessarily provide consistent comparisons between audits, and they may be open to misuse, and even abuse, (see chapter 2, clause 2.5). The need for quantitative measures may not appear so important if there is justifiable confidence in qualitative assessment. This confidence should evolve if hazard engineering is developed as a discipline, safety auditing a specialist activity, and hazard auditors are trained to make such assessments.

The practical need for a discipline of hazard engineering would seem to be illustrated by Lord Cullen's, (1990), view that safety cases, as formal safety assessments, should be used to demonstrate the safety of offshore installations. Safety cases, that demonstrate the safety of an installation, are already a requirement of the Control of Industrial Major Accident Hazards (CIMAH) Regulations, (1984), for onshore major hazard installations. More recently, with regard to construction, the Health and Safety Commission have proposed, (HSC consultative document, 1992, clause 12.4, page 66), a requirement that principal contractors "prepare risk assessments which should address risks to employees and to other persons who may be affected by their activities such as members of the public".

7.3 Hazard engineering.

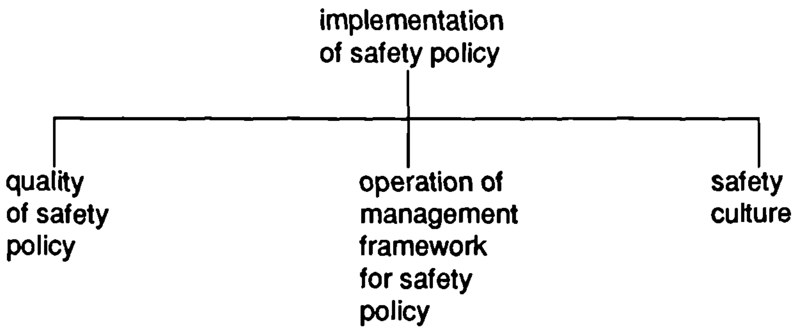
Hazard engineering is concerned with the identification and management of hazards, such that while overall objectives are achieved, safety, (freedom from danger), is ensured as far as is possible, and the consequences of failure to provide for safety are mitigated as far as is possible.

The range of knowledge, products and processes that is available for hazard engineering is evaluated in terms of the concepts shown below. The hierarchical development of these concepts, which is described in this chapter, is shown in fig. 7.1 at the end of the chapter.



7.4 Implementation of safety policy.

Safety policy describes health and safety policy. Damage to health is one of the consequences of a failure to ensure safety. The maintenance of health is inherent in the provision of safety. Safety policy is therefore, the policy that deals with the provision of safety and the mitigation of the consequences of a failure to do so. Its implementation is assessed in terms of the concepts described in chapter 5, (clauses 5.2 and 5.3), of which the top level is reproduced here.



7.4.1 Quality of safety policy.

Legislation, (Health and Safety at Work etc. Act 1974), requires, from employers with five or more employees, a written statement of policy, with respect to the health and safety at work of the employees. Concepts for an assessment of the quality of policy are outlined in chapter 5. Evaluations of quality of safety policy are a matter of judgement by experienced safety practitioners. Guidance on producing these policies can be found in publications such as Davies and Tomasin, (1990), and the Health and Safety Executive, (1980). Much depends, though, on the identified needs of particular organisations and situations.

7.4.2 Management framework for safety policy.

The functioning of a management framework is discussed in chapter 5. The management framework for safety is part of a management framework for overall policy, but it may function differently.

Organisational arrangements for safety are integral to overall policy. If safety is actively pursued as an objective in the same way as production, the management roles for safety can be expected to be similar to those for overall policy. There may of course, as with any activity, be special roles of responsibility, authority, decision making, and accountability. Health and safety committees and safety representatives, for example, are used to secure formal participation, of a work-force, in the control of health and safety, (Health and Safety Executive, 1991). The influence exerted by these groups or individuals, will be more significant if they function with internal organisational arrangements, (defined in chapter 5, clause 5.5), having some accountability. This implies a degree of authority and decision making capability.

The role of safety advisors is a special case. It should not be compromised by an alternative role in an organisation or prejudiced by conflicting priorities. Being advisory does not contradict the need for clarity of definition of responsibilities, authority, decision making, and accountabilities. However, being advisory, the roles are naturally limited, and much of the ability to influence is a function of reputation, knowledge, character and personality, as distinct to the ability to influence others by the use of legitimate power, through position, (Handy, 1985). Status, training, education and remuneration are fundamental if safety is to be a priority issue. Status in particular should not be viewed in personal terms. It is a legitimate means of allowing for influence. For those directly involved in the practice of safety, such as safety personnel, a desire to increase the priority afforded safety would seem natural. Among other things it should make their jobs easier. Training and education should improve competence and add to experience. This is likely to lead to recognition in terms of status, reputation, added responsibilities, authority, accountability, and not least, remuneration. The characteristics described in this paragraph should provide the platform (status, reputation and authority), the means (training, education, experience and competence), and the incentive (self esteem and remuneration) to work towards a higher priority for safety. Status and reputation are important features. An improvement in the status and reputation of safety personnel should be encouraged and actively pursued.

7.4.3 Safety culture.

Safety culture is defined in chapter 1. The characteristics for an evaluation of culture are outlined in chapter 5, clause 5.14.

Legislation, economics, and ethics all provide a motivation for adherence to safety. Setting examples also influences behaviour. All are considerations in the development of a culture in an individual or group.

The law does not necessarily reflect the views of the majority of society (i.e. the "done by"), if the "doers" do not, for whatever reason, provide for the needs and wants of the "done by". "Doers" and "done by" are terms used by Vickers, (1970). If legislation alone is left to provide the impetus for safety, the outcome may not be as society wishes. Certainly, legislation alone does not provide a firm or stable foundation for a culture. For example, the law deals with theft. Ethical considerations also contribute to the prevention of theft. Despite legislation, I believe that if theft was not, in general, thought to be unethical, its incidence would be higher. The situation is more complex than this, as other judgements such as the perception of fairness are also relevant. The point is that the provision of safety cannot be left to a need to conform to legislation or regulation. There is a need to create a safety culture that is deep rooted and includes a belief that it is ethical to provide for safety.

Similarly a culture based on economic considerations does not necessarily reflect the wishes of society. It is as likely to be a reflection of the interests of the most powerful in society, often using legislation as a tool to promote their aims. If the basis for improvements in safety is championed as profitability, there may be changes in behaviour, but it is the culture relating to economics that is reinforced. The safety culture that develops is based on another, (the economic), culture, and is therefore not as deeply rooted as it could be.

Promoting safety culture through considerations of economics and legislation will aid its development, but does not provide the best foundation. A better quality, stable, long term safety culture, needs the foundation of ethical values. An evaluation of safety culture should address the issue of whether values and beliefs in relation to safety are reflections of values and beliefs relating to conformity with regulation, to a desire for profitability, or whether the primary motivation is a moral conviction that people have a right to be free from danger. This should be implicit in an evaluation of cultural bias, which involves comparison of shared beliefs and values for safety, with those for other characteristics like: environmental issues, profitability, and the development of technology.

Creating a culture by example may also be possible, but without conviction it will not be deeply rooted. Working in a safe manner because others do so, would be expected to improve safety, but people may not be convinced about, or understand, the need to work in such a way. They may easily change when the circumstances are different. Education and training is necessary to ensure that the reasons for behaving in a certain way, namely safely, are understood. On the same theme, habits or ritual, may be easily changed if the reasons underlying them lack conviction or understanding, or have been forgotten. Education and training, which is essential for the development and maintenance of a strong culture, is evaluated in particular contexts of society, industry, project, and project phase. (See chapters 8 -11).

7.5 Technical hazard engineering.

The state of the art of technical hazard engineering is the range of engineering knowledge, products, and processes that is relevant to and available for the provision of safety and the mitigation of the consequences of failure to ensure safety.

Auditing procedures and risk and reliability techniques are processes, but because of their importance to hazard engineering they are included in the hierarchy as separate categories. They are discussed separately in clauses 7.7 and 7.8.

Evaluation is in terms of the concepts of the hierarchical expansion for the state of the art of technical engineering, which is described in chapter 6. There is an overlap between technical engineering and hazard engineering. Structural safety, for example, should be inherent in models of scientific knowledge with the necessary approximating assumptions, and in rules of thumb. Similarly, safety measures built into engineering products and processes are part of the technical engineering. The category of technical hazard engineering has been included to provide for an examination of knowledge products and processes that relate specifically to safety. This covers both safety and emergency measures. For example, equipment such as harnesses, helmets, and goggles, have a dual purpose in providing safety and mitigating the consequences of failure. Gas detectors for mining and tunnelling are intended to ensure safety. Fire extinguishers, first aid facilities, and the knowledge of how to use them mitigate the consequences of failure.

No matter how relevant to a situation, how acceptable the knowledge, products, and processes, or how good the research and development, the state of the art of technical hazard engineering is poor, if its extent, in terms of the "the range and knowledge about", within the context of an examination is poor. This of course also applies to technical engineering, but is more likely to be the case for hazard engineering, because safety can often be regarded as a secondary issue.

7.6 Human factors engineering.

Also known as ergonomics, this has been defined as "the scientific study of the relationship between man and his environment", (Murrell, 1965). Described by Oborne, (1987), as a way of thinking about people at work, the role of ergonomics is to highlight the concordance between the environment and the human operator by understanding and measuring the operator's capabilities and then arranging the environment to fit them. Dhillon, (1986), defines human factors as "the body of scientific facts concerning the characteristics of human beings", and human engineering as "the area of human considerations that makes use of scientific facts in the design of items to produce effective man-machine integration and utilization".

For this research, human factors engineering will be defined as:

The body of knowledge, concerning the characteristics of human beings, that relates to the interactions between human beings and the artefacts that they have developed to enable them to function in their social and physical environment.

The recognition of human factors engineering as a formal discipline occurred in the 1940's, (Oborne, 1987; Dhillon, 1986). It is multi-disciplinary, encompassing: physiology, anatomy, medicine, psychology, social sciences, science, and engineering. As one of its aims is to maximise human operator's safety, (Oborne, 1987), it is an integral part of hazard engineering. In their publication to encourage and guide people in the management of human factors, the Health and Safety Executive, (1989), emphasised the management of human factors as vital to the control of risk.

For a general view, the state of the art of human factors engineering is considered in terms of the concepts shown below.

- state of the art of human factors engineering
  - state of the art in the understanding of the psychological parameters that influence human behaviour
  - state of the art in the understanding of the physical human characteristics
  - state of the art in the understanding of information processing
  - state of the art in the understanding of disease and health hazards

Although hierarchical expansions for the separate "states of the art" are similar to that for the state of the art of technical engineering, some aspects such as psychological behaviour require further consideration of the criteria to be used for evaluations, particularly those relating to dependability. A detailed expansion of this concept is not attempted. Expertise from practitioners of human factors engineering would be required to fully develop this portion of the hierarchy.

The understanding of how humans behave or are likely to behave in any situation is a feature of management. In terms of prevention of failure, this often centres around human error. Books dealing with human factors engineering such as Sanders and McCormick, (1987), Oborne, (1987), and Rasmussen, (1986), devote some discussion to this phenomenon. Reason (1990), in his book on Human Error defines error as "all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the involvement of some chance agency", (page 9). Much of the discussion about human error focuses on psychological factors. Reason, (1990), distinguishes between active errors, whose effects are felt almost immediately and latent errors whose effects only manifest themselves in combination with other factors. He comments, page 173.

> There is a growing awareness within the human reliability community that attempts to discover and neutralise these latent failures will have a greater beneficial effect upon system safety than will localised efforts to minimise active errors. To date, much of the work of human factors specialists has been directed at improving the immediate human-system interface (i.e. the control room or cockpit). While this is undeniably an important enterprise, it only addresses a relatively small part of the total safety problem, being aimed primarily at reducing the "active failure" tip of the causal iceberg. One thing that has been profitably learned over the last few years is that, in regard to safety issues, the term human factors embraces a far wider range of individuals and activities than those associated with the front-line operation of a system. Indeed, a central theme of this chapter is that the more removed these individuals are from these front-line activities (and, incidentally, from direct hazards), the greater is their potential danger to the system.

Latent failures, as described by Reason, (1990), reflect Turner's, (1978), proposition that disaster develops under conditions that allow for its incubation. Auditing in the broad context suggested in this thesis addresses the problem of "latent failures", as well as the more active type of failure. Part of the audit, though, needs to check that there is understanding of the psychological factors that influence human error. This is done under the concept of the **state of the art of understanding of the psychological parameters that influence human behaviour**, which can be defined as the range of knowledge, products and processes available for the understanding of the psychological parameters that influence human behaviour in the development and occurrence of human error. This concept covers the understanding of organisational-individual dependencies and the development of culture.

The **state of the art of understanding of the physical human characteristics** is the range of knowledge available for the understanding of the physical human characteristics that determine the physical capabilities of humans in their interactions with both their working environments and the artefacts that they have developed to facilitate this interaction.

Human information processing is a psychological characteristic. It is the way in which people make sense of their surroundings and deal with, (perceive, organise, store, and use), information. In human-machine interactions, it links the decision making process, physical action, and machine as a system. It is particularly significant for computer based control systems. Computers are themselves part of a human-machine relationship, but they also provide a link between humans and larger machines such as power stations and aircraft. Machines, such as an abacus, have in the past been used to aid mental activities, but their main purpose has been to supplement physical capabilities. It is comparatively recently that computers, which can reproduce and greatly enhance some mental activities, have become such a central feature in human-machine relationships. Technological systems have become larger and more complex. The consequences of failure are more severe. Humans are still fundamental to the systems, but they can err, and computers, of course, are only machines, which can malfunction. Humans have become more distant from machines, but increasingly reliant on computers to carry out certain mental processes which are integral to information processing in human-machine relationships. A category for the **state of the art of understanding of information processing** with respect to human-machine interactions has been included to allow for an evaluation. Human-computer-machine interaction is a specific but significant example of information processing in human-machine systems. Rasmussen, (1986), provides a detailed discussion of information processing where computer based control systems are integral to the management of the overall system. Further discussion on information processing may be found in Mortensen, (1972), and Littlejohn, (1983).

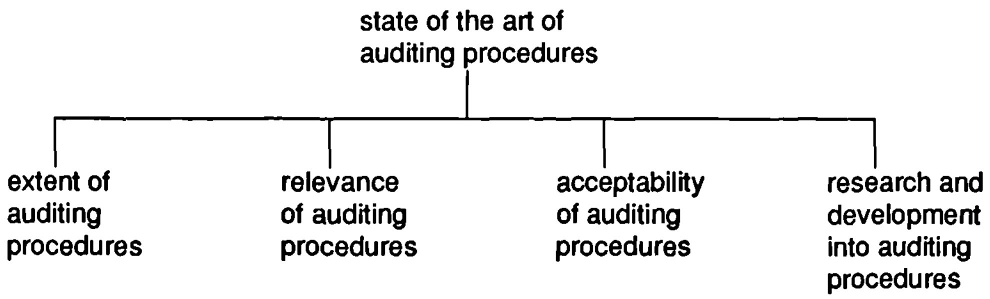
In matching machines to particular capabilities, other human characteristics, not initially thought to be of significance, may be altered. For instance, visual displays may be easy to read, but constant use over a period of time may change the physical capabilities of the users such that they become unable to operate as originally intended. Typing, for example, can result in repetitive strain injury. More appropriate to the construction industry, the use of percussive tools can cause injury. Damage to health through machine use is evidence of a poor state of the art of human factors engineering, and therefore of proneness to failure. This condition is assessed under the **state of the art of understanding of disease and health hazards**, which is defined as the range of knowledge, products and processes that provide for an understanding of disease and health hazards, that can or may result from the interaction of humans with both their working environment and the artefacts that have been developed to facilitate this interaction.

7.7 Auditing procedures.

Although an audit is a snap-shot in time it should allow for an assessment of the continuing safety state. Concepts relating to features such as culture, state of the art, and the functioning of procedures provide for this. These and other concepts that monitor how audits are being carried out also provide for a check as to whether auditing is being used simply to "pay lip service" to the provision of safety.

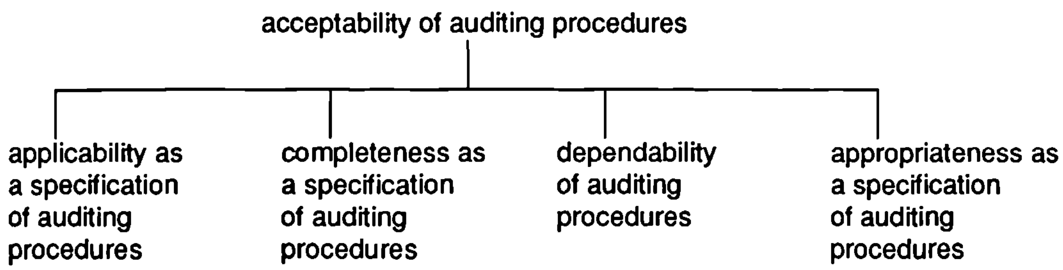
Bias that affects the perception of risk may influence the use of audits and their analyses. The skills of auditors need to be cultivated to enable the recognition of bias and to take account of it. Of particular relevance is the heuristic bias that leads to over-confidence. Slovic, Fischoff and Lichtenstein, (1982), list a number of examples where events that could lead to disaster have been overlooked or misjudged because of over-confidence. These include misdiagnosis of the events in the incident at Three Mile Island, USA, in 1979, which resulted in considerable costs to the operating company and insurers, and the release of small quantities of radioactive material into the atmosphere. The Teton Dam collapse in 1976, also quoted by Slovic et al, is an example of over-confidence in experts who failed to recognise their lack of knowledge. Over-confidence in auditing must be avoided as there will always be unforeseen hazards. An examination of a situation must seek to go beyond the boundaries imposed by an audit.

As shown in the following diagram, an examination of the state of the art of auditing procedures follows the same pattern as that for the state of the art of hazard engineering. The **extent** of the knowledge available and the knowledge about auditing procedures, their **relevance** as audits, and the **research and development** associated with auditing are evaluated in the same way as the respective concepts under the state of the art of technical engineering. (Chapter 6, clauses 6.6.1, 6.6.2, and 6.6.4).



7.7.1 Acceptability of auditing procedures.

As described in chapter 6, (clause 6.6.3), acceptability is evaluated in terms of applicability, completeness, dependability, and appropriateness.



Applicability of an audit as a proposition, without reference to an application, may seem to be a contradiction. However, if a state of the art of auditing develops to any great extent, general standards of usefulness and practicability should emerge, against which audits can be compared.

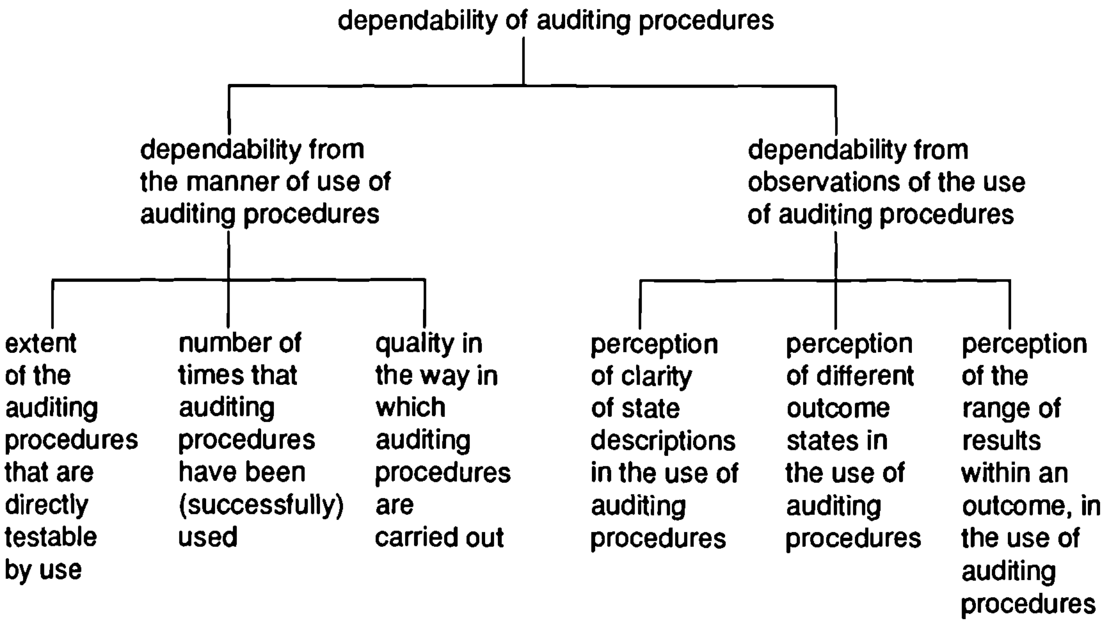
Similarly for completeness, once a state of the art has developed, generally agreed levels of standards of completeness should develop. Audits, irrespective of their specific application can be compared to these standards.

Dependability is discussed in the following clause, 7.7.2.

For appropriateness, assessments of precision and clarity are as outlined in chapter 6, (clause 6.6.3.4). Truthlikeness, (chapter 6, clause 6.6.3.4), requires comparison between the content of the audit and what is known or believed to be fact. Truthlikeness, in the absence of testable propositions, needs to be judged in relation to the predominant views amongst experts in a particular field.

7.7.2 Testing of auditing procedures.

The dependability of auditing procedures is based on testing. Hazard auditing is a safety procedure. It is possible to model a situation and test that the use of the audit does result in recognition of evidence of proneness to failure. This would aid the development of an audit, but obviously, the models for "testing", should be developed independently of the audit. The best, and possibly only realistic test is use. Because of the socio-technical nature of auditing, evaluating dependability from use is not as straightforward as for technical engineering. The concepts for an evaluation are similar but interpretations are different.



Dependability from the manner of use of auditing procedures, needs to be judged by competent experienced auditors.

It may not always be possible to assess the **extent of the auditing procedures that are directly testable by use**. For example, successive audits of a situation may indicate improvements in a number areas and consequently provide less evidence of proneness to failure, but because of inter-dependencies between concepts, it may be difficult to establish the reasons for particular improvements. The greater the complexities and inter-dependencies of the categories of an audit, the less the extent that its parts are testable. Concepts are likely to be of low testability within the context of high level audits. They will be more testable within lower level audits. For example, if after the introduction of regular maintenance checks, (an audit), of a particular type of machine, the frequency of breakdowns decreases, there can be a justifiable increased confidence in the audit. If the incidence of breakdown worsens, or is unchanged despite the use of maintenance checks, confidence in the audit for this particular application is not enhanced. There has been a falsification of the implied hypothesis that regular maintenance checks will reduce the frequency of breakdowns. A programme of auditing, incorporating audits of different levels, can provide tests of the parts of high level audits.

Successful use of an audit is demonstrated by a perceived reduction of evidence of proneness to failure, or the maintenance of an acceptable level. An evaluation of the **number of times that auditing procedures have been (successfully) used**, should not be prejudiced by the resources or effort put into auditing. Audits are not unsuccessful simply because the cost for their implementation is judged to be excessive.

An assessment of the **quality in the way in which auditing procedures are carried out**, is judged by comparison with the instructions or specifications for a particular audit and the standards set by experts.

Assessments of many of the concepts under **dependability from observations of the use of auditing procedures** are based on high levels of intersubjective perception. Consistency in perceptions between auditors is only possible if there is a common basis. Evaluations of the same circumstances will be more consistent, if auditors, as a result of their education and training, possess basic common knowledge, and through discussion and exchange of ideas have developed common standards. Blockley, (1980) describes all perceptions as being subjective or intersubjective, with objective perceptions being those intersubjective perceptions, the intensity of which we can measure. Developing hazard auditing as a specialist activity will help to create conditions that allow for some degree of objectivity in what would otherwise be highly subjective perceptions.

The **perception of clarity of state descriptions in the use of auditing**

procedures, relates to the clarity with which it is possible to identify the different audit concepts within the situation being audited. The identification of state descriptions is clearer in concepts taken from the lower levels of the proneness to failure hierarchy. This is illustrated in chapter 8, where the parameter descriptions of concepts relating to the "state of society" are especially difficult to establish. As suggested, considerable research will be required, if auditing at the level of society is to be of value.

If there are **perceptions of different outcome states in the use of the auditing procedures**, the dependability of the audit is compromised. There are only two different outcome states for assessment of concepts, in that there is, or there is not, evidence of proneness to failure. If it agreed that a particular concept can influence proneness to failure, different examinations of the same circumstances should produce the same outcome state. There may be variation in judgements as to the extent that there is evidence of proneness to failure, in the same or similar circumstances. This is assessed under the **perception of the range of results within an outcome, in the use of auditing**. The likelihood of perceptions of different outcomes, or of a wide range within an outcome, will be reduced if auditing is developed as a specialist activity that will enable the setting of common standards of evaluation. Expertise is required to recognise whether circumstances are in fact similar, when there appears to be different perceptions of outcomes or range in outcomes.

The preceding discussion indicates that hazard auditing should be developed as a specialist activity.

7.8 Reliability and risk assessment techniques.

Reliability and risk assessment techniques are concerned with the treatment of uncertainties, and the associated problems of decision making. Details of the methods and procedures that form the state of the art, can be found in publications such as; (Melchers, 1987; Thoft-Christensen and Baker, 1982; Cooper and Chapman, 1987; McCormick, 1981). The following discussion deals with the assessment of quantitative methods and techniques.

A hierarchical expansion for the state of the art of reliability and risk assessment techniques is of the same form as that outlined for technical engineering, described in chapter 6.

- state of the art of reliability and risk assessment techniques
  - extent of reliability and risk assessment techniques
  - relevance of reliability and risk assessment techniques
  - acceptability of reliability and risk assessment techniques
  - research and development into reliability and risk assessment techniques

In their classical form, reliability and risk assessment techniques deal with uncertainty by quantification of reliability and risk in probabilistic terms. Reliability deals with failure, and risk assessment with failure and its consequences, be they fatality, injury, or economic. Uncertainties about parameters that influence the performance of a system can take several forms, (Melchers, 1987, Thoft-Christensen and Baker, 1982). Essentially, they can be considered as either parameter or system uncertainties, (Blockley, 1980). Parameter uncertainties are associated with parameter values. These may be physical, such as material properties whose variability can be represented by probability distributions. There may in turn be uncertainties about the values of statistical parameters, particularly if sample sizes are small. System uncertainties are associated with how closely a model describes a system. Sometimes, influences on a system are unclear. For convenience other influences are neglected to facilitate modelling, (chapter 6, clause 6.5.1). Examination of these uncertainties, (parameter and system), is part of an assessment of acceptability of reliability and risk assessment techniques as state of the art.

7.8.1 Acceptability of reliability and risk assessment techniques.

Reliability and risk assessment techniques require evaluation for acceptability as mathematical propositions and as models of particular systems. The expertise, essential to evaluation, is likely to be found in those with specialist knowledge of reliability analysis of appropriate systems. This should not preclude input from others with specialist knowledge of either a system or the theory underlying reliability methods. The concepts for evaluation, shown in the following diagram, develop in the same way as for technical engineering, (chapter 6, clause 6.6.3).

acceptability of reliability
and risk assessment techniques

applicability as a specification of reliability and risk assessment techniques	completeness as a specification of reliability and risk assessment techniques	dependability of specification of reliability and risk assessment techniques	appropriateness as a specification of reliability and risk assessment techniques

Assessment in terms of **applicability** and **completeness**, (chapter 6, clauses 6.6.3.1 and 6.6.3.2), is as a mathematical proposition. Evaluation of **appropriateness**, (chapter 6, clause 6.6.3.4) is in terms of the following criteria:

- Precision as a mathematical proposition. This relates to mathematical approximations. Simpson's Rule, for example, is an approximation to the area under a curve.

- Clarity as a mathematical proposition. Lack of clarity is indicated by ambiguities in the derivation of a proposition.

- Truthlikeness as a mathematical proposition. For correspondence with the facts, a mathematical proposition must accord with the axioms and laws of mathematics.

- Truthlikeness in the correspondence between the parameters of the model and the parameters that influence the system. This relates to system uncertainty.

- Truthlikeness of the values of the model parameters, including, of course, that of the outcome parameter, probability of failure. This relates to parameter uncertainty.

Reliability and risk assessment techniques are used to assess what are usually low probabilities of failure of systems that are part of a relatively small population. The opportunities to test are limited. Prototype, proof, and laboratory tests, (chapter 6, clause 6.6.3.5), are usually inappropriate or impracticable, but can provide valuable information about model behaviour and parameter values. Laboratory testing, for instance, may be used to test the reliability of components that are available or manufactured on a large scale. The most appropriate test is that of use. Even in tests through use, there is often a limited amount of test data. For example, there is comparatively little dependable data available on failures of structures as systems, or of numbers of successful structures. However, comparisons between models and systems are necessary to establish truthlikeness and dependability. **Dependability** is discussed in chapter 6, clause 6.6.3.3. Its assessment in connection with reliability and risk assessment techniques is outlined in the following discussion. Reference can be made to clause 7.7.2, where its hierarchical development is reproduced.

For construction projects, the **extent of the reliability and risk assessment techniques that are directly testable** is likely to be low. So much cannot be seen, and failures of components can go unnoticed. The **number of tests** is, as stated, likely to be small. Assessment of the **quality of tests** through use in construction requires caution. (See chapter 6, clause 6.6.3.5). The variability of quality throughout construction is large. Choosing representative samples against which to test a risk assessment analysis is difficult. This means that it will be difficult to achieve quality in tests of reliability and risk assessment techniques for construction. The **perception of clarity of states**, refers to how clearly the separate parameter and the outcome states can be identified. Poor clarity may be evidenced in a difficulty in identifying failure scenarios, particularly if human factors are considered in the build up to an accident. Consider a hypothetical example of a falsework collapse, triggered by inadequate bracing. To what extent should this be attributed to a poor supervision in the falsework erection, poor workmanship in erecting the falsework, or poor checking of the completed temporary structure? The **perception of different outcome states** is assessed as high if test observations show a large number of different failure scenarios leading to overall failure. The **perception of the range of results in an outcome**, applies to intermediate states and the final state. That the observed range of reliabilities can be of orders of magnitudes illustrates the requirement for expert judgement about the implications for dependability and hence acceptability.

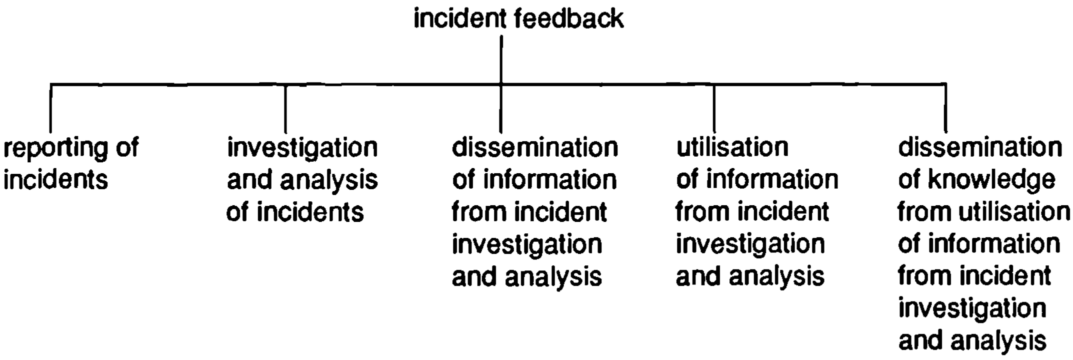
If reliability and risk assessment techniques for construction are to be tested, monitoring of the construction process and completed structures is necessary. This provides scope for research, which could, for example, look at the influence of human factors in construction such as human error, workmanship, and supervision.

If parameters are unforeseen, decision making is in ignorance, and outcomes are unexpected. To try to minimise this possibility, clear precise descriptions of the model and its parameters should be given. This provides the opportunity for others to identify missing parameters. Confidence in reliability and risk analysis methods may be reduced if proponents of a method are perceived to have been aware of, but failed to specify, its shortcomings.

7.9 Incident feedback.

The technical details of a failure may be peculiar to a particular industry, but the conditions which allow for the incubation of disaster are not, (Turner, 1978). Even minor incidents can be traced back to common management influences, (Kletz, 1985a and 1988). Learning from incidents, whatever their scale, should not be restricted to the industry in which they occur. The occurrence of incidents as evidence of proneness to failure is included in the hierarchy in the contexts of society, industry, project, and project phase. (See chapters 8, 9, 10, and 11 respectively). Incident feedback, because it is the means of learning from incident occurrence, has a direct effect on the state of the art of hazard engineering.

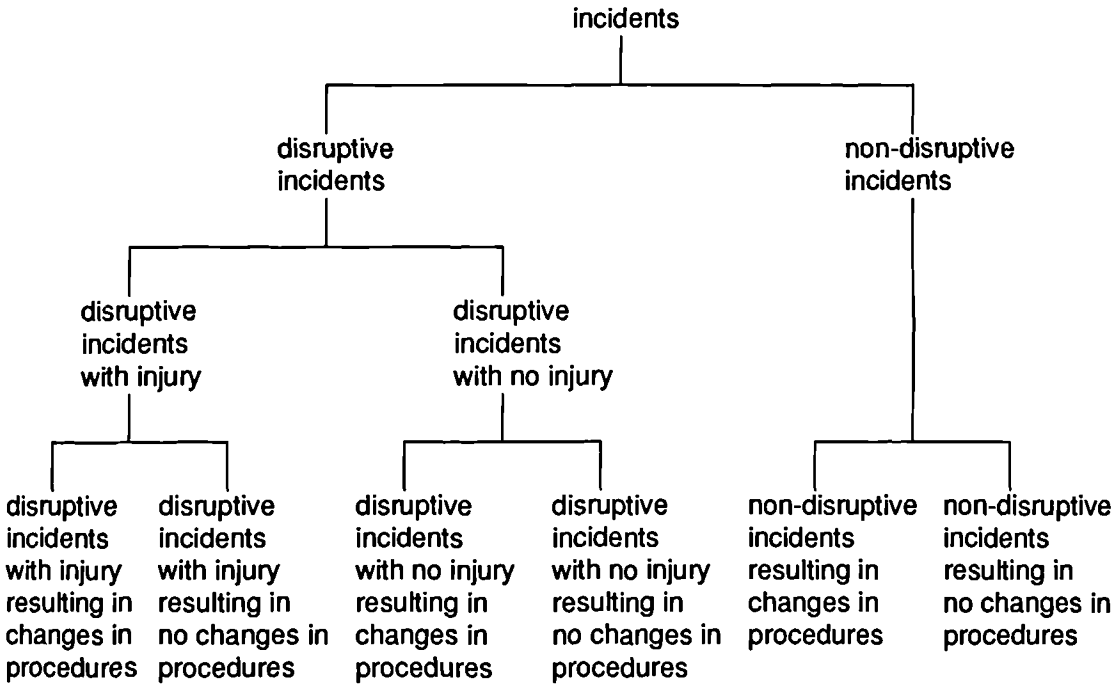
Incident feedback comprises: reporting; investigation and analysis, both individually and collectively; dissemination of information from investigation and analysis; utilisation of this information; and the dissemination of knowledge gained from utilisation. This cycle of learning, should allow for open learning, in that information is disseminated as widely as possible. Other objectives, such as those linked to commercial interests, may compromise this cycle of learning.



7.9.1 Classification of incidents.

The classification of incidents reduces the diversity and number to manageable parts. It should simplify recording, monitoring, and handling of information. Clear distinctions make the classification process easier.

The suggested classification is as follows:



Principal definitions are as follows:

Incident: A short term incident or event that represents failure or an immediate increase in proneness to failure.

Disruptive incident: An incident that results in disruption producing material loss or suspension in operation over and above the need for nominal clearing up, and/or temporary delays which can be made up immediately after the incident.

Disruptive incident with injury: A disruptive incident which involves personal injury requiring medical attention of any form.

Disruptive incident with no injury: A disruptive incident which involves no personal injury requiring significant medical attention.

Disruptive incident with injury resulting in changes in procedures: A disruptive incident with injury that results in fundamental changes in methods or procedures as a direct result of the incident occurrence, rather than as a result of incident investigation and analysis.

Disruptive incident with injury resulting in no changes in procedures: A disruptive incident with injury that results in no fundamental changes in methods or procedures as a direct result of the incident occurrence rather than as a result of incident investigation and analysis.

Non-disruptive incident: An incident that results in no injury, material losses or suspension in operation other than the need for nominal clearing up, and/or temporary delays which can be made up immediately after the incident.

This classification means that injury is necessarily a disruptive incident.

The terms, near miss, accident and disaster are not used. Near miss can have different interpretations. Feelings of relief, for example, that an incident "could have been a lot worse", might lead to its classification as a near miss. Accident is all encompassing, and if classifications are too general there can be uncertainty about the significance of a particular incident. The emotive interpretation of disaster can be counter productive, because the prevailing atmosphere in the aftermath of a disaster is not necessarily conducive to learning. A preoccupation with the allocation of blame, and as a consequence the avoidance of blame, can compromise subsequent investigation and analysis, (Toft, 1990). Legal action, or the threat of it, is therefore likely to detract from the investigation and analysis of incidents, because recourse to law implies a desire to allocate blame.

In summary, the classification of incidents has been chosen for the following reasons:

- To provide manageable groups of elements to facilitate information handling.
- To distinguish between classifications as clearly as possible, although it is accepted that there will be uncertainties when it is felt that particular incidents could be included in more than one category.
- To prevent as far as possible prejudicing incident investigation and analysis.

7.9.2 Reporting of Incidents.

Reporting of incidents follows the classification shown in clause 7.9.1.

If, as suggested by Langer, (1980), page 107, "people want to be responsible for their successes, but not for their failures", a lack of reporting is not surprising, particularly if one purpose of investigation is perceived to be the apportionment of blame. Punishment of non-reporting may reinforce the perception of a "blaming culture". Reporting of incidents in industry, is governed by the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985, (RIDDOR, 1985). Although it includes dangerous occurrences, the emphasis is upon those incidents involving injury or events adversely affecting health, and the scope is therefore limited. Accident statistics can be found in the (HSC ANNUAL REPORT). A degree of under reporting, of reportable incidents, is acknowledged by the Health and Safety Commission, (HSC, 1989/90).

7.9.3 Investigation and analysis of incidents.

This is defined as the investigation and analysis of incidents, individually and collectively, to identify factors that contribute to the occurrence of incidents or the development of conditions that increase proneness to failure.

Collective investigation and analysis may uncover factors not obvious in individual examinations or even in the analysis of collective incidents that have been investigated individually.

The hierarchical expansions of the investigation and analysis of incidents, both individually and collectively take the form of the classification system shown in clause 7.9.1.

investigation and analysis of incidents

- investigation and analysis of incidents, individually
- investigation and analysis of incidents, collectively

Fear of blame compromises investigation. Toft, (1990), highlights this as a drawback of public inquiries in the examination of disasters. Walster, (1966), comments:

> Although many disaster reports explicitly deny that victims and observers tend to blame others for disasters, (Bucher 1957), the reports themselves reveal a tremendous number of attempts to assign responsibility to someone.

Despite the deleterious effects of a "blaming culture", it appears to be difficult to change, as illustrated in interview K, where, even when blame free investigations were advocated, the threat of blame still existed. In answer to the question as to whether punitive measures are used in cases of poor safety, the reply was:

> No. That used to be done. The way we proceed is .... There is an immediate inquiry set up, the object of which is purely to establish the facts of the case, which are often difficult to bring out. It is a deliberate part of the terms of reference of that report, that blame is not attached. ..... In other words, establish the facts and the lessons and produce recommendations. Then if there's a disciplinary matter, that's another forum, totally. .... So there should be no blame attached at the time of the analysis of the thing.

A blame free culture surrounding the investigation and analysis of incidents may be a utopian ideal particularly if, as suggested by Walster, (1966), the tendency to assign blame increases as the severity of the consequences of an accident increases. However, for incidents not involving disruption, injury or loss, there does not appear to be any reason for blame. If a culture is fostered such that it is clear that no blame or unfavourable consequences will result from such an incident, a relatively untapped source of information will become available.

