System Dynamics Modelling of Occupational Safety: A Case Study Approach

A thesis submitted to the University of Stirling for the degree of Doctor of Philosophy

by

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DECLARATION

This thesis has been composed in its entirety by the candidate. Except where specifically acknowledged, the work described in this thesis has been conducted independently and has not been submitted for any other degree.

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Date____

ABSTRACT

Occupational safety is gaining a higher profile across all sectors of the United Kingdom's economy. This is largely a result of developments in legislation, increased indemnity insurance and the successful promotion of safety practice through the work of the Health and Safety Executive and the writings of health and safety professionals. This thesis has been undertaken to develop a dynamic simulation model of occupational safety strategy using system dynamics and empirically test it in an industrial setting. The work also seeks to capture a measure of the suitability of the occupational safety model as a pedagogic and decision-making aid. The results show that the occupational safety model was successfully developed, tested and evaluated within a firm. A range of alternative scenarios which suggested reductions in accidents at work and the costs of running a safety management system were predicted by the model. The relevant managers of the industrial enterprise were able to appreciate the model's capability for acting as an instruction tool to improve safety in the workplace. They were also able to judge the usefulness of the model for reducing occupational accidents and their related costs.

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CHAPTER ONE

An Introduction to Modelling Occupational Safety

1.1 Introduction to the Occupational Safety

The standards of occupational safety enjoyed by the current labour force in the United Kingdom are largely a combination of developments in criminal and common law dating back over two centuries (Stranks, 1994a). Important statutes have included the Health and Morals of Apprentices Act 1802, Factories and Workshop Acts 1878 and 1901, and the Factories Acts of 1937 and 1961.

Contemporary United Kingdom health and safety legislation stems from the Health and Safety at Work Act 1974, which arose from the Government Committee of Inquiry into health and safety law of 1970-72 (Waring, 1996). The prescriptive legislation of the previous 150 years was largely consolidated and the legislation of the period from 1974 to date encourages more self-regulation and active management of health and safety at work. Employers are responsible for managing the risks in the workplace that they create, rather than simply seeking to comply with specific health and safety regulations. Self-regulation requires proactive management, employee participation in decision-making and a generally positive culture. It was not until 1993 that any new significant health and safety management legislation was introduced in the United Kingdom. These arose from six European Directives resulting from the Single European Act of 1987. These were translated into United Kingdom law (HSE, 1993a). They required employers to take additional measures to manage health and safety. In particular, develop and document their occupational safety management systems. Since these Regulations were passed there has not been any more substantial changes to legislation.

Occupational accident and ill-health statistics, published up to 1992 by the Department of Employment, and thereafter by the Health and Safety Executive show a gradual downward trend over a long period in reported accidents and ill-health. The figures also show that there has been an increase in prosecutions brought against employers for contraventions of health and safety legislation. In addition, magistrates have increased fines for breaches of statutes. Indeed, a number of manslaughter prosecutions have also been brought against employers for negligence of duty (RoSPA, 1993).

A number of studies have indicated that successful business and good health and safety practice are closely associated (HSE, 1991a, 1994b; Everley, 1995a; 1995b; Knutton, 1995). Employers should regard health and safety actions not as cost centres but as contributions to profit. Practical concern for health and safety can contribute to financial performance through the prevention of avoidable loss (Waring, 1996). All accidents, occupational diseases and dangerous occurrences result in loss to firms. These incidents can be regarded as measures of failure (HSE, 1991a). These costs may be considered as direct or indirect. Many firms managers understand some of the direct financial costs such as increased insurance premiums, but fail to appreciate that it is the indirect costs often hidden in other costs that are the highest.

The background offered in the previous paragraphs all point to the legal, moral and financial benefits of maintaining thorough safety management systems. Although, statistics such as one fatality per 100,000 employed in the United Kingdom is the lowest in the world, there is not too much scope for self-congratulation (Davies, 1998). There are still unacceptably high incidences of occupational accidents and ill-health, and the costs to business of the average accident are now estimated to be as high as £3,500. Waring (1996) suggests that a major problem may lie with the content of many health and safety management publications. Often they are narrow and prescriptive and can give the impression that success can be delivered if a particular systematic 'formula' is acted upon. If health and safety management systems are to exploited to good effect then both systematic and systemic aspects of health and safety need to be understood. The use of models to explore and understand the consequences of decisions before action is taken may prove to be valuable in the evaluation by firms of alternative occupational safety strategies.