If it were the responsibility of independent, external, agencies, the investigation and analysis of incidents throughout industry, or in society, would appear to be an awesome task. If, though, the climate under which investigations and analyses are conducted is essentially one of a desire to learn, and self imposed, unbiased investigations are part of the policy and culture of organisations, the problem is less daunting. Within organisations, the scale reduces to manageable parts, although the problem of dissemination of information still exists, (clause 7.9.4).

7.9.4 Dissemination of Information.

This is the dissemination of information obtained as a result of the investigation and analysis of incidents. The hierarchical expansion therefore follows the same pattern as that for the investigation and analysis of incidents.

dissemination of information from the investigation and analysis of incidents

dissemination of information from the investigation and analysis of incidents, individually

dissemination of information from the investigation and analysis of incidents, collectively

The findings of incident investigations and analysis are sometimes reproduced as summaries or extracts, often to illustrate particular points. In an account of the Aberfan disaster in 1966, Kletz, (1988), emphasises; a failure to learn from the past, a failure to inspect adequately, and a failure to employ competent well trained people. For the same disaster, Turner, (1978), places the emphasis on the underlying "culture", within which the disaster occurred. He stated: (Page 54).

> However, although the situation was complex, and there were many contributing factors, the Tribunal of Inquiry found that the dominant pattern which contributed to the disaster was one which was located in the National Coal Board and in the coal industry in general and which might be characterized as a pervasive institutional set of attitudes, beliefs and perceptions which led to a collective neglect of the problems of safety relating to tips by almost everyone concerned.

Dissemination of information relating to incidents should not be over reliant on such accounts, which although valuable, are selective, providing analyses of particular aspects. There is a requirement to ensure that all the information from incident investigation and analysis is disseminated. This should, I believe, be primarily the responsibility of those responsible for the investigation and analysis. Although potential beneficiaries of information might be expected to search it out, they may not be aware of an incident. Even when the information is available, there can be difficulties in recognising situations where it is relevant. Toft, (1990), discusses this in terms of organisational isomorphism, which relates to the "occasions in which organisations exhibit similar patterns of behaviour", and might therefore learn from particular incidents. Having established correctly the relevance of an incident, there is then a need to guard against concentrating on the prevention of similar occurrences, at the expense of not identifying other potential hazards. Turner, (1978), describes this as a decoy problem.

The management of the dissemination of information presents a considerable problem. The representative organisations within an industry could perhaps play an important role in dealing with the problem. (See chapter 9, clause 9.9).

7.9.5 Utilisation of Information.

Utilisation is distinguished between incidents occurring within and outside society, (a social environment), industry, project, or phase of project.

Utilisation is considered in terms of lessons learned and action taken. This provides for a definition of the utilisation of information from investigation and analysis of incidents as, "the lessons learned or action taken, as a result of information obtained from the investigation and analysis of incidents".

Further development of the following section of hierarchy is of the same form as that for the investigation and analysis of incidents, both individually and collectively.

- utilisation of information from the investigation and analysis of incidents
  - utilisation of information from the investigation and analysis of incidents occurring within: society; industry; project; phases of project
    - lessons learned from information from the investigation and analysis of incidents occurring within: society; industry; project; phase of project
    - action taken as a result of information from the investigation and analysis of incidents occurring within: society; industry; project; phase of project
  - utilisation of information from the investigation and analysis of incidents occurring outside: society; industry; project: phase of project
    - lessons learned from information from the investigation and analysis of incidents occurring outside: society; industry; project; phase of project
    - action taken as a result of information from the investigation and analysis of incidents occurring outside: society; industry; project; phase of project

If no action is taken, then either lessons have not been learned, or lessons that have been learned are not acted upon, in which case they are not tested. That incidents repeat, does not necessarily mean that lessons have not been learned. Certain incidents may be judged as acceptable, but an awareness of the potential for failure may make the consequences easier to deal with. However, in an assessment of utilisation, the lack of action is of particular significance to proneness to failure. If actions are taken, lessons have necessarily been learned, even if they are later falsified. As Toft, (1990), page 90, states: "There is little point in learning how to prevent a disaster, if no active steps are taken to prevent it".

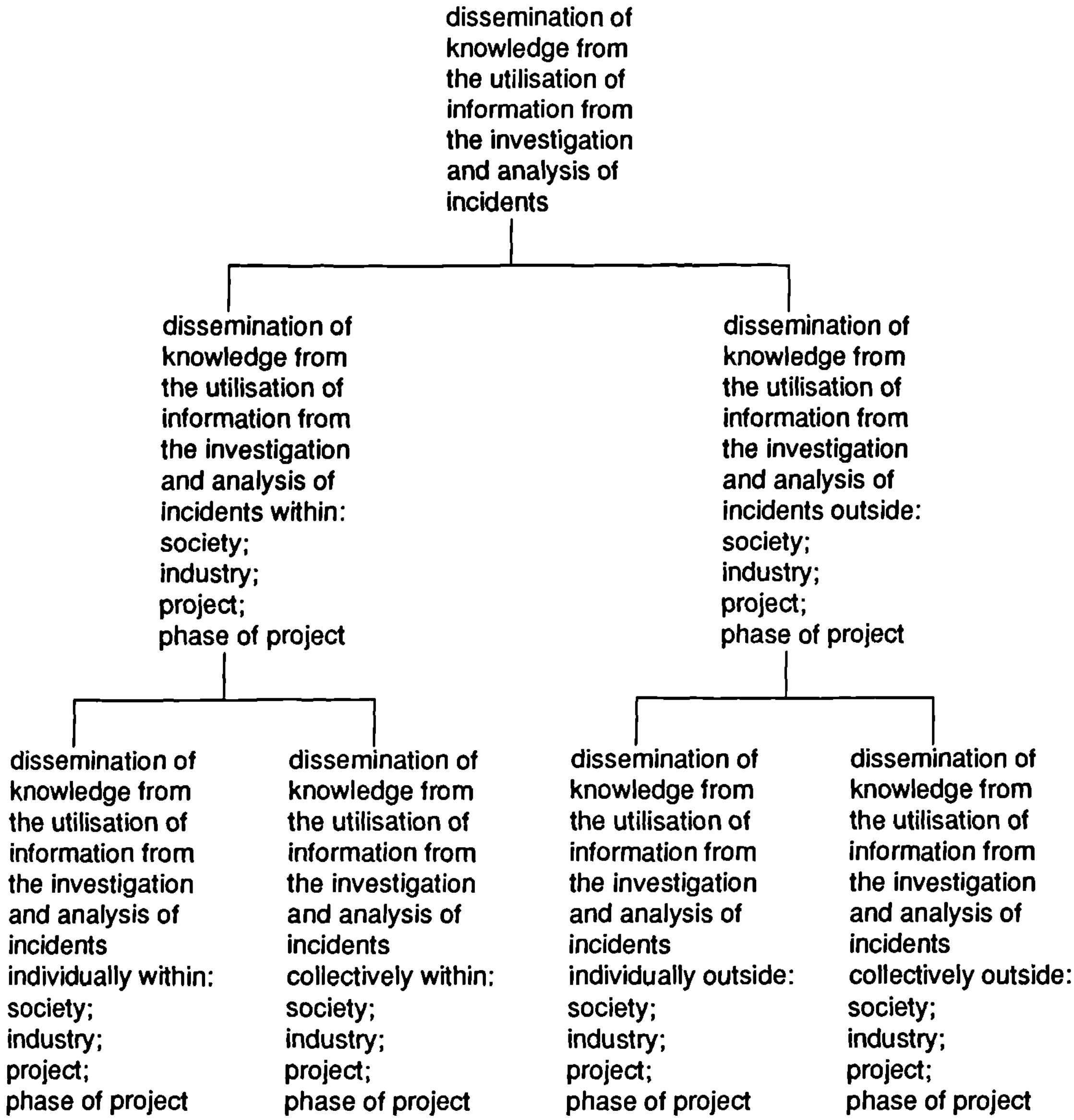
The failure to take action despite lessons learned from occurrences of incidents is illustrated in the following comment by Taylor, (1990), in the report for the inquiry into the Hillsborough Stadium disaster in the U.K. in 1989. (Page 4, para 22.)

> In my Interim Report I set out what happened at Hillsborough and why. That it was allowed to happen, despite all the accumulated wisdom of so many previous reports and guidelines must indicate that the lessons of past disasters and the recommendations following them had not been taken sufficiently to heart. I appreciate how easy it is to criticise with hindsight and that a new situation can always arise in human affairs which has not previously been envisaged. But many of the deficiencies at Hillsborough *had* been envisaged.

7.9.6 Dissemination of knowledge from utilisation.

"Information" and "knowledge" are used to distinguish between pre and post utilisation respectively. The term knowledge is used here to imply a greater degree of learning than information.

The concept descriptions shown in the following section of hierarchy represent definitions. Further development is in the form of incident classification described in clause 7.9.1.



The dissemination of knowledge from utilisation means that the cycle of: occurrence, reporting, investigation and analysis, dissemination of information, utilisation, and dissemination of knowledge from utilisation, can be joined again. This should be at the problem stage, (i.e. the original incident or incidents). If action does not appear to have dealt with the problem, joining the cycle at, for example, the investigation and analysis stage may prove ineffective, particularly if the full extent of the problem has not been recognised.

The full cycle from incident occurrence through incident feedback, and back to occurrence, is analogous to "Popper's" scientific method of: Problem, proposed solution, deduction of testable proposition, and preference between competing theories. (Magee, 1982). Breaking the cycle reduces the opportunity to learn, not only in the restricted context within which an incident occurs, but also in the broader sense that knowledge is unavailable to a wide population.

7.10 Health monitoring and feedback.

In the same way that incident feedback relates to the occurrence of incidents, health monitoring and feedback relates to the manifestation of health hazards, which is included in the hierarchy in the contexts of: society, industry, project, and project phase. Incidents are recognisable because of their immediacy. If ill health can be immediately associated with an incident, it can be thought of as an injury, and is part of the incident feedback cycle. The manifestation of health hazards refers to a delayed onset of ill health from either an incident or an activity which was not previously regarded as hazardous. There is a requirement to actively search for cases of *ill* health. The learning process comprises a search for the problem, followed by a feedback cycle of reporting, investigation and analysis, etc, similar to that for incident occurrence.

Health *monitoring* and *feedback* is the *active* search *for* cases of apparent ill health that are the consequences of either past incidents or activities which at the time were not thought to be hazardous; and following identification, the process of reporting, investigation and analysis, (individually and collectively), dissemination of information from the investigation and analysis, utilisation of this information, and the dissemination of knowledge gained from utilisation; of the health hazards that have manifested themselves.

The following hierarchical expansion is similar to that for incident feedback, with an additional category that relates to monitoring for the manifestation of health hazards. A classification for the manifestation of health hazards has not been attempted.

health monitoring and feedback

- monitoring for the manifestation of health hazards
- reporting of the manifestation of health hazards
- investigation and analysis of the manifestation of health hazards
- dissemination of information from investigation and analysis of the manifestation of health hazards
- utilisation of information from investigation and analysis of the manifestation of health hazards
- dissemination of knowledge from the utilisation of information from the investigation and analysis of the manifestation of health hazards

7.11 Summary and conclusions.

The demands of society, and the nature of the multi-disciplinary activities that are integral to the management of hazards is evidence of the need to recognise hazard engineering as a discipline in its own right.

A hazard audit is a tool for hazard management. The requirements of auditing and the skills that are necessary to maximise the benefits of hazard auditing, indicate that it should be developed as a specialist activity of hazard engineering.

Human factors engineering is specialist discipline. Further research is necessary to establish a detailed hierarchical development of concepts that may provide evidence of proneness to failure.

Qualitative evaluations are more dependable if carried out by appropriately trained people. A hazard audit should itself be audited for acceptability as state of the art of hazard engineering. The qualitative nature of the appropriate examination is further evidence for the need to afford hazard engineering status as a separate discipline and hazard auditing the status of a specialist activity.

Reliability and risk assessment techniques are concerned with the treatment of uncertainties. Quantification of reliability for structures, often based on small amounts of available data, is usually in terms of low probabilities of failure. Because of this, opportunities to test techniques for truthlikeness are limited. With reference to construction projects, this suggests the need for further research to establish system behaviour, the parameters associated with the system, and values of parameters. A suitable area for study could be the effects of human factors such as human error, workmanship, and supervision. The analysis of failure scenarios, and the monitoring of construction processes and completed structures would be an essential part of this.

There is a need to develop and foster a culture that removes, as far as possible, fear of recriminations that surround the occurrence of incidents and manifestations of health hazards and the subsequent investigations and analyses.

Safety culture is central to the provision of safety. It will have stronger roots if based on a moral obligation to ensure the safety of others, rather than a requirement to conform to legislation or a belief that it is profitable to be safe.

To fully utilise the opportunities to learn from the occurrence of incidents and manifestation of health hazards, and to disseminate knowledge to as wide a population as possible, a cycle of problem, hypothesis, test, and preference between hypotheses should be maintained. For incident occurrence and manifestation of health hazards, this requires a cycle of: reporting, investigation and analysis, dissemination of information from investigation and analysis, utilisation of information in the form of action, and dissemination of the knowledge gained from the utilisation. One consequence of this would be the availability of relevant information for the development of reliability and risk assessment techniques.

The manifestation of health hazards is not always apparent in relation to previous incidents or activities. There is a requirement to actively monitor for the development and occurrence of health hazards.

Fig 7.1, at the end of the chapter, shows the hierarchical development of the state of the art of hazard engineering.

Fig. 7.1. Hierarchical expansion of "state of the art of hazard engineering". (Sheet 1 of 2).

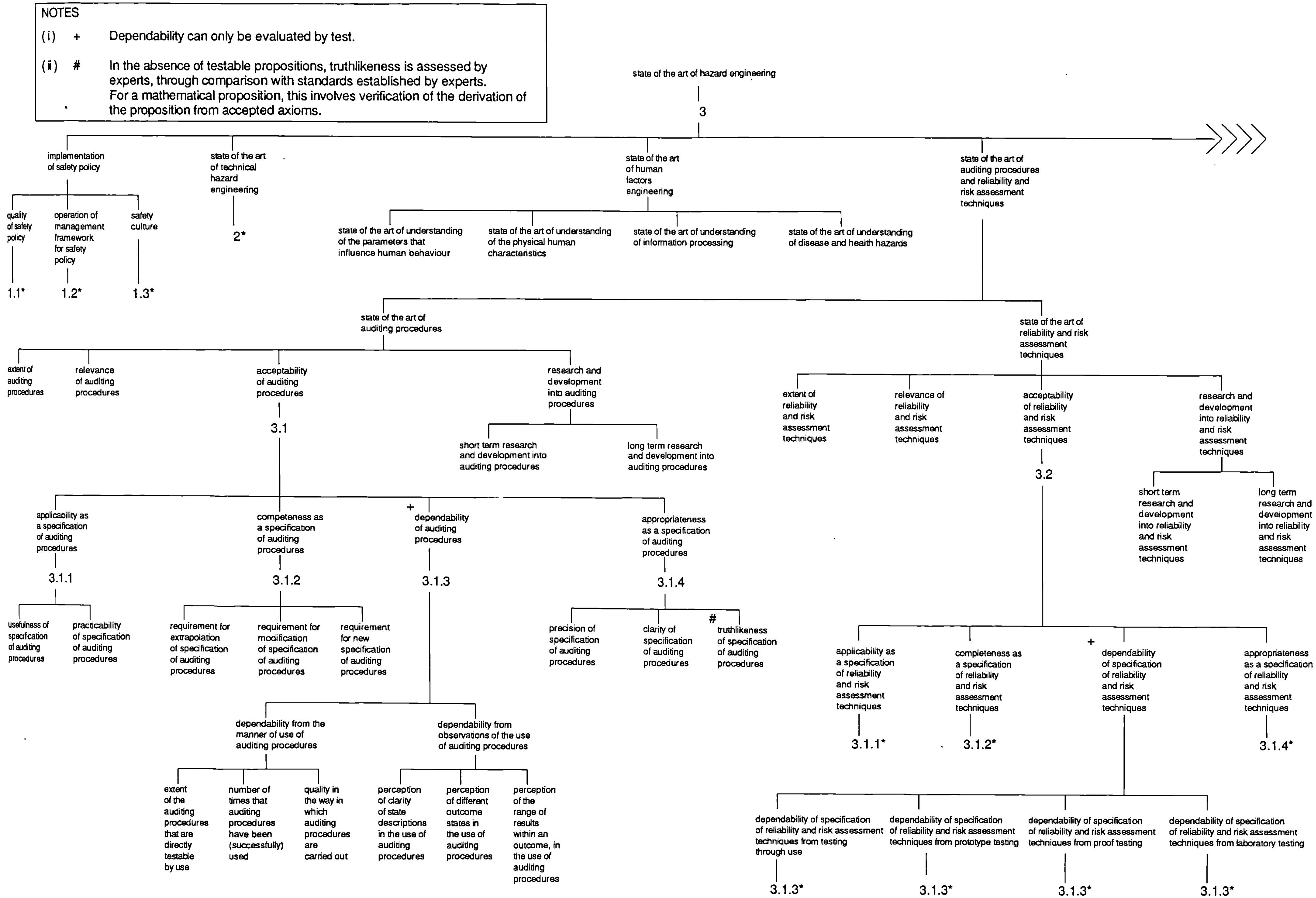
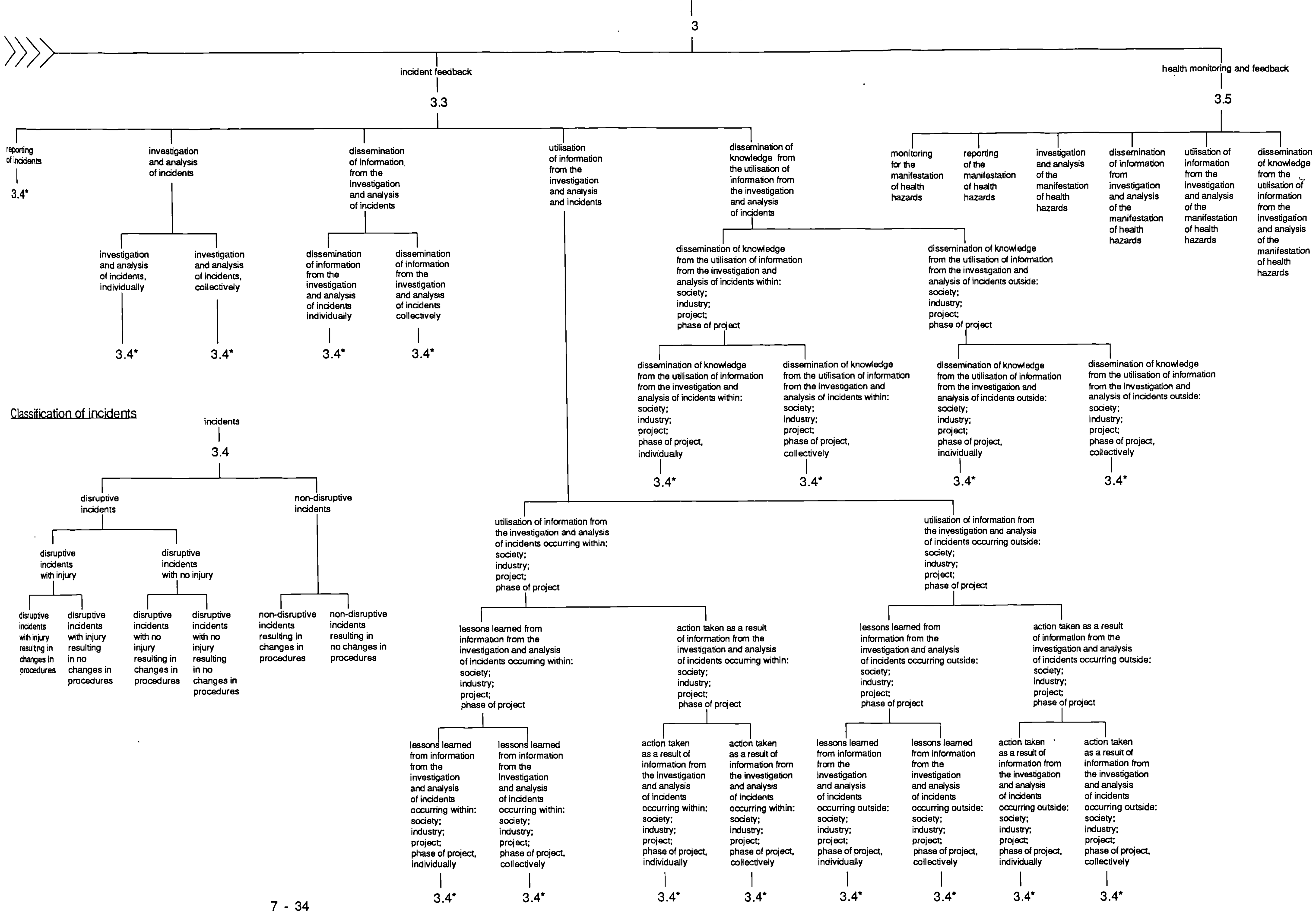


Fig. 7.1. Hierarchical expansion of "state of the art of hazard engineering". (Sheet 2 of 2).



Chapter 8.

State of society.

8.1 Objectives.

1 To outline the context of "state of society" with respect to its influence on proneness to failure in the development, use, and withdrawal from use of a technological project.

2 To discuss concepts that influence the "state of society".

3 To present a hierarchy of concepts that can provide for an evaluation of the state of society for evidence of proneness to failure.

8.2 Introduction.

Society, science, and technology are inter-dependent. The issue dealt with in this chapter, is the potential influence of society on proneness to failure of a technological project. Scientific knowledge is a component of engineering knowledge. (Chapter 6. clause 6.5.1). If society creates a situation such that "incorrect" scientific or engineering knowledge is adopted, there is evidence of proneness to failure. It may be that the ethics of scientific research mitigate against this, but as Casti, (1989), comments, (page 54), there are forces outside the world of science, creating a climate that can drive scientists to manufacture and artificially enhance what they claim are the "facts". O'Hear, (1989), states, (page 211), that "there can be no doubt that scientists, individually and collectively, can be influenced by extra-scientific forces, including non-scientific myths". These cultural influences may not result in the deliberate fraud described by Casti, but they may obscure thinking such that the expected standards of scientific development are compromised. Such forces are social influences. Aside from this argument, there are clear examples in the inter-dependencies between society and technology that demonstrate society's effects on technological development and consequently the hazards associated with it.

The effects of technology on society can be seen in living and working environments, waste and pollution. Society, it might be said, decides to live this way and creates the situation and the technology. Society makes choices between technological alternatives, such as the means of power generation and therefore affects the use and future development of technology. MacKenzie and Wajcman, (1985), presented a series of readings, to illustrate how technology has been shaped by society. Three examples are given here with respect to the technology of production, domestic technology, and military technology. Hughes, (1985), described the development of the electric lighting system, emphasising economic considerations and cost analyses which, it was suggested, were central to the development and production of a system that needed to compete with the existing gas lighting systems. In particular, Hughes, attributed the motivation for the discovery of a high-resistance lamp filament to the need to cut costs. In the development of the domestic refrigerator, Cowan, (1985), argued that the ascendency of the electric domestic refrigerator over gas, was in part due to the availability of capital and skilled personnel within the electric companies, and the competition that existed between them. These characteristics, according to Cowan, did not exist among the manufacturers of gas refrigerators. Kaldor, (1985), considered competition to be a factor in the choice of weapons systems. She suggested that political decisions are influenced by the power of large industrial corporations competing for business.

Society-technology relationships are discussed by Rybczynski, (1983), in examples such as: assembly lines of mass production, to satisfy mass consumption; communication technology, to service the information needs of the Western world; military technology to provide for deterrent against politically opposed governments. He concluded that people and technology are inextricably linked and that control of technology requires control of ourselves. This implies that control of technology and therefore its hazards requires control of the socio-technical system within which it exists.

Because of the difficulty in forecasting the social impact of technologies, Collingridge, (1980), argued for the need of flexibility within a technology. This, he proposed, allows for control, such that when undesired social consequences are discovered, the cost, effort and time necessary for change can be kept to a minimum. Factors, said by Collingridge to influence flexibility include: scale of the project or technology; entrenchment such that control cannot be exercised without alterations to associated technologies; competition; lead time for a new technology; increasing dependency on the new technology coupled with a state that makes it the only viable alternative; dogmatism of a social group that is characterized by attempts to hinder control. These factors are themselves influenced by the wants and needs of society, which again implies that control of technology is dependent upon society being able to control itself.

Society, through its complex social, political, economic and technical interactions, influences technology and its development. Control of the socio-technical system of technology is necessary if technological hazards are to be managed effectively. In the context of assessment of proneness to failure of a technological project, the conditions within society that influence technological development are potential hazards. The state of society, defined as "the capacity of society to ensure the safe development, use and withdrawal from use of a project, as intended", needs to be examined for evidence of proneness to failure.

8.3 State of society.

The concepts shown in the following section of hierarchy provide for an examination of the state of society for evidence of proneness to failure. The hierarchical development of the state of society, shown in fig. 8.1 at the end of the chapter, is based on the following discussions.

state of society

implementation of overall policy in society	state of the art of technology in society	state of the art of hazard engineering in society	education and training arrangements in society
(clause 8.4)	(clause 8.5)	(clause 8.6)	(clause 8.7)

regulation in society	occurrences of incidents in society	manifestation of health hazards in society	pressures in society
(clause 8.8)	(clause 8.9)	(clause 8.10)	(clause 8.11)

Before discussing the concepts shown in the diagram above, it is useful to consider the state of society in general terms. An audit of the state of society looks for factors, (hazards), that might influence the proneness to failure of a construction project. The features underlying such an audit are the relationships that society has with: the construction industry; safety in general; and more specifically, safety in the construction industry. I would emphasise, that this is an overview. The characteristics outlined in this clause, (8.3), are not hierarchy concepts. They are not subject to direct examination in an audit. Their examination should, however, be implicit in an audit designed using the hierarchy. As will be clear from this overview, assessment of concepts under the state of society does present particular problems. These are described in clause 8.3.1.

In the context of an examination for evidence of proneness to failure, the following set of questions characterise society's relationship with the construction industry.

- How essential is the construction industry to society?

- What realistic expectations does society have of the construction industry?

- To what extent does society, through the construction industry, have the capability to provide for its own expectations?

- How well does the construction industry perform its service to society? The answer to this question should be interpreted as a reflection of the quality of service that society is able to provide for itself.

These questions represent characteristics of: importance, expectations, capability, and quality of service. They indicate that at least some hierarchy concepts will involve evaluation by construction experts, and/or elicitation of views from representatives of society. The problem is who represents society? (See clause 8.3.1). Expectations have to be realistic. This suggests joint evaluation by non-experts and experts. Assessment of concepts linked to a society/construction industry relationship is achieved through comparison with society's relationship with other industries such as: medicine, agriculture, financial, aerospace, and information technology.

The characteristics that describe a society/construction industry relationship also apply to society's relationship to safety. These, in question form, are as follows:

- How essential, or important, is safety to society?

- What are society's expectations in relation to safety?

- To what extent has society the capability to provide for its own expectations for safety?

- How well does society provide for the safety of its members and environment?

Comparisons for safety are difficult to establish. Blockley, (1980), (page 28), states that "designers judge the quality, safety, and economics of their structures on the basis of their training experience and judgement". Quality in society is comprised of features that model perception of quality of life. Safety is one feature together with others such as leisure, the environment, and convenience. These have to be balanced against cost. Extensive research will be necessary to establish a model of the safety/quality/economic relationship. Without this model, there is no reference for comparisons. (See clause 8.3.1).

Society's relationship to safety in the construction industry constitutes a separate system. Again, in the form of questions, the underlying characteristics of the system relate to: importance, expectations, capability, and quality of service.

- How essential is safety in the construction industry, to society?
- What expectations does society have with regard to safety in the construction industry?
- How capable is society of providing for its expectations of safety in the construction industry?
- How good is the level of safety in the construction industry? The answer reflects the quality of service that society provides for itself.

This set of questions indicates that the extent of expertise involved in an audit of the state of society should cover construction and hazard engineering.

Bearing in mind that society is the subject of examination, assessment of its views about safety in the construction industry is obtained through comparison with its views about safety in other industries. It is therefore acceptable to refer to society's policy about the construction industry and safety in the construction industry as an overall policy, (clause 8.4), because the frames of reference for evaluation are the same, (comparison with other industries).

In summary, the features that constitute the state of society are produced from society's relationship with the construction industry, safety in general, and safety in the construction industry. The characteristics of importance, expectations, capability, and quality of service underlie each of these relationships.

An assessment for evidence of proneness to failure would be complex if the reasoning processes of an evaluation tried to integrate directly the different frames of reference associated with the construction industry and safety. This is not a problem if assessments are linked to lower level concepts, where assessments are in terms of single frames of reference. Concepts are assessed for evidence of proneness to failure. This is then the frame of reference for judgement and interpretation of the accumulated evidence for proneness to failure of a project.

The overview illustrates a requirement to assess the state of society through low level hierarchy concepts. Expert evaluation is required from construction and hazard engineering disciplines. There is a need to elicit representative views of society.

Changes in society are slow and can go unnoticed, particularly if there are no clear standards and criteria with which to compare. Dependability of assessment is compromised if standards for comparison are non-existent or ambiguous. Standards and criteria for assessment need to be clearly defined.

8.3.1 Assessment of the "state of society".

Obtaining an accurate representation of society's views and establishing bases for comparison are two of the main problems in an assessment of the state of society.

It is impracticable to survey the whole of a particular society for its views and beliefs. Use of specific groups requires caution, as they may not be representative. Politicians, for example, do not always represent the will of the people. This is illustrated in the recent debate in Europe over the future direction of the European Economic Community. Pressure groups do not necessarily reflect the views of society as a whole, and their evaluation of a situation may be influenced by specific objectives. For example, circumstances could be evaluated as far worse than they are if there is an overwhelming desire, in a particular group, for change. Collective behaviour, simply because it is vocal or visible, does not necessarily reflect the views of the majority. The media has its own priorities and objectives. They cannot always be relied upon to accurately represent the state of society. The most appropriate means of determining the views of society would seem to be through properly conducted studies of representative cross sections. These studies, which need to set a basis for assessment, require clear descriptions of the subject domain. The hierarchy concepts provide a starting point, but as with many problems, a clear description will only evolve as study and research progresses. This entails establishing the parameters for assessment and the nature of the links between them. Research to investigate the safety/quality/economic relationship would, for example, facilitate assessments of safety culture, (chapter 7, clause 7.4.3).

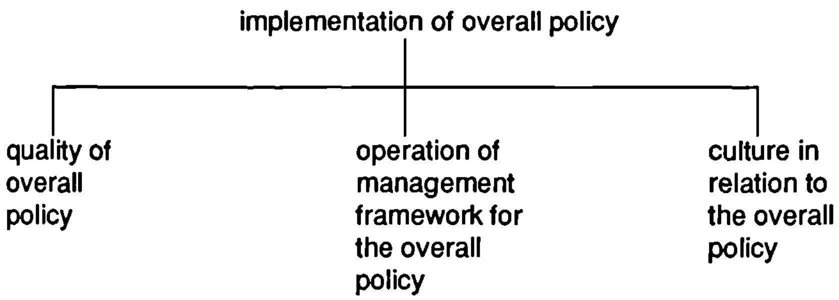
To summarise, the first step in assessing the state of society, is to clearly establish a base against which assessments can be made. This requires research in which the views of society have to be elicited from representative cross sections of society. Having initially established the basis for assessment, each subsequent assessment will necessitate properly conducted surveys of society.

The research into establishing the bases for assessments will inevitably highlight other areas in which the action, or inaction, of society can influence safety. Therefore, it should be looked upon as part of a requirement for continuing research into the recognition and understanding of the hazards that exist and develop in society. One area of study should be that of culture, relating to overall policy, in society. (See clause 8.4.3).

The complex nature of assessment, the need for interpretation of expert evaluations, and the process of eliciting evaluations from representative cross sections of society, means that hazard auditors will have to be specialists, trained and educated in auditing processes and in the discipline of hazard engineering. Because of slowness of change it is envisaged that audits of society, would be staggered over several years. For some concepts, such as regulation, (clause 8.8), and pressures, (clause 8.11), there is a direct link to project development. Provision for evaluation of such concepts, has been made in the appropriate section of hierarchy under overall project management, (chapter 10), and project history, (chapter 11).

8.4 Implementation of overall policy in society.

This refers to the policy of society relating to the role of the construction industry in society and the level of safety provided by the construction industry whilst carrying out its role. Structural safety, occupational safety, and the safety of all members of society, whether or not they are part of the industry, are included in this. Society's specific policy for safety is evaluated separately under the concept of the "state of the art of hazard engineering in society", (clause 8.6). Policy is described in chapter 5, clause 5.3. The top level of its hierarchical development, in relation to the overall policy of society, is given here.



Assessment should be made at lower levels in the hierarchy. However, even at lower levels there is a need for detailed research to establish the bases for comparison, as in, for example, "culture in society relating to overall policy", (clause 8.4.3).

8.4.1 Quality of overall policy in society.

I would suggest that there is no clear policy in society, outside of that within the industry, for the construction industry. Policy for safety in the construction industry, and safety in general, is represented in legislation, (The Health and Safety at Work etc. Act 1974). Within the conditions of the legislation, it is expected that the provision of safety be left to self regulation, (Robens, 1972; Health and Safety Executive, 1980; Eisner, 1991). Information about this policy, (see chapter 5, clause 5.3), is produced by the Health and Safety Executive. A list of available guidance notes is given in a twice yearly publication by the Health and Safety Executive, (BIANNUAL). Further regulation and information should result from the current proposals from the Health and Safety Commission (HSC consultative document, 1989 and 1992) and the European Communities Commission Council Directives, (1989 and 1992), the later of which deals with the implementation of minimum safety and health requirements at temporary or mobile construction sites.

8.4.2 Operation of a management framework in society, (for overall policy).

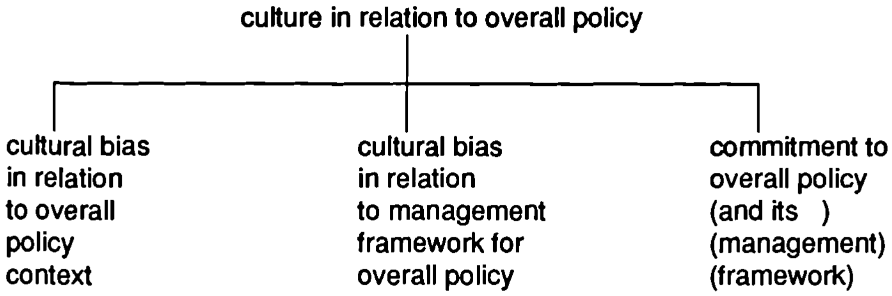
This is the operation of a framework of organisational, information, and planning arrangements, in society, for the control of activities, systems, and procedures adopted for the implementation of overall policy. Assessment of management framework is discussed in Chapter 5.

Policy in society is usually enunciated by Government. It is backed by the power of Government. Although Government, may not always represent the wishes of society, its actions are particularly relevant to the functioning of a management framework. There is no clear management framework in society for the implementation of an overall policy. Some industries, for example, education and health are the subjects of specific government departments. In these and in others, such as the nuclear industry, elements of society may also form unofficial organisational frameworks to monitor and influence policy. These external organisational arrangements, (see chapter 5, clause 5.5), are part of a management framework. For society's overall policy towards the construction industry, what management framework there is, relates to safety, and exists primarily in the Health and Safety Commission (and Executive).

8.4.3 Culture in society, (relating to overall policy).

Based on the definition of culture given in chapter 1, this is "the set of beliefs, norms, attitudes, roles, and social and technical practices, in society, that are concerned with the implementation of its overall policy". In terms of the overview of clause 8.3, this can be interpreted as relating to: the importance to society of construction and safety in construction; the expectations that society has of the construction industry and safety in the construction industry; the capability of society to enable it to provide for its own expectations.

Because of its abstract nature, evaluation of this concept is difficult. It is necessary therefore to go to lower levels in the hierarchy. These are described in chapter 5, clause 5.14. The top level is reproduced here.



Of the lower level concepts in the diagram shown above, cultural bias can be evaluated in terms of a single frame of reference, (clauses 8.4.3.1 and 8.4.3.2). Evaluation of commitment, (clause 8.4.3.3), however, is linked to behaviour and resources, and would be best achieved at lower hierarchy levels.

8.4.3.1 Cultural bias, in society, in relation to overall policy.

Defined as "the comparative value of belief, exhibited by society, towards the construction industry and safety in the construction industry, compared to values of belief in the functioning of other industries and their capabilities operate safely", this concept relates to the importance, and the expectations that society has, of the construction industry and safety in the construction industry.

Cultural bias can be associated with policy makers, managers, and users, (chapter 5, clause 5.14.1). In society, these are associated with respectively: Government; the Health and Safety Executive, and law enforcement agencies; and the general public. Research to establish cultural bias will involve eliciting views from all of these groups.

Different industries have different images in society. The civil engineering and building industry seems to have a poor image, (Contract Journal, 1991). Certain projects, such as large span bridges, may catch the imagination of some people, but construction would probably rate low in public esteem. Being held in low esteem by others outside an industry can be mirrored by a lack of self esteem within that industry. This may be detrimental to motivation and care about performance. The human resources available to an industry of low esteem, may be smaller in number and less able, than those available to highly regarded industries and professions, (Contract Journal, 1991). Education and training may be adversely affected, and pressures from society may increase. Poor cultural bias in society towards an industry may therefore be damaging to that industry. It would appear that the cultural bias, in society, towards the construction industry and its safety is poor. I would suggest that the industry itself must accept some responsibility for this. It could perhaps, through its representative organisations, take positive steps to improve its image. This issue is discussed further in chapter 9.

Comparison with other industries provides the reference for assessment of cultural bias towards safety in the construction industry. One factor that probably influences cultural bias towards safety is the severity of the consequences of major failure and its impact on society. This point was made during the author's interviews with safety practitioners. For example, in referring to aircraft, and accidents involving them, it was stated in Interview C:

> It carries passengers, so if there's an accident it's big news, and they have a very high profile attitude to safety which also, of course, rubs off onto the safety of the crew. This is purely a personal opinion. Whereas in the marine industry, 95% is cargo ships carrying cargo, with small crews. If one goes down it doesn't make big news. It's a voluntary exposure on the part of the crew. The crew know to an extent, the risk they're taking. The attitude to safety is not the same as say in the aircraft industry.

If society finds it difficult to show concern about safety in the construction industry, the "leaders" of the industry should think about taking the initiative. (See chapter 9).

8.4.3.2 Cultural bias, in society, in relation to a management framework for overall policy.

This is the cultural bias exhibited by society towards the functioning of a management framework for the implementation of its overall policy. Assessment is through comparison with the cultural bias shown by society towards the functioning of other management frameworks associated with society's policies for other industries and their capacity to operate safely.

Because of the number of concepts, particularly at low levels in the hierarchy, (chapter 5, and fig. 8.1), the task of assessment is a major undertaking. A selective examination of concepts deeper in the hierarchy, though, may be of value in indicating particular problem areas.

8.4.3.3 Commitment, of society, to overall policy and its management framework.

This is defined as the commitment of society to an overall policy and the functioning of a management framework for that policy. Hierarchical expansion is in terms of behaviour and resources made available for the development and implementation of policy. This is described in chapter 5, (clause 5.14.2). Problems of assessment are more manageable, if taken to lower hierarchy levels where behaviour and resources can be evaluated within single frames of reference. An auditor requires training and education to assess behaviour. An assessment of "the resources made available" involves elicitation of knowledge from experts, and views of a representative cross section of society.

8.5 State of the art technology in society.

The definition and hierarchical expansion of the state of the art of technology are described in chapter 6. In society, the state of the art is the extent and availability, to society, of knowledge, products and processes in a particular domain. Society will not possess a "poorer" state of the art than that an industry. It may appear to be "better", if a particular industry is not aware of, or does not have access to, technology that is available elsewhere in society.

The expertise required for evaluation is unlikely to be found in a single individual. It will probably be necessary to consult, and liaise between, a number of "experts". Academic institutions and research establishments appear well placed to provide this expertise. In practical terms, through liaison amongst themselves and with industry, these institutions can help disseminate relevant knowledge to industries and engineering disciplines. Good functioning of information arrangements, (chapter 5), are essential. Reliance on informal systems should not be considered adequate. A managed system of formal information arrangements is preferential. Perhaps the industry, through its representative organisations could play a leading role in encouraging and setting up such a system, (chapter 9).

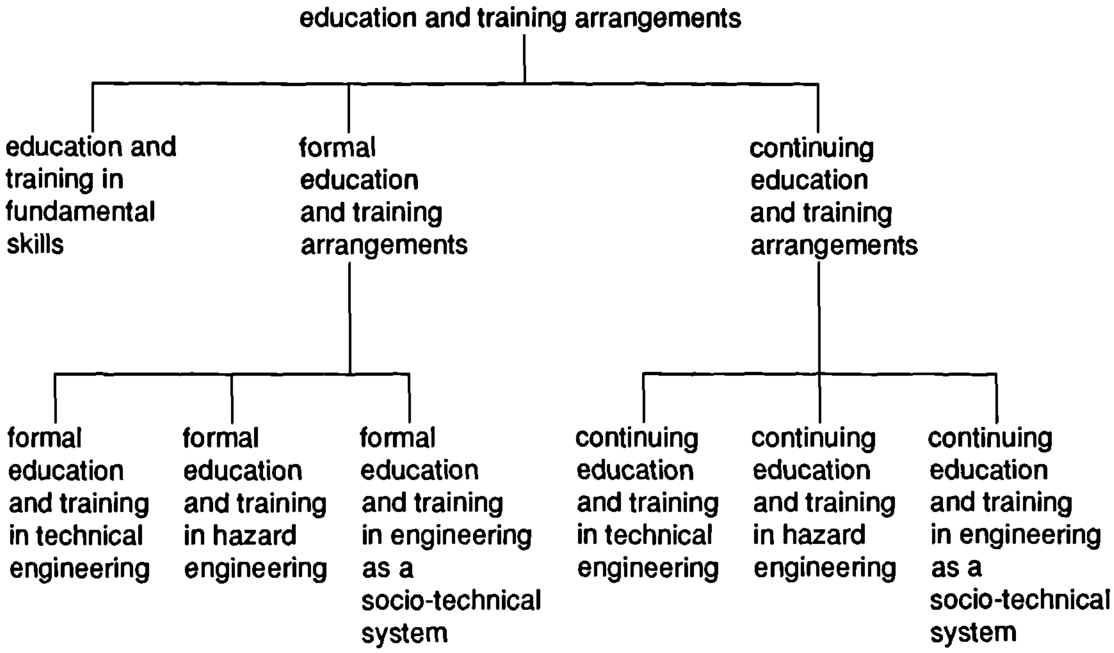
8.6 State of the art of hazard engineering in society.

The definition and hierarchical expansion of the state of the art of hazard engineering are described in chapter 7. For society, assessment concerns the highest possible level of the state of the art available. This is an accumulated set of knowledge, products, and processes, available throughout society. A discipline of hazard engineering would contain this knowledge, etc, thus aiding assessment.

I would suggest that safety culture in society is particularly significant for the development of a "good" state of the art in hazard engineering. The CBI, (1990), stress the importance of this with respect to organisations. The inter-dependencies between society and industry should be mutually beneficial to safety culture in both systems. Any assessment of safety culture in society would, at present, appear to have limited credibility because there is no clear basis for comparison. As suggested in clause 8.3.1, research is needed to establish a system description of, for example, a safety/quality/economic relationship.

8.7 Education and training in society.

This refers to "the arrangements for education and training in society to develop the capability to ensure the safe development, use and withdrawal from use of a project as intended". Education and training for people associated with the construction industry, should prepare them for their interaction with society. This is a two way interaction, and in the context of mitigating construction hazards, society outside of the industry, should be educated and trained to understand the way in which the construction industry functions. Evaluation of this concept, therefore, involves a judgement about the education and training for society; of those directly involved in construction, and those outside of the industry, such that the construction industry is integrated into society. The hierarchical expansion is shown in the following diagram.



Arrangements are classified into fundamental, formal, and continuing. Fundamental applies to basic skills of language, communication, and reasoning. In this classification, formal should be interpreted to exclude fundamental skills, which because of their importance should be assessed separately. Bearing this in mind, "formal" applies to education and training undertaken as a principal activity over a prolonged period, usually prior to paid employment. Education and training undertaken as part of employment, as necessary preparation for employment, should also be considered "formal". This includes apprenticeships and sandwich courses. "Continuing" applies to education and training that is not a principal activity over a prolonged period, but may be undertaken in conjunction with another principal activity such as paid employment.

Both formal and informal education and training are classified into that for technical engineering, hazard engineering, and engineering as a socio-technical system.

A representative cross section of expertise from education, industry, and society in general, should be involved in the evaluation process.

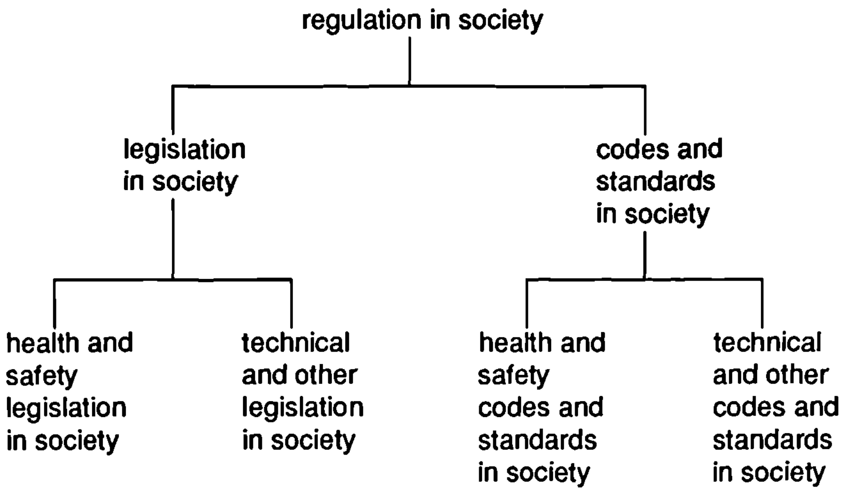
Civil engineering is inherently a technically imprecise and dangerous industry. If education and training, in society, is such that these characteristics are advanced as valid reasons for poor safety performance, and the construction industry is promoted as relatively unimportant, there is unlikely to be progress in improving safety. Education and training that places little emphasis on safety is potential evidence of proneness to failure. Education can affect values and beliefs. Beliefs are influenced by perceptions. Risk perception, for example is subject to heuristic influences such as availability and over-confidence. (Slovic, Fischoff, Lichtenstein, 1982). These can lead to large and persistent biases, (Slovic, 1987). To minimise bias, for the benefit of judgement and decision making, Slovic, et al, suggested that appropriate education should begin in schools. Attributional processes, (chapter 4), influence the way in which people "process information in determining the causality of an event". Dejoy, (1985), recommends various actions that offer ways of reducing the effects of attributional processes in relation to occupational safety. One recommendation, that:

> managers need to be made aware of the complex and multi-causal nature of accidents and the need to integrate safety into the total management system;

implies a need to educate; to provide a reason for action. The larger the population that is educated, the greater the potential for development of a state of the art.

8.8 Regulation in society.

This is legislation, codes and standards; developed for society, by society; designed to provide for the safe development, use, and withdrawal from use of a project as intended. In the context of construction, this covers regulation that applies to, but is not necessarily specific to, the construction industry, as for example, the Health and Safety at Work, etc. Act (1974), (HSW Act). Most technical codes and standards are produced by industry; possibly to conform to society's wishes, but they do not directly emanate from society. For this concept, they are not part of regulation in society. "The Building Regulations", (1985), however, which are specific to the construction industry, are relevant for evaluation, because they emanated from society. The hierarchical expansion of "regulation" is as follows.



A distinction has been made between legislation and regulation in the form of codes and standards which are deemed to satisfy the requirements of legislation.

Regulation is evaluated in terms of whether it has been formulated properly as a piece of regulation. In other words, does regulation meet the standards that are required for its formulation? More specifically, have legislation, codes and standards, been formulated so that they are clear, understandable, and workable? The question of whether regulation is necessary, is a separate issue. If the subject matter of regulation has been established as having a beneficial effect on proneness to failure it can be introduced as a separate concept within the hierarchy. If the effect of regulation is thought to be detrimental to safety, it can be assessed as a regulatory pressure, (clause 8.11.6).

Both legislation and codes and standards have been divided into that dealing with health and safety, and that dealing with all other aspects, technical or otherwise. In practice this distinction can be unclear. For example, the Building Regulations, (1985), cover health and safety, technical safety, and energy conservation; and the HSW Act implies a requirement for technical safety (e.g. structural safety) and occupational safety. The demarcation between safety and health and technical and other regulation is not particularly relevant. The classification is made to ensure that all regulation that is significant to safety is considered for assessment.

8.9 Occurrences of incidents in society.

The occurrence of incidents, in whatever context: society, industry, project or phase of project, is a symptom of proneness to failure. It indicates the level of safety, (the quality of service), provided by society, (clause 8.3). The classification of incidents is given in chapter 7, clause 7.9.1. It should be remembered, that accident frequency and incidence are not reliable guides to safety effort, (chapter 2, clause 2.5). Hazard auditing is intended to provide this guide.

8.10 Manifestation of health hazards in society.

As for occurrences of incidents, the manifestations of health hazards are evidence of proneness to failure. This concept applies to "delayed, identifiable symptoms of disease or injury in society, that have developed as a result of health hazards which may or may not have been identifiable at the time of their occurrence".

8.11 Pressures in society.

This category refers to factors, not specifically dealt with in other concepts, that may adversely influence proneness to failure. Pressures result from concerns or characteristics that appear to be outside of what is considered to be "normal". Concerns and pressures in society, such as economic recession, can filter through and add to pressures on industry, project or phase of project.

A concern that is judged by others to be unreasonable is real enough to those experiencing it. It is therefore a pressure. The existence of such a concern may also be evidence of a deficiency in education and training.

Pressures may manifest themselves as other pressures, (Blockley, 1980). For example, economic pressures could be the result of professional, political, or environmental pressures.

Generally, pressures become progressively more noticeable and easier to evaluate with the passage of time. However, systematic examination, prior to or early in a project, of pressures in society, may indicate a need to allow for contingencies at later stages.

8.11.1 Ethical pressures in society.

These are concerns or characteristics of society, related to ethics, or moral principles, which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

One reason for the provision of safety is a moral obligation. For example, in answer to the question as to why safety should be considered as a priority, the response from interview A was:

> Two reasons.
> Moral. A duty to see that people don't get hurt.
> Economic. Don't want assets or plant or products to be destroyed.

and the response from interview B was:

> ... So there's two basic reasons. Firstly there is a desire to care for people, and secondly it makes good business sense.

A belief that there is no moral obligation to ensure the safety of others is an ethical pressure which would probably also be reflected in an assessment of safety culture. Other principles, which may, for instance, preclude the use of certain medical aids can also indicate proneness to failure.

8.11.2 Religious pressures in society.

These are concerns or characteristics of society, related to religious practices, which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

Practices and beliefs are linked, but this concept has been included to ensure that pressures resulting from religious practices, which may be overlooked in an evaluation of ethical pressures, are specifically considered. The following example, based on my own experience, illustrates the possible effects of religious pressures in society filtering through to project construction. In practising Islamic cultures, the time taken for daily prayer is unusual by U.K. standards. This will obviously result in reduced outputs. Of greater effect is the adherence to fasting during daylight hours in the month of Ramadan. Basic working hours are likely to be reduced, often by law. There may be reduction in physical capabilities as a result of fasting, often in very hot climates. Output is reduced. Underestimating such effects creates pressure on construction. Knowledge of local labour laws does not guarantee that such effects will be highlighted; because local laws are developed within the culture in which they are to apply, and knowledge of the culture is taken for granted.

8.11.3 Professional pressures in society.

These are concerns or characteristics of society, related to professional practices, including: incompetence, inexperience, poor liaison among professions, (engineering, scientific, and social), which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

Pugsley, (1969), describes the Tacoma Bridge, USA, failure, 1940, and Ronan Point, UK, collapse, 1968, as examples of disasters influenced by professional pressures. For the Tacoma Bridge, Pugsley suggests that bridge engineers failed to benefit from knowledge in aeronautical engineering. For the Ronan Point disaster, it was suggested that there was evidence of a failure to check design calculations and a lack of cooperation between engineers and architects.

For this category, professions should be interpreted to cover professions and trades and the disciplines and industries with which they are associated. There can sometimes appear to be a "barrier" between professions. This can provide the breeding ground for more evident professional insularity at industry and project level. For example, the public images of architecture and civil engineering appear to be different. It might even be argued that civil engineering, in the UK, is not always perceived as a profession. It can appear at times that these images are reflected in attitudes and behaviour of individual members of the professions. This is not conducive to a healthy relationship. That such conditions exist is part of human nature. Their recognition, as professional pressures within society, can be a warning of potential problems within an industry or on a project.

8.11.4 Political pressures in society.

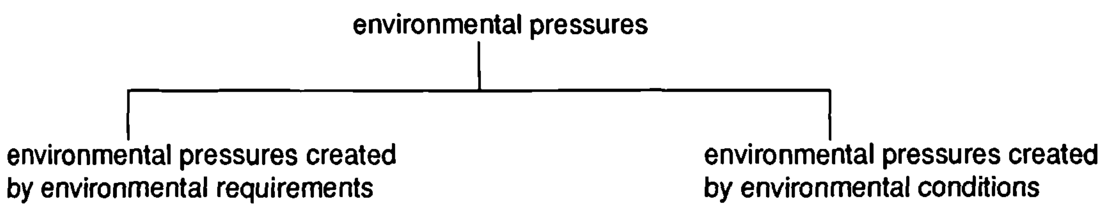
These are concerns or characteristics of society, related to political manoeuvrings or decision making, which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

Pugsley, (1969), described the events leading up to the R101 airship crash in 1930 as an example of political pressures contributing to failure. Blockley, (1980), argued that political pressure in the development of the Olympic Stadium in Montreal, Canada, in 1976, contributed to an accident on site. In both cases there was political pressure for completion. Both are examples of pressures on a project resulting from political pressures from society or parts of society. These pressures can be covert and difficult to recognise, and often, only in hindsight do they become clear.

Political decisions can have a positive effect. The introduction of legislation is an example.

8.11.5 Environmental pressures in society.

Environmental pressures in society are created by society's actions or demands, such that the effect on, or from, the environment produces pressures that could add to the proneness to failure of a project.

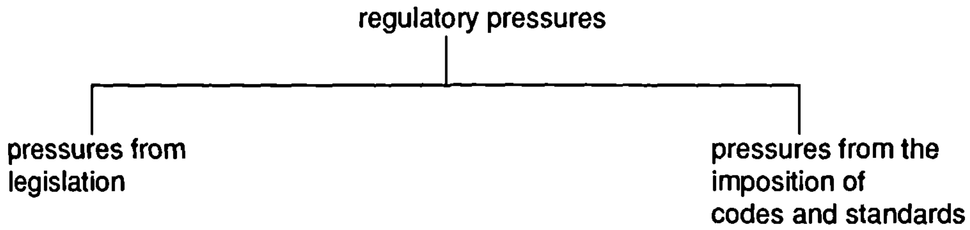


Environmental issues appear to be increasing in prominence particularly with regard to the impact that society has on the environment. Countering potential environmental damage may benefit society, but can produce pressures on an industry or project. The efficiency and the cost of the construction process may be adversely influenced by environmental requirements. Non-recognition of these pressures can have repercussions which increasingly add to the proneness to failure as a project progresses. For example, failure to account for noise restrictions as either an environmental or regulatory pressure in society, may result in unexpected temporal and economic pressures at the construction phase. Piling operations, for instance, may be restricted to certain times.

Another form of environmental pressure results from the need to overcome or accommodate natural phenomena, such as earthquake, hurricanes, and extreme heat or cold. The existence of such conditions is evidence of proneness to failure, which becomes stronger if an audit indicates that there has been a failure to recognise them. Not attempting to deal with these conditions is a lost opportunity to mitigate the severity of the consequences of failure. This in itself is evidence of proneness to failure.

8.11.6 Regulatory pressures in society.

Regulatory pressures in society are created if the requirement to comply with regulation, adds to the proneness to failure of a project. This is distinct to the category of "regulation in society", (clause 8.8), for which assessment relates to the way in which regulation is formulated.



Legislation that is considered inconvenient or inexpedient is not a pressure unless it produces a net increase in potential for proneness to failure. The HSW Act is not a pressure because it does not appear to add to proneness to failure. It may be that the quantity or sheer bulk of regulation makes its use unmanageable and thus produces pressure.

Too much regulation can be seen as undermining initiative and self responsibility. Too little can be seen as encouraging irresponsibility and lowering standards. Establishing a level that provides for the most benefit to safety, without imposing restrictions that are unacceptable to society or unworkable to an industry, is an especially complex open world problem, (chapter 3, clause 3.3). Further research is necessary if judgements are to made as to what level of regulation is appropriate.

8.11.7 Economic pressures in society.

These are concerns or characteristics of society, which are thought could, or do, produce economic pressures that may add to the proneness to failure of a project.

The construction industry is a service industry to most other industries and is influenced by conditions in them. In time of economic recession, economic constraints throughout society are passed on in some degree to the construction industry. The availability of work reduces and employment is lost. Consequently when demand on the industry increases, there is a shortage of skilled, trained, and experienced personnel. People may be employed in jobs for which they neither have the training or experience, thus adding to their susceptibility to accidents, (BBC2, 1988).

Another scenario outlined in interview E, is that in an effort to gain contracts during a recession, construction companies tend to cut their prices and programme times. It was stated:

> That means the money's not about, the work's not about, so you've got all the resources looking for work. This gives a tremendous increase in competition, so that they all did the same thing. The bloke in .... used to tender for jobs by saying something like, "there's this job reckoned to be something like a two year job and £37 million. We'll do it for £37 million in 1 year and 9 months. That's totally unscientific. He never got the programme out". .... But what you've done then is put a time pressure on those who've got to do the job. You've given them, for the price, impossible jobs to do.

Unrealistic programmes and budgets put pressure on the project management. Not surprisingly corners are cut, often in the provision of safety.

8.11.8 Temporal pressures in society.

These are concerns or characteristics of society, related the availability of time, which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

Temporal pressures, as with economic, are often the results of other pressures such as political or industrial. Most projects will be subject to both temporal and economic pressures in some form.

8.11.9 Quality related pressures in society.

These are concerns or characteristics of society, related the requirement for quality, which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

Generally, a move towards improving quality should reduce proneness to failure. Therefore, pressures from society for reduced quality, possibly for economic reasons, may add to proneness to failure. If, however, the requirement for quality is beyond the capabilities of an industry, safety may be sacrificed to satisfy demands for what may be unrealistic standards. As implied in interviews E and K, this could be a requirement for aesthetically pleasing forms. In the following extract from interview K, it was stated that too much attention to aesthetics, could affect constructability, and as a consequence, safety.

> ... but it wouldn't have been constructed if the contractor hadn't gone to phenomenal lengths and phenomenal cost to actually construct it. It's a beautiful bridge, but I don't believe the consultant really looked at constructability and hence the safety during construction, seriously enough.

8.11.10 Scientific and Socio-technical pressures in society.

Scientific and socio-technical pressures in society are created by the decisions and actions of society, that adversely affect the dependability of scientific knowledge and the understanding of the socio-technical nature of engineering

This concept covers both scientific and socio-technical pressures. Although easier to recognise in industry or on a project, there are conditions in society that might produce scientific and socio-technical pressures. If society allows academic research to be dictated and financed by industry, the areas of research undertaken may not be those most beneficial to society, or even to industry in the longer term. A similar situation could arise if society allows the academic fraternity a free hand in deciding upon research that needs to be carried out. The consequences, either way, may be scientific and socio-technical pressures because society does not possess adequate knowledge and understanding to provide for its wants and needs.

8.11.11 Industrial pressures in society.

These are the concerns or characteristics in society that are related to industrial practices, or industrial relations, resulting from decisions or actions of society, which are thought could, or do, produce pressures that may add to the proneness to failure of a project.

Poor industrial climate, as outlined by Pugsley, (1969), included poor training of work-force, inexperienced supervision, and lack of control over work-force. Blockley, (1980), stated that poor industrial relations on the construction of the Olympic Stadium in Montreal, 1976, and the West Gate Bridge, Australia, in 1970, contributed to programme delays and accidents.

Industrial pressures are most noticeable at the project stage, but symptoms may be recognisable in society. For example, it might be judged that a political decision to privatise an industry is a stimulus for industrial pressures at project level.

8.11.12 Other pressures in society.

Other pressures in society are concerns or characteristics of society, other than those specifically detailed in the hierarchy, that are thought could, or do, produce pressures that may add to the proneness to failure of a project.

The hierarchy will never be complete and a systematic formal auditing process may inhibit the search for factors, likely to increase proneness to failure, beyond the specifics of an audit, (see chapter 7, clause 7.7). Some categories, such as this one, have been included to help guard against complacency. This will not be enough to avoid complacency, but experienced, qualified auditors may be reminded to look for other pressures.

8.12 Summary and conclusions.

Society influences the development of technology and its associated hazards. These influences and the conditions that produce them are potential hazards. Society needs to be examined for hazards which may influence the proneness to failure of a technological project.

The context of the "state of society" concerns the relationship of society with the construction industry, safety in general, and safety in the construction industry. Assessment of this relationship for evidence of proneness to failure through high level concepts of the "state of society" is impracticable. An examination of the state of society should be focussed on low level concepts.

The means for comparison is fundamental for assessment. Standards need to be established that will enable comparison. For hierarchy concepts relating to the state of society, such standards do not exist, even at low levels. There is a requirement, therefore, for research to establish standards and define as fully as possible the properties of the systems to which these standards apply. This is particularly relevant for the safety/quality/economic relationship in society.

Research into, and evaluation of, factors that influence the state of society will involve elicitation of the views and beliefs of society. Properly conducted surveys and studies of representative cross sections of society appears to be the most appropriate means of determining society's views and beliefs.

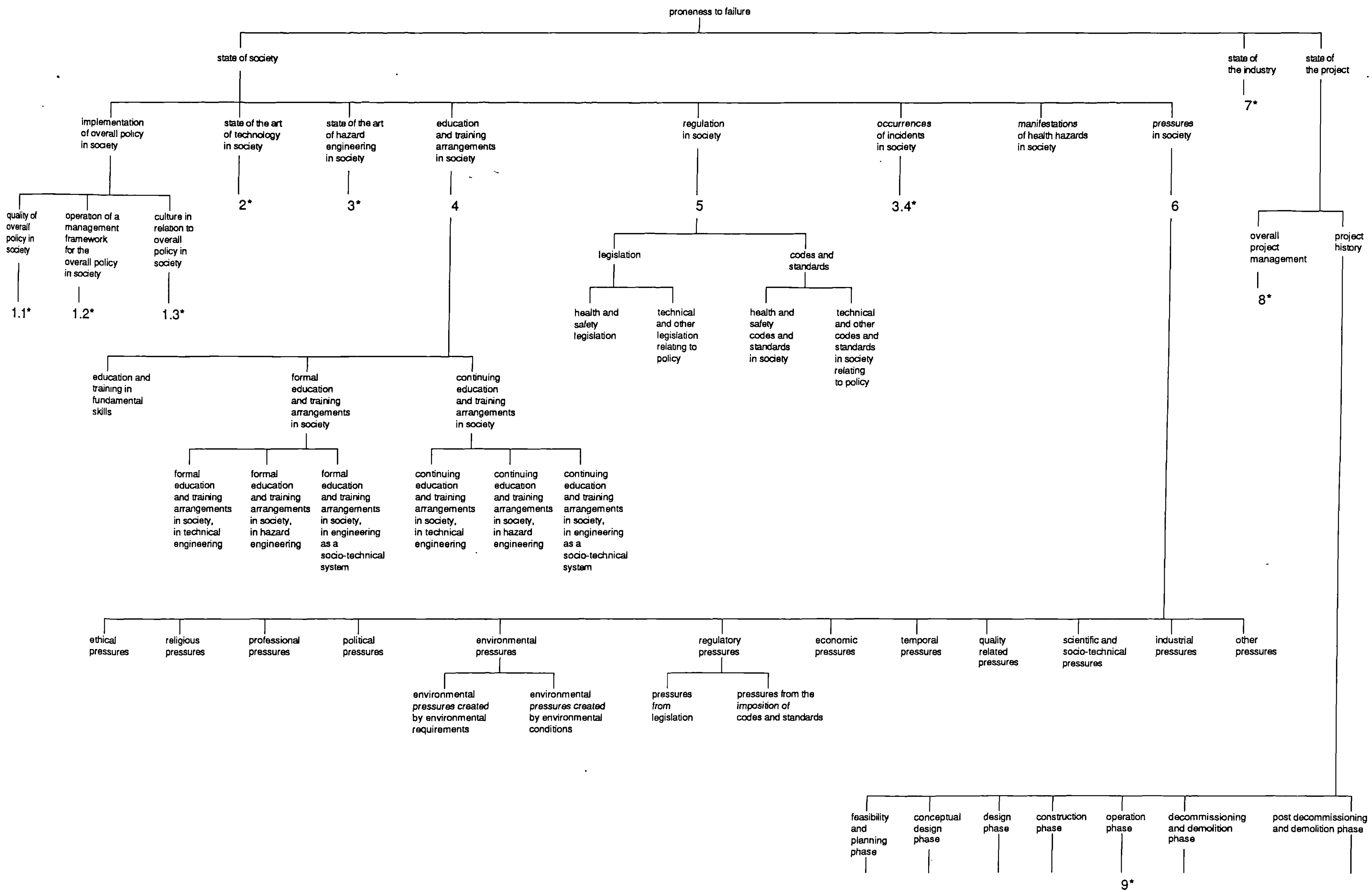
A broad spectrum of expertise is required for evaluation of the state of society. This expertise will come from a variety of specialised fields. Most of this expertise would be available within construction, and hazard engineering if it existed as a discipline. Auditors will have to be specialist, well trained, and educated in auditing processes and in hazard engineering.

There is an indication that society's view towards safety in the construction industry is indifferent. The industry, through its representative organisations, could take action to improve its image in society. With respect to safety, this would be aided by recognition of the unacceptability of its poor safety performance record, and a long term initiative to improve the situation.

An examination of the state of society can be diagnostic and allow for the mitigation of potential problems of safety that might develop in an industry or project. An evaluation of pressures in society is particularly relevant in this respect.

Fig. 8.1, at the end of the chapter, shows the hierarchical development of the state of society.

Fig. 8.1. Hierarchical expansion of "state of society". (Sheet 1 of 1).



Chapter 9.

State of the industry.

9.1 Objectives.

1 To outline the concepts that can provide evidence of a "poor state of the industry" with respect to the proneness to failure of a project.

2 To develop and discuss hierarchy concepts under the "state of the industry", with particular emphasis on organisational roles and information arrangements in the construction industry.

3 To present a hierarchy of concepts that can provide for an evaluation of the state of the industry for evidence of proneness to failure.

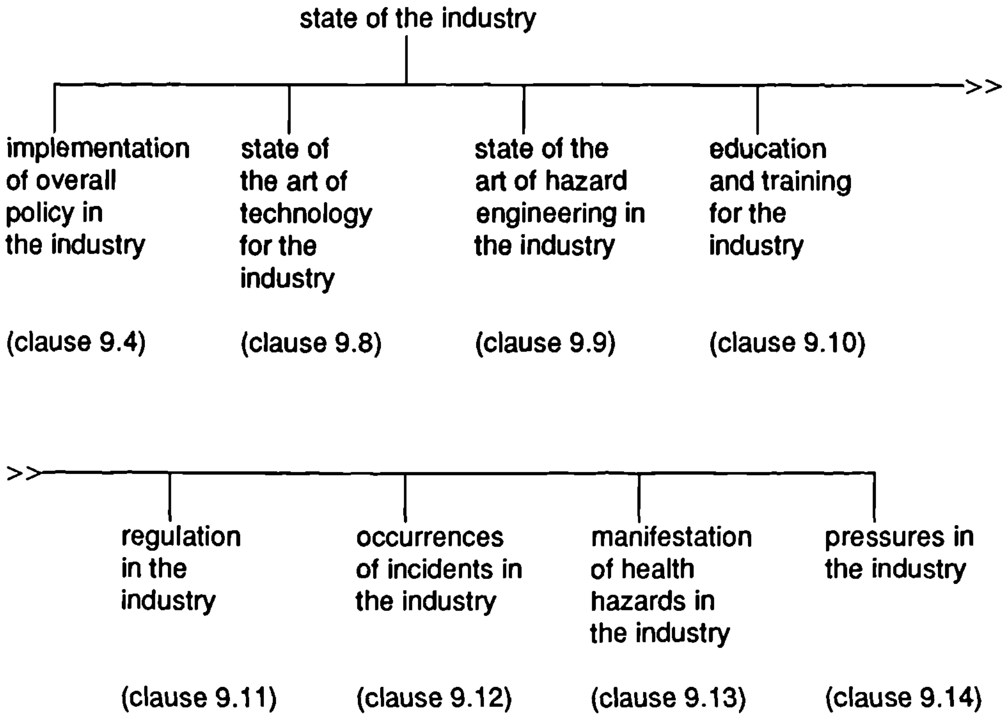
9.2 Introduction.

The industry, in the context of this thesis, is the construction industry, but factors that relate to its effect on proneness to failure are common to other industries. The properties and functioning of the construction industry, (defined in chapter 1), are influenced by individuals, organisations, knowledge, products and processes associated with civil/structural engineering and building. As described in chapter 8, (clause 8.4.1), UK society does not have a specific policy for the construction industry, and the implementation of safety policy is left mainly to self regulation, (Robens, 1972; Health and Safety Executive, 1980; Eisner, 1991). The way in which the industry operates is therefore primarily in the hands of the individuals and organisations associated with it. The influence of industry-based organisations was recognised in the Government commissioned review of safety and health in employment, (Robens, 1972), which referred to, (Page 25), the "very great contribution" that can be made by industry-based organisations to the development of industrial self-regulation in safety and health. The nature of this contribution is dependent upon the relative influence of different types of organisations that have different priorities. If corporate business interests are the predominant influence, profitability is likely to be an overriding objective and safety may be afforded relatively low importance, unless it can be established that the provision of high levels of safety is profitable, or there are strong ethical beliefs about ensuring the safety of individuals. For construction accidents, loss of production and business is comparatively less financially damaging than is the case for accidents in other industries such as chemical or manufacturing. According to Leopold and Leonard, (1987), most of the cost of a construction accident is covered by insurance premiums, which they suggest can only be influenced significantly by the largest contractors. Consequently, although "good safety" may be financially beneficial in some industries, (Butler, 1989; Fido and Wood, 1989; CBI, 1990), the likelihood of increasing profitability (to companies in the construction industry, not to society), through efforts to improve safety in construction is, I believe, questionable. This, coupled with the nature of construction, that it is transitory, competitive, and inherently dangerous to the individual, means that if left to self regulation by companies within the industry, safety may not be afforded the priority that is in the best interests of individuals that work in the industry. In addition, there does not appear to be much public pressure to improve safety in construction, (chapter 8, clause 8.4.3.1), despite the fact that its safety performance record is very poor, (chapter 2, clause 2.2). This may be partly because single construction incidents are not usually newsworthy enough to attract the amount of adverse publicity associated with other industries where single incidents can produce very severe consequences. I would suggest that if companies within the industry are to genuinely address safety as a priority, the motivation needs to come from a belief that the existing safety performance within the industry is poor, that it can be improved, and that the industry has a moral obligation to ensure that it is improved. Therefore, if control of the industry lies primarily with corporate business interests, there needs to be a strong safety culture at company management level, if safety is to be a genuine priority issue. One alternative is that society imposes legislation upon the industry, with appropriate punishment for breaches of regulations. If, however, individuals have a strong influence in determining policy within an industry it might be expected that their own safety would be high on a list of priorities. This indicates a requirement to balance the objectives of quality, safety, and profitability to satisfy the different priorities of individual and company interests and to comply with the requirements of society.

Companies influence by virtue of resource power, (Handy, 1985), in that they provide employment. They are able to exert influence as: separate organisations, collectively through their own representative bodies such as the Federation of Civil Engineering Contractors, and indirectly through professional institutions. If representative bodies such as unions, and professional institutions promote safety as being in the best interests of the individuals they represent, they can provide a balance to corporate business influence. In the case of professional institutions, though, individual members with the greatest influence are often in senior positions within companies and are perhaps not entirely unprejudiced by corporate business objectives. To produce balance, representative organisations for individuals must primarily represent the interests of individuals, as distinct from company interests. They need to work at developing power, so that they are able to influence policy. Functioning in this way, professional institutions, could, for example, influence education and training so that safety of construction activities is viewed in the same way as the provision of structural integrity. They are also well placed to encourage the development of a safety culture amongst individuals, and because of their natural affiliation to company interests, the opportunity exists to encourage corporate safety culture.

9.3 State of the Industry.

The state of the industry is defined as the capacity of the industry to ensure the safe development of a project, as intended. The top level concepts of its hierarchical expansion are shown in the following diagram. Further development of the hierarchy is shown in fig 9.1 at the end of the chapter.



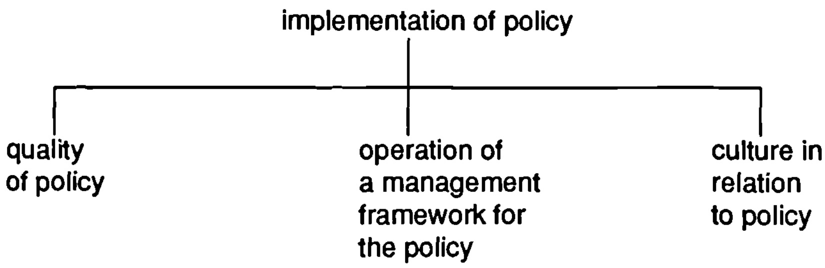
The construction industry is considered in terms of the following activities, which are referred to in the hierarchy as disciplines:

- Research and development, which although a separate discipline is also part of other disciplines.
- Design, which includes civil and structural engineering design, building design, and architecture.
- Construction, which is the implementation of design intention.
- Services design and installation, which refers to the design, fabrication, and installation of products, which although not traditionally thought of as being within the direct ambit of civil/structural engineering, building, or architecture, are necessary for the functioning of a completed project. This includes mechanical and electrical components.
- Demolition, which, by tradition, is closely associated with the construction industry, having a common basis in knowledge, products, and processes.

An examination of the state of the industry for evidence of proneness to failure needs to cover the industry as a whole and its separate disciplines. Effective functioning of the industry to mitigate hazards requires coordination of its separate disciplines. Such a role could be undertaken by representative organisations within the industry, provided, of course, that these organisations are themselves able to work together with common objectives and an agreed means of achieving them.

9.4 Implementation of overall policy.

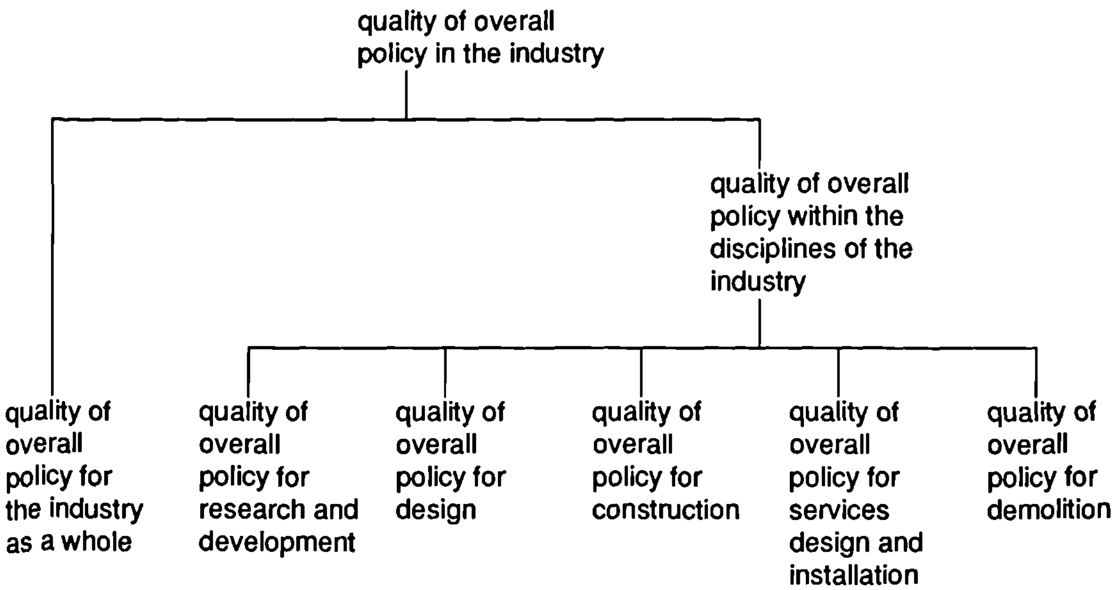
For an industry, this is the combined policy linking the state of the art of technical engineering, safety, and commercial objectives. Quality is intrinsic to a state of the art, and safety is a feature of quality, (chapter 8, clause 8.3; chapter 10, clause 10.14.5). This relationship, discussed with respect to an overall policy of an industry, is analogous to a quality/safety/economic relationship. The hierarchical expansion for policy implementation follows the format described in chapter 5, the top level of which is as follows:



The provision for examination of separate policies for the state of the art of technical engineering and safety is made in the respective hierarchical developments of the "state of the art of technology for the industry", (clause 9.8), and the "state of the art of hazard engineering for the industry", (clause 9.9). These policies are implemented within an overall policy which incorporates commercial objectives. In industry, provision of quality and safety requires resources. The availability of resources, in a UK type society, is linked to commercial success. Development of quality and safety cultures at the expense of a culture recognising the need for commercial viability may be self defeating, because in the long term quality and safety policies may suffer through lack of resources. There needs to be a balanced quality/safety/economic culture. The optimum balance represents a common base for comparisons in assessments of culture relating to the separate policies of: overall, state of the art of technical engineering, and safety. The overall policy is essential for the implementation of the others. The optimum balance will need to be judged through consensus of corporate and individual members of an industry. For the construction industry, I would suggest that it is beneficial to improve the existing balance such that safety culture is improved. This is possible if the appropriate culture exists at positions of power within the industry. Through its representative organisations, the industry can guide and educate, and if necessary, influence the use of contractual arrangements, so that they specify clear requirements for safety, (chapter 11, clause 11.5.5).

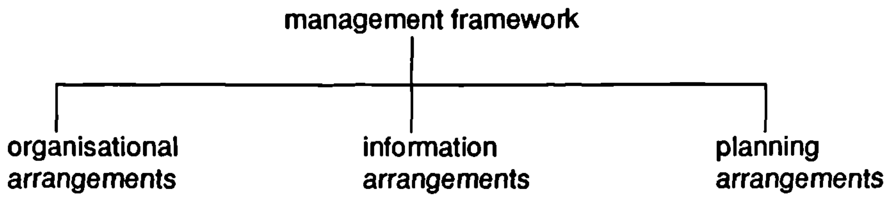
9.5. Quality of overall policy.

As indicated below, evidence of poor quality of policy may be found in each of the separate disciplines of the industry and the industry as a whole. Further development in terms of "quality of overall policy", is described in chapter 5, clause 5.3.