1.2 Modelling and the Methodological Approach to the Occupational Safety Study

A model may be regarded as a simple representation of reality (Pidd, 1996). It can be physical or abstract in nature. Physical models are usually scale models. They are three-dimensional representations of the problem under study. Common applications include architecture, civil engineering and water management. A scale model is concrete in form and highly specific (Pidd, 1988). To experiment with a scale model always requires physical alterations to the model. As such they are rather inflexible and certainly not appropriate for tackling management issues which are more subtle and open to greater interpretation.

Abstract models have uses well beyond those of physical models. They can be static or dynamic, mathematical or mental, and explicit or implicit. These models offer the opportunity to explore the possible consequences of alternative decisions before taking any action. It is beyond the scope of this work to offer a critique of alternative modelling approaches. This has been done already by a number of authors (Ackoff, 1979; Jackson and Keys, 1984; Lane, 1994; Pidd, 1996).

There are a number of advantages to experimentation with a model rather than reality. Thus the cost of experimentation with a model is usually much less than using reality. Further to, the time it takes to explore options in a model is much lower than in the real world. A model can be used as a vehicle to facilitate debate and discussion amongst decision-makers, which can lead to new insights into their problems, and finally the danger of experimentation in the real world may be avoided using a model.

Given the diversity of models and their advantages over real world experimentation, they are more than mere simplifications of reality. Pidd described them as tools for thinking, and thus defines a model as:

> ...an external and explicit representation of part of reality as seen by the people who wish to use that model to understand, to change, to manage and to control that part of reality (Pidd, 1996, p.15).

The modelling process determines the nature of a model. This process can be regarded as the method of study or methodology. Many modelling methodologies may be used to examine occupational safety strategies. Before they are introduced, the term methodology should be understood. Hussey and Hussey (1997) suggested that a methodology refers to the approach one takes to the process of research, from its theoretical underpinning to the collection and analysis of data. More specifically, Harvey, a geographical modeller, argues that methodology is concerned primarily with:

> ...the logic of explanation, with ensuring that arguments are rigorous, that inferences are reasonable, that method is internally coherent (Harvey, 1969, p.6).

Operational research and management science models using linear programming and decision theory (fault tree analysis) are methodologies which have been successfully applied to the evaluation of safety decisions where uncertain outcomes exist. The domains include systems reliability and process control (Amendola, 1988; Jazwinski and Wazynska-Fiok, 1990; Carpienano, 1994). These methodologies are well suited to tackling problems where the ability of a system to change over time is unimportant to the study. Forecasting models which use time-series data have been used to make temporal predictions of accident rates (Frievalds and Johnson, 1990; Haastrup and Funtowicz, 1992; Bhattacherjee *et al.*, 1994). The main limitation of these time-series models lies in the inability of the models to include causal influence and the need for variables to remain fixed, when it is evident that they are not in the real world.

It appears that the established modelling methodologies may not be suitable for exploring high level decisions about safety at work. This thesis will apply and further develop the methodology of system dynamics to construct an operational model of safety in an industrial setting.

System dynamics was created by Forrester (1961, 1968, 1971), and originally called industrial dynamics. It was developed as a response to a situation in which many problem solving techniques were failing to provide adequate insights into and understanding of strategic problems in complex systems (Wolstenholme, 1990). It is an approach that can be applied to evaluate decisions in any managed system. The system dynamics process involves building models to represent and to study the behaviour of real world systems. The purpose of the modelling effort is to understand and control problematic system behaviour. Its strength lies in its ability to facilitate understanding of the relationship between a system's behaviour over time and its underlying structure, strategy and policies. The structure of a model is contained within interrelated causal feedback loops and based on difference equations. Dynamic model behaviour is achieved using computer simulation. Through repeated experimentation with the simulation model, the design of improved system behaviour can be achieved.