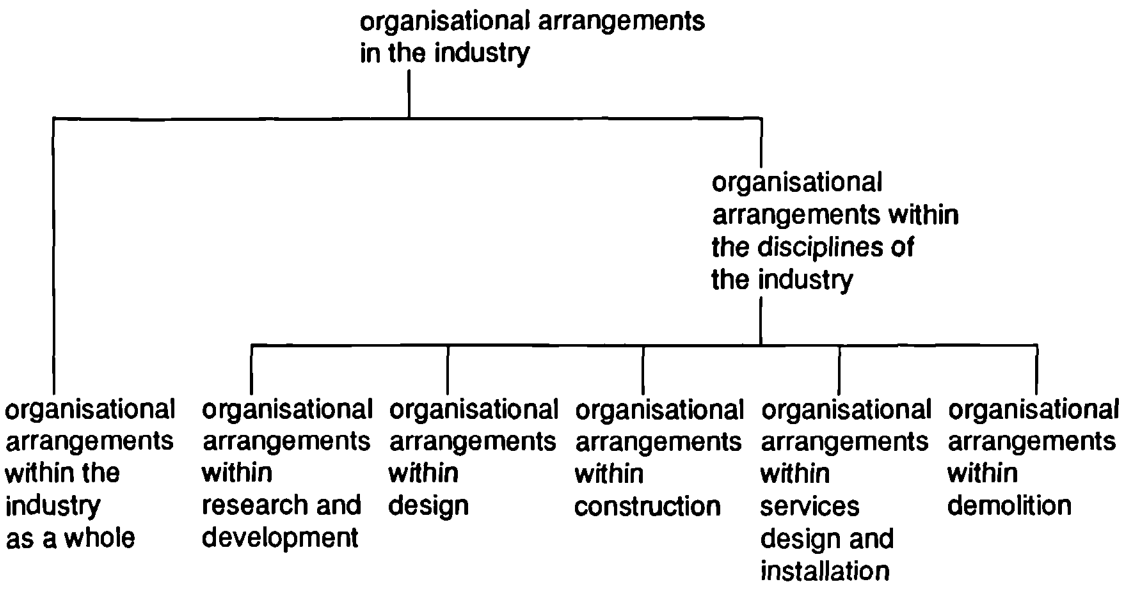
9.6 Management framework for overall policy.

Evaluation of the functioning of a management framework for the implementation of policies in industry, is based on the hierarchical expansion outlined in chapter 5, clause 5.4, the top level of which is reproduced below.



9.6.1 Organisational arrangements.

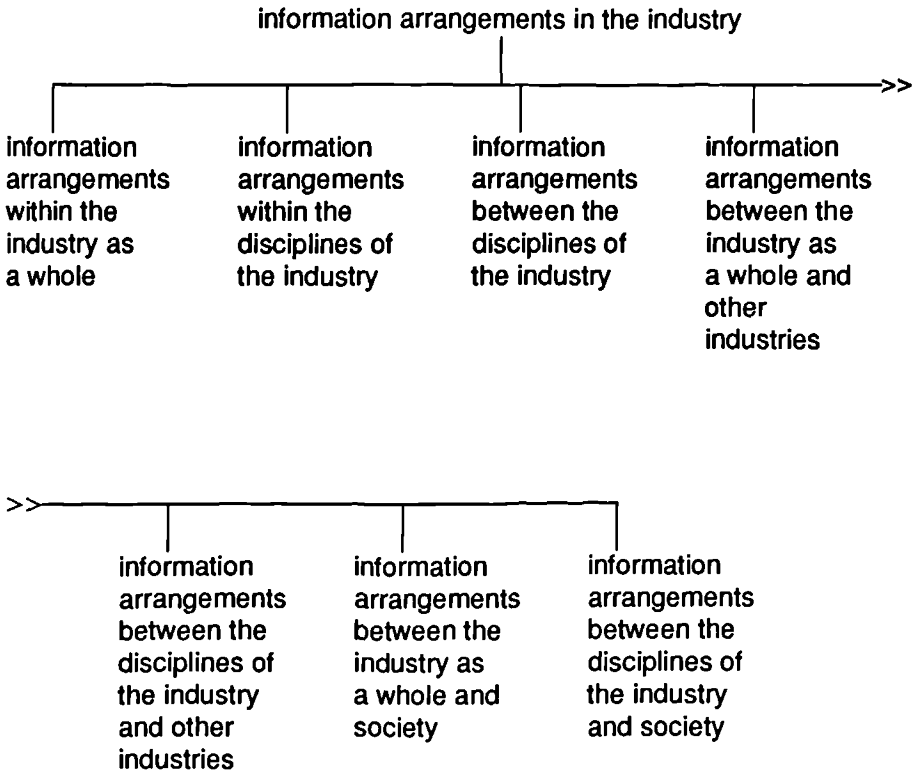
The organisational arrangements for the industry are somewhat loose and informal. They consist mainly of self interest groups, such as professional institutions, unions, and corporate business organisations, operating separately and collectively. These are "external" organisations, (in terms of the classification of form outlined in chapter 5, clause 5.5), in that they are not accountable for the way in which the industry functions, although they are accountable for the way in which they, as separate organisations, operate. It is organisations such as these, and their individual members, that determine and implement policy in the industry. An evaluation for evidence of proneness to failure relates to the actions of the various organisations and their individual members in the context of a stated or implied policy. As indicated in the following diagram, this involves a detailed study of the different representative and business organisations for the industry as a whole and its separate disciplines. The hierarchical framework of concepts that provides for an examination of organisational arrangements is discussed in chapter 5, clause 5.5.



As suggested earlier in this chapter, professional Institutions such as the Institution of Civil Engineers, the Institution of Structural Engineers, and the Royal Institution of British Architects could play prominent roles in determining the way in which the industry functions and develops in relation to producing policy, providing a basis for the implementation of policy, and encouraging the development of a positive culture in relation to policy. The professional institutions are in a position to encourage a responsible approach to providing for society's expectations, while ensuring the safety of both its own members and members of society. Some benefit to construction may accrue from an improved image, (chapter 8, clause 8.4.3.1), if the industry is promoted positively to society.

9.6.2 Information arrangements.

The following section of hierarchy is based on the need for an examination of information arrangements in the industry to account for: inter-dependencies between the disciplines of the industry, interaction of the industry and its disciplines with other industries, and interaction with society.



The extent of an examination of information arrangements in the industry, for evidence of proneness to failure, is dependent upon the number of disciplines into which the industry is classified, and the number of industries and sections of society with which it exchanges information. When expanded further, the hierarchy reaches very large proportions, (as will be clear from clauses 9.6.2.1 to 9.6.2.7). Practical considerations of available resources and the potential value of information likely to be gained from an audit will determine the detail to which an audit is taken. In this respect, assessments of more general concepts at high levels in the hierarchy should indicate the lower levels that are appropriate to a particular audit.

9.6.2.1 Information arrangements within the industry as a whole.

This concept provides for an overview of how well the separate information arrangements for the disciplines of the industry have been coordinated into an overall system for the industry as a whole. The structure for a detailed examination is of the form described in chapter 5.

9.6.2.2 Information arrangements within disciplines.

As for the industry as a whole, examinations of the disciplines of the industry for evidence of proneness to failure in the way they handle information are based on the hierarchical expansion of information arrangements, (chapter 5).

9.6.2.3 Information arrangements between disciplines.

Five disciplines are considered. These, (clause 9.3), are: research and development, design, construction, services design and installation, and demolition.

For these five, (n), disciplines, there are ten, [(n-1)+(n-2)+.....+1], separate concepts, each relating a pair of disciplines, that require assessment. Each of these ten concepts develops further in terms of **informal liaison, formal information arrangements,** and **arrangements for meetings, discussions and conferences**, for which detailed hierarchical expansions are described in chapter 5. A rigourous evaluation should examine the <u>exchange</u> of information between each pair of disciplines. This necessitates questioning representatives of each of the participating disciplines, with regard to how well information is being passed and received <u>to</u> and <u>from</u> the others.

The problem of who represents the disciplines, and the industry is not of the same scale as that described in chapter 8, (clause 8.3.1), in connection with representation of society. An industry's representative organisations are well placed to assist the elicitation of information from its members. Although this would entail properly conducted surveys, it is not an insurmountable problem.

9.6.2.4 Information arrangements between the industry as a whole and other industries.

The following categories are included in the hierarchy as representing industries with which the construction industry could exchange information:

Chemical and allied industries.

Manufacturing and allied industries.

Aeronautic and aerospace industry.

Marine industry.

Other industries.

"Other industries" has been included as a reminder that the list of industries is representative. There are other industries that are appropriate to the development and operation of the construction industry, whether in terms of the state of the art of technology or hazard engineering. Poor information arrangements with such industries is evidence of proneness to failure.

The hierarchy for information arrangements between the construction industry and each of the other industries listed above, develops in terms of **informal liaison**, **formal information arrangements**, and **meetings, discussions and conferences**, (chapter 5).

9.6.2.5 Information arrangements between the disciplines of the industry and other industries.

This concept provides for an examination of the information arrangements between each of the disciplines of the construction industry and other industries or relevant disciplines of other industries. Between the five disciplines of the construction industry, (clause 9.3), and the other industries listed in clause 9.6.2.4, (5 No), there are twenty five concepts, each of which develops further in terms of **informal liaison**, **formal information arrangements**, and **meetings, discussions and conferences**.

9.6.2.6 Information arrangements between the industry as a whole and society.

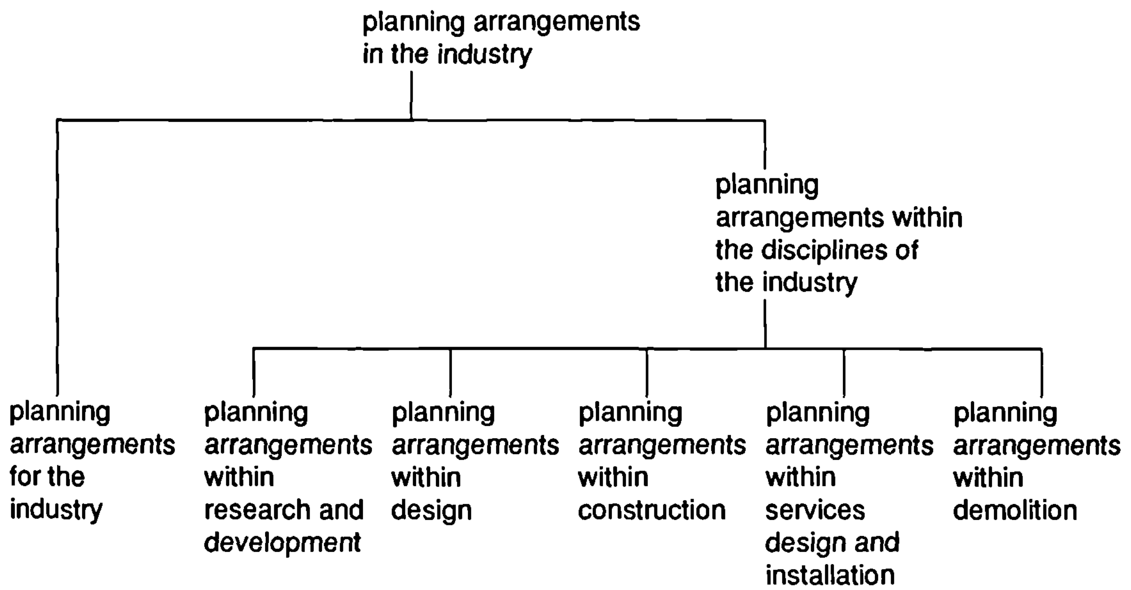
Rather than attempt to identify which sectors of society are relevant to the functioning of the construction industry, it is more convenient to consider the issues that are likely to influence it. In this respect, an evaluation of evidence of proneness to failure relates to the information arrangements between the construction industry and the appropriate parts of society that are relevant to particular issues. These issues could be environmental, legal, political, cultural, historical, industrial, residential, employment, or any other matter that can influence the way in which the industry operates. Again, further hierarchical development is in terms of **informal liaison, formal information arrangements**, and **meetings, discussions and conferences.**

9.6.2.7 Information arrangements between the disciplines of the industry and society.

This concept allows for a separate evaluation of the information arrangements in terms of **informal liaison, formal information arrangements**, and **meetings, discussions and conferences** between the disciplines of the construction industry and society.

9.6.3 Planning arrangements.

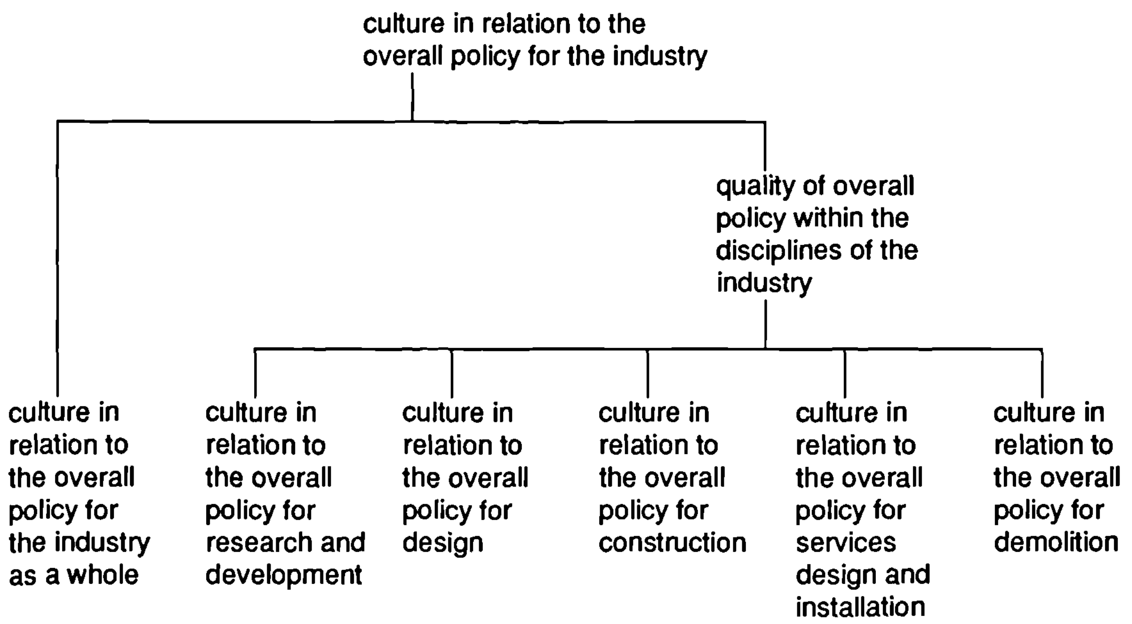
Evaluation as a hierarchy concept is associated with the functioning of the arrangements, within the industry and its disciplines, for planning. Each lower level concept of the following hierarchical expansion is of the form described in chapter 5, (clause 5.13).



9.7 Culture of the industry.

The overall culture of the industry links the cultures relating to: the state of the art of technology, safety, and commercial interests, (clause 9.4). Safety covers all aspects of technical and human safety. For example, attention to structural safety by designers does not represent a good safety culture if no thought is given to the occupational safety of those required to implement the design.

The representative organisations are well placed to coordinate the development and maintenance of a combined overall culture in the industry and its disciplines. The hierarchical expansion of "culture", for each of the lower level concepts of the following section of hierarchy, is described in chapter 5, clause 5.14.



9.8 State of the art of technology.

As for the other concepts that form part of an examination for evidence of a poor state of the industry, the state of the art of technology in the industry needs to be considered with respect to the industry as a whole and its separate disciplines. Each of these six concepts develop further in terms of the hierarchical expansion for the state of the art of technology, which is described in chapter 6. Assessments should be based on evaluations by experts in particular areas of technology.

9.9 State of the art of hazard engineering.

The hierarchical expansion of this concept, for the industry as a whole and its separate disciplines, is in terms of the concepts described in chapter 7.

Learning from incidents, or more specifically from failure, is a basic process in the development of knowledge. The construction industry which has a particularly poor accident record, (HSC, 1989/90), would therefore seem to have a good opportunity to learn, if it can effectively manage the incident feedback cycle described in chapter 7, (clause 7.9). The basis for "managed" learning is a recognition that lessons can be learned and that the process of incident feedback, described in chapter 7, can facilitate learning. Attitudes towards the reporting of incidents, for which the construction industry has also a poor record, (HSC, 1989/90), could probably be improved if the investigation and analysis of incidents are perceived as not being primarily aimed at allocating blame, (chapter 7, clause 7.9.3). A "blaming culture" not only discourages reporting, it tends to cloud the issues in investigations and analyses. The motivation to implement an incident feedback process comes from belief in the value of learning from incidents, belief in the process of incident feedback, and importantly, a safety culture that perceives the provision of safety as high priority. If systems for the management of safety, including those for incident feedback and health monitoring and feedback, are to operate at industry level, the impetus for their development and implementation will require the consensus and cooperation of those within the industry. I would suggest that representative organisations within the construction industry could and should play an active management role, which involves the development of conditions that are conducive to effective management of safety.

An important element in the management of safety is the dissemination of information about incidents. This covers dissemination within an industry and dissemination to, and liaison with, other industries and society. Toft, (1990), suggested that for major failures, an organisation at national level may be appropriate for the dissemination of information from investigations. Such an organisation, I feel, would be hard pressed to handle information arising out of investigations of incidents of all types, (chapter 7, clause 7.9.1). The dissemination of knowledge as a result of utilisation, (chapter 7, clause 7.9.6), for example, would present difficulties to an organisation, or organisations, at national level. Again, I feel that representative organisations throughout industry are well placed to promote a role at industry level, such that information from incident investigation and analysis and knowledge gained from utilisation of this information are disseminated as widely as possible.

Much of the discussion in this chapter has been linked to the role of the construction industry's representative organisations. Safety, it is accepted, is already being promoted within the industry. This may be a consequence of the European Communities Council Directives, (1989 and 1992), but hopefully it will continue. It is anticipated that any changes in the roles of representative organisations would be gradual. Audits of the industry would, as for society, (chapter 8, clause 8.3), be staggered over several years. Initially, it is necessary, through research, to establish bases to facilitate assessments.

9.10 Education and training.

For the industry as a whole and its separate disciplines, the structure of an examination for evidence of proneness to failure in education and training is described in chapter 8, (clause 8.7).

Education and training in fundamental skills should not stop after school education. Because of its importance, it as relevant to assess it separately in the context of the industry, as it is for society.

In the context of the industry, "formal" education and training, described in chapter 8, clause 8.7, relates to preparation for a particular type of employment. This includes university education of engineers and architects, and training of persons in construction skills, as an integral part of their employment. "Continuing" education and training for the industry, applies to the arrangements that are adopted to supplement the skills and knowledge of those employed in the industry, whose formal education and training as preparation for employment in an industry has been completed. Safety training, which is not a specific requirement as qualification for a particular profession or trade, comes into this category.

9.11 Regulation.

For an industry, this is defined as "the legislation, codes and standards that have been designed to provide for the safe development, use, and withdrawal from use of a project. This refers to any project with which the industry may be associated. The hierarchical expansion, described in chapter 8, (clause 8.8), applies to the industry as a whole and its separate disciplines. An evaluation for evidence of proneness to failure covers all regulation that is relevant to the industry. This is distinct to an evaluation of regulation in the context of society which covers only regulation, relevant to an industry or project, that emanates directly from society.

9.12 Occurrences of incidents.

The classification of incidents is described in chapter 7, clause 7.9.1. Although most incidents occur during construction, use, or demolition, they can be relevant to any of the disciplines of the industry. Their significance, though, may not be clear until investigation and analysis has been completed.

9.13 Manifestations of health hazards.

The definition given in chapter 8, clause 8.10, in relation to society, can be modified to apply to the industry. As for occurrences of incidents, particular instances of health hazard manifestations can be significant to any of the industry disciplines, as well as to the industry as a whole.

9.14 Pressures.

Pressures in the industry may be produced by the actions of the individuals and organisations of the industry, or they may be manifestations of pressures that have developed in society. The various forms of pressures described in chapter 8, (clause 8.11), also apply to the industry. Some, however, are particularly relevant in that the industry can have a significant effect on their development and mitigation.

Professional institutions can influence **professional pressures**, (chapter 8, clause 8.11.3): by setting and demanding standards of competence among their members, and by encouraging liaison between different professions.

If decisions about the need for regulation are based on studies carried out in the aftermath of incident occurrence, they may be subject to bias. Specifically, the judgemental heuristic of availability, (Chapter 4; Tversky and Kahneman, 1974; Slovic, Fischoff and Lichtenstein, 1982), may lead to bias in determining the causality of an event, (Dejoy, 1985). Such judgemental biases could produce **regulatory pressures** (chapter 8, clause 8.11.6), in the form of unworkable or excessive regulation. Professional institutions can help to mitigate these pressures by continually monitoring and planning the requirement for regulation so that, while society is protected as far as is possible from potential failures, the industry is not overburdened by regulation.

Poor quality can adversely influence safety, and demands for standards of quality that are beyond the capabilities of an industry may compromise the provision of safety, (chapter 8, clause 8.11.9). It was argued in chapter 8, that these factors represent **quality related pressures**. To provide a base for evaluation, it is necessary to establish standards of quality with respect to what is acceptable to society, appropriate to the provision of safety, and achievable by the industry.

The development of scientific knowledge and the understanding of socio-technical systems are central to the development of the industry. Coordination of the development and dissemination of knowledge could reduce the likelihood of **scientific and socio-technical pressures**, (chapter 8, clause 8.11.10).

The development of technology inevitably brings changes to industrial practices. If **industrial pressures** resulting from changing practices are to be kept to a minimum, the organisations, (unions and professional institutions), that represent individuals likely to be directly effected by changing practices, need be involved in the management of the industry. Because industries do not function in isolation, the management process would involve interaction with other industries.

9.15 Summary and conclusions.

An industry is an amalgam of individuals and organisations who have certain common objectives, but different priorities associated with the objectives.

In the construction industry, the link between efforts to improve safety and increased profitability is, I have suggested, not as obvious as in some other industries. Consequently the relative priorities attributed to safety and profitability are likely to differ between individuals working in the industry and corporate business interests.

If the construction industry is to function in the interests of all its members, both individual and corporate, different priorities have to be balanced. Representative organisations have an important role to play in achieving this balance.

Corporate business interests are well served by their own representative organisations, as well as through the power which they are able to wield as separate organisations. If safety is to be a priority issue, a safety culture needs to be developed. If there is to be balance, organisations with an interest in promoting the industry and representing individuals associated with it, need to develop their own power through which to influence the way in which the industry operates.

Using this influence, representative organisations are in a position to encourage the development of both individual and corporate safety culture. They can participate in producing and implementing policy. They can promote the construction industry to society. I would propose that the roles of representative organisations, specifically the professional institutions within the industry, are especially significant to the following activities:

- Information arrangements and in particular, those for the process of incident feedback.

- Education and training for employment in the industry.

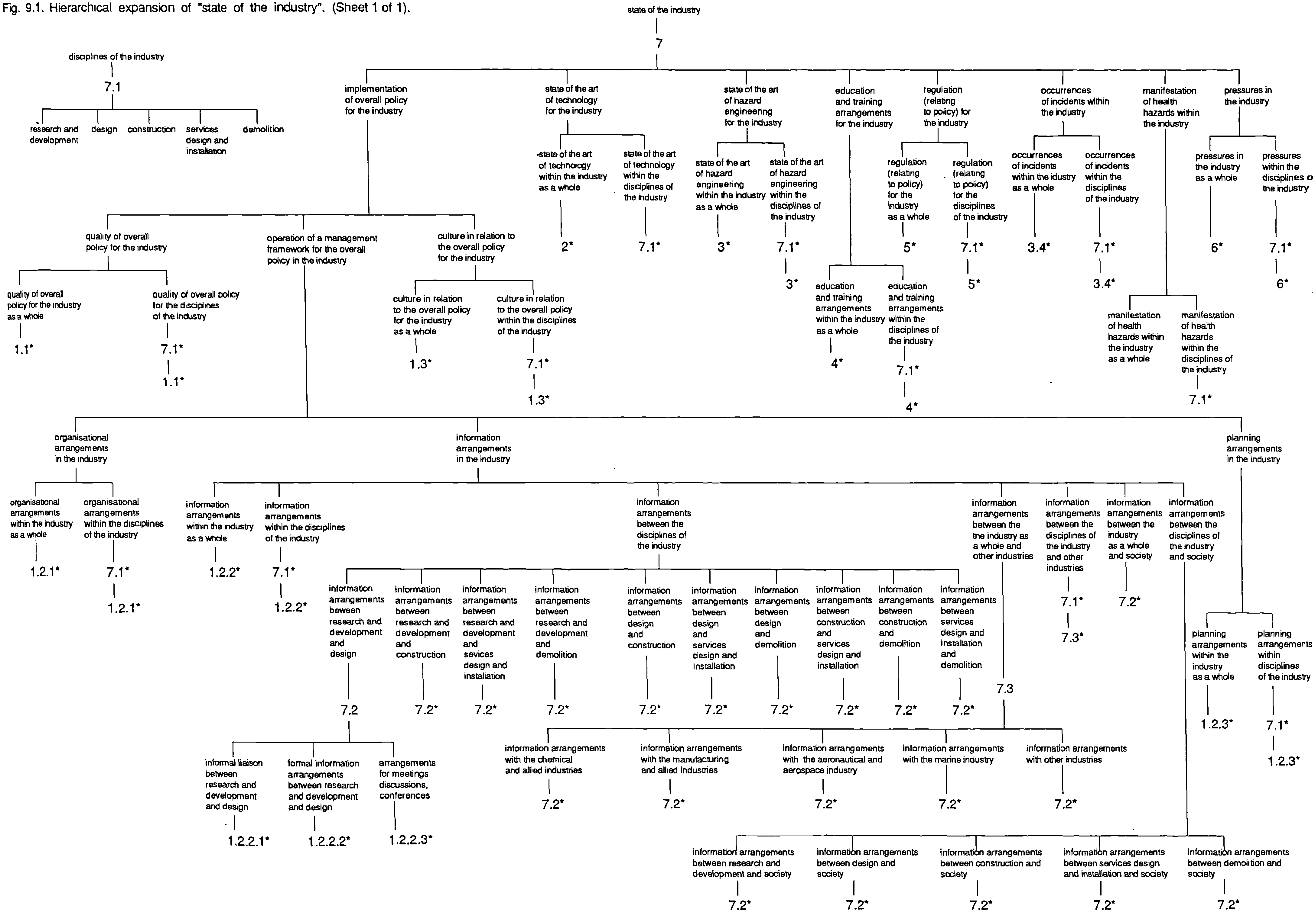
- The mitigation of pressures, (professional, regulatory, quality, scientific and socio-technical, and industrial).

The quality/safety/economic relationship that characterises the way in which the industry functions needs to be balanced. This balance should be such that quality and safety are not compromised by commercial interests, and that commercial viability is not compromised by quality and safety objectives which in the long term could be detrimental to the provision of safety.

Evaluation of an industry's overall policy is an important element in an examination of its influence on proneness to failure. Overall policy provides the framework within which other policies relating to the state of the art of technical engineering and safety are able to function.

The hierarchical development of "the state of the industry", in terms of concepts that may provide evidence of proneness to failure, is given in fig. 9.1 at the end of this chapter.

Fig. 9.1. Hierarchical expansion of "state of the industry". (Sheet 1 of 1).



Chapter 10.

Overall project management.

10.1 Objectives.

1 To detail the scope of an examination, within the context of a project, for evidence of its proneness to failure.

2 To discuss factors relating to overall project management that may influence proneness to failure of a project.

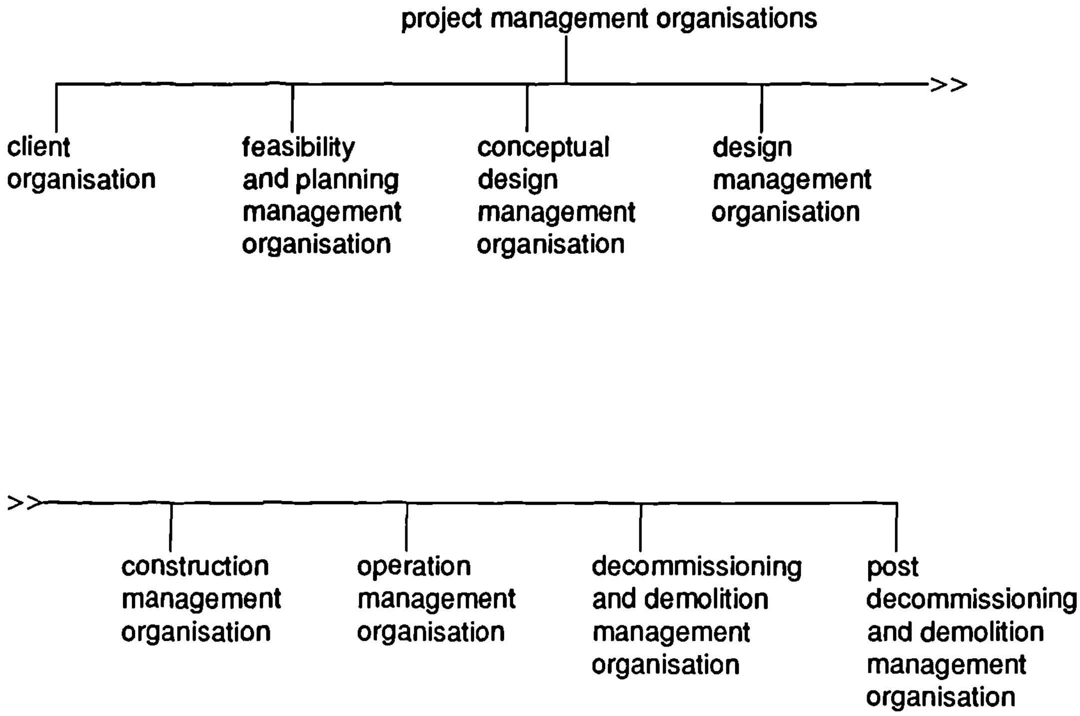
3 To present a hierarchy of concepts that can provide for an examination of overall project management for evidence of proneness to failure.

10.2 Introduction.

Problems associated with an examination for evidence of proneness to failure of a project are reduced to more manageable proportions if the larger uncertainties of society and industry are excluded. In this context, the state of the project, is defined as "the capacity within a project to provide for its safe development, use, and withdrawal from use, as intended". As described in chapter 2, (clause 2.3), a project can be conveniently divided into phases of: feasibility and planning, conceptual design, design, construction, operation, decommissioning and demolition, and post decommissioning and demolition.

Evidence of a poor state of the project may be found in the "overall project management" and "project history". The discussion in chapter 11 deals with the construction phase of project history. Overall project management, which is described in this chapter, is concerned with the interaction of project phases.

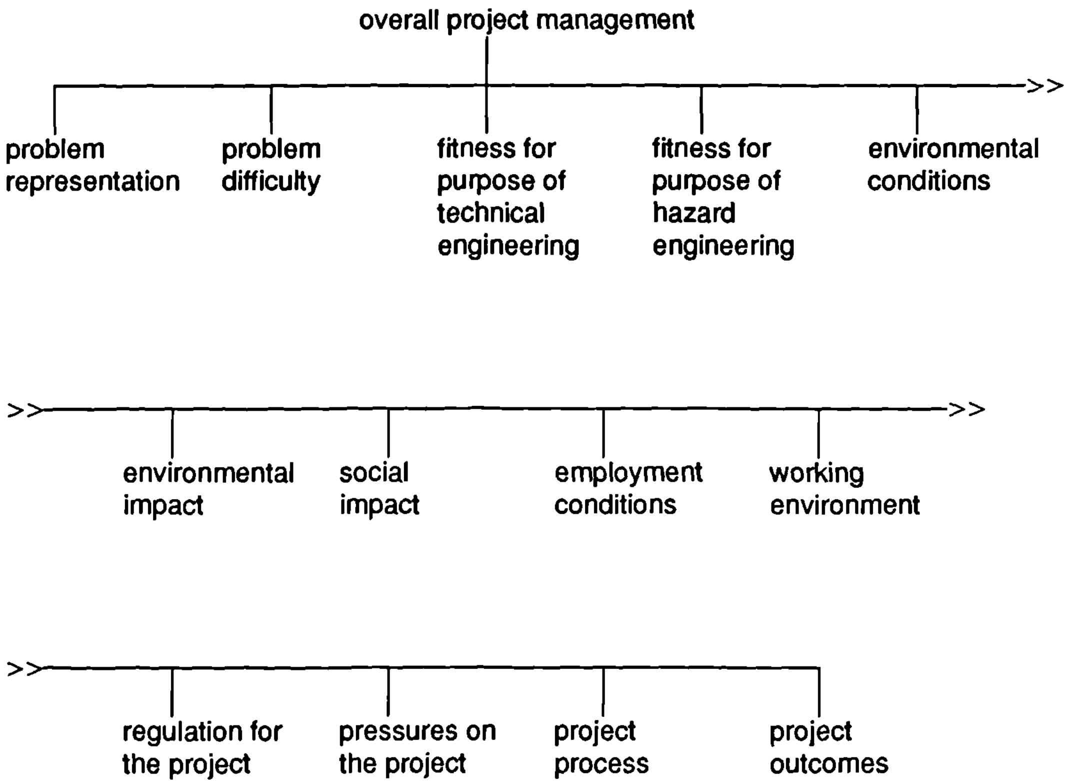
The following diagram shows the principal organisations involved in overall project management. These are the client organisation for management of the project as a whole and the management organisations associated with each phase.



The functioning of a project phase can be affected by decisions taken about any phase at any time, and by action or inaction within a phase or any preceding phase. The hierarchical development of overall project management, shown in fig 10.1, at the end of this chapter, allows for these inter-dependencies. In the event of an incident, legal proceedings, will after all, investigate these dependencies, whether or not they are explicit in a contract.

Evidence of proneness to failure gained from an examination of the "states of society and industry", described in chapters 8 and 9, comes from "general" influences of society or industry. More specific effects, discussed in this chapter, can emanate from society as a direct response to a project's existence.

Overall project management is defined as "the combined set of activities, systems, and procedures adopted for the management of a project". It includes coordination of the separate project phases, involving interactions amongst the project management organisations and relevant sections of society. In this respect, the use of the term society applies to sections of society that interact with a project. The concepts shown in the following section of hierarchy provide for an examination of overall project management.



The remainder of this chapter describes the way in which the concepts shown above are developed to produce the hierarchy shown in fig 10.1. This figure should be referred to for the rest of this discussion.

10.3 Problem representation.

The development, use, and withdrawal from use of a project represents a problem. If, because of poor representation, a problem is not appreciated or understood by those faced with it, there is potential for failure. This applies to the project management organisations and relevant sections of society, (fig. 10.1). Poor problem representation may be evidenced in the following characteristics:

- **Clarity of definition.** Problem description should conform to established standards of the domain with which the problem is associated. Assessment, therefore, requires expert judgement as to how clearly the problem has been described.

- **Completeness of definition.** A complete problem description should include, if appropriate, details of what is not required. For example, bridge designers must be aware of any form of bridge, or construction method, that is unacceptable to a client.

- **Understanding of the problem.** This is the level of understanding of what the project entails, by each of the project management organisations and relevant sections of society.

- **Compatibility of problem representation.** This refers to a lack of compatibility, amongst project management organisations and relevant sections of society, in evaluations of clarity, completeness, or understanding.

10.4 Problem difficulty.

Difficult problems are especially susceptible to failure. This concept deals with the perception of problem difficulty, as judged by persons experienced in the appropriate problem domain. Evaluation is based on: the distinctiveness of features that render a problem difficult, the availability and suitability of resources, and the adequacy of the solution to the problem. These characteristics are described in clauses, 10.4.1, 10.4.2, and 10.4.3.

10.4.1 Distinctive project features.

Proneness to failure may be evidenced by: the variety and changeability of types of work, the variety and changeability of types of task, unusualness, complexity, and tightness of coupling. These features, discussed here, are shown in hierarchical form in fig. 10.1.

- **Variety and changeability of types of work** is a feature of construction. As described in chapter 3, (clause 3.4.2) the changing nature of construction was referred to in several interviews, (E,F,G,H,I,J,K,L), as a contributing factor to the poor safety performance of the construction industry. A characteristic of changing nature is the variety and changeability of work or tasks, (chapter 3, clause 3.4.2). "Work" is to be taken to apply to distinct types of work, such as steel erection, excavation, and air conditioning installation.

- The **variety and changeability of tasks**, applies to tasks which make up a particular work activity. For example, the tasks required for tunnelling are influenced by ground conditions and the size and form of tunnels. A single project can contain a variety of tunnel sizes and forms in differing ground conditions, for which the tasks, that are all part of the tunnelling process, can differ considerably.

- Defined as "the extent to which a project or phase is in any way unusual with respect to what would be considered normal for that particular type of project", **unusualness** represents a lack of dependability. It is therefore evidence of potential problem difficulties. Further development of this concept, (fig. 10.1), covers: size, whether large or small; type of location, which could, for example, relate to the siting of an airport in a city centre or to a location that is so widespread in area that site operations are adversely effected; prestigiousness of a project; and novelty of a project or any part of it.

- **Complexity** is to be interpreted as describing a problem of many parts or intricacy, (Chambers English Dictionary, 1988). It includes both operational and physical complexity. **Operational complexity** encompasses technical and social problems, such as technical problems of design, social problems of organising a design team, and the socio-technical problems of producing a design. Complexity may be evidenced by, (fig. 10.1): a large number of different operations; extensive interaction amongst operations; lack of appreciation or understanding of operational problems by those confronted with them; perceived difficulties, by experienced practitioners, of operational problems; and uncertainty, in experienced practitioners, about operational problems. "Number of operations" has been included in this list, despite there being separate concepts relating to variety and changeability of work and tasks. This is to ensure that procedures or systems that might be considered integral to a type of work or task are not overlooked as features that may add to complexity. The introduction of quality systems, (clause 10.14.5), for example, can add to operational complexity. Although quality systems are intended to benefit the systems to which they are applied, there is potential evidence of proneness to failure because of added complexity. **Physical complexity** may be evidenced by: number of different forms of the separate parts of a project, extent of interactions between the separate parts of a project; confined or compressed area occupied by a project; and geographic dispersion of separate parts of a project. A chemical process plant, for instance comprising many different interacting elements, is more physically complex than a tunnel, comprised of comparatively few different interacting elements.

- **Tightness of coupling** is the degree to which distinct processes within a system are linked in time or function. Perrow, (1984), discusses this in some detail. A system in which the sequence of operations cannot be changed is tightly coupled. A system which cannot be changed to achieve objectives is also tightly coupled. An example given by Perrow, (1984), compares nuclear power plants for the production of electricity, which are dependent upon a single fuel, with oil plants that can change to coal and are therefore more loosely coupled. There is tightness of coupling for example, where the time between observation of a warning signal and the requirement for action is small. In effect, a tightly coupled system means that there is limited scope for action. This can create difficulties in the prevention of undesired interactions within a system and escalation of what might be relatively minor incidents into more disastrous failure. Robust structures that are able to accept abuse would be regarded as loosely coupled systems. A simply supported beam, designed to achieve failure from collapse by the formation of a single plastic hinge represents a tightly coupled system. A beam that is encastré at both ends requires the formation of three plastic hinges for collapse. This is a more loosely coupled system if the design ensures that hinges do not form simultaneously.

10.4.2 Availability and suitability of resources.

This refers to the resources that are specified in the solution to a problem. The non availability, or suitability, of resources may lead to difficulties in that alternative solutions may have to be sought. Human, financial, and temporal resources, facilities and services, and "other", are included in the hierarchy under this category, (fig. 10.1). If there are financial or temporal constraints, a lack of suitable resources may create pressures. This is assessed under a separate concept relating to pressures, (see clause 10.13).

10.4.3 Adequacy of solution.

In the drive to achieve objectives, a problem is often overcome by the most expedient solution. This may not necessarily be the least hazardous solution. Sometimes, perhaps, what might normally be considered as unacceptable risks become accepted. Adequacy of solution relates to the extent to which a solution is thought to deal with a problem whilst ensuring an acceptable level of safety. Establishing the acceptability of solutions is a matter for expertise. The solution of problems can sometimes be left to the practical application of good engineering practice, (Kletz, 1990). In circumstances where there are well established methods of solution to common problems this can be appropriate. For example, the layout of electrical and plumbing installations may be left to good engineering practice at the time of installation. However, this approach to problem solving should not be seen as an excuse to avoid dealing with inconvenient problems. At some time these problems have to be dealt with, and if, as is often the case, persons left to deal with them are under pressure, the solutions are often inadequate. For instance, how often have cranes overturned during "one-off" lifts for which they do not have the capacity? How often have people fallen from hastily erected scaffold for a "one-off" operation? These are the consequences of inadequate solutions to problems. Such a situation, resulting in a fatal accident, was described in interview E. This incident, which involved a fall from a "makeshift" access, was used to exemplify what is fairly common behaviour in construction. The interviewee stated that in many similar non-fatal incidents, a typical explanation for such behaviour was:

> I was only going to be there for three or five minutes................if I put a board across there, nip in and hold with my good hand, I should be able to do that job and be off and finished.

This is not good engineering practice.

Although inadequacy of solution has been considered as potential evidence of problem difficulty, it has a wider significance. It may be the result of an inability, and not just an unwillingness, to deal with problems until they can be no longer avoided. It is symptomatic of poor planning, (chapter 5, clause 5.13). The type of incidents described here demonstrate that planning is as important for the one-off operations of construction as it is to the main processes. It might be argued that a good safety culture would mitigate against people adopting inadequate solutions. It could equally well be argued that if a good safety culture existed, the conditions in which inadequate solutions are adopted should not arise. Inadequate solutions, therefore, may indicate a poor safety culture.

10.5 Fitness for purpose of technical engineering.

Assessment of the state of the art of engineering knowledge, products and processes, (Chapter 6), involves comparison with established standards of technology, industry, or engineering discipline. In contrast to this, assessment of fitness for purpose relates to a specific application of knowledge products or processes. The concepts that provide for an evaluation of fitness for purpose of engineering knowledge, products and processes are as follows:

- **Relevance** to the proposed use.
- **Applicability** to proposed use. Assessment involves comparison between the specification and the requirements of use. In other words, is the engineering knowledge, product, or process, as defined by its specification, applicable to a particular use? The characteristics of evaluation are usefulness and practicability, (chapter 6, clause 6.6.3.1).
- **Completeness** for proposed use. Assessment of this concept also necessitates

comparison between the specification and requirements of use. The characteristics for evaluation, (chapter 6, clause 6.6.3.2), are the requirements for: extrapolation, modification, and change of specification, that are necessary to render the knowledge, product, or process fit for use.

- **Appropriateness** for the proposed use. The characteristics of evaluation are the same as those described in chapter 6, (clause 6.6.3.4). These are: precision, clarity and truthlikeness. Assessment is by comparison of the specification with requirements of use.

- **Acceptability as propositions.** To be fit for purpose, knowledge, products and processes should be acceptable as "state of the art". This means compliance with standards of the relevant technology, industry, or engineering discipline. Evaluation is described in chapter 6, (clause 6.6.3).

10.6 Fitness for purpose of hazard engineering.

Hazard engineering, which is the subject of chapter 7, encompasses technical hazard engineering, human factors engineering, hazard auditing procedures and reliability and risk assessment techniques. The hierarchical development of fitness for purpose of hazard engineering, shown in fig. 10.1, is based on the discussion in clause 10.5.

10.7 Environmental conditions.

For a project, this is the set of environmental conditions that affect its development, use, and withdrawal from use. It includes naturally occurring atmospheric and ground conditions, which as shown in fig. 10.1, are taken to be: climate, geology and soil type, topography, (or landscape), water, (marine, river, lake), and natural phenomena such as earthquake. There may be some uncertainty about where certain conditions such as ground water should be evaluated, (soil type or water?), but provided there is consistency, this should not present problems. Pollutants are also treated as environmental conditions, (fig 10.1). They may have been created by human interaction with the environment, but their presence is such that they can be regarded as part of that environment.

That environmental conditions can influence proneness to failure is apparent in numerous examples ranging from minor structural damage caused by storms and floods to disasters involving plague and earthquake. Some conditions such as earthquake, or extreme heat or cold, are universally regarded as adverse. Other conditions, though, may be perceived differently by different people. Familiarity with a situation, for example, may produce over-confidence, (chapter 4). The risk in certain environmental conditions may be underestimated, even to the extent that hazards are not recognised. There is a need to balance any tendency towards a blasé view of hazards by practitioners familiar with construction under particular environmental conditions, with perceptions of those with varying degrees of familiarity with the situation. To be in a position to do this, an auditor needs to be aware of the potential for bias, and to be able to judge whether it exists. This requires experience, and knowledge, not only of auditing, but of the subject of the audit, (that which is being audited), and the characteristics of evaluation. A need for specialisation is indicated.

10.8 Environmental Impact.

This is the impact that a project or phase of project has on the environment. The hierarchical expansion is similar to that for "environmental conditions", (see fig. 10.1). Often it is the actual failure that produces significant impact on the environment. The Chernobyl Nuclear Plant disaster in 1986, is a well publicised example. It is important to audit that considerations have been given to the consequences of failure, and that precautions have been adopted to mitigate consequences.

The disaster at Love Canal, which is summarised in chapter 4, illustrates the impact of a project on the environment. It also exemplifies the effects of environmental conditions, (those following waste disposal operations), on a project, (subsequent development in the Love Canal area). More recent examples of the inter-dependency between project and environment can be seen in the debate about the development of contaminated land, (Pearce, 1992). Love Canal and cases of contaminated land where gasworks once stood, represent situations where at the time of operation immediate benefit appeared to submerge thoughts of remote hazards. In these circumstances a strong safety culture might have helped in the identification of hazards and in the motivation for their mitigation.

10.9 Social Impact.

General influences on proneness to failure from outside a project can be examined in the concepts that form the hierarchical expansions for the states of society and industry. These are described in chapters 8 and 9. The more immediate influences of society are dealt with under concepts such as "pressures on the project" and "project process". Other indirect effects of society's influence are inherent in concepts such as "regulation for the project", and "fitness for purpose". However, proneness to failure may also be evidenced in the **social impact of the project**, which is defined as "the impact that the project has on existing and future social conditions with respect to: employment, housing, essential services, business, social amenities, health and any other social related feature", (fig. 10.1). An example of this is the Bhopal disaster in India in 1984, where, according to Kletz, (1990), the death toll would have been lower if a shanty town had not been allowed to build up near the plant.

10.10 Employment conditions.

Employment conditions are defined as the conditions, within any organisation involved in the management of a project, that could influence the proneness to failure of that project at any time during its development, use, and withdrawal from use. These conditions are classified into reward packages and health and welfare facilities, (fig. 10.1).

Reward packages include basic pay, bonuses, pension schemes, and any other benefit schemes including the provision of car, housing, and luncheon vouchers. Poor reward packages may adversely influence morale, motivation, and reason to care about a job of work, (see clause 10.11). This may adversely affect job performance and compromise the safety of employees and the quality of the product or service being produced. This in turn, could endanger others in receipt of that product or service.

The lack of **health and welfare facilities** can similarly affect morale, motivation, and reason to care. More directly, it represents a failure to prevent or mitigate the consequences of injury or illness. Health facilities cover medical checking and the arrangements for dealing with ill health and injury. Welfare facilities cover transport, canteen, washing and changing, accommodation, leisure, and any other services that may influence people's welfare. Concepts are distinguished between those provided within and outside the work environment. Assessment relates to the necessity for such facilities and the standards to which they are provided. Standards, not established through regulation, should be established by consensus amongst experts.

10.11 Working environment.

This is the working environment in which those with any role in the development, use, and withdrawal from use of a project have to operate whilst carrying out that role. Fig. 10.1 shows the hierarchical development of this concept.

Physical or mental harm represents failure. Danger, which is the exposure to harm, is therefore a hazard. Certain work environments are regarded as dangerous because it is perceived that failure can result in harm. The **perception of danger** therefore represents a poor working environment and may be evidence of proneness to failure. The **severity of working conditions** judged with respect to what is considered normal for a particular type of work, is also evidence of a poor work environment. Low **morale** within the work environment, for whatever reason, may result in a lack of motivation and care about a work activity. Handy, (1985), reproduces part of a list compiled by Child, (1984), of things that can be wrong if an organisation is not properly designed and structured. The list includes lack of morale, the implication being that it is detrimental to management. A caring relationship, whether between people and things, or people and people, according to Lessem, (1991), is intrinsic to both quality and learning. It is therefore intrinsic, to the prevention of failure. Although long **hours of working** may result in low morale, any resulting tiredness represents an immediate potential for failure. Poor or inappropriate **facilities**, whether office or equipment, may be the direct cause of failure. Indirectly, they represent conditions that can produce low morale.

10.12 Regulation for the project.

The hierarchical expansion of regulation and the criteria for assessment are described in chapter 8, clause 8.8. Its evaluation in the context of a project relates to all legislation, codes and standards that are relevant to the development, use, and withdrawal from use of a project, (see chapter 9, clause 9.11).

10.13 Pressures on the project.

These are the concerns about, or characteristics of, a project, other than those that are considered "normal", that could, or do, produce pressures that may add to the proneness to failure of a project. The following discussion assumes reference to fig. 10.1.

Information about the project refers to the information that is necessary and sufficient to facilitate the formulation of policy. For the construction phase this is the enquiry information and the information produced by a tender, (chapter 11, clause 11.2). Evidence of poor information about a project may found in the following characteristics:

- The existence of errors in information may create doubts about its accuracy.
- Inadequate information can contain or result in ambiguities and uncertainties.
- Lack of experience and qualifications of the personnel producing the information may result in a lack of confidence in the information.
- A lack of, or use of inappropriate, resources in the production of information can produce concerns about the end product. Assessment covers the availability of time and finance, the availability and suitability of human resources, and the availability and suitability of facilities.

Programme pressures can result from poor programme coordination of project activities, or poor scheduling of time.

Pressures can arise out of concern, (chapter 8, clause 8.11). The **concerns of each of the project management organisations involved in a project** are classified into those about competence and those about the project.

Concerns about competence are those that each organisation has for its own competence and for the competence of the other management organisations. Because of its association to organisations, competence should be interpreted as the capability, as distinct to the ability, to carry out a role. Concerns about management personnel are implicit in an evaluation of this concept.

The set of **concerns about the project**, is made up of the following concerns.

- Concerns about quality.
- Concerns about the contract. (Contractual arrangements).
- Concerns about technical problems.
- Concerns about the project programme.
- Concerns about project information.
- Concerns about safety.
- Concerns about requirement for changes.
- Other concerns.

Society's concerns are those that society has about the competence of each of the project management organisations and those about the project, which are given in the immediately preceding list.

The concerns that each of the management organisations might have about society or relevant parts of it are implicit in the concept labelled, **external pressures on the project**. These pressures are described in chapter 8, clause 8.11.

Labour, as distinct from management personnel, can also be a source of concern. **Labour pressures on the project** may result from concerns about:

- Labour relations.
- Programming of labour.
- Characteristics of the labour force, which, as potential evidence of proneness to failure are, (fig. 10.1): labour turnover, availability, suitability, experience and training, competence, and age. Hinze, (1978), stated that safety performance can be improved by reduced work-force turnover. This view was implied in several interviews, (E,F,H,I,L), in which the changing nature of the labour force on a construction project was given as a contributing factor to the poor safety record of construction. The importance of job training and the influence of experience were other factors suggested in the interviews, (E, H), as being significant to the provision of safety. In interview E, for instance, while talking about pressures on construction, it was stated that:

> By using cheap labour you're losing training and professional ability. If you don't know what you're doing and you've never been taught, and you've never had safety awareness and so on, when somebody tells you to go up and work in an unsafe place, then you don't rebel against it. You think that must be the custom and practice in an industry and so you stand on some unsafe place where you shouldn't be. Then when you fall of, whose fault is it? Obviously that's grossly oversimplified, but it's fundamental, and a root cause of it, in my estimation.

Safety training is discussed in clause 10.14.4.2. The characteristics of availability and suitability are described in the following paragraph. Incompetence describes a lack of ability or capability to perform a task. Age, although not specifically mentioned in the interviews, is I suggest a reasonable inclusion in this list. Cohen, (1977), suggested that a large core of older, married workers with significant lengths of service was a characteristic of successful safety programmes. Insurance companies, for example, do penalise youth in their assessments of risk.

Material pressures and **plant and equipment pressures** may be evidenced by poor availability, suitability, and/or quality of materials, (plant and equipment), in either permanent or temporary works. The earlier discussion of availability and suitability of resources, (clause 10.4.2), was linked to problem difficulty. Although it increases potential for failure, problem difficulty does not necessarily add to the pressure to produce a solution. However, pressures can result if resources are either unavailable or unsuitable under conditions of temporal or financial constraint.

10.14 Project process.

The term process is intended to convey a meaning of "a series of actions or events", (Chambers English Dictionary, 1988). The hierarchical development of concepts under "project process", is taken to a level of detail that is appropriate to overall project management. This does not include specific activities, systems and procedures. The section of hierarchy associated with project history, (chapter 11), does allow for examination of activities, systems, and procedures that are particular or fundamental to an appropriate process such as construction. Other activities, systems, and procedures are subjects for lower level audits, (chapter 2, clause 2.6). Hazard audits designed from the hierarchy need to check that appropriate lower level audits are being used properly, (see clause 10.14.4.2).

10.14.1 Conditions for management.

Poor **contractual arrangements** give rise to uncertainties and ambiguities. They therefore represent potential for failure. The criteria for their evaluation are as follows:

- Formulation of contractual arrangements. This requires expert assessment that combines judgement about the necessity and suitability of arrangements, with evaluation of the standard (or quality) of formulation.

- Clarity of the contractual arrangements to the contracted parties. Assessment is of the clarity of understanding by those who are involved in the arrangements.

- Familiarity of contractual arrangements to the contracted parties.

Contractual arrangements should ensure that an appropriate level of control can be exercised by those contractually responsible for an undertaking, over those contracted to them. Poor contractual arrangements are not conducive to control. This is described further in chapter 11, (clause 11.5.5).

Lack of **experience and competence of the project management organisations,** does not necessarily represent incapability, but it is, nevertheless, evidence of proneness to failure. Assessment involves an evaluation of experience and competence, for both individuals and organisations, (see chapter 11, clause 11.4.1). Questioning a person's competence may understandably undermine confidence, and morale. Sensitivity, as well as experience and competence, is necessary in dealing with evidence of low levels of competence. It could be argued that a lack of appreciation of this is itself evidence of poor experience and competence.

Poor **relationships on the project**, as was the situation leading up to the collapse of the West Gate Bridge, in Australia, in 1970, (Blockley, 1980), can produce conditions for the incubation of disaster. A detailed examination of this concept involves evaluation of the relationships that exist between the eight project management organisations, of which there are twenty eight, (i.e. any two from eight), and the relationships between the project management organisations and relevant sections of society.

10.14.2 Project policies.

These are the overall and safety policies for the project.

The overall policy describes the objectives of the project and the bases from which it is intended to achieve these objectives. Objectives relate to the successful development, use and withdrawal from use of a project in terms of functionality, profitability, quality, safety, and any other features that are thought necessary for a project's successful undertaking.

The safety policy describes the objectives for safety on the project and the bases for achieving these objectives.

The hierarchical expansion for the **implementation of policies** is described in chapter 5. Policy implementation, which is evaluated in terms of quality of policy, operation of management framework, and culture, needs to be considered for each of the project phases as well as for the project as a whole. An assessment of information arrangements in the "management framework", should include the numerous combinations resulting from the inter-dependencies of the project management organisations, sections of society, and other projects or activities that are relevant to the project under consideration, (fig 10.1).

Although the actual statements of objectives of the overall policies for the separate project phases will differ, the coordinated characteristics of functionality, profitability, quality and safety can be compared. Poor **compatibility of project policies** between the management organisations may be evidence of proneness to failure.

10.14.3 Incidents and health hazards.

Occurrences of incidents and the **manifestation of health hazards** are evidence of poor project process, and consequently of *proneness to failure*. **Incident feedback** and **health monitoring and feedback**, as discussed in chapter 7, (clauses 7.9 and 7.10), are essential to learning from incidents. The classification of incidents, and hierarchical expansions are described in chapter 7, clause 7.9.1.

10.14.4 Activities, systems and procedures.

Defined as "the set of activities, systems and procedures, necessary for the implementation of policies", these are classified by association with either overall or safety policies. Their hierarchical development is described in the following clauses, (10.14.4.1 and 10.14.4.2). As an aid to this discussion, reference should be made to fig. 10.1.

10.14.4.1 Activities, systems, and procedures associated with overall policies.

A **framework for activities systems and procedures** is provided by: training arrangements; formally recorded activities, systems, and procedures; and traditional "tried and tested" unrecorded activities, systems, and procedures.

- **Training arrangements**, are those that operate for the training and education of personnel in the activities, systems and procedures that are necessary for the implementation of policy. The importance of training arrangements is illustrated in clause 10.13 in which the lack of training is viewed as a potential pressure. The significance of safety training is discussed in clause 10.14.4.2.

- Activities, systems, and procedures can be described and explained in documented form, such as method statements or instructions about the use of equipment, materials, or methods of work. The need for method statements was expressed in interview F as follows:

> One of the things we do now before we employ a sub-contractor we ask from him, first of all, a copy of his safety policy, and we examine it, and we read it, and if there is anything we need to discuss with him regarding points to check, we will discuss it before he starts work. The second thing we ask him to do is to produce a method statement. Not just a method statement of how he's going to do the work, but how he's going to do it safely.

The requirement for **formally recorded activities, systems and procedures** should be established by practitioners and experts who are judged by their peers as qualified to do so. An audit should include a check that such descriptions and explanations exist, and are presented and implemented properly. Assessment of their implementation is essential, because as pointed out by one interviewee, (Interview H), procedures for safe working were not difficult to obtain from sub-contractors, but implementation in accordance with them was. That such documentation is deemed necessary implies that their absence, poor presentation and/or improper use, is evidence of proneness to failure.

- Not all activities, etc, are recorded or need to be. Many have operated for years, and may be thought of as "tried and tested" through use. It does not follow, though, that they represent safe methods of working. Assessment of **traditional unrecorded activities, systems and procedures** should first question the need for them. For example, one interviewee, (Interview M), considered traditional practices to be a factor in the high accident rate of the construction industry. Kletz, (1990), describes custom and practice as a term used to justify practices that cannot be justified in any other way. If traditional practices are thought necessary, there should be an assessment of the way in which they are understood and implemented, and importantly whether they are safe.

Assessment of **failures in the functioning of activities, systems and procedures** requires an active search for failure. By linking assessment of failures to the <u>use</u> of equipment, materials or methods, (see fig. 10.1), there is an implied requirement that evaluation considers human failure as well as failure in a product or process. For example, a piece of equipment is judged to fail if there is a human failure in operating the equipment, or a lack of performance, (or breakdown), of the equipment. Specific activities, systems and procedures are examined in lower level audits, (clause 10.14).

Financial auditing provides a check on "economic health", which, if poor, can create pressures on a project. **Arrangements for financial auditing** should be interpreted broadly to include not only the legal requirements, but also "internal" financial monitoring of both a project and separate processes.

The significance of **quality systems** is discussed in clause 10.14.5.

10.14.4.2 Activities, systems, and procedures associated with safety policies.

The **framework for activities, systems, and procedures** is described in clause 10.14.4.1. In the context of safety policy, initial **safety training** (safety induction), is of particular significance. Levitt and Parker, (1976), and Hinze, (1978), state the need for training of newly hired workers in safe working methods. This requirement is apparent, if, as reported in the New Civil Engineer, (1992a), nearly 20% and 50% of accidents occur in the first day and week respectively, of work on site. The need for immediate safety induction was remarked upon in several interviews, (B, F, I, J, L). In interview B, for example it was stated, that safety was a condition of employment, and that:

> It is necessary to train everyone to work safely. That is why the induction begins on day one.

To avoid, as far as is possible, wide discrepancies in an assessment of the **adequacy of budgeting for safety**, judgements about what is adequate, should be made by persons, who by virtue of their training and expertise, are regarded as suitably qualified to do so. This again suggests the need for a specialist activity of hazard auditing, (chapter 7), in which practitioners, (auditors), have been trained to provide a consistent and dependable service.

Procurement arrangements for safety products and processes is expressed in terms of the functioning of procedures that relate to the procurement of any product or process. These are:

- Ordering.
- Collection and delivery.
- Monitoring and chasing up.
- Storage.
- Maintenance.
- Issue.
- Monitoring of use and re-ordering.

The concept of **pre-activity hazard assessment procedures** is subdivided further into, (see fig. 10.1):

- Pre-activity hazard identification procedures.
- Pre-activity hazard analysis techniques.
- Reliability and risk assessment techniques.

Assessment is by comparison of the use or non use of such procedures with the requirement for use, as judged by practitioners and experts. If used, assessment is determined by whether they are appropriate, and if so whether they are being used properly. (The existence and suitability of such techniques are evaluated implicitly under concepts relating to the "state of the art", (chapters 6 and 7), and "fitness for purpose", (clauses 10.5 and 10.6)). The reference to pre-activity does not preclude use in an ongoing situation, to assess a risk in the wake of changes, or predicted changes.

The requirements for **hazard auditing arrangements**, which are project dependent, should be established by experts, (auditors and hazard engineers). Because a category labelled "other" has been included, (fig. 10.1), the following selection of audit types will cover requirements.

- High level of the type designed from the hierarchy presented in this thesis.
- Management.
- Technical operations.
- Unsafe acts.
- Unsafe conditions.
- Safety surveys.
- Other audit arrangements.

The characteristics of evaluation, (fig 10.1), are as follows:

- Suitability.
- Appropriateness of the frequency of use.
- Utilisation of results in terms of lessons learned and action taken.

- Feedback from the utilisation of results. (i.e. What is the outcome of lessons learned, or action taken as a result of utilisation?)

- Effectiveness of auditors. This can be judged in terms of: training and experience; competence; impartiality of auditors; status and respect afforded auditors; relationship between auditors and management; relationship between auditors and those being audited, which should include management; accessibility of top management to auditors, which is an indicator of the commitment of top management to safety.

Any checking or auditing system is circular in the sense of "who audits the auditors"? There is no way in which this circularity can be avoided. Ultimately the whole system rests on confidence and trust. Confidence in society that the auditors are capable of carrying out their job, and trust that audits and their analysis will be carried out without prejudice. Auditors provide a service that includes advice. They are not usually part of line management and therefore do not make the ultimate decisions about corrective action that might be indicated by a hazard audit. It is essential, therefore, that those who do make these decisions have confidence in hazard auditing and in auditors. To produce confidence and trust, it is necessary to build a reputation which is itself an assurance of competence, experience, integrity, and responsibility.

Information from hazard audits may be used in deciding upon action to alleviate proneness to failure. Decision making is itself influenced by the perceptions of danger, (exposure to harm), risk, (chance of incurring harm, loss or bad consequence), and the safety culture of the decision makers. A hazard audit, therefore, is part of a recursive cycle. Its effectiveness is dependent upon many of the factors that it assesses, which in turn can affect the assessment. Hazard auditors should be aware of these influences and try to mitigate the effects of any bias that these might produce.

In chapter 2, clause 2.6, the issue of independent auditors was raised, when it was suggested that high level audits should be carried out by auditors who are external to the organisations directly involved in project management. More generally, the requirement for internal or external auditors is influenced by the type of audit. For example, audits of unsafe acts are probably more effectively carried out by persons, familiar with a specific project, who, provided impartiality is maintained, may be internal to the project management organisation. Because of the dependency between type of audit and background of auditor, a distinction between "internal" and "external" auditors has not been made in the appropriate hierarchical expansions. Judgement in this respect should be implicit in assessments of suitability of the audit and effectiveness of the auditors.

A separate category of **arrangements for safety inspections** has been included to cover more general safety inspections which may not necessarily be formal or systematic. The characteristics of assessment are the same as those outlined for hazard auditing. Safety inspections are classified as either "controlled", or "independent". "Controlled" applies to inspections of situations that are ultimately under the control of the organisation managing that situation. This could apply, for example, to an informal walk around a site by a company safety adviser, or a planned inspection by safety consultants under contract to a management organisation. "Independent" refers to inspections that are independent of the project management organisations in that there is no allegiance or connection to them. This includes inspections by Health and Safety Executive inspectors.

It is generally recognised that major incidents are rarely the result of a single failure, (Turner, 1978; Kletz, 1988). Failure to mitigate the consequence of a failure represents another failure. This is the case if the consequences of an accident are exacerbated because of inadequate **emergency arrangements**. An investigation for evidence of proneness to failure should therefore include an examination of emergency arrangements. The concepts that provide for this are itemised below:

- **Framework for activities, systems, and procedures.** This is described in clause 10.14.4.1.

- **Failures in the functioning of, activities, systems and procedures.** This is described in clause 10.14.4.1.

- The **provision of emergency precautions**. Assessment is based on a comparison between what is considered necessary by the appropriate experts, and what is provided.

- The **maintenance of emergency precautions**. Emergency arrangements may not have to be implemented. It is necessary, therefore, to regularly check that systems are in working order, (e.g. fire extinguishers and hoses), activities are well practiced, (e.g. fire drills), and procedures function properly, (e.g. administration of first aid).

- **Liaison with the emergency services**, (police, fire, and medical).

- **Maintenance of access for the emergency services.**

10.14.5 Quality systems.

Safety can be viewed as safety of an artefact, occupational safety, or even financial safety. Safety of an artefact applies to its structural safety or safety of form, both of which relate to the safety of materials and equipment. In these terms, safety and quality are linked. Quality systems, which are increasingly being promoted as fundamental to the success of businesses and business survival, (Collard, 1989; Knowles, 1992), are also fundamental to the provision of safety.

The definition of quality, (BS 4778; Part 1: 1987), is "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs". This definition applies to a concept of quality at a given time; but the concept can be changed by assigning different characteristics, or different combinations of characteristics, to it. In a natural course of events, it would be hoped that stated or implied needs change such that the characteristics that describe quality are perceived to represent an improvement. A quality system, is defined as "the organisational structure, responsibilities, procedures, processes and resources for implementing quality management", (BS 4778: Part 1: 1987). Such a system should be aimed at the achievement of excellence as well as the satisfaction of needs, so as to generate higher expectations in the combination and type of characteristics that are judged to represent quality. Its assessment, therefore, should check that the system functions to ensure the satisfaction of needs, while attempting to increase expectations, by continually improving the product or outcome to which the quality system relates.

Documentation is integral to a quality system, and as such creates a danger that the generation of paperwork becomes a self serving system in itself. It is important that the functioning of the quality system is assessed in relation to the objectives of the system that it serves. This is particularly relevant to assessments of quality management, quality auditing, quality surveillance and monitoring, quality review and quality assurance. Bearing this in mind, proneness to failure as a result of poor quality systems may be evidenced in the following concepts, (fig. 10.1):

Quality management is the set of activities, systems, and procedures that provide for control of the development and implementation of the quality policy.

Quality policy is the statement of intention with regards to standards of quality and the course of action to be adopted for the achievement of these standards.

A **quality plan** is "a document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, service, contract or project", (BS 4778: Part 1: 1987).

A **quality procedure** is a documented description of an independent process and the means of controlling it. An independent process is one which can be conveniently described as a separate series of actions or events. A procedure, is a description of how a particular process is carried out, and how it is controlled. It can be classified as follows:

- Procedures relating to the quality system. For example, the way in which a quality audit is conducted, or the way in which quality is reviewed.
- Procedures that relate to a department or section. For example, The way in which a planning department, design section, or purchasing department functions.

- Procedures that relate to a project or project phase. For example the way in which correspondence is handled, (collected, circulated, issued, and dispatched), or the way on which a particular type of excavation is to be carried out.

Quality auditing arrangements is defined as the arrangements for "systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives", (BS 4778: Part 1: 1987). Evaluation follows the format outlined for hazard auditing arrangements, in clause 10.14.4.

A **quality manual** is "a document that sets out the general quality policies, procedures and practices of an organisation", (BS 4778. Part 2. 1979).

Quality surveillance and monitoring is "the continuing monitoring and verification of the status of procedures, methods, conditions, processes, products and services, and analysis of records in relation to stated references to ensure that specified requirements for quality are being met", (BS 4778: Part 1:1987).

Quality review is a "formal evaluation by top management of the status and adequacy of the quality system in relation to quality policy and new objectives resulting from changing circumstances", (BS 4778: Part 1: 1987).

Quality assurance is "all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality", (BS 4778: Part 1: 1987). Assessment requires evaluation of whether such confidence exists.

10.15 Project outcomes.

This is defined as the set of outcomes of a project in relation to expectations and intentions. The following concepts should be examined for evidence of poor project outcomes:

Compatibility of outcome with design. (Does the outcome comply with design intention?) This should be interpreted to cover design changes and changes that are made during the implementation of a design, that must, of necessity, be subject to a design check.

Information about outcome. This requires a check that information about outcomes is produced, and corresponds to facts. In effect, this concept requires an assessment of the records of a project's history. For example, have "as built" drawings been produced and do they correspond with what has been built? In construction this could apply to the layout of conduits and pipe-work which may only be finalised at the time of installation. Accurate "as built" information, which should include records of remedial work and modifications, is especially important for demolition and proposed changes to a structure's use.

Dependability of outcome. This requires an assessment of whether outcomes have been tested adequately, and if so, of the degree of correspondence between test results and design intentions. The commissioning of a process plant or parts of a building such as fire alarm systems are examples.

Guidance on subsequent situations to outcome. This is guidance about action that is necessary to ensure that systems continue to operate as intended. It applies to information such as maintenance manuals or requirements for soil testing following decommissioning and demolition.

Fitness for purpose of materials to situations subsequent to outcome. Materials, for example, that have been incorporated into a project for use during operation may be damaged during construction. This concept provides for consideration of such occurrences.

Fitness for purpose of equipment to situations subsequent to outcome. Again, in the construction - operation interaction, there is considerable scope and opportunity for equipment that has been designed for use during the operation phase, to be used and possibly abused, during construction.

Effect of the outcome on existing situations. Concepts described earlier in clauses 10.8 and 10.9 relate to the environmental and social impact of a project. This concept has been included to elicit an assessment of the impact of the outcomes of a project on situations that may not obviously be associated with environmental or social conditions. This could include political situations.

Effect of the outcome on subsequent situations. Assessment requires evaluation of what the outcome of a project or its phases might be on subsequent situations. This necessitates prediction of future situations to compare what might have been, in the absence of project outcomes, with what is likely to be as a result of project outcomes.

10.16 Summary and conclusions.

An examination for evidence of proneness to failure in the context of a project is focussed on particular applications of knowledge, products and processes. The more general influences of society and industry can be examined using separate sections of the hierarchy. It is necessary, however, to include in the part of the hierarchy dealing with overall project management, those influences in society that interact directly with the project, but are outside of the immediate physical and organisational environment of a project.

A project is classified in terms of the phases that describe its development, use and withdrawal from use. These phases are feasibility and planning, conceptual design, design, construction, operation, decommissioning and demolition, and post decommissioning and demolition. A search for evidence of proneness to failure in "overall project management", needs to identify the influences that arise from the inter-dependencies amongst the project phases. These influences are allowed for in the hierarchical development shown in fig. 10.1.

The section of hierarchy associated with overall project management does not include concepts that deal with specific activities, systems, and procedures. Lower level audits such as those for technical systems, unsafe acts, and safety surveys, are used to examine particular activities, etc, for evidence of proneness to failure. It is necessary, though, to include in this section of the hierarchy, concepts that provide for an examination of the use of low level audits.

Familiarity with hazards may affect the perception of risk, and possibly obscure hazards. Auditors, need to be aware of situations where the perception of risk and hazard may be subject to bias as a result of familiarity. Recognition of this process provides the opportunity to make allowances for bias. This implies a need for auditors to be experienced in auditing, in the problem area being audited, and in the subject matter of the audit. This implies a specialist activity.

Society, which sets the requirements for safety, and decision makers who determine the necessary action to provide for the requirements, need to have confidence and trust in hazard audits and auditors. To establish confidence and trust, hazard auditors, as a group, need to develop a reputation that is an assurance of competence, experience, integrity and responsibility.

Safety is integral to quality. The absence or malfunctioning of systems to ensure quality may be evidence of proneness to failure.

Fig. 10.1, at the end of the chapter, shows the hierarchical development of overall project management.

Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 1 of 9).

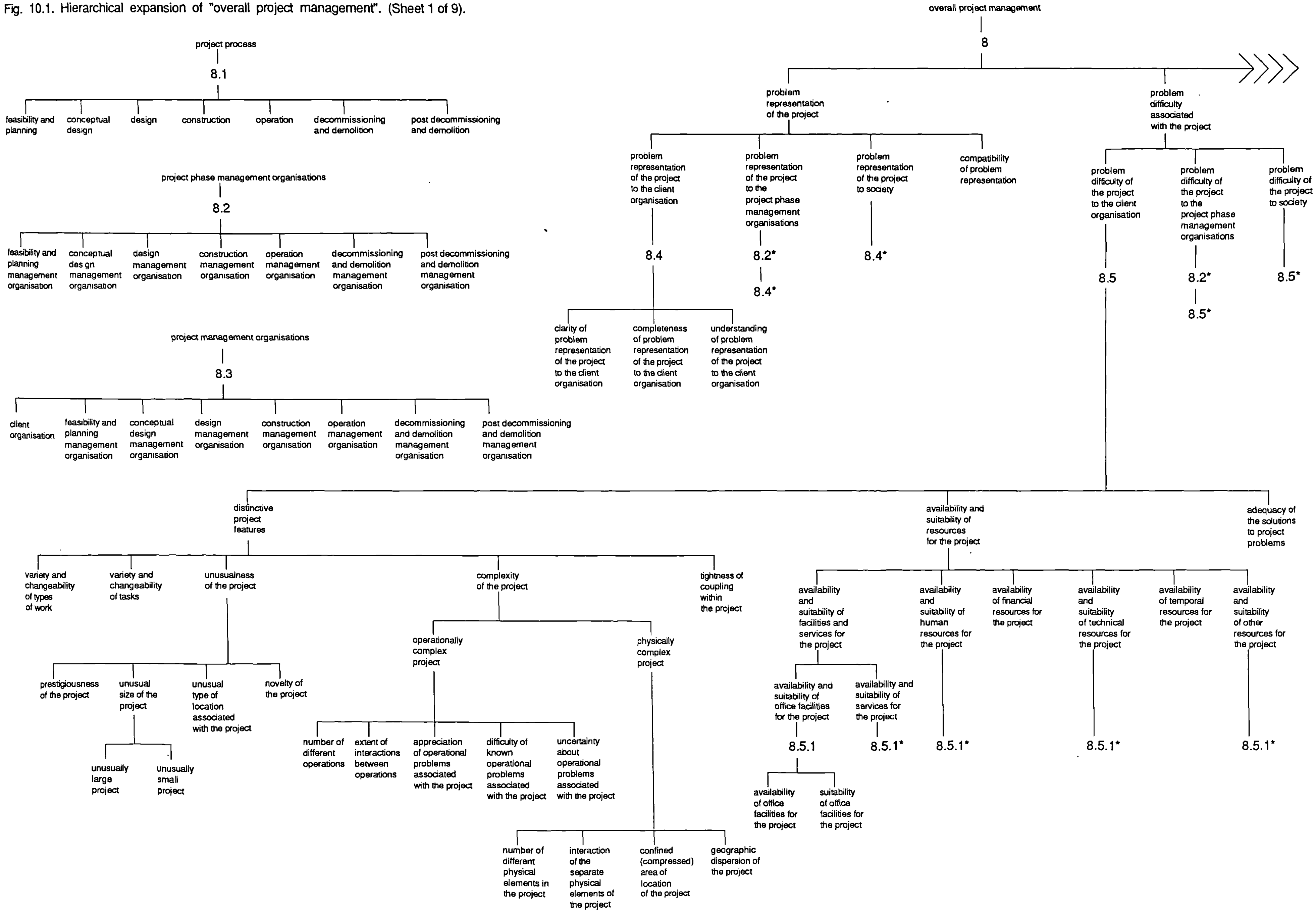


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 2 of 9).

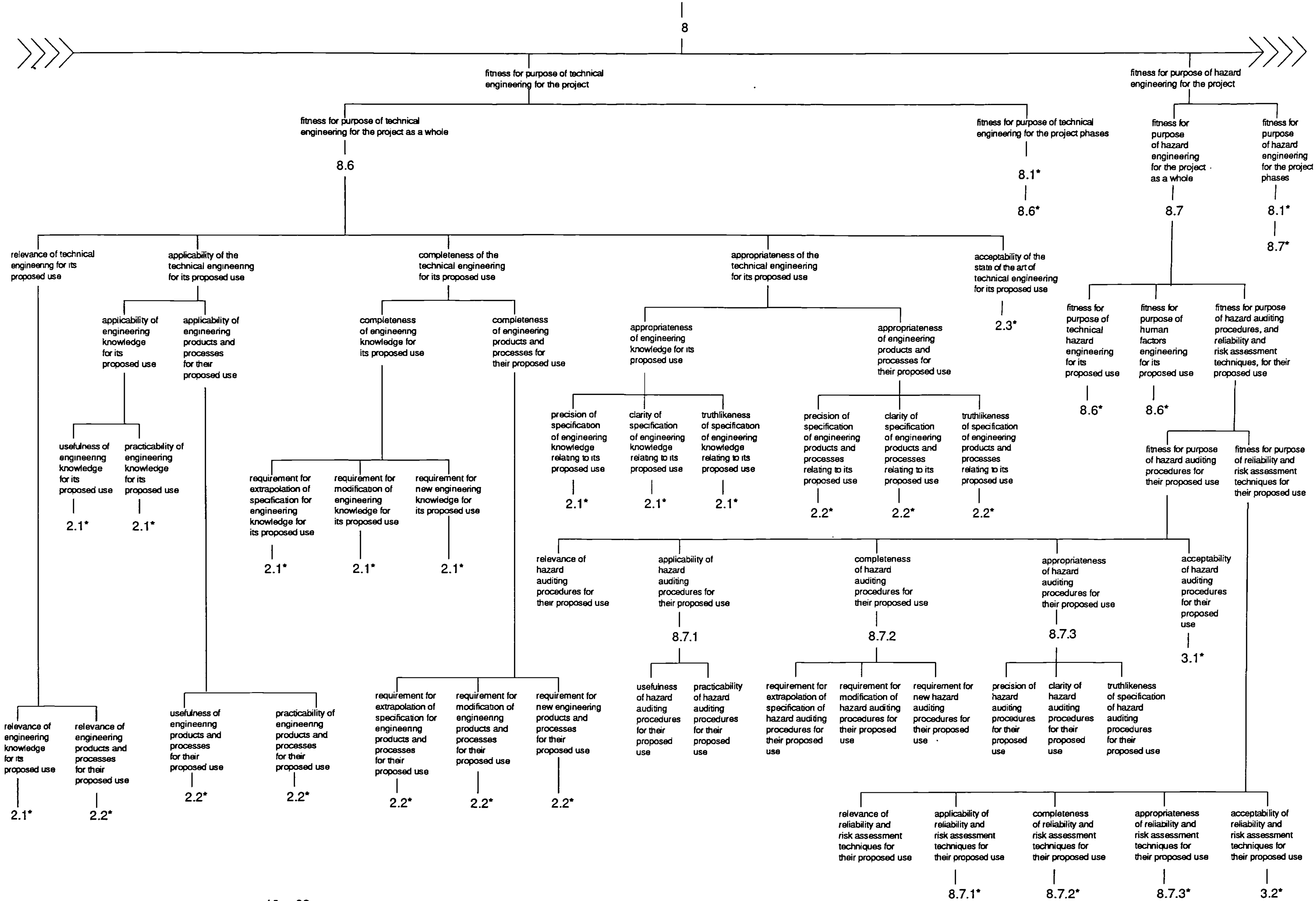


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 3 of 9).