A criticism of system dynamics modelling is the absence of real world data from many models. The belief that policies embedded in an untested model are appropriate is a problem, and this has been considered unacceptable in the past by other more quantitatively orientated modellers (Nordhaus, 1973). However it may not be the methodology that deserves criticism but its use. Concern has also been raised within the system dynamics community about an absence of empirical evidence in many operational models to support their predictions (Maloney, 1993; Homer, 1996, 1997; Lyneis, 1999). Logic dictates that the best way to verify the accuracy and use of a system dynamics model which purports to be representative of reality is to accurately calibrate it with real data, and to measure its simulated behaviour against a real system. Moffatt (1991) partially agrees with Forrester and Senge's (1980) argument that the plausibility of a model lies in its structure, but he argues that this should not allow statistical tests to be abandoned. Fortunately, some system dynamics model builders have proposed a number of formal tests (Graham, 1980; Sterman, 1984; Eberlein and Wang, 1985; Kleijnen, 1995; Barlas, 1989, 1996; Clemson *et al.*, 1995).

Unlike some earlier system dynamics models of industrial systems which were built for specific host firms (Risch *et al.*, 1995; Ford and Sterman, 1998; Zahn *et al.*, 1998) the present study will involve the development of a generic model of occupational safety to be applied to an industrial concern. The host firm is located in central Scotland and engaged in timber and wood processing.

1.3 The Purpose of the Study

A review of relevant literature did not reveal any published work detailing the application of system dynamics modelling to occupational safety in specific firms. The opportunity to make a unique contribution to the body of safety and modelling knowledge exists. The purpose of the work is to explore the feasibility and plausibility of a simulation model of safety at work.

(a) Aim

The aim of this study is to develop a dynamic simulation model of occupational safety using system dynamics and apply the model to a real world manufacturing setting.

(b) Objectives

A total of five objectives need to be met in order to fulfil the aim of the study. These are to:

- Give a critical exposition of the system dynamics method.
- Develop a generic system dynamics model of occupational safety.
- Apply the generic workplace safety model to a real world industrial setting.

- ➢ Simulate different occupational safety policies in order to reduce the numbers of accidents and safety costs in the workplace.
- ➢ Examine the use of the model as a pedagogic tool to investigate the causal links which lead to accidents and other safety performance in the workplace.

The work focuses on the examination of injury accidents in the workplace. Safety at work is the overall theme of the research, although on many occasions, particularly in discussing literature it is necessary and appropriate to study both health and safety together. Occupational health and hygiene lie within the domain of the medical profession, and often due to the long gestation periods for ill-health and disease it is difficult and sometimes impossible to trace causes back to work, and more specifically to certain workplaces. This does not necessarily preclude the study from being of use to those interested in improving health at work, as there are generally strong correlation's between the control of hazards, accidents and ill-health.

1.4 The Structure of the Thesis

The material presented in this study is divided into eight chapters. The thesis clearly falls into two halves. The first half (Chapters Two to Four) concentrates on a discussion of occupational safety and of systems modelling, and with the latter (Chapter Five to Eight) emphasising the development and use of the system dynamics model of workplace safety.

Chapter Two outlines occupational safety at the macro level. The principal legislation which relate to the management of health and safety at work are described. In addition, data on levels of occupational accidents and health and safety enforcement activity in recent years across the United Kingdom are presented and discussed. The chapter finishes with an analysis of the financial costs of accidents at work to both employers and to the national economy. A description of the legislation, enforcement activity and financial costs associated with health and in particular safety is useful as they underpin the safety management systems which are in operation in many places of employment.

The components of an occupational safety management system are examined in Chapter Three, which looks at the development of a systematic approach to safety through a sequential framework developed by the Health and Safety Executive (1991a). The chapter also attempts to show the systemic nature of safety management. The principal components of a safety management system are shown to be policy development, risk assessment and control, staff recruitment and training, and safety monitoring and review.