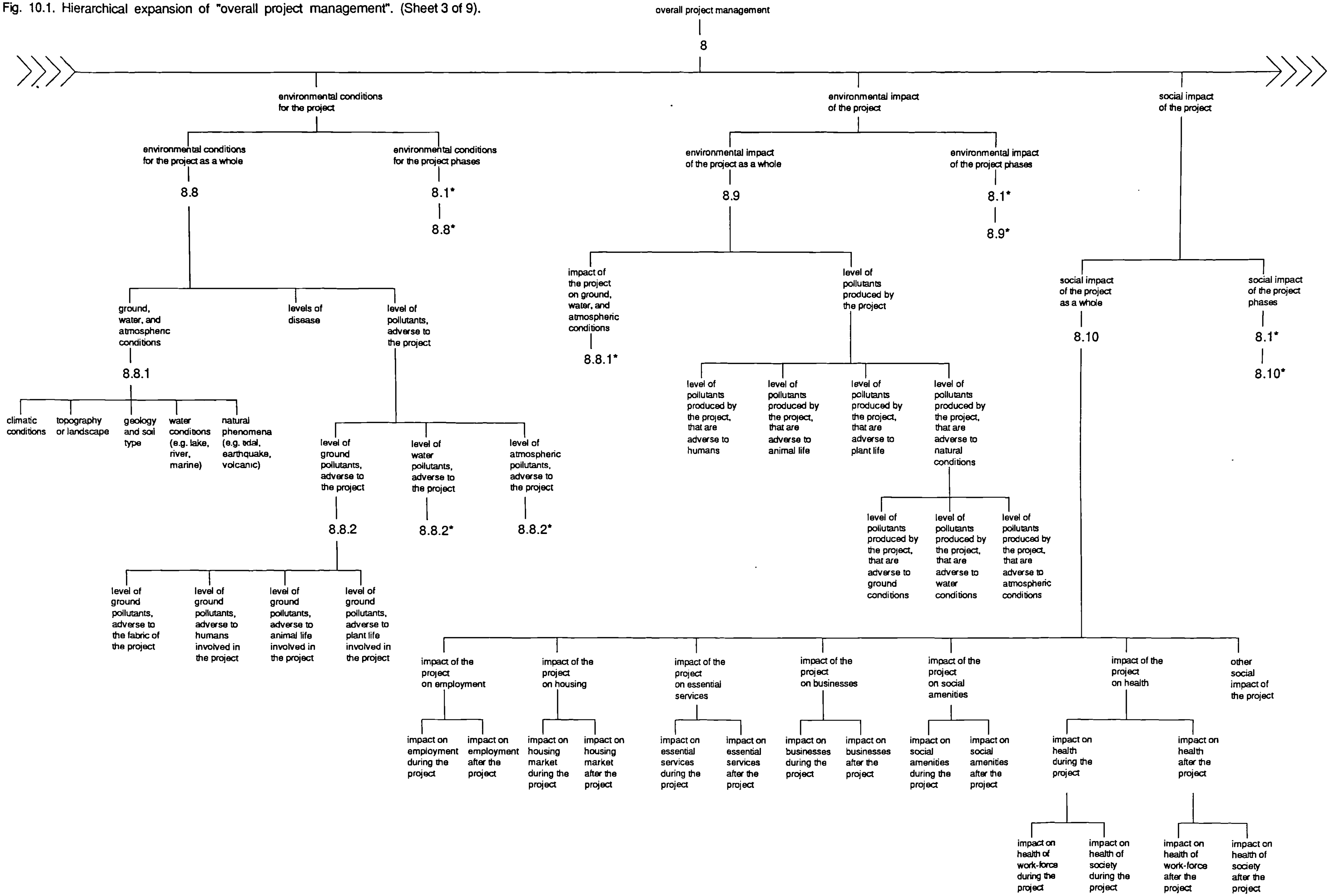


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 4 of 9).

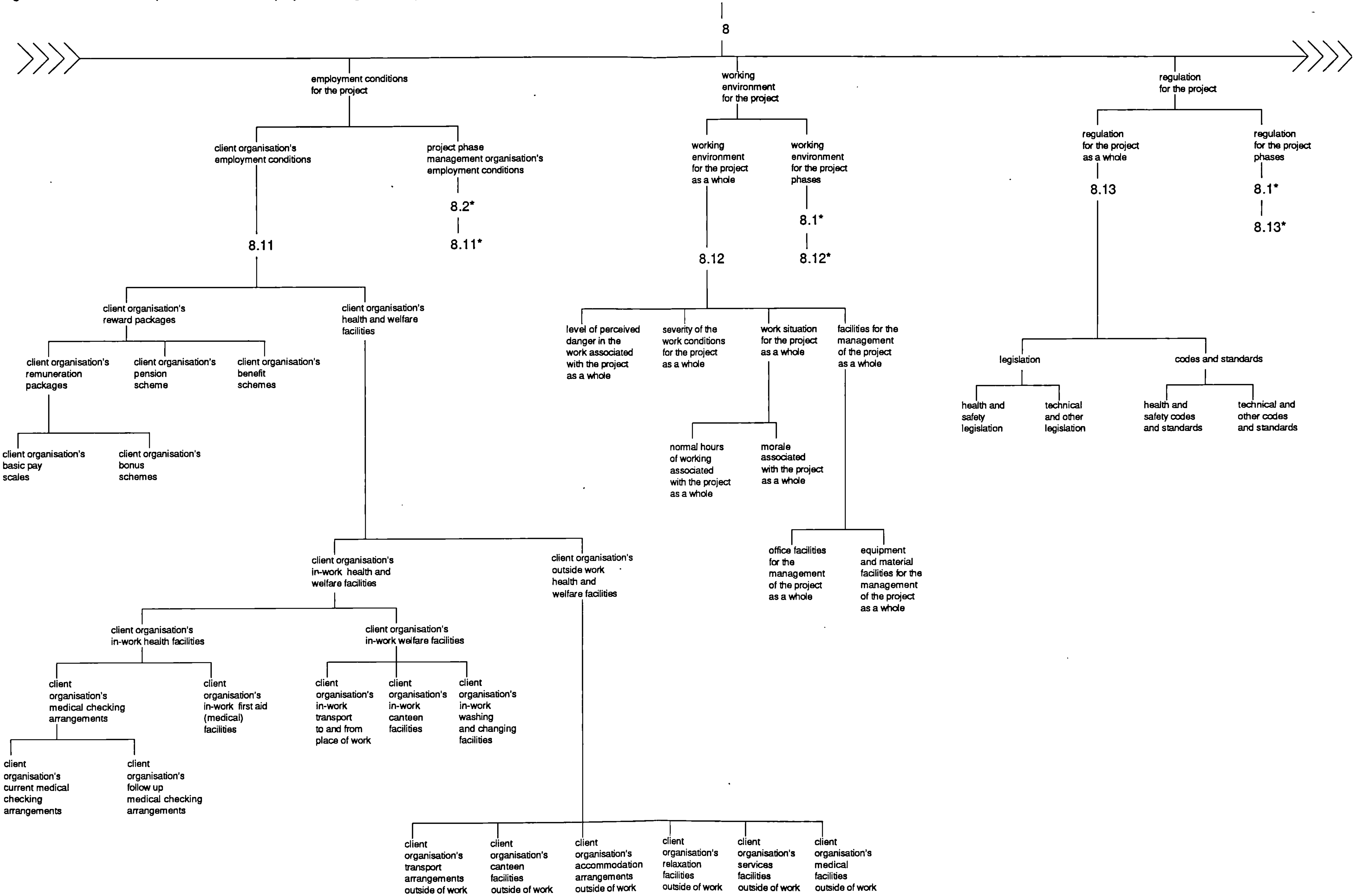


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 5 of 9).

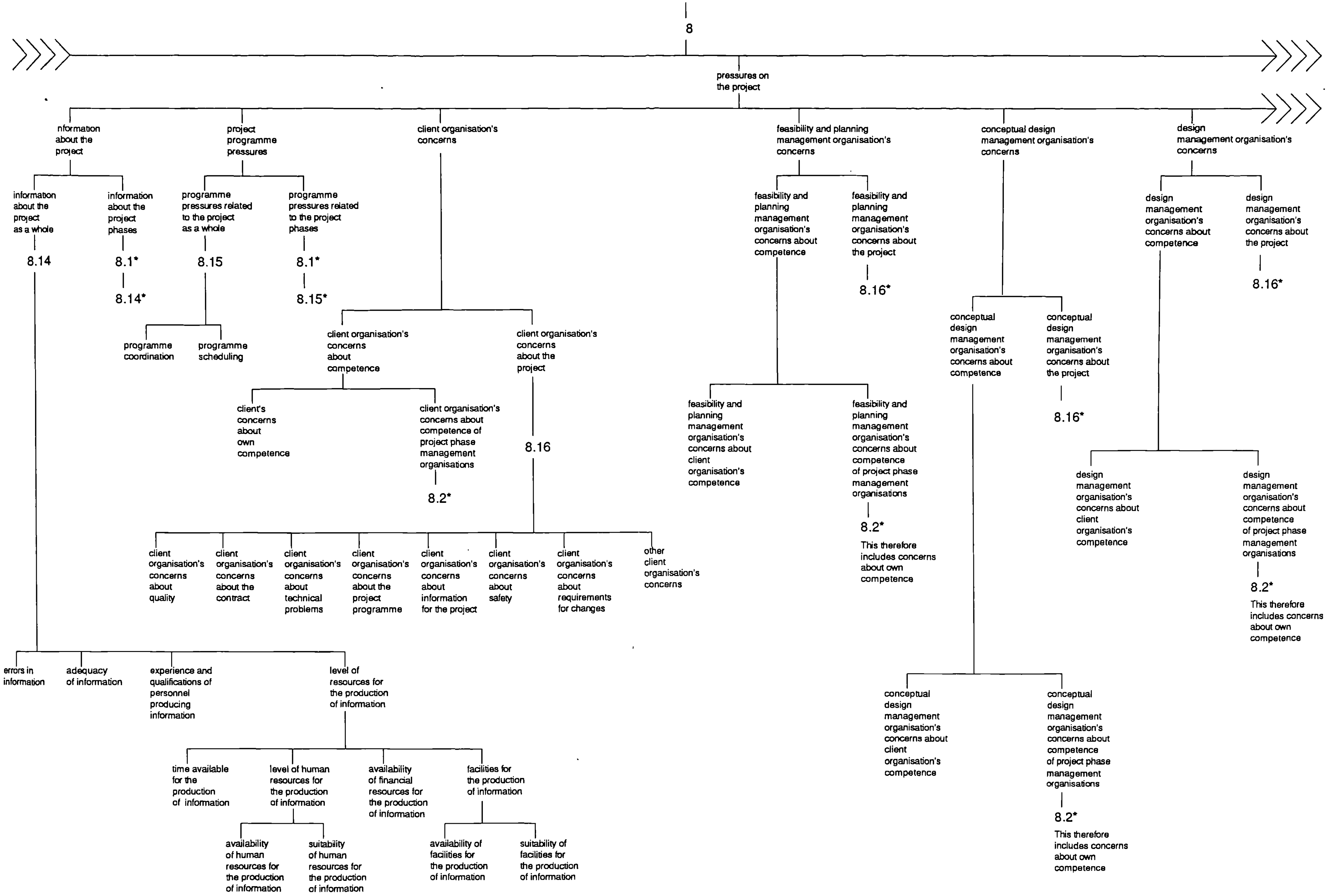


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 6 of 9).

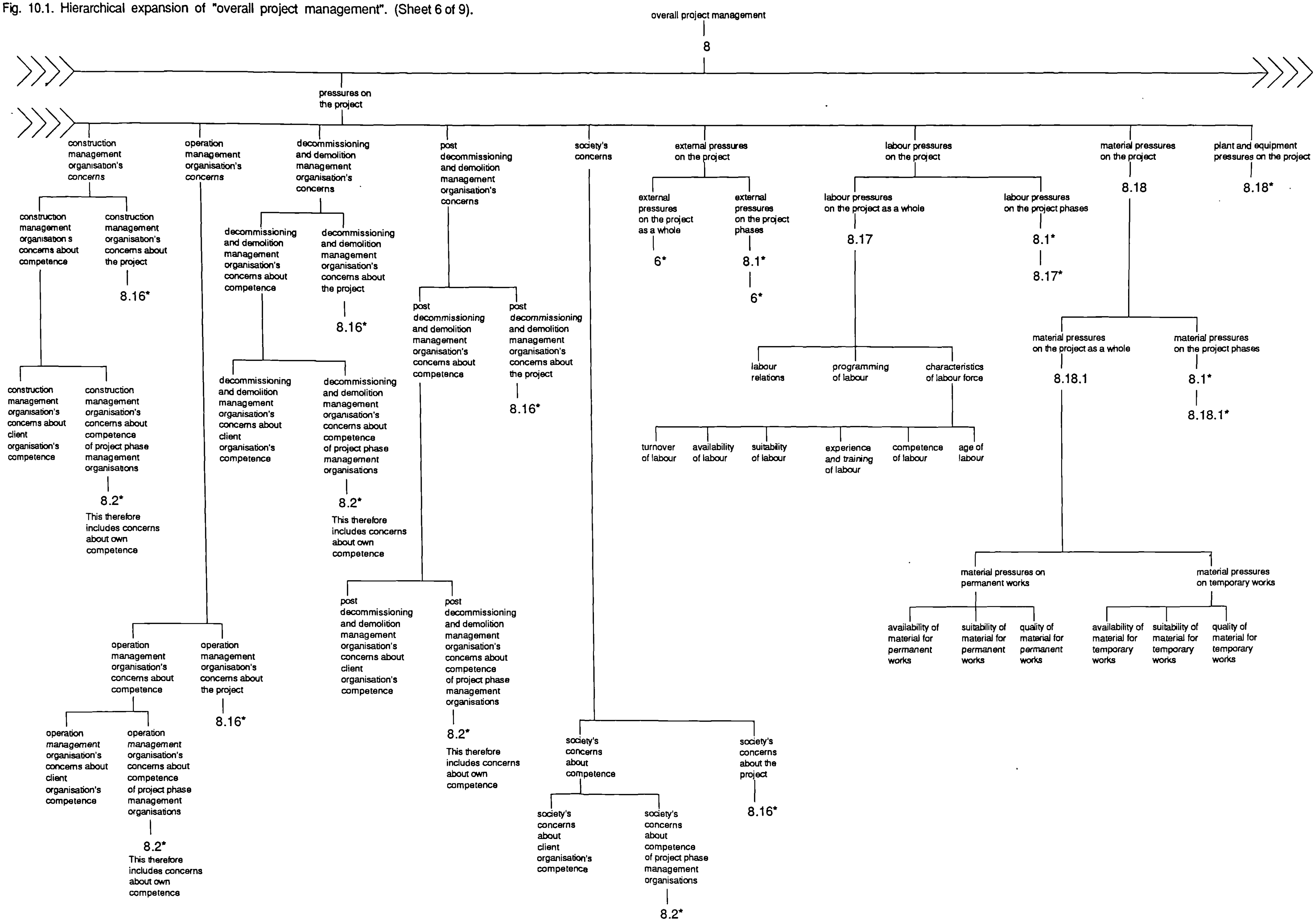


Fig 10.1. Hierarchical expansion of "overall project management". (Sheet 7 of 9).

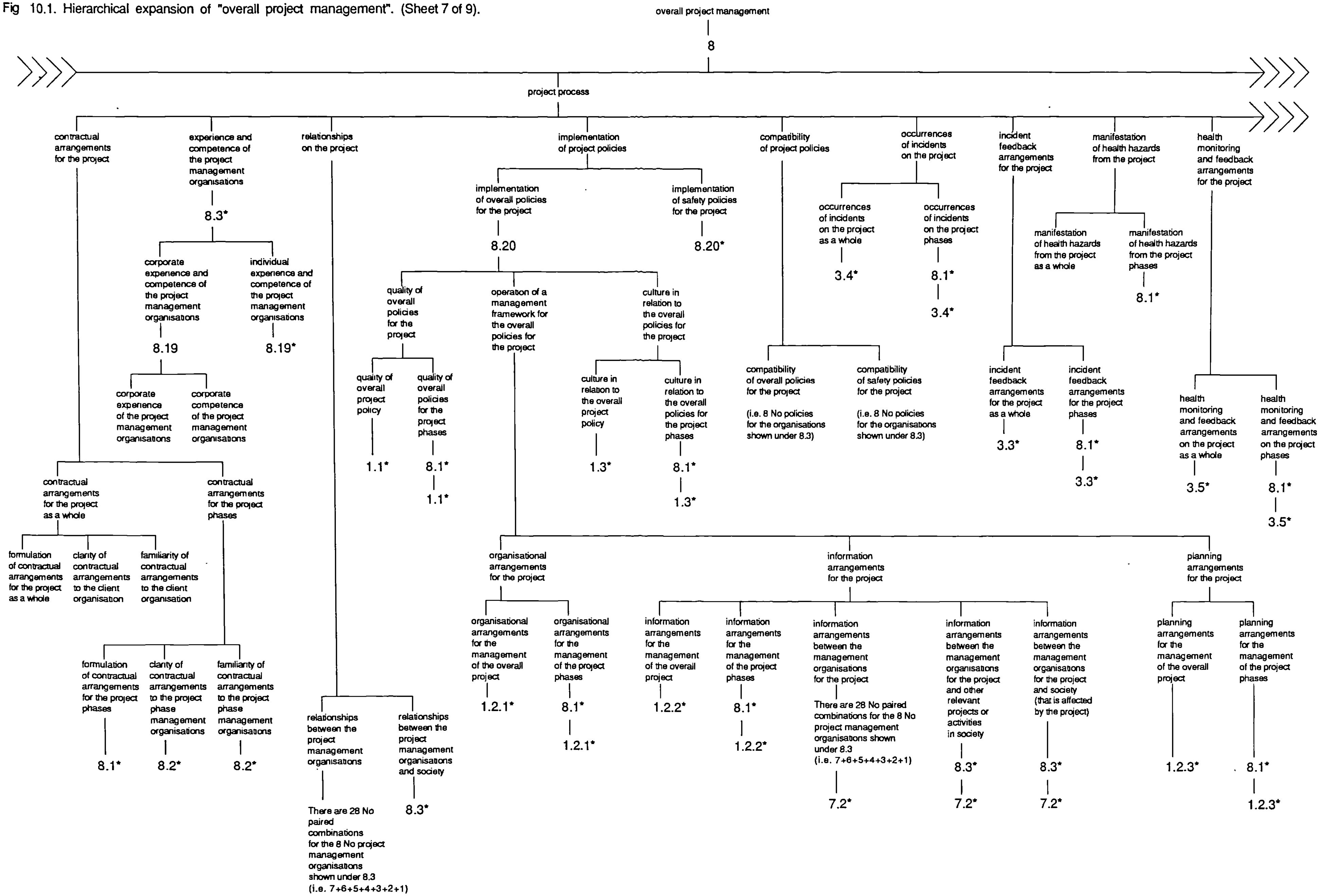


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 8 of 9).

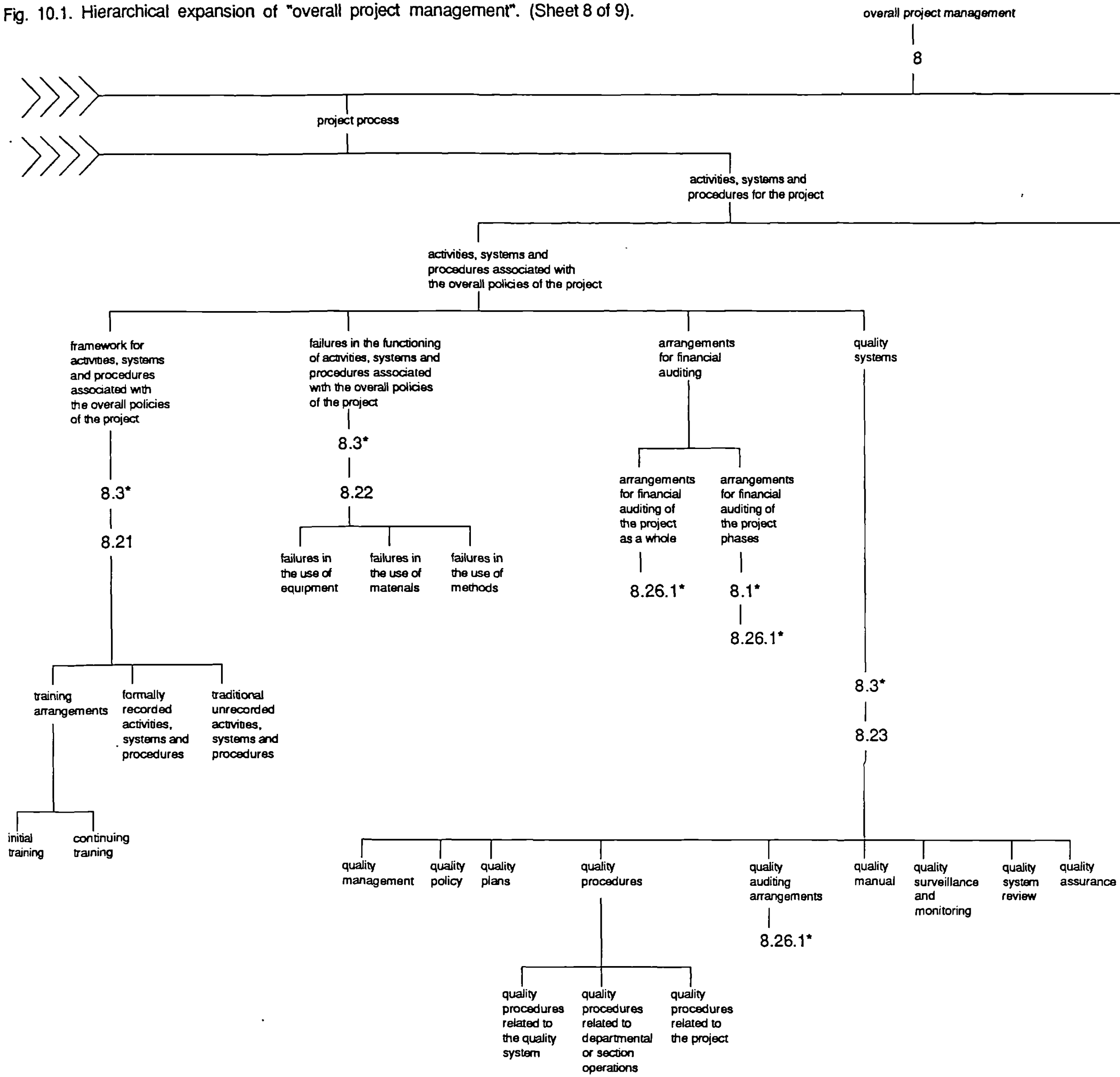
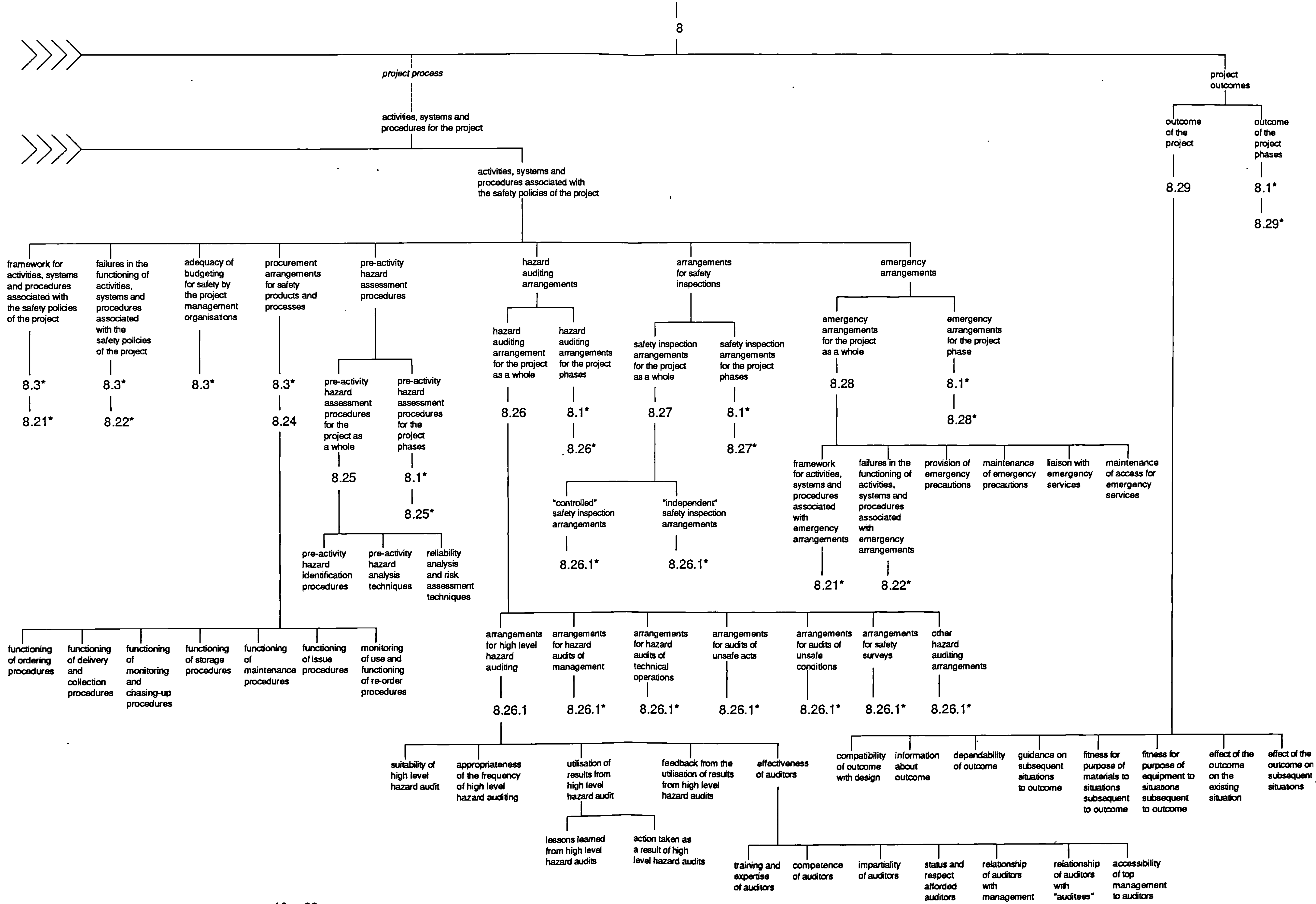


Fig. 10.1. Hierarchical expansion of "overall project management". (Sheet 9 of 9).



Chapter 11.

Project history.

11.1 Objectives.

1. To outline, with respect to proneness to failure, the development of the hierarchical model of project history.

2. To discuss concepts that can provide evidence of proneness to failure in the construction phase.

3. To present a hierarchy of concepts that can provide for an evaluation of the construction phase of project history for evidence of proneness to failure.

11.2 Introduction.

The following definitions apply to terms that are relevant to the hierarchical development of the "construction phase".

Design engineer: The individual or organisation, that is responsible for the design of a project.

Engineer: In the context of a construction project, the term engineer refers to the individual or corporate group of engineers or architects, appointed to supervise, (monitor and check), construction for compliance with design.

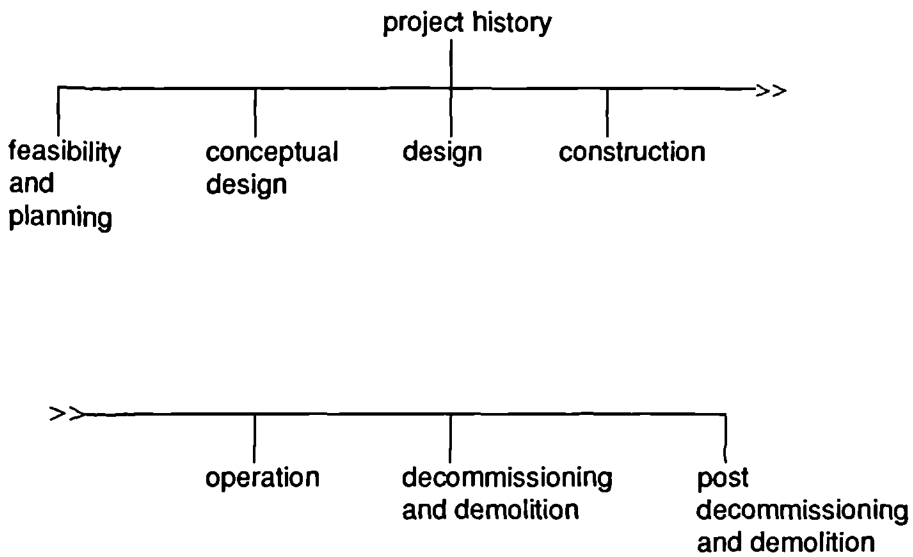
Specialist engineer: A specialist engineer, (individual or corporate), is appointed by, and is responsible to, the design engineer or engineer, for the design or supervision of any specific part of the project.

Management contractor: The organisation, appointed by a client or client's representative to manage any part of the development of a project.

Contractor: A contractor has a direct contractual relationship with the client, or client's representative, to carry out construction.

Sub-contractor: A sub-contractor has a contractual relationship, (other than an employer-employee contract), with a management contractor or contractor, for any part of the construction of a project. Sub-contractor includes the special case of nominated sub-contractor.

Proneness to failure may be indicated by a poor state of the project. Evidence of this can be found in the overall project management, (chapter 10), and in project history. As described in chapter 2, (clause 2.3), project history is developed hierarchically as shown below.



The distinction between the processes associated with project phases, such as between conceptual design and design, can be fuzzy. There may also be time overlap in their functioning. The discussion in this chapter will be focussed on the construction phase.

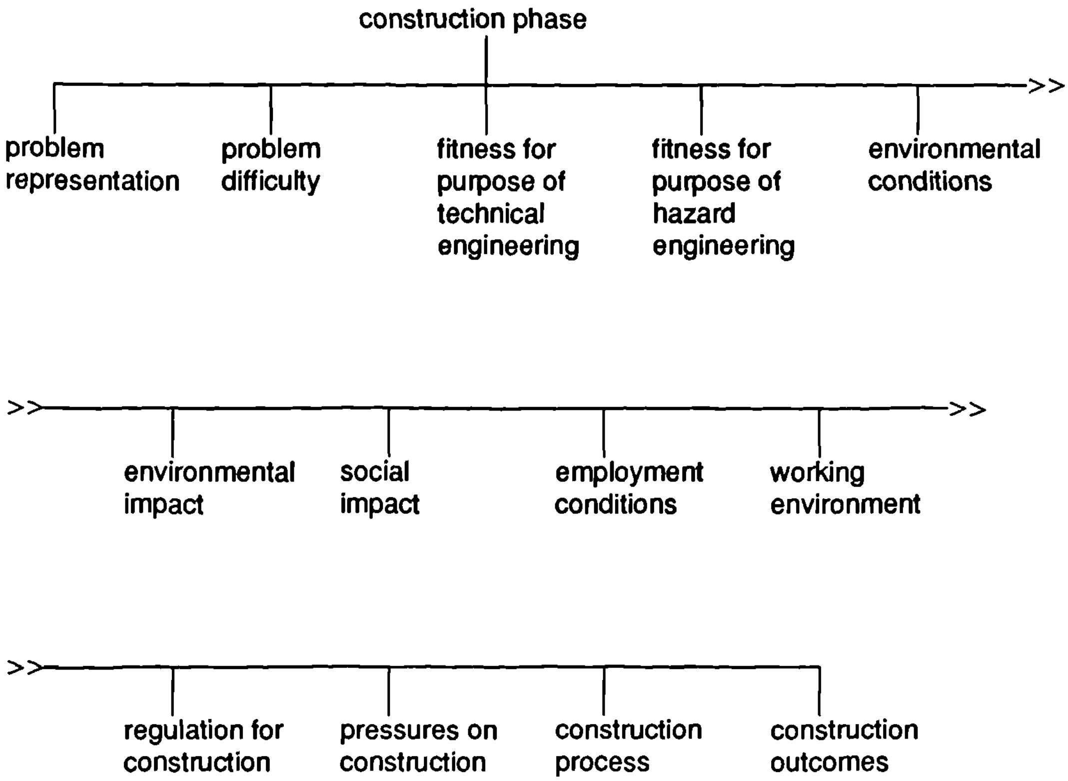
The activities, systems and procedures used in construction are diverse and varied. Generally, sets of activities, systems and procedures, relating to certain skills, knowledge, products and processes, can be associated with particular types of organisation. For example, a contractor is associated with the implementation of design, and the engineer is associated with the supervision of design implementation. The following section of hierarchy shows the principal types of organisation which are used to describe the separate interacting processes of the construction phase.

principal construction phase processes
(associated with
principal construction phase organisations)

- client
- engineer
- specialist engineer
- management contractor
- contractor
- sub-contractor

Apart from the more general influences of society, the presence of a construction project creates an interaction with sections of society. Where appropriate, this inter-dependency is incorporated into the hierarchy, (see chapter 10, clause 10.2).

The top level hierarchy concepts that have a potential to provide evidence of a poor construction phase, (or any other phase), are the same as those described for overall project management in chapter 10. These are reproduced here in the context of the construction phase. The hierarchical development of these concepts is shown in fig. 11.1, at the end of this chapter.



Apart from the obvious context difference the hierarchical expansions of the concepts shown in the preceding diagram are similar to those described in chapter 10. Differences are apparent in comparisons of the respective hierarchical expansions, (figs. 10.1 and 11.1). For example, "pressures from information about the project", (chapter 10, clause 10.13, and fig. 10.1), compares to pressures on construction from enquiry information and tender information, (fig. 11.1). The hierarchical expansion of the construction phase, (as part of project history), differs most significantly to that for overall project management in the "construction process". Further discussion in this chapter, therefore, deals with the "construction process".

Inter-dependencies amongst project phases are considered in an examination of overall project management. As part of project history, the construction phase has the potential to influence subsequent phases. These effects are evaluated under construction outcomes.

11.3 Construction process.

This is the set of activities, systems and procedures adopted for the construction of a building or civil engineering project. Some of the fundamental elements of construction, such as the use of temporary works and the procurement of materials and equipment, are included as separate hierarchy concepts. Although other activities, systems, and procedures are not included for specific assessment, provision is made for the evaluation of the use of lower level audits which examine specific activities, systems, and procedures, (chapter 10, clause 10.14). Management of the construction process is not self contained within the physical and organisational arrangements of a construction site. It can be considered as a system that comprises both off-site and site arrangements. This distinction provides the initial classification in the hierarchical development of "construction process". The following discussion assumes reference to fig. 11.1.

11.4 Off-site arrangements.

Off-site arrangements provide essential support for site management. Poor arrangements may be evidenced in: experience and competence, the support given to site, interaction between site and off-site management arrangements, and off-site inter-organisational relationships. These features are described in the following clauses, (11.4.1; 2; 3 and 4).

11.4.1 Off-site experience and competence.

Experience and competence are context related. For example, an evaluation of a purchasing department should be linked to experience and competence in purchasing for appropriate project activities, such as tunnelling or bridge construction. At a corporate level, assessment applies to the organisation as a system. For instance, a company deciding to specialise in tunnelling may recruit experienced tunnelling personnel at its top management level and for key positions in relevant departments. This, however, does not represent corporate experience because the system as a whole can be regarded as new.

11.4.2 Off-site support.

This relates to how effectively the construction process is supported by an organisation's top level management, and how well the off-site system for the provision of services operates.

A CBI report, (1990), describes leadership and commitment by top level management as the most important feature in the development of a safety culture. Management commitment is demonstrated by support given to policy implementation. Poor **support from company top management** may be evidenced by poor accessibility of company management to the site management and/or a lack of constructive participation by company management in site management. Constructive participation does not mean active involvement in site management. It is support in terms of advice, use of influence, and preparedness to act, if necessary, to assist and enable site management to function as it needs to. Levitt and Parker, (1976), give guidelines of action that can be taken by top management to reduce accidents. The list includes: insistence on being provided with accident and loss statistics, using safety performance as one of the criterion for evaluating site management, provision for training of new workers, insistence on planning separate job activities. As implied by this list, it should be clear in an assessment of the type of support given by top management whether there is commitment to safety.

Off-site services cover the provision of equipment, materials and specialist services. The distinction between temporary works and permanent works is used as a convenient classification in evaluations of **off-site support with equipment** and **materials**. In each case, the criteria for evaluation are related to:

- Procurement, for which the characteristics of evaluation relate to: ordering, delivery and collection, monitoring and chasing up, storage, maintenance, issue, monitoring of use and re-ordering. (Chapter 10, clause 10.14.4.2).

- Ensuring, as far as is possible, that equipment and materials are of the specified standard.

The provision of **specialist off-site support** applies to knowledge and skills which are not possessed by site personnel but which are necessary to the construction process. This encompasses technical, financial, labour, legal, safety, and any "other" expertise that is not available on site. In the case of technical expertise, Kletz, (1988 and 1990), warns against over-reliance on expertise from outside a company. The implication is that there should be "in-house" capability, either on or off-site, to ensure that an undertaking, even if sub-contracted, is carried out properly. This would appear to be fundamental if a company is to exercise the control that is essential for management.

Off-site arrangements usually serve a number of different construction projects. The perception of priorities may not accord with those of the site management of a particular project. However, if a hazard audit is applied to a project, the performance of the off-site management system must be evaluated in this context.

11.4.3 On-site - off-site arrangements.

The interface between off-site and site arrangements provides the potential for ambiguities and malfunctioning of either set of arrangements. "On-site - off-site arrangements" relates to the coordination that is necessary between the two sets of management systems if they are to operate effectively as a single system. Assessment is based upon an evaluation of the on-site - off-site clarity of roles and information arrangements.

The characteristics of assessment of **clarity of roles** are, as described in chapter 5, (clause 5.5.2), responsibility, decision making, authority, and accountability. Evaluation, here, involves determination of whether there is ambiguity, between a company's site and off-site management organisations, as to who does what. The hypothetical example given in clause 11.4.4 illustrates the need to maintain clarity of roles in the on-site - off-site arrangements.

The hierarchical expansion of **information arrangements** develops in terms of informal liaison, formal information arrangements, and meetings and discussions. These concepts are described in chapter 5. One problem of communication between site and off-site organisations was described in Interview L. The interviewee expressed the view that the need for off-site personnel to go through a contractual chain of sub-contractors can create problems in getting information to where it is required when it is required. As a general rule, contractual requirements should not be by-passed for convenience, but there are situations when circumstances may dictate that it is prudent to do so. In such cases, compromise of site control is minimised if the appropriate site manager, as distinct to off-site personnel, initiates any changes to the usual system, and if on-site - off-site arrangements are clearly defined and function well, (fig 11.1).

11.4.4 Off-site relationships.

Good **off-site relationships** between the principal construction phase management organisations can aid the construction process, particularly if contractual difficulties put site relationships under strain. In this respect, poor off-site relationships may be evidence of proneness to failure. There is also the possibility that poor relationships off-site can filter down and adversely affect otherwise good site relationships, (clause 11.5.3). A number of more obvious off-site relationships, (which reflect contractual arrangements), have been included in the hierarchy, (fig. 11.1). Because this is a selected set, a category of "other" is also included. The criteria for assessment are that particular off-site relationships either do or have the potential to compromise working relationships, on or off-site.

Another possibility is that inappropriate off-site relationships may develop between individuals or the organisations they represent. A hypothetical example is if decisions about methods of working are made by a contractor's contracts manager in consultation with an engineer's principal design engineer, without reference to site management. Quite apart from the fact that the decision maker might not possess all the relevant information for such decisions; the authority and confidence of site management may be undermined, (clause 11.4.3).

11.5 Site arrangements.

This is the set of arrangements, adopted on site, for the implementation of the construction process. Much of the hierarchical development, shown in fig. 11.1, has been described in chapter 10 and needs no further discussion. This applies to the following concepts, where descriptions can be found in the clauses indicated.

- Implementation of construction policies. (Clause 10.14.2).
- Compatibility of construction policies. (Clause 10.14.2).
- Occurrences of incidents. (Clause 10.14.3).
- Incident feedback arrangements. (Clause 10.14.3).
- Manifestation of health hazards. (Clause 10.14.3).
- Health monitoring and feedback arrangements. (Clause 10.14.3).

Obviously, for the construction phase, the concepts relate to the appropriate processes, organisations, sections of society, and their interactions.

11.5.1 Contractual arrangements.

The hierarchical expansion of contractual arrangements is described in chapter 10, (clause 10.14.1), in terms of formulation, clarity, and familiarity. For the construction phase, formulation should be looked at in the context of the construction project as a whole. Assessment of clarity and familiarity applies to each of the contracted parties.

11.5.2 Site experience and competence.

Although some site personnel may have worked together previously, each new construction project tends to involve a collection of individuals with no previous history of working with one another. For this reason, site experience and competence is not distinguished in terms of corporate and individual. Rather, the hierarchical development of this concept, is linked to: senior site management, junior and supervisory site management, and labour force, (fig. 11.1). In the absence of bias through over-confidence, which may indicate a proneness to failure, experience and competence can be regarded as beneficial to an undertaking. Deficiencies in these characteristics may therefore be evidence proneness to failure. Overall assessment of experience and competence requires interpretation of the interactions amongst the different levels of site management and the labour force. These interactions are influenced by circumstances and the characters and personalities of individuals. The circumstances and individuals on a construction project are continually changing. (Chapter 3, clause 3.4.2; chapter 10, clause 10.13). It is difficult, for example, to predict, the overall effect of the combination of an inexperienced project manager and an experienced competent general foreman in particular situations. Although these sort of predictions are, out of necessity, always being made, there are no rules governing them. Assessment should be based on judgement, by an auditor, that takes account of character and personalities of site personnel and the circumstances of the construction project. This indicates the need for auditors to develop a standard of performance that is the assurance that they are able to make such judgements.

11.5.3 Construction site relationships.

The concepts for an examination of construction site relationships are the same as those for off-site relationships described in clause 11.4. The example given in chapter 10, (clause 10.14.1) of the West Gate Bridge collapse in Australia, in 1970, is an extreme example of the influence of poor relationships. From my own observations I would suggest that people in senior management positions do not always behave as professionally and impartially as they would have others believe. Their power, through position, (Handy, 1985), means that decisions and actions of senior management are particularly significant to producing conditions for failure. Such conditions are exacerbated if decisions and actions are compromised by personal feelings. Auditors must have the security and independence to make judgements, which are in effect assessments of character and may be unpalatable, about any level of management, on or off-site, without fear of reprisal.

11.5.4. Activities, systems, and procedures for construction.

The concepts that provide for assessment of this concept, are distinguished by association with either overall or safety policy. Apart from context, much of the hierarchical development is the same as that described in chapter 10, (clause 10.14.4), for overall project management. What differences there are occur in concepts associated with overall policies for construction. These are outlined in the following clause, (11.5.5).

11.5.5 Activities, systems and procedures associated with the overall policies for construction.

Fig. 11.1 should be referred to as an aid to this discussion. Apart from context differences, the descriptions of the following concepts given in chapter 10 can be applied to the construction process.

- Framework for activities, systems and procedures. (Clause 10.14.4.1).
- Failures in the functioning of activities, systems and procedures. (Clause 10.14.4.2).
- Arrangements for financial auditing. (Clause 10.14.4.1).
- Quality systems. (Clause 10.14.5).

The following concepts have been included specifically as categories of activities, systems and procedures associated with overall policies for construction.

- Procurement arrangements for materials. For both materials and equipment, procurement arrangements are distinguished in terms of association with temporary works or permanent works. The criterion for evaluation is the functioning of procedures for procurement, which for inclusion in the hierarchy are: ordering, delivery and collection, monitoring and chasing up, storage, maintenance, issuing, monitoring of use and re-ordering. (Chapter 10, clause 10.14.4.2).
- Procurement arrangements for equipment.

- Temporary works arrangements. These are central to the production of permanent works and have been associated with many construction failures. Kaminetzky, (1991), describes several temporary works failures. Excavation collapses, shutter failures, scaffold collapses, are common occurrences during construction, and all represent failures of temporary works. Assessment involves an evaluation of the procedures for checking and coordinating both design and implementation of the design of temporary works. Consideration of contractual arrangements is necessary in determining involvement in these procedures. The provision of temporary works for the construction of a reinforced concrete roof slab might involve, for example: a design and design check by the contractor, a check and comments on design by the engineer, construction of the temporary works and a check by the contractor, a check of the constructed temporary works by the engineer.

  Changes in permanent works, such as lap positions for reinforcement or structural steelwork connections, may be required to accommodate a method of construction. Any such changes require a check of the permanent works design. That such checks are carried out should be part of an audit of temporary works arrangements. The outcomes of any changes of course would also be examined under construction outcomes, (see fig. 11.1), which are described in chapter 10, clause 10.15. For the example given here, the appropriate concepts would be "compatibility of outcome with design", and "information about outcome".

  The content and requirement for temporary works is project dependent. Detailed procedures for its use needs to be established for each project. As stated, temporary works are fundamental to construction, and consideration should be given to the use of separate detailed temporary works audits as part of an audit programme.

- Arrangements for access. An assessment of the arrangements for access is based on a judgement as to whether access is adequate. This means that contractual requirements for the provision of access are irrelevant to assessment. Evaluation relates to processes rather than to the organisations associated with the processes. Of course, if access is assessed as poor, it should be clear from contractual arrangements who is responsible for corrective action.

- Housekeeping. Similarly to arrangements for access, assessment of housekeeping, (site tidiness), is process related. The responsibility for corrective action, if required, is determined by contractual arrangements.

The remarks in the previous two paragraphs about contractual arrangements, highlight an essential feature of a contract, which is to provide for control. (Chapter 10, clause 10.14.1). It was pointed out in interview J, that as the contract provides for control, it could be used to clearly specify requirements for safety.

11.6 Summary and conclusions.

Much of the hierarchical development of the construction phase follows the same pattern as that for overall project management. The differences lie primarily in the different processes that are particular to construction. It is probable that the hierarchical development of other project phases would follow a similar pattern.

The management of the construction process is unlikely to be self contained within the control of the site management. Off-site arrangements provide essential support to site management and can have a significant influence on the proneness to failure of the construction process. The effect of top company management, who by active support can demonstrate commitment to safety, is of particular significance.

The hierarchy provides the structure for the design of high level hazard audits. In this context, the hierarchical expansion of the construction phase, which is shown in fig. 11.1, does not, in general, deal with specific activities, systems, and procedures of construction. Essential processes, involving the procurement of materials and equipment and the use of temporary works are included as separate concepts. Other processes, such as excavation, scaffolding, shuttering, and concreting, are not included. These, and the detailed processes of temporary works and procurement of materials and equipment are subjects for detailed low level audits. The use of low level audits should be examined in higher level audits such as those designed from the hierarchy developed in this research.

Many situations are dependent upon human relationships and the complex inter-dependencies associated with them. The state of these relationships are influenced by character or personality and circumstances. There are no set rules for assessment of this. Assessment of hierarchy concepts that are associated with such conditions are a matter of judgement at a particular time in given circumstances. To be credible, those making judgements, (e.g. auditors), need to be accepted by society as being qualified to do so.

Fig. 11.1, at the end of the chapter shows the hierarchical development of the construction phase.

Fig. 11.1. Hierarchical expansion of "construction phase". (Sheet 1 of 5).

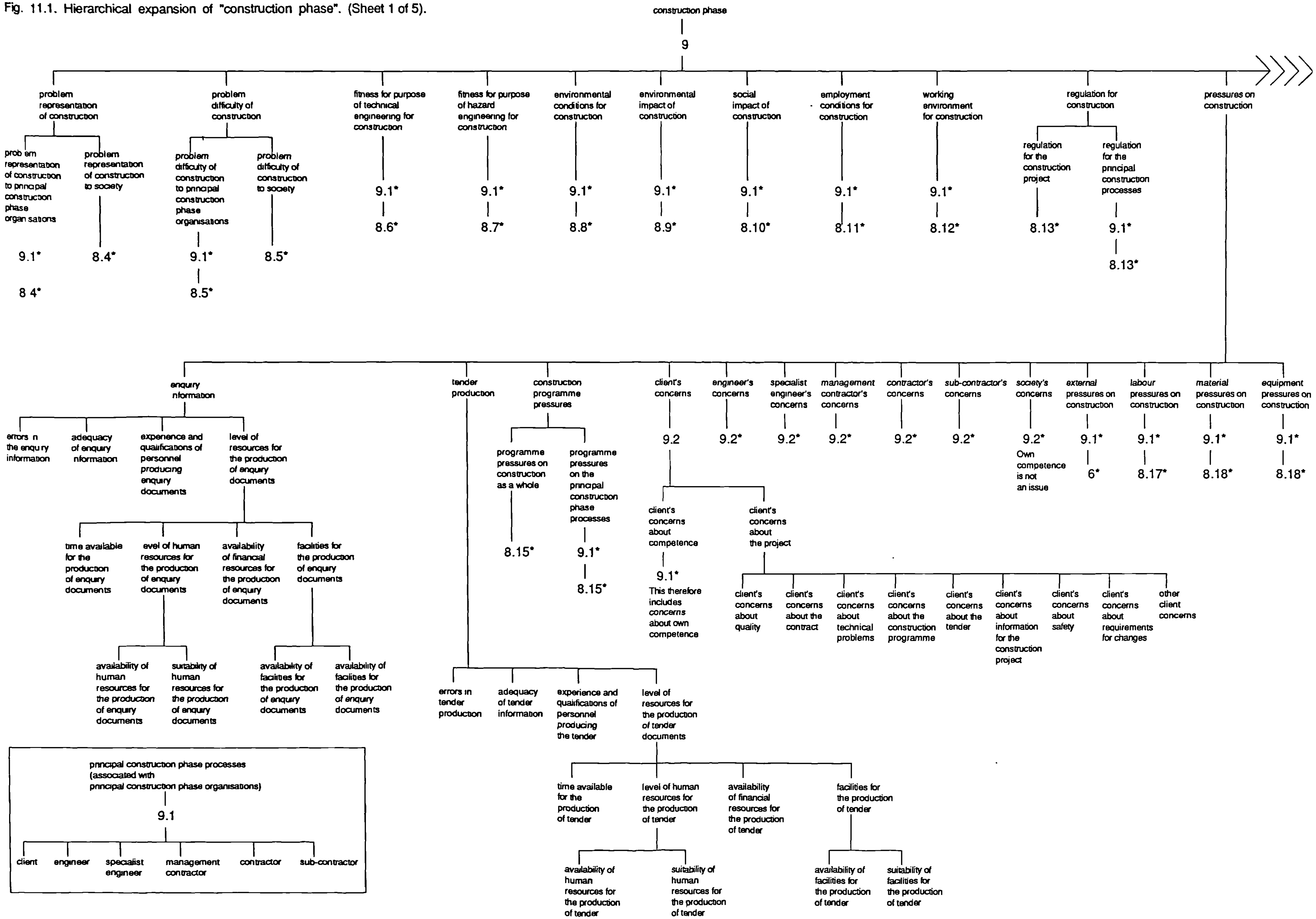


Fig. 11 1. Hierarchical expansion of "construction phase". (Sheet 2 of 5).

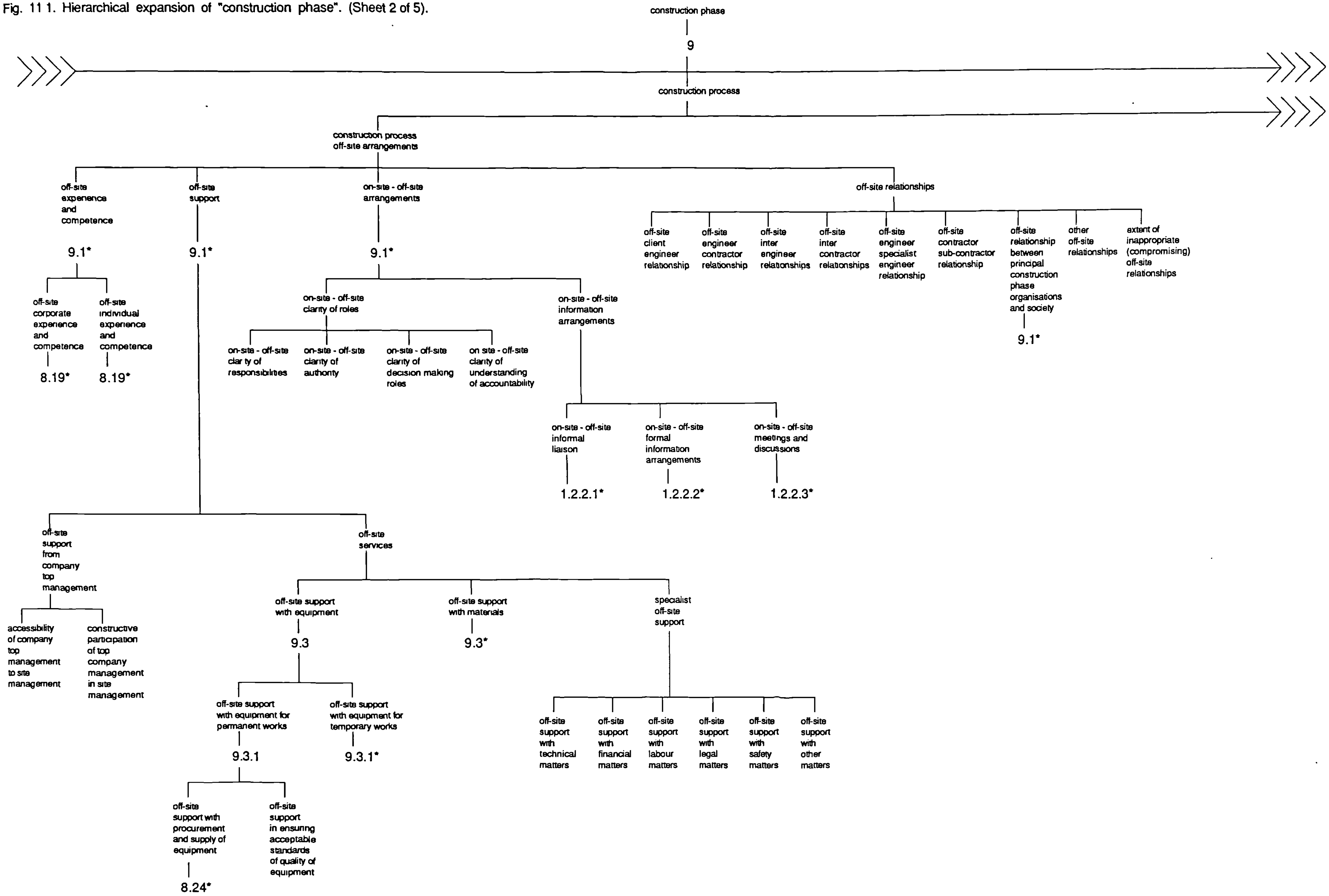


Fig. 11.1. Hierarchical expansion of "construction phase". (Sheet 3 of 5).

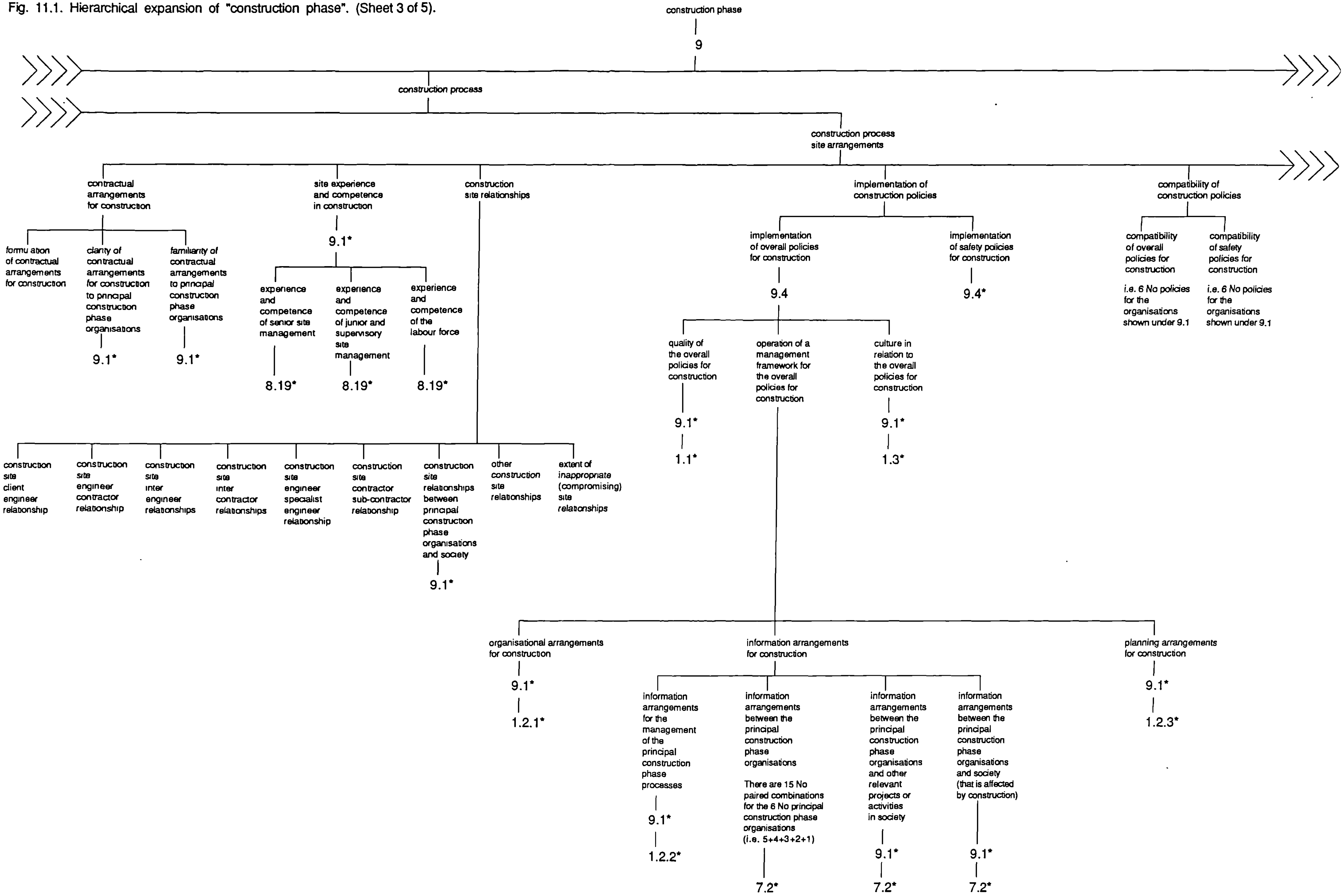


Fig. 11.1. Hierarchical expansion of "construction phase". (Sheet 4 of 5).

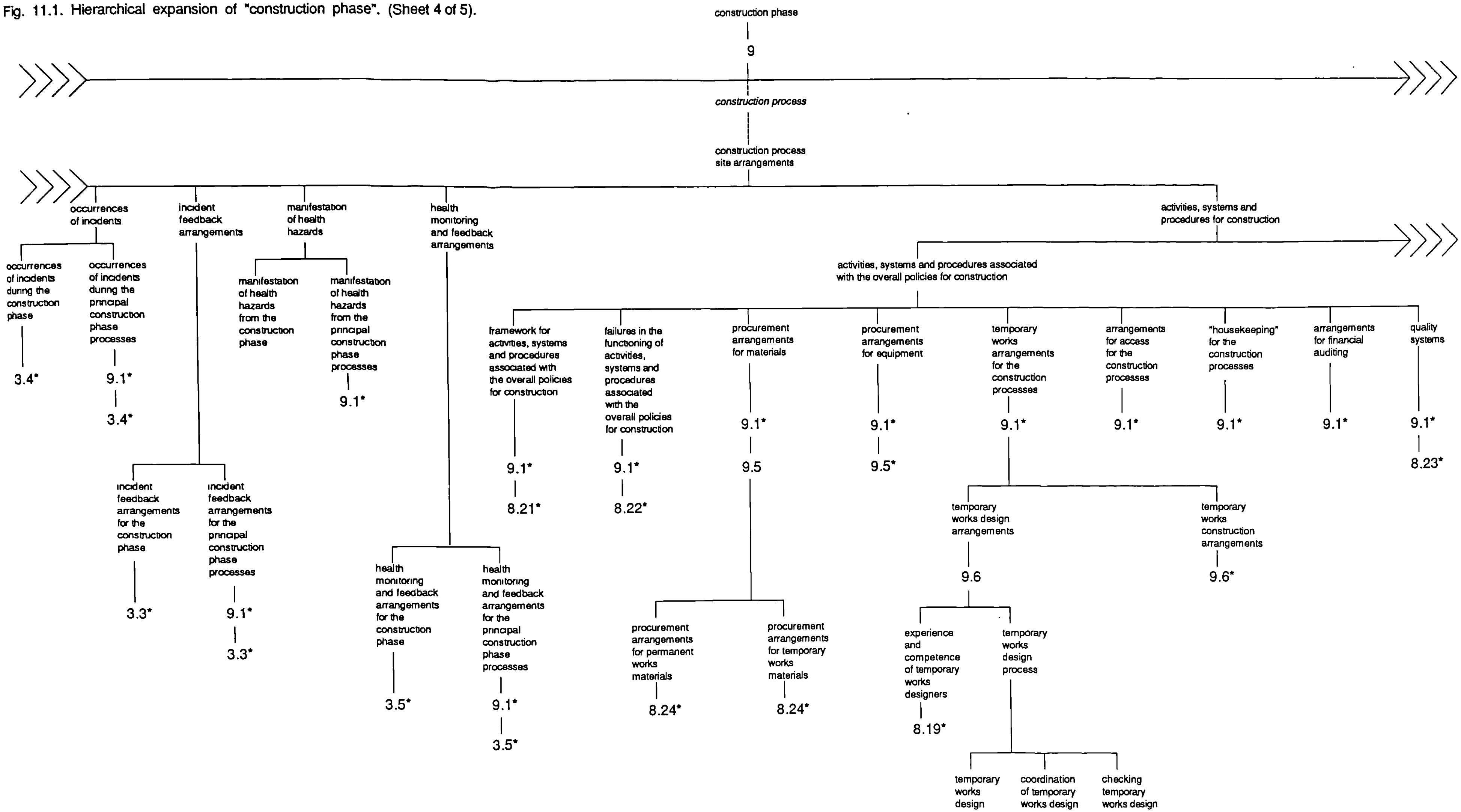
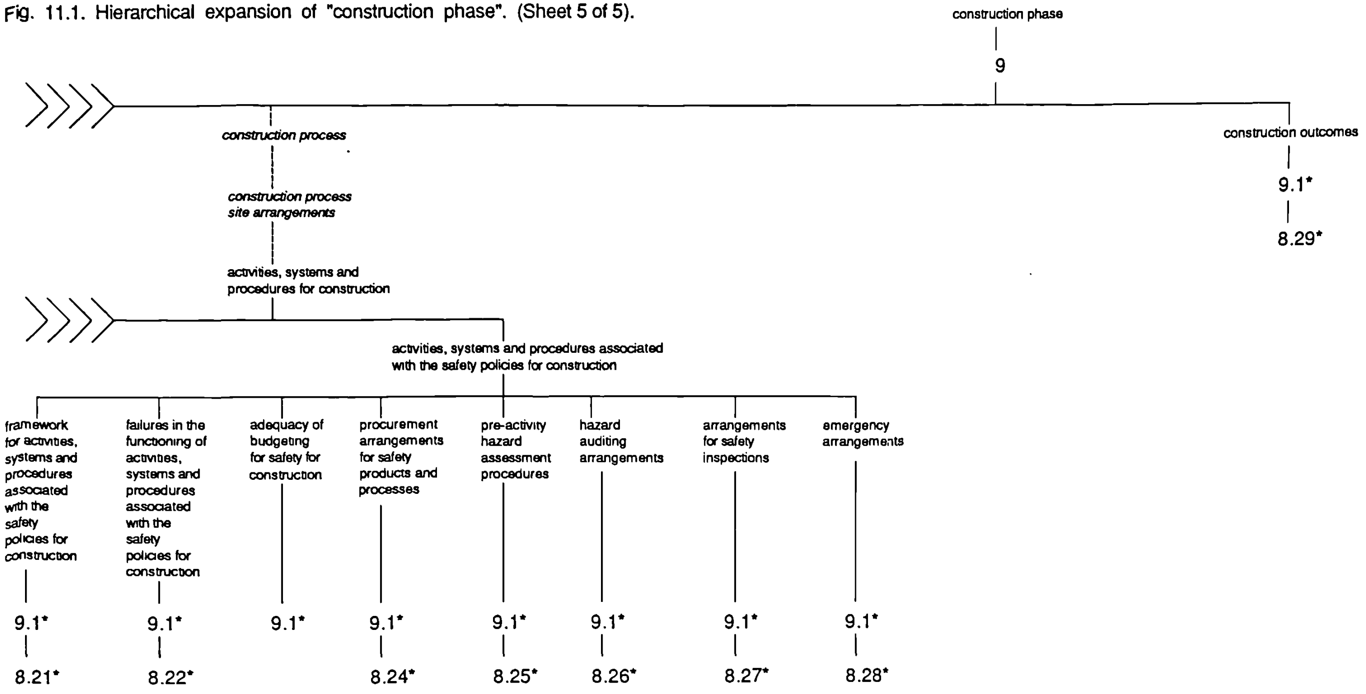


Fig. 11.1. Hierarchical expansion of "construction phase". (Sheet 5 of 5).



Chapter 12.

Conclusions.

1 The identification of hazards is fundamental to their management. Hazard auditing is a formal systematic examination of a situation for the identification of hazards.

2 The development of a hierarchy of concepts that have the potential to provide evidence of proneness to failure, (chapter 2), is described in this thesis. The hierarchy is a structure that can be used in the design of hazard audits. Sections of the hierarchy are presented at appropriate positions in the thesis.

3 The construction industry has a particularly poor record for safety. The construction of a project provides the reference for the hierarchical structure developed in this thesis.

4 A search for hazards should not be restricted to an examination of a closed system. Hazards can exist and develop outside that system and manifest themselves within the system. There are no time constraints on the development of hazards. For a construction project hazards should be looked for in the larger systems of an overall project, industry, and society.

5 Continuing knowledge acquisition within a problem solving cycle is central to the methodology of this research. Many of the concepts included in the hierarchy arise out of knowledge that is qualitative and subjective to the extent that perceptions about influence on proneness to failure can be personal with no obvious basis for comparison. The influence and interaction of perception and worldview are intrinsic to the problems of this research that involve identifying and linking concepts in a structural form. A reflective practice loop, (Blockley, 1992), models this process.

Knowledge acquisition, as part of the reflective practice model of problem solving, may come from a variety of sources, including, but not restricted to, "experts". The interpretation of the researcher's own experience with knowledge acquired from experts is an importance part of the process.

6 Semi-structured interviews of experts is a useful means of acquiring knowledge from a domain that is primarily qualitative and not restricted to a well defined context.

7 A grounded theory approach, (Glaser and Strauss, 1967), to the elicitation of knowledge from interviews with experts, provides a method of generating theory.

8 Policy implementation can be considered in broad terms as being dependent upon a policy, a management framework, and culture.

9 Objectives are fundamental to any undertaking. Formulating objectives in a policy statement establishes them. They are then less prone to unnoticeable change, neglect, or abandonment.

10 A management framework of organisation, information arrangements, and planning arrangements, provides a basis for the development and control of all activities, systems, and procedures that are necessary for the achievement of objectives.

11 The characteristics of culture, (a set of beliefs, norms, attitudes, roles, and social and technical practices), are influential in stimulating and motivating the conception, development, and implementation of policy.

12 The state of the art of technology describes the extent of knowledge, products and processes that is available within a technology. This is a socio-technical system whose functioning is dependent upon the interaction of individuals, organisations, and technical knowledge, products and processes.

13 An investigation for evidence of proneness to failure in the state of the art of technology requires evaluation by experts. This means that evaluation of knowledge,

products, or processes should be based on the judgement of experts in the appropriate domain, (technology). Assessment requires comparison with standards, established by, or implicit to, experts in the appropriate technology.

14 There is a need to establish requirements for research and development in technology. This requires that the consequences of the development of technology be extensively researched to mitigate against failure and its consequences. An understanding of technology as a socio-technical system is inherent to this.

15 The expectations of society for safety, and the multi-disciplinary nature of hazards indicate a need to treat the identification and management of hazards as a separate, distinct discipline of hazard engineering.

16 The development of hazard engineering requires that relevant knowledge from domains such as sociology, psychology, philosophy, science, and engineering be gathered together as a distinct body of knowledge.

17 A hazard audit, for the identification of hazards is central to hazard engineering. Hazard auditors should be knowledgeable about the subject being audited as well as in the procedures used for auditing. It is envisaged that hazard auditing would be developed as a specialist activity.

18 Hazard audits and auditors need to be credible to both society and those whose decisions are influenced or dependent upon the results of an audit. This requires that there be confidence and trust in hazard auditors who therefore need to develop a reputation that is an assurance of competence, experience, integrity, and responsibility.

19 The use and development of reliability and risk assessment techniques is an activity of hazard engineering. Further research could be undertaken in the application of reliability and risk assessment techniques in the construction industry. This would involve the collection of data for both failed and successful structures. The influences

of human factors such as human error, workmanship, and supervision could be investigated.

20 There are no set rules for the assessment of concepts that relate primarily to human interactions. Character, personality, and circumstances influence these interactions. Assessment requires interpretation of the combination of judgement and knowledge in a given situation. Auditors need to possess a reputation such that there can be confidence in both their judgements and interpretations of situations.

21 Occurrences of incidents and manifestations of health hazards provide the opportunity to add to the knowledge domain of hazard engineering. The learning cycle should consist of: incident, reporting, investigation and analysis, dissemination of information from investigation and analysis, utilisation of this information, dissemination of knowledge gained from utilisation. The potential for development of knowledge is improved if the number of people having access to knowledge is increased; providing of course that the knowledge has some relevance to those in receipt of it. The dissemination of information/knowledge is of particular importance.

22 The development of a strong safety culture is central to the implementation of policy that has safety, (and consequently the minimising of hazards), as a main priority. A safety culture will have stronger roots if it is based on a moral obligation towards ensuring the safety of others; as distinct to a belief that safety can be profitable or a requirement to conform to legislation.

23 As evidence of proneness to failure on a construction project, the "state of society", can be considered in terms of its relationship with the construction industry, safety, and safety in the construction industry.

24 Recognition and understanding of the hazards that exist or develop in society and industry are important to the management of hazards in any context or situation. Considerable research and study of such influences is required to facilitate the

recognition and understanding of such hazards.

25 Assessment requires that there be standards with which comparisons can be made. There is a lack of standards associated with concepts that provide for an evaluation of the state of society for evidence of proneness to failure. Research is needed to determine standards. This involves establishing clear precise descriptions of the characteristics of evaluation and the relationships between them. Of particular significance, is the quality/safety/economic relationship that exists in society. Research will involve the elicitation of information from both experts and society. Properly conducted surveys of representative cross sections of society is probably the most effective means of gauging society's views. Having established the basis for comparison; the effort, commitment, and resources required for subsequent assessments will be similar to those needed for the initial research.

26 An industry represents the link between society, (a social environment), and projects associated with that industry. An industry influences both society and the individual members of that industry. The nature of that influence will be determined by those who possess the greatest power within the industry.

27 For the construction industry, the link between safety and profitability is not as obvious as in some other industries. The priorities of safety and profitability are likely to differ between corporate business interests and individuals working in the construction industry.

28 Representative organisations for individual members of the industry, such as professional institutions and unions, should have a self interest in the promotion of safety. Such organisations need to develop power if they are to be a position to promote these interests.

29 It is important to evaluate the implementation of overall policy for evidence of proneness to failure. Overall policy, for industry, project, and project phase, deals

with the quality/safety/economic relationship. Quality and safety should not be pursued at the expense of commercial viability. In the long term this may be self defeating because, in a UK type society, the availability of resources for the provision of quality and safety is linked to commercial success. Overall policy provides the framework for the implementation of policies relating to safety and the state of the art of technical engineering.

30 A standard needs to be established for the quality/safety/economic relationship in an industry. This provides a common base for assessments of culture relating to safety, the state of the art of technical engineering, and overall policy.

31 A project can be classified into phases that represent definable stages in the development, use, and withdrawal from use of a project. These phases are: feasibility and planning, conceptual design, design, construction, operation, decommissioning and demolition, post decommissioning and demolition.

32 Part of an examination of a project for evidence of proneness to failure can be focussed on the project as a closed system. An examination in this context needs to look for hazards within the system as a whole, (i.e. the project), in the separate subsystems, (i.e. the project phases), and in the inter-dependencies amongst the subsystems.

33 The development, use, and withdrawal from use of a project can be affected by society's reaction to it. Even if considered as a closed system, an examination for evidence of proneness to failure of a project, or project phase, should investigate the interaction between project and society, that is a consequence of a project's existence.

34 The perception of risk influences the identification of hazards. The perception of risk may be biased by heuristic processes, (Slovic, Fischoff and Lichtenstein, 1982). This may bias judgement about the presence of hazards or the extent to which they

represent evidence of proneness to failure. Similar biases due to attributional processes, (Dejoy, 1985), can influence judgement about the causality of an event. This may affect decision making based on the results of an audit. Auditors need to be aware of such processes and be able to take appropriate action to mitigate the effects.

35 An examination of the construction phase of a project as a closed system should be taken to include both off-site and site arrangements. It should cover the separate processes, organisations, and individuals and the inter-dependencies amongst them.

36 A disaster sequence describes the conditions and events associated with disaster. This sequence can be interpreted to cover all the conditions and events between the "normal situation" before, and the "normalised situation" after, a disaster, (Turner, 1978). Hazard audits may be described by their association with conditions and events in a disaster sequence. High level hazard audits cover the full extent of the disaster sequence. Low level hazard audits relate to particular positions within the disaster sequence. They are used to examine specific activities, systems and procedures. Audits that deal with activities, systems, and procedures associated with conditions and events later in the disaster sequence are of the lowest level.

37 The hierarchy presented in this thesis is a framework that can be used in the design of high level hazard audits, (chapter 2). Hazard auditing should be looked upon as a programme comprising low and high level audits to provide a structured examination of a project at different levels of detail. It should encompass the conditions that make up a disaster sequence. High level audits need to examine the use of low level audits for evidence of proneness to failure. An audit should also provide for a self examination of its own use.

38 Safety is integral to quality. Deficiencies in producing quality may be evidence of proneness to failure.

39 The hierarchy will, and should be subject to continual change. This will include

modifications, removal, and addition of concepts.

Chapter 13.

Suggestions for further work.

13.1 Objectives.

1. To outline the principal requirements for further work in the development of the hierarchy as a structure that can be used in the design of hazard audits.

2. To indicate areas of further study that need to be undertaken to facilitate audit assessments of particular elements of the hierarchy.

3. To suggest areas of research for the development of the hierarchy as a knowledge based system on a computer.

4. To outline the contractual and legal implications of the introduction of hazard auditing into the traditional contractual relationships of the construction industry.

5. To outline briefly, other problem domains, where the development of similar structures to that presented in this thesis may be of value.

13.2 Continuing development of the hierarchy.

The hierarchy presented in this thesis relates to the development, use and withdrawal from use of a project. It is focussed upon the construction phase of a project. The hierarchical developments of other project phases are obvious areas for further work.

Human factors engineering, as an influence on proneness to failure is an area of the hierarchy that could be refined. The current state of the art in human factors engineering should provide a sound basis for the hierarchical development of what is a specialist activity of the discipline of hazard engineering. Hazard auditing procedures and the skills associated with their use should, I would suggest, be continually developed as another specialist activity of hazard engineering. There is scope for study into the use of reliability and risk assessment techniques, (chapter 7), in construction. This could include studies into the influences of human factors, such as workmanship, supervision, and human error, on reliability in construction. This is linked to human factors engineering.

The absence of a credible base or yardstick, against which comparisons can be made, presents a basic problem for assessment. This situation exists to a large extent in concepts that relate to assessment of the "state of society" and "state of the industry" for evidence of proneness to failure. Open world problems, (Blockley, 1989), associated with social systems are particularly complex, and can be further complicated by the diversity and extent of the social environment. Considerable study and research are necessary if assessment of the "state of society, (chapter 8, fig. 8.1), in particular, is to be credible. It is necessary to establish the basis against which subsequent evaluations can be compared. This requires that systems, (concepts), be as clearly and precisely defined as is possible, in terms of characteristics and the relationships between them. For example, establishing a quality/safety/economic relationship and a standard for comparison is important in every context, (society, industry, project, and project phase), because of its relevance to evaluation of culture and policy implementation. Determining society's beliefs is especially difficult and will necessitate extensive research. An initial assessment produced through research will provide a basis for subsequent assessments. The work required for subsequent assessments of the state of society would require similar effort and resources to that of the initial research. This area of research, would be expected to generate further research into the recognition and understanding of hazards in society.

13.3 Utilisation of the hierarchy in future developments in hazard auditing.

At the present state of this research, the design of an audit from the hierarchy, and its analysis, would be, primarily, a manual process. Further research could investigate the development of this knowledge based-system on a computer. In practice, this could be a step by step development, beginning with those sections of the hierarchy that might prove most amenable to such development. The most amenable, being those sections in which inter-dependencies between concepts appear least complex. This would be situations where the interpretation of the combination of judgement and knowledge appears most straightforward. For example, assessment of the "state of the art of technical engineering" would appear to be less complicated than that of the "construction process" that involves judgement and interpretation of complex individual and organisational interactions that are dependent upon circumstances.

Presenting the concepts in an object data base, as described in chapter 2, clause 2.6, may be useful if an object orientated method of programming is used to implement the knowledge-based system on computer. This would not be a knowledge-based expert system in the sense that non-experts could use it to predict proneness to failure. It would be a knowledge-based support system, used by experts. The hierarchy presented in this thesis could provide the basis for this system. The potential and effectiveness of the system could be continually enhanced by adding concepts to the knowledge base and by obtaining further evidence to support the inclusion of concepts in the knowledge base. Elicitation of knowledge from experts can be used to add to the knowledge base. Another source of information is case histories. Developing a knowledge base of case histories is therefore another area that could benefit from further research, (Stone, 1989). The development of knowledge needs to address the problems linked to the maintenance of the learning cycle following an incident or manifestation of health hazard. This cycle, as described in chapter 7, (clauses 7.9 and 7.10), consists of: incident, reporting, investigation and analysis, dissemination of information from investigation and analysis, utilisation of information, dissemination of information from utilisation. Resources and access to information in the "incident learning cycle" are basic requirements for the development of the knowledge bases described here. It is envisaged that these requirements would be available within a very large organisation, (construction or otherwise), where the scale of operations provides the potential for data. The system could be expanded to cover a number of separate organisations operating similar systems. This would not preclude access to any other information.

To summarise, the development of knowledge-based systems linked to the identification of hazards, can be thought of as two complementing systems. These are:

- A knowledge-based support system for the investigation of evidence of proneness to failure. This would be based upon the hierarchy developed in this thesis. It is a tool for the expert.

- A knowledge-based system for learning from case histories of incidents. This would provide support for the inclusion of concepts in the "proneness to failure" hierarchy.

13.4 Legal Implications.

The implementation, as regulation, of the European Communities Commission Council Directives, (1989 and 1992), for safety and health in construction, may, according to some, (Anderson, 1992; Davies, 1992; New Civil Engineer, 1992b), affect the legal responsibilities associated with construction. The position will become clearer, after the introduction of regulation. However, new legislation will have little effect if it isn't used. Considerations about legal implications should address the issue of the use of existing legislation as well as the introduction of new legislation. Two cases, reported in the New Civil Engineer, (1990b and 1991), illustrate this. In the first, a client, Derby City Council, was fined for safety breaches that resulted in a fatal accident during work being carried out by a contractor. In the second case, a consulting engineer, Kenchington Little, was found guilty of breaching the Health and Safety at Work Act, 1974, with regard to protecting the public. In this incident, the consultants were supervising refurbishment when part of the building collapsed. According to the above mentioned reports these cases were unusual in that client and engineer respectively were held liable for incidents during construction. These rulings were not the results of new legislation; they were based on the use of existing legislation. I am not suggesting that new legislation will not produce changes, but it is use of legislation that will determine the extent of changes. In this respect, an increasing consciousness in society about the need to improve safety may influence the use of the law. The law may have to adapt if individuals and organisations adopt specialist roles to deal with safety related issues. For construction, this *could be the introduction of hazard auditing as a specialist* activity, involving the services of hazard engineers and hazard auditors. Traditional contractual arrangements for construction may need to be changed to accommodate this. In a high level hazard audit of a construction project, the auditor would require access to all processes and organisations involved in the project. This indicates that the auditor's role should be accommodated within contractual arrangements. There is a need to study the implications of this in terms of the legal responsibilities of the auditor and the possible effect on the responsibilities of other contracted parties.