In Chapter Four the background to systems thinking, the theory and methodological framework of system dynamics, and a discussion of occupational safety models is presented. As well as the principles and method of study in system dynamics, the importance of validation and confidence building is emphasised.

The process by which the generic model of occupational safety is constructed and validated is described in Chapter Five. The chapter contains the results of a number of validation tests of the structure and behaviour of the model.

Chapter Six describes the background to safety in the host firm. The system of collecting and analysing the firm's data, and calibrating the model to fit the firms past safety behaviour is detailed. The chapter finishes by showing the results of behaviour replication tests.

The result of a semi-structured interview conducted with a number of managers in the firm is discussed in Chapter Seven. In the interview it was sought to ascertain the potential of the model as both a policy making and as a learning tool. Following this discussion, the implications of alternative policies adopted by the firm are reviewed by exploring a number of alternative scenarios.

Chapter Eight is the conclusion. The modelling process, its overall usefulness in industrial settings, and implications for further research are presented.

Due to the ongoing debate by modellers on the methodology of system dynamics methodological rigour will be applied to develop a plausible, robust, internally coherent and empirically testable model. If such a model can be developed it should have a policy relevance to be applied in a real world context to reduce accidents at work and to improve the cost effectiveness of occupational safety management systems. This is introduced in Chapter Four, and emphasised throughout Chapters Five and Six.

CHAPTER TWO

United Kingdom Occupational Health and Safety Legislation, Enforcement Activity and Financial Costs

2.1 Introduction to Health and Safety in the United Kingdom

Many employers understand the need for good health and safety practice in the workplace. In recent years the reductions in rates of occupational accidents and illness have been principally driven by the enforcement of the law, although employers have clearly begun to see the financial benefits of good safety management. This has resulted in an increase in health and safety activity.

The purpose of this chapter is to review the principal health and safety statutes and legislation that have helped to raise the effectiveness and profile of health and safety management, and examine the general character of health and safety across the United Kingdom. Section 2.2 introduces the statutes under which health and safety legislation is passed in the United Kingdom. The legal developments in occupational health and safety since the Heath and Safety at Work Act of 1974 are described in Section 2.3. Next, in Section 2.4 recent national accident statistics are presented and the extent of regulatory enforcement activity is discussed. The costs to employers of workplace accidents and ill-health are described in Section 2.5. Finally, in Section 2.6, the contents of the chapter are summarised.

2.2 The Background to Health and Safety Legislation

Since 1974 there has been substantial changes in both the law and practice of occupational health and safety (Stranks, 1994a). Previously, prescriptive standards were thought to suffice. A management-orientated approach with more emphasis on human factors, risk assessment and with employers appointing competent persons to deal with health and safety is now required. This need has been set out in statute (Health and Safety at Work Act, 1974). In order to appreciate how these changes affect health and safety in the workplace a review of the main legislation, past, and particularly present, has been conducted. Table 2.1 is a summary of the main United Kingdom health and safety statutes.

Principal Statutes	Year
Factories Act	1961
Office, Shops and Railway Premises Act	1963
Employers' Liability (Compulsory Insurance) Act	1969
Fire Precautions Act	1971
Health and Safety at Work Act	1974

Table 2.1 Summary of the main United Kingdom health and safety statutes

(a) The Legal Situation with Health and Safety Prior to 1974

The law relating to health and safety at work has its foundations in statute and common law dating back to the early nineteenth century (Stranks and Dewis, 1986). Until the Health and Safety at Work Act (HASAWA) was passed in 1974, protective employment legislation consisted of a number of statutes passed on an *ad hoc* basis (Stranks, 1992). The developments in laws and regulations up to the HASAWA had sought to protect health and safety, and to impose exact safety standards in respect of specific types of factory and the use of certain machines, processes and substances. Attempts had been made to gain uniformity of health and safety across industry but these became ineffective as new hazards were recognised. A total of four Acts passed before the HASAWA are still on the statute book and still relevant to health and safety at work, although parts of these Acts were repealed when the HASAWA came into being. These are the Factories Act, 1961; the Office, Shops and Railway Premises Act, 1963; the Employer's Liability (Compulsory Insurance) Act, 1969; and the Fire Precautions Act, 1971. The contents of these four Acts need to be briefly outlined in order to understand their relevance to current occupational health and safety.

(b) The Factories Act 1961

The Factories Act is a consolidation Act which was consolidated for the last time in 1961 (Simpson, 1990). Most of its major provisions concerning health, safety and welfare continue in force, although parts of the Act have been repealed and replaced with the set of Health and Safety Regulations of 1992 (Stranks, 1994a). The Factories Act solely deals with health and welfare provisions (Factories Act, 1961). It allows the Minister responsible for health and safety at work to make regulations for providing medical supervision when illness appears to have developed through work, or when there may be a risk to health resulting from a change in working conditions. Provisions are also made in the Act to ensure that moving parts of machinery are adequately fenced (Stranks, 1992).

(c) The Offices, Shops and Railway Premises Act 1963

This Act makes provision for securing the health, safety and welfare of persons employed in offices, shop premises and certain railway premises (Offices, Shops and Railway Premises Act, 1963). It superseded parts of the general safety, health and welfare provisions of the Factories Act (Simpson, 1990).

(d) The Employers' Liability (Compulsory Insurance) Act 1969

This Act places a duty on employers to take out and maintain approved insurance policies with authorised insurers against injury or ill-health sustained by employees during their employment (Association of British Insurers, 1995). An employer must be insured for at least £2 million in respect to claims arising out of any one occurrence (Bamber, 1993). Employees made ill or injured at work are entitled to sue their employers for compensation in the civil courts (HSC, 1992b).

(e) The Fire Precautions Act 1971

If any premises is used as a place of work, a certificate is required from the fire authority (Simpson, 1990). The fire authority must be satisfied with the means of escape in case of fire, the means of fire fighting and the means of giving persons in the premises warning in case of fire.

(f) The Robens Committee

The Robens Committee was set up in 1970 in response to criticisms made by many organisations such as trade unions that existing legislation was inadequate (Simpson, 1990). Its remit was to examine the frequency of accidents and dangerous occurrences in places of employment (Jackson, 1979). The investigation encompassed all workplaces. Accidents, health hazards and safety standards were assessed and compared to those overseas.

The recommendations of the Robens Committee were far-reaching. The proposed changes were centred on a movement away from a system of prescriptive health and safety legislation to one of 'self-regulation' (Waring, 1996). The report called for legislation to extend the minimum legal requirements of existing statute (Howells and Barrett, 1975). The recommendations involved granting wider powers for inspectors, and burdened employers with more responsibility. It was expected that those who created risk should manage it in a competent way, as they would be expected to do for any other aspect of running an organisation (Waring, 1996). The legal framework of the Health and Safety at Work Act (HASAWA) of 1974 was based on the recommendations of the Robens Report (Howells and Barrett, 1975; Carthy, 1992).

(g) The Health and Safety at Work Act 1974

The HASAWA did not repeal or replace existing legislation relating to specific workplaces (Carthy, 1992). Instead it is an enabling Act which gives powers to the Secretary of State for Employment to make regulations to replace current legislation (Simpson, 1990). It established a co-ordinating enforcement authority, the Health and Safety Commission (HSC), and provided it with the power to propose health and safety regulations and Approved Codes Of Practice (ACOP) (Simpson, 1990; Dewis, 1985). It set up the Health and Safety Executive (HSE), with the responsibility for enforcing the health and safety laws. Substantive enforcement powers were given to health and safety inspectors, and it made provision for the appointment of safety representatives on behalf of the workforce to monitor health and safety in the workplace, and also for the appointment of safety committees. The regulations and ACOPs were intended to unify all legislation covering health, safety and welfare.

Anyone in breach of the regulations can be prosecuted under the Act (Carthy, 1992). An ACOP provides guidance on health and safety, but does not have legal force. It is an interpretation of an Act or regulations, and is frequently complemented by Guidance Notes. In the event of a prosecution, and when it has been established that the relevant provisions of the Code have not been adhered to, the defendant