13.5 Auditing within other domains.

Hierarchies that provide the structures for the design of audits could be applicable to other domains such as quality and environmental issues.

It was argued in chapter 10, that safety is integral to quality, (clauses 10.15.5 and 10.17), and it is reasonable to suggest that the framework of activities, systems, and procedures for the provision of safety and quality are similar. Because of this, the hierarchy developed in this thesis might serve as a starting point for the development of a structure that can be used in the design of quality audits.

The growth of knowledge, expanding population, and use of technology has determined that what happens in one part of the world or in particular societies cannot be contained. Hazards are created that impact on the environment, societies, and individuals in disparate and unexpected ways. This can affect the ways of life of separate human populations and the planet itself. There is a requirement to investigate and identify these environmental hazards. Environmental audits provide a tool for the identification of environmental hazards. A hierarchy of concepts that relate to the potential to provide evidence of proneness to failure in the environment could provide a structure that can be used in the design of environmental audits.

13.6 Summary and conclusions.

The hierarchy is not complete, and it is to be expected that concepts will be added, changed, and removed at different times. It could be said that there is scope for additional work in just about every concept of the hierarchy. It was an objective of this research to consider safety in as wide a context as possible so that the open world nature of the problems associated with safety were not reduced to convenient "models" of proneness to failure by ignoring those influences that appear most distant or the most difficult to deal with.

A few of the more obvious areas that could benefit from further work have been suggested. That relating to human factors engineering represents a refinement of the hierarchy in its present form. That for hierarchical development of the project phases, other than construction, is a natural extension of research to broaden the problem domain addressed by the hierarchy. The research suggested, relating to the state of society is necessary to facilitate assessment and add to the understanding of influences on proneness to failure that emanate from society. If this particular area of research is not pursued, assessments associated with these influences cannot be credible. Development of knowledge-based systems, on computer, will reduce the scale of the manual process required for auditing and analysis. They provide a tool for the expert, and a means of developing knowledge.

It has been argued that there is a need to develop hazard engineering as a discipline in its own right. It has also been argued that hazard auditing be developed as a specialist activity. For the construction industry, this may mean changes to traditional contractual arrangements. Consideration needs to be given to the possibility of such changes and the legal implications that may result.

The use of hazard audits, designed from the hierarchy, is essential if their effectiveness is to be tested and their value demonstrated. It is envisaged that the most appropriate context for use would be major construction projects which are of a scale that allows for the implementation of a properly designed programme of auditing.

If there is sufficient desire to mitigate failure, there is no reason why the continuing development of the hierarchy, the development of knowledge-based systems as support for experts, and the use of audits designed from the hierarchy, should not progress simultaneously. The cost of further development in comparison with the cost of failures, even in construction, is likely to be negligible, certainly in the long term. So called reasons for justifying existing efforts put into ensuring safety and health may be excuses for not making greater efforts. Quoting the introduction of new legislation as evidence of an improving attitude towards safety might even come into this category. The use of hazard audits is not a panacea for failure, but recognition of hazards is the first step in dealing with them. I would suggest that the development of hazard auditing, as an essential part of hazard engineering, is a worthwhile and potentially profitable area for further research.

References.

ABERCROMBIE, N., HILL, S. AND TURNER, B. S. (1984). *Dictionary of Sociology.* Penguin Books Ltd. London, UK.

ABERFAN DISASTER. (1966). *Report by the Tribunal appointed to inquire into the Disaster at Aberfan on October 21st 1966.* HC 553. 1967. HMSO. London, UK.

ADAMS, E. E. (1985). Accident investigation procedure. - Some guide-lines for classification. *Professional Safety.* Volume 30, No 8. August 1985. Pages 30 - 33.

ADAMS, J. G. U. (1985). *Risk and Freedom: The Record of Safety Regulation.* Transport Publishing Projects. London, UK.

ADAMS, J. G. U. (1988). Risk homeostasis and the purpose of safety regulation. *Ergonomics.* Volume 31, No 4. Pages 407 - 428.

ANDERSON, P. W. P. (1992). Paper Three. What the new duties and responsibilities may mean for major clients' organisations. *Construction Engineering Safety Conference.* 29 September, 1992. Institution of Civil Engineers. London, UK.

ASHBURN, J. H. AND MACDONALD, C. (1987). Implementation of the management safety audit system. *Canadian Institute of Mining and Metallurgy Bulletin.* Volume 80. December, 1987. Pages 25 - 28.

ASHFORD, J. L. (1989). *Quality management in construction. - Certification of product quality and quality management systems.* Special Publication 72. CIRIA. London, UK.

BAKER, M. J. (1986). Quality Assurance. - A critical review. *IABSE Symposium, Tokyo, 1986.* Reports of the working commissions (International Association for Bridge and Structural Engineering.) Volume 51. Safety and Quality Assurance of civil engineering. Published by: IABSE, Zurich, Switzerland, 1986. Pages 15 - 20.

BAYLEY, H. (1986). Developing a safety conscious approach to plant management and operation. *Transactions of the Institution of Diesel and Gas Turbine Engineers.* October 1986. Pages 1 - 8.

BBC2. (1988). *Construction Accidents.* Shown on 18-10-88. Brass Tacks Series.

BLOCKLEY, D. I. (1980). *The nature of structural design and safety.* Ellis Horwood Limited. Chichester, UK.

BLOCKLEY, D. I. (1989). Open World Problems in Structural Reliability. In: Ang, A. H-S., Shinozuka, M. and Schuëller. (Eds). *Structural Safety and Reliability. Proceedings of ICOSSAR '89, the 5th International Conference on Structural Safety and Reliability.* San Francisco. Aug 7-11, 1989. Volume 3. Pages 1659 - 1665.

BLOCKLEY, D. I. (1992). Engineering from reflective practice. *Research in Engineering design.* No 4. Pages 13 - 22.

BLOCKLEY, D. I. AND HENDERSON, J. R. (1980). Structural failures and the growth of engineering knowledge. *Proceedings of the Institution of Civil Engineers.* Part 1, November 1980. Volume 68. Pages 719 - 728.

BLOCKLEY, D. I., TURNER, B. A. AND PIDGEON, N. F. (1991). *Hazard Engineering.* (Unpublished Manuscript).

BRITISH CHEMICAL INDUSTRY SAFETY COUNCIL. (1969). *Safe and Sound. - Report on Safety Practices in the U.S. Chemical Industry.* Chemical Industries Association Ltd. London, UK.

BRITISH CHEMICAL INDUSTRY SAFETY COUNCIL. (1973). *Safety audits. - A guide for the chemical industry.* Chemical Industries Association Limited. London, UK.

BS 4778: Quality vocabulary. Part 1: 1987. International terms. British Standards Institution. London, UK.

BS 4778: Quality vocabulary. Part 2: 1979. National terms. British Standards Institution. London, UK.

BS 5750. Quality Systems. Part 0. Principal concepts and applications. Section 0.1, 1987. Guide to selection and use. Section 0.2, 1987. Guide to quality management and quality system elements. British Standards Institution. London, UK.

BSI HANDBOOK. (1990). *Quality Assurance.* British Standards Institution. London, UK.

BUCHER, R. (1957). Blame and hostility in disaster. *American Journal of Sociology.* 1957. Volume 62. Pages 467 - 475.

BUILDING ADVISORY SERVICE AND HEALTH AND SAFETY TECHNOLOGY AND MANAGEMENT LTD. (1990). *Construction Chase.* HASTAM Ltd & Building Advisory Service. London, UK.

BUILDING REGULATIONS. (1985). HMSO. London, UK.

BURGESS, R. G. (1984). *In the Field. An Introduction to Field Research.* Allen and Unwin. UK.

BUTLER, B. (1989). Safety first. - Profits last? *Quality and Reliability Engineering International.* Volume 5. 1988. Pages 95 - 100.

CASTI, J. L. (1989). *Paradigms lost. Images of man in the mirror of science.* Abacus. London, UK.

CBI. (1990). *Developing a Safety Culture.* London, UK.

CHAMBERS ENGLISH DICTIONARY. (1988). W & R Chambers Ltd and Cambridge University Press. Cambridge, UK.

CHECKLAND, P. (1981). *Systems Thinking, Systems Practice.* John Wiley and Sons. Chichester, UK.

CHEMICAL INDUSTRIES ASSOCIATION. (1991). *Guidance on safety, occupational health and environmental protection auditing.* Chemical Industries Association. London, UK.

CHILD, J. (1984). *Organization: A guide to problems and practice.* Harper and Row. London, UK.

CHURCHMAN, C. W. (1968). *The systems approach.* Dell Publishing Co. Inc. New York, USA.

CIMAH. (1984). *Control of Industrial Major Hazards (CIMAH) 1984 Regulations.* HMSO. London, UK.

CIRIA. Special Publication 55. (1988). *A clients guide to quality assurance in construction.* CIRIA. London, UK.

CIRIA. Technical Note 121. (1985). *Sample quality assurance documents.* CIRIA. London, UK.

COHEN, A. (1977). Factors in successful occupational safety programmes. *Journal of Safety Research.* Volume 9, No 4. December 1977. Pages 168 - 178.

COLLARD, R. (1989). *Total Quality. Success though people.* Institute of Personnel Management. London. UK.

COLLINGRIDGE, D. (1980). *The Social Control of Technology.* Open University Press. Milton Keynes. UK.

COMERFORD, J. B. AND BLOCKLEY, D. I. (1992). Managing Safety and Hazards through Dependability. *Journal of Structural Safety.* In Press.

CONSTRUCTION WEEKLY. (1990). *TML in race with time to implement safety rating.* 11th July. Page 6.

CONTRACT JOURNAL. (1991). *Civils "gets the dumbos".* 27th June 1991. Page 6.

COOPER, D AND CHAPMAN, C. (1987). *Risk Analysis for Large Projects. Models, Methods and Cases.* John Wiley and Sons Ltd. Chichester, UK.

COWAN, R. S. (1985). How the refrigerator got its hum. In: MacKenzie, D. and Wajcman, J. (1985). (Eds) *The social Shaping of technology.* Open University Press. Milton Keynes, UK.

CUI, W. AND BLOCKLEY, D. I. (1990). Interval Probability Theory for Evidential Support. *International Journal of Intelligent Systems.* Volume 5. Pages 183 - 192. John Wiley and Sons Inc.

CULLEN, W. G. (1990). *The Public Inquiry into the Piper Alpha Disaster.* (2 Volumes). Report by the Hon Lord Cullen. HMSO. London, UK.

DAVIES, V. J. (1992). Paper Four. What the new duties and responsibilities may mean for Professional advisors. *Construction Engineering Safety Conference.* 29 September, 1992. Institution of Civil Engineers. London, UK.

DAVIES, V. J. AND TOMASIN, K. (1990). *Construction Safety Handbook.* Thomas Telford. London, UK.

DEJOY, D. M. (1985) Attributional Processes and Hazard Control Management in Industry. *Journal of Safety Research.* Volume 16, No 2. Summer. Pages 61 - 71.

DHILLON, B. S. (1986). *Human Reliability. With Human Factors.* Pergamon Press. New York, USA.

DOUGLAS, M. (1982). *In the Active Voice.* Routledge and Kegan Paul. London, UK.

EISNER, H. (1991). Safety: the perils of self regulation. *New Scientist.* 12th January, 1991.

Page 22.

ERICSSON, K. A. AND SIMON, H. A. (1984). *Protocol Analysis: Verbal Reports as Data.* MIT Press. Cambridge, MA, USA.

EUROPEAN COMMUNITIES COMMISSION COUNCIL DIRECTIVES. (1989). Council Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work. 12 June 1989. *Official Journal of the European Communities. (No. L183).*

EUROPEAN COMMUNITIES COMMISSION COUNCIL DIRECTIVES. (1992). Council Directive 92/57/EEC on the implementation of minimum safety and health requirements at temporary or mobile construction sites. Original proposal. 24 June 1992. *Official Journal of the European Communities.*

FEYNMAN, R. P. (1989). *What do you care what other people think.* Unwin Paperbacks. London, UK.

FIDO, A. T. AND WOOD, D. O. (1989). *Safety management systems.* Further Education Unit. London, UK.

FREEMAN, R. A. (1985). The Use of Risk Assessment in the Chemical Industries. *Plant/Operations Progress.* Volume 4, No 2. April, 1985. Pages 85 - 89.

GAINES, B. R. AND SHAW, M. L. G. (1980). New directions in the analysis and interactive elicitation of personal construct systems. *International Journal of Man-Machine Studies.* Volume 13, 1980. Pages 81 - 116.

GAMMACK, J. G. AND YOUNG, R. M. (1985). Psychological techniques for eliciting expert knowledge. In: Bramer, M. A. (Ed). *Research and Development in Expert Systems.* Cambridge University Press. Cambridge, UK.

GAUNT. L. (89-2). Research Report. *The effect of the International Safety Rating System (I.S.R.S.) on organisational performance.* The Centre for Risk Management and Insurance Research. Georgia State University. U.S.A.

GIDDENS, A. (1989). *Sociology.* Polity Press. Cambridge, UK.

GITTUS, J. H. (1986). Risk Assessment. *Physics in Technology.* Volume 17, No 2. March 1986. Pages 75 - 82.

GLASER, B. G. AND STRAUSS, A. L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Aldine de Gruyter. New York, USA.

GORDEN, R. L. (1975). *Interviewing: Strategy, Techniques, and Tactics.* The Dorsey Press. Homewood, Illinios, USA.

GROSS, J. G. (1986). Building Structural Failures. - Their Cause and Prevention. *Journal of Professional Issues in Engineering. A.S.C.E.* Volume 112. October, 1986. Pages 236 - 248.

HALE, R. A. AND GLENDON, A. I. (1987). *Individual behaviour in the control of danger.* Elsevier Science Publishers B. V. Amsterdam, The Netherlands.

HANDY, C. B. (1985). *Understanding Organisations.* Penguin Books Ltd. London, UK.

HEALTH AND SAFETY AT WORK ETC. ACT 1974. HMSO. London, UK.

HEALTH AND SAFETY EXECUTIVE. (1976). *Success and Failure in Accident Prevention.* HMSO. London, UK.

HEALTH AND SAFETY EXECUTIVE. (1980). *Effective policies for health and safety.* HMSO. London, UK.

HEALTH AND SAFETY EXECUTIVE. (1989). *Human factors in industrial safety.* HMSO. London, UK.

HEALTH AND SAFETY EXECUTIVE. (1991). *Successful Health and Safety Management.* HMSO. London, UK.

HEALTH AND SAFETY EXECUTIVE. (BIANNUAL, January and July). *Publications in series: List of HSC/HSE Publications.* Sheffield, UK.

HEIERMANN, H. (1988). Increasing safety consciousness as an employers task. *Glüehauf and Translation.* Volume 124, No 3. Feb 4, 1988. Pages 72 - 76. English translation. Pages 141 - 144.

HEINRICH, H. W., PETERSON, D. AND ROOS, N. (1980). *Industrial Accident Prevention: A Safety Management Approach.* McGraw-Hill Book Company. New York, USA.

HINZE, J. (1978). Turnover, New Workers, and Safety. *Proceedings of the American Society of Civil Engineers.* Volume 104. Division CO. December 1978. Pages 409 - 417.

HINZE, J. AND HARRISON, C. (1981). Safety Programs in Large Construction Firms. *Proceedings of the American Society of Civil Engineers.* Volume 107. Division CO. September 1981. Pages 455 - 465.

HINZE, J. AND PARKER, H. W. (1978). Safety: Productivity and Job Pressures. *Proceedings of the American Society of Civil Engineers.* Volume 104. Division CO. March 1978. Pages 27 - 34.

HOWARD, W. B. (1988). Process safety technology and the responsibility of industry. *Chemical Engineering Progress.* Volume 84. September 1988. Pages 25 - 33.

HSC CONSULTATIVE DOCUMENT. (1989). *Consultative document: Construction management: Proposals for regulations and an approved code of practice. 1989.* Health and Safety Executive. UK.

HSC. CONSULTATIVE DOCUMENT. (1992). *Consultative document: Proposals for Construction (Design and Management) Regulations and Approved Code of Practice.* 1992. Health and Safety Executive. UK.

HSC NEWSLETTER. (February 1992). *HSC Annual Report 1990/91.* No 81. Health and Safety Commission. Bootle, UK.

HSC. (1989/90). *Annual Report. 1989/90.* HMSO. London, UK.

HUGHES, T. P. (1985). Edison and electric light. In: MacKenzie, D. and Wajcman, J. (1985). (Eds) *The social Shaping of technology.* Open University Press. Milton Keynes, UK.

INTERNATIONAL ATOMIC ENERGY AGENCY. (1980). *Quality Assurance Auditing for Nuclear Power Plants: A Safety Guide.* International Atomic Energy Agency. Vienna, Austria.

INTERNATIONAL LOSS CONTROL INSTITUTE. (1988). *International Safety Rating System.* Institute Publishing. (Division of International Loss Control Institute). Loganville, GA,. U.S.A.

KALDOR, M. (1985). The armament process. In: MacKenzie, D. and Wajcman, J. (1985). (Eds) *The social Shaping of technology.* Open University Press. Milton Keynes, UK.

KAMINETZKY, D. (1991). *Design and Construction Failures. Lessons from Forensic Investigations.* McGraw-Hill, Inc. New York, USA.

KHARBANDA, O. P. AND STALLWORTHY, E. A. (1986). *Management disasters: and how to prevent them.* Gower Publishing Company. Aldershot, UK.

KLETZ, T. A. (1985a). *What went wrong? Case histories of process plant disasters.* Gulf Publishing Company. Houston, USA.

KLETZ, T. A. (1985b). *An engineer's view of human error.* Institution of Chemical Engineers. Rugby, UK.

KLETZ, T. A. (1985c). *Cheaper, safer Plants.* Institution of Chemical Engineers. Rugby, UK.

KLETZ, T. A. (1986). *HAZOP and HAZAN. Notes on the identification and assessment of hazards.* Institution of Chemical Engineers. Rugby, UK.

KLETZ, T. A. (1988). *Learning from Accidents in Industry.* Butterworths. London, UK.

KLETZ, T. A. (1990). *Critical Aspects of Safety and Loss Prevention.* Butterworths. London, UK.

KNOWLES, R. (1992). The Quality Professional in the 1990's. *Quality Forum.* Volume 18. Number 2. June 1992. Pages 63 - 68.

KOESTLER, A. (1967). *The Ghost in the Machine.* Picador. London, UK.

KRIPPENDORFF, K. (1975). *Information theory.* In: Hanneman, G. J. and McEwan, W. J. (Eds). *Communication and behaviour.* Addison-Wesley Publishing Company. USA. Pages 351 - 389.

LANGER, E. (1980). The Psychology of chance. In: Dowie, J. and Lefrere, P. (Eds). *Risk and Chance.* Open University Press. Milton Keynes, UK.

LAUFER, A. (1987). Construction Accident Cost and Management Safety Motivation. *Journal of Occupational Accidents.* Volume 8, No 4. April 1987. Pages 295 - 315.

LEOPOLD, E. AND LEONARD, S. (1987). Costs of construction accidents to employers. *Journal of Occupational Accidents.* Volume 8, No 4. April 1987. Pages 273 - 294.

LESSEM, R. (1991). *Total quality learning.* Basil Blackwell Ltd. Oxford, UK.

LEVITT, R. E. AND PARKER, H. W. (1976). Reducing Construction Accidents. - Top Management's Role. *Proceedings of the American Society of Civil Engineers.* Volume 102. Division CO. September 1976. Pages 465 - 478.

LITTLEJOHN, S. W. (1983). *Theories of Human Communication.* Wadsworth Publishing Company. California, USA.

LOWERY, R., MOORE, S. L., AND THOMAS, E. J. (1988). Safety performance: Results can be achieved. *Professional Safety.* Volume 33, No 8. August 1988. Pages 11 - 18.

MACKENZIE, D. AND WAJCMAN, J. (1985). (Eds) *The Social Shaping of Technology.* Open University Press. Milton Keynes, UK.

MAGEE, B. (1982). *Popper.* Fontana. London, UK.

MAGYAR JR., S. V. (1983). Measuring safety performance. A management guide. *Professional Safety.* November, 1983. Pages 18 - 25.

McCORMICK, N. J. (1981). *Reliability and Risk Analysis: methods and nuclear power applications.* Academic Press. Boston, USA.

McKENNA, F. P. (1987). Behavioural Compensation and Safety. *Journal of Occupational Accidents.* Volume 9, No 2. August 1987. Pages 107 - 121.

MELCHERS, R. E. (1987). *Structural Reliability. Analysis and Prediction.* Ellis Horwood Limited. Chichester, UK.

MENDEZ, S. R. (1987). Defining and developing and operating an effective safety and health programme. *Solar Cells. - Their source, technology, allocation and economics.* Volume 19, No 3-4. January 1987. From *Proceedings of the SERI Photovoltaics Safety Conference.* Lakewood, CO, USA. January 16 - 17, 1986. Pages 333 -336.

MERKHOFFER, M. W. (1987). Quantifying Judgemental Uncertainty: Methodology, experiences and insights. *IEEE Transactions on Systems, Man and Cybernetics.* SMC 17. Pages 741 - 752.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD. (1977). *Water for Irrigation.* HMSO. London, UK.

MONK, D. (1988). The Fine Art of Safety Audits. *Chemical Engineering Progress.* Volume 84, No 9. September 1988. Pages 34 - 37.

MOORE, G. (1988). Risk Assessment. - Black art or science? *IEE Review.* Volume 34, No 4. April 21, 1988. Pages 151 - 153.

MORTENSEN, C. D. (1972). *Communication: The study of human interactions.* McGraw-Hill. New York, USA.

MURRELL, K. F. H. (1965). *Ergonomics. Man in His Working Environment.* Chapman and Hall. London, UK.

NEW CIVIL ENGINEER. (1990a). *Policy on safety.* 24th May, 1990. Pages 25 - 26.

NEW CIVIL ENGINEER. (1990b). *Girls death prompts site safety rethink.* 15th February, 1990. Page 7.

NEW CIVIL ENGINEER. (1991). *Kenchington Little found guilty of endangering public.* (Page 8). *Legal Shock Waves.* Pages 10 and 11. 25th July, 1991.

NEW CIVIL ENGINEER. (1992a). *Active role for site safety.* 8th October, 1992. Page 28.

NEW CIVIL ENGINEER. (1992b). *Designer Safety.* 1st October, 1992. Page 15.

NEWELL, J. E. (1987). Human Factors in the Attainment of Quality and Safety in Design.

The Nuclear Engineer. Volume 28, No 3. May-June, 1987. Pages 66 - 73, and 85.

NOVEGNO, A. AND ASCULAI, E. (1987). In Perspective: The role of safety assessment and risk management. *International Atomic Agency Bulletin.* Volume 29, No 2. Vienna, Austria. Pages 33 - 38.

O'HEAR, A. (1989). *Introduction to the Philosophy of Science.* Oxford University Press. New York, USA.

OBORNE, D. J. (1987). *Ergonomics at Work.* John Wiley and Sons Ltd. Chichester, UK.

OLIVER, G. B. M. (1990). *Quality management in construction. - Interpretations of BS 5750. (1987). - "Quality Systems" for the construction Industry.* Special Publication 74. CIRIA. London, UK.

PEARCE, F. (1992). Sitting on a toxic time bomb. *New Scientist.* 15th August, 1992. Pages 12 - 13.

PERROW, C. (1984). *Normal Accidents: Living with High-Risk Technologies.* Basic Books. New York, USA.

PIDGEON, N. F., TURNER, B. A. AND BLOCKLEY, D. I. (1991). The use of Grounded Theory for conceptual analysis in knowledge elicitation. *International Journal of Man-Machine Studies.* Volume 35. 1991. Pages 151 - 173.

PIDGEON, N. F., TURNER, B., BLOCKLEY, D. I. AND TOFT, B. (1991). Corporate Safety Culture: Improving the Management Contribution To System Reliability. In: Matthews, R. H. (Ed). *Proceedings of European Reliability 1991 Conference.* (1991). Pages 682 - 690. Elsevier Applied Science. London, UK.

PIÉSOLD, D. (1991). *Civil Engineering Practice: Engineering success by analysis of failure.* McGraw-Hill Book Company (UK) Limited. Maidenhead, UK.

POPPER, K. R. (1972). *Conjectures and Refutations. The Growth of Scientific Knowledge.* Routledge and Kegan Paul. London, UK.

POWER, R. D. (1985). *Quality assurance in civil engineering.* Report 109. CIRIA. London, UK.

PUGSLEY, A. P. (1969). The engineering climatology of structural accidents. In: Freudenthal, A. M. (Ed), *Proceedings of International Conference on Structural Safety and Reliability.* Smithsonian Institute of History and Technology, Constitution Avenue, Washington, D. C. April 9, 10 and 11, 1969. Pergamon. New York, USA.

RAMSEY, J. D., BURFORD, C. L. AND BESHIR, M. Y. (1986). Systematic classification of unsafe worker behaviour. *The International Journal of Industrial Ergonomics.* Volume 1, No 1. August 1986. Pages 21 - 28.

RASMUSSEN, J. (1986). *Information Processing and Human-Machine Interaction. An Approach to Cognitive Engineering.* Series Volume 12. North-Holland, Elsevier Science Publishing Co., Inc. New York, USA.

REASON, J. (1990). *Human Error.* Cambridge University Press. Cambridge, UK.

REED, D. A. AND HINZE, J. (1986). A study of Construction Safety in Washington State, USA. *Reports of the working commission (International Association for Bridge and Structural Engineering). Volume 51. IABSE Symposium. Tokyo. 1986. Safety and quality assurance in civil engineering structures. Preliminary report.* Pages 345 -

350.

RIDDOR. (1985). *The reporting of injuries, diseases and dangerous occurrences regulations 1985.* HMSO. London, UK.

ROBENS, LORD. (1972). *Safety and Health at Work Cmnd 5034.* 1972. (Robens Report) Para. 28. HMSO. London, UK.

RUSSELL, M. AND GRUBER, M. (1987). Risk Assessment in Environmental Policy-Making. *Science.* Volume 236. 17 April, 1987. Pages 286 - 290.

RYBCZYNSKI, W. (1983). *Taming the Tiger. The Struggle to Control Technology.* Penguin Books. New York, USA.

SAMELSON, N. M. AND LEVITT, R. E. (1982). Owner's Guidelines for Selecting Safe Contractors. *Proceedings of the American Society of Civil Engineers.* Volume 108. Division CO. December 1982. Pages 617 - 623.

SANDERS, M. S. AND McCORMICK, E. J. (1987). *Human Factors in Engineering and Design.* McGraw-Hill Book Company. New York, USA.

SHANNON, C. AND WEAVER, W. (1963) *The Mathematical Theory of Communication.* University of Illinois Press. Urbana, USA.

SIBLEY, P. G. AND WALKER, A. C. (1977). Structural accidents and their causes. *Proceedings of the Institution of Civil Engineers.* Part 1. Volume 62. May 1977. Pages 191 - 208.

SLOVIC, P. (1987). Perception of risk. *Science.* Volume 236. 17 April, 1987. Pages 280 - 285.

SLOVIC, P., FISCHOFF, B. AND LICHTENSTEIN, S. (1982). Facts versus fears: Understanding perceived risk. In: Kahneman, D., Slovic, P. and Tversky. (Eds). (1982). *Judgement under uncertainty: Heuristics and biases.* Cambridge University Press. Cambridge, UK.

STEINER, V. (1987). Assessing the Safety Climate of a Plant Yields Long Term Benefits. *Plant Engineering.* (Barrington, Illinois). Volume 41, No 8. April 23, 1987. Pages 26 - 29.

STONE, J. R. (1989). *Expert System Learning from Structural Failures.* Ph. D. Thesis. University of Bristol. UK.

STRAUSS, A. L. (1987). *Qualitative Analysis For Social Scientists.* Cambridge University Press. Cambridge, UK.

TAYLOR, P. (1990). *The Hillsborough Stadium Disaster. 15th April, 1989.* Inquiry by the Rt Hon Lord Justice Taylor. Final Report. HMSO. London, UK.

THE ROYAL SOCIETY. (1983). *Risk Assessment. A Study Group Report.* The Royal Society. London, UK.

THOFT-CHRISTENSEN, P. AND BAKER, M. J. (1982). *Structural Reliability Theory and Its Applications.* Springer-Verlag. Berlin, Germany.

THOMPSON, M., ELLIS, R., AND WILDAVSKY, A. (1990). *Cultural Theory.* Westview Press. Colorado, USA.

TOFT, B. (1990). *The failure of hindsight.* Ph.D. Thesis. University of Exeter. UK.

TOMLINSON, M. J. (1986). *Foundation Design and Construction.* Longman Scientific and Technical. Harlow, UK.

TURNER, B. (1978). *Man Made Disasters.* Wykeham. London, UK.

TUSA, W. (1986). Risk Assessment: Engineering Tool. *Civil Engineering (New York).* Volume 56, No 2. February, 1986. Pages 59 - 61.

TVERSKY, A. AND KAHNEMAN, D. (1974). Judgement under Uncertainty: Heuristics and Biases. *Science.* Volume 185. 1974. Pages 1124 - 1130.

VARADARAJAN. S. (1986). Safety and quality in chemical industry. *Chemical Age of India.* Volume 37, No 1. January 1986. Pages 25 - 29.

VICKERS, G. (1970). *Freedom in a Rocking Boat.* Penguin Books Ltd. London, UK.

VICKERS, G. (1983). *The art of judgement: A study of policy making.* Harper and Row Limited. London, UK.

VINCK, W. F., GILBY, E. V. AND CHICKEN, J. C. (1987). Quantified Safety objectives in High Technology: Meaning and Demonstration. *Nuclear Safety.* Volume 28, No 4. October-December, 1987. Pages 461 - 471.

WALSTER, E. (1966). Assignment of responsibility for an accident. *Journal of Personality and Social Psychology.* 1966. Volume 3, No 1. Pages 73 - 79.

WILDE, G. J. S. (1982). The Theory of Risk Homeostasis: Implications for Safety and Health. *Risk Analysis.* Volume 2, No 4. Pages 209 - 225.

WILSON, B. (1990). *Systems: Concepts, Methodologies and Applications.* John Wiley and Sons. Chichester, UK.

APPENDIX A.

CONCEPTS FROM LITERATURE SURVEY

DIRECTLY RELATED TO SAFETY.

1.1 ACCIDENT RECORDS.
1.2 NEAR MISS AND MINOR ACCIDENT REPORTING.
1.3 INVESTIGATION OF ACCIDENTS.
1.4 ANALYSIS OF ACCIDENTS AND INCIDENTS.
1.5 CONSTRUCTION ACCIDENTS.
1.6 ACCIDENT INVESTIGATION AND ANALYSIS AS A WHOLE OR IN GROUPS.
1.7 INDEPENDENT INVESTIGATION OF ACCIDENTS.
1.8 ACCIDENT COSTS PUT AGAINST PROJECT.
1.9 ACCIDENT COSTS SHOULD BE CIRCULATED.
1.10 ACCIDENTS ARE MULTI-CAUSAL.

2.1 DESIGN INTENTION.
2.2 LAYOUT AND LOCATION OF PROJECT.
2.3 DESIGN PROCESS. EXPERIENCE, WORKING ENVIRONMENT, SOCIAL INFLUENCES, ECONOMIC INFLUENCES, DESIGN METHODS, USE OF EQUIPMENT, ETC.
2.4 STRUCTURAL SAFETY.
2.5 DESIGN INFLUENCE ON SAFETY DURING CONSTRUCTION.
2.6 DESIGN INFLUENCE ON SAFETY DURING OPERATION.
2.7 DESIGN CONSTRUCTION OPERATION INTERACTION.
2.8 PRE DESIGN, CONCEPT DESIGN.
2.9 THE APPROPRIATENESS OF THE CODES BEING USED IN DESIGN.
2.10 VARIATIONS IN DESIGN.

3.1 UNSAFE ACTS.

4.1 UNSAFE CONDITIONS.

5.1 MANAGEMENT COMMITMENT AND INVOLVEMENT.
5.2 MANAGEMENT COMFORTABLE WITH AUDIT.
5.3 AUDIT OF MANAGEMENT SYSTEMS. - SEE THE ISRS METHODOLOGY.

6.1 DETAILED PLANNING, PROGRAMMING OF CONSTRUCTION INCLUDING METHOD STATEMENTS, PROCEDURES, SAFETY IMPLICATIONS ETC.
6.2 CONSTRUCTION PROCESS. EXPERIENCE, WORKING ENVIRONMENT, SOCIAL INFLUENCES, ECONOMIC INFLUENCES, CONSTRUCTION METHODS, USE OF EQUIPMENT. ETC.
6.3 THE INFLUENCE OF CONSTRUCTION ON DESIGN.

7.1 SAFETY CULTURE.
7.2 ORGANISATIONAL INFLUENCES.
7.3 INDIVIDUAL INFLUENCES.
7.4 THE DEVELOPMENT OF SAFETY CULTURE, BY: LEARNING, FOSTERING, PROMOTION, DISCUSSION, DESIRE, NOT COMPROMISING PRODUCTION.

7.5 ASSESSMENT OF SAFETY CULTURE.

8.1 STORAGE DURING CONSTRUCTION AND OPERATION.

9.1 MAINTENANCE ON THE COMPLETED PROJECT.

10.1 HOUSEKEEPING.

11.1 LIST OF QUESTIONS FROM "THE NATURE OF STRUCTURAL DESIGN AND SAFETY" BY D BLOCKLEY.

12.1 LIST OF QUESTIONS FROM "BUILDING FAILURES" BY T. McKAIG.

13.1 PATTERNS FROM PAST FAILURES.
13.2 LEARNING FROM PAST EXPERIENCE.

14.1 COMMUNICATION ACROSS HIERARCHY. MANAGEMENT - SUPERVISION - WORK-FORCE.
14.2 INFORMATION ON RISKS MADE KNOWN ACROSS THE ORGANISATION.
14.3 COMMUNICATION REQUIRED TO BALANCE PERCEPTIONS.
14.4 COMMUNICATION OF ACCIDENT RECOMMENDATIONS.

15.1 THE EFFECT OF WORK-FORCE TURNOVER.
15.2 WORK-FORCE TURNOVER IS INEVITABLE. MEASURES ARE REQUIRED TO COUNTER THE EFFECTS.
15.2 MARITAL STATUS AND AGE OF WORK-FORCE.
15.3 LENGTH OF SERVICE OF THE INDIVIDUALS IN THE WORK-FORCE.
15.4 APPROPRIATENESS FOR PARTICULAR WORK.
15.5 JOB ASSESSMENT, JOB PLACEMENT AND JOB ADVANCEMENT.
15.6 EMPLOYEE SUPPORT SERVICES.
15.7 EMPLOYEE ACTIONS.
15.8 PRESSURE ON LABOUR FORCE FROM SUPERVISORS.

16.1 PRESSURE ON SUPERVISORS FROM MANAGEMENT.

17.1 WORKING ENVIRONMENT.

18.1 TRAINING IN SAFETY PROCEDURES.
18.2 ONGOING INSTRUCTION IN SAFETY PROCEDURES.

19.1 TRAINING IN JOB SKILLS.
19.2 FOLLOW UP INSTRUCTION IN JOB SKILLS.

20.1 EQUIPMENT AND PROCESS DESIGN.

21.1 HAZARDS OF MATERIALS.

22.1 SAFETY CENTRES.
22.2 SAFETY COMMITTEES.

23.1 EMERGENCY PROCEDURES.

24.1 MANAGEMENT MUST BE GIVEN ACCIDENT RATE INFORMATION.
24.2 MANAGEMENT AND SUPERVISOR SALARIES SHOULD BE INFLUENCED BY THEIR SAFETY RECORDS.
24.3 ACCIDENT RATE INFORMATION SHOULD BE MADE KNOWN THROUGHOUT THE ENTIRE ORGANISATION.

25.1 SAFETY TREATED THE SAME AS PRODUCTION AND QUALITY.

26.1 SAFETY EQUIPMENT NOT CHARGED TO PROJECT?

27.1 INSURANCE COSTS.

28.1 SAFETY PROGRAMMES.

29.1 INCENTIVES.
29.2 PUNITIVE ACTION.

30.1 RESPONSIBILITY.
30.2 ACCOUNTABILITY.
30.3 AUTHORITY.
30.4 RELATIONSHIP BETWEEN RESPONSIBILITY, ACCOUNTABILITY AND AUTHORITY.
31.1 STATUS OF SAFETY PERSONNEL.

32.1 IS THE COMPANY HIERARCHY SHALLOW OR DEEP?

33.1 GEOGRAPHIC DISPERSION OF PROJECT.

34.1 COST v. BENEFIT OF SAFETY AUDIT.
34.2 COST v. BENEFIT OF SAFETY MEASURES.

35.1 RELATIONSHIP BETWEEN SAFETY PERFORMANCE AND SITE PERFORMANCE?

36.1 SAFETY IS AN "OPEN WORLD" SITUATION.

37.1 DECOMMISSIONING.
37.2 DEMOLITION.

38.1 QUALITY ASSURANCE CHECKS. - QUALITY AUDIT.

39.1 THE EFFECT OF THE AVAILABILITY HEURISTIC.
39.2 THE EFFECT OF OVER-CONFIDENCE OF JUDGEMENTS BASED ON HEURISTICS. - MIND SET, OVER-CONFIDENCE IN CURRENT KNOWLEDGE, FAILURE TO CONSIDER TECHNOLOGICAL SYSTEMS AS A WHOLE, SLOWNESS TO DETECT CUMULATIVE EFFECTS, FAILURE TO ANTICIPATE HUMAN RESPONSE TO SAFETY MEASURES i.e. A FALSE SENSE OF SECURITY IN A SAFETY MEASURE, FAILURE TO ANTICIPATE COMMON MODE FAILURES e.g. COMMON LOCATION OF SERVICE LINES.

40.1 THE INFLUENCE OF ATTRIBUTIONAL PROCESSES.

40.2 EDUCATION REQUIRED AS TO HOW ATTRIBUTIONAL PROCESSES INFLUENCE RESPONSES.

41.1 SAFETY AUDITING IS AN AID TO IMPROVING SAFETY.

42.1 INCREASING LITIGATION INFLUENCING INVOLVEMENT OF ENGINEERS IN CONSTRUCTION.
42.2 STRICT LIABILITY.

43.1 CONTRACTUAL ARRANGEMENTS.
43.2 DISSATISFACTION WITH CONTRACTUAL ARRANGEMENTS.

44.1 FINANCIAL PRESSURES.
44.2 TEMPORAL PRESSURES.
44.3 POLITICAL PRESSURES.
44.4 PROFESSIONAL PRESSURES.

45.1 RISK ASSESSMENT ANALYSIS.

46.1 INDOCTRINATION INTO SAFETY.

47.1 SAFETY SURVEYS.

48.1 MORALE.

49.1 FORMAL POLICY STATEMENT.

50.1 SYSTEMS CONSIDERED BOTH AS A WHOLE AND AS CONSTITUENT PARTS.

51.1 EMPLOYEE, MANAGEMENT RELATIONS.

<u>RELATED TO AUDIT.</u>

100.1 MANAGEMENT COMFORTABLE WITH AUDIT.

101.1 AUDIT IS AN OBJECTIVE EXAMINATION.

102.1 AUDIT EASILY COMMUNICATED AND UNDERSTOOD.

103.1 AUDIT PROVIDES THE BASIS FOR OBJECTIVES AND MEASURES REAL PROGRESS.

104.1 AUDIT CAN BE USED AS A BASIS FOR BONUS OR INCENTIVES.

105.1 AUDIT GENERATES OBSERVABLE IMPROVEMENTS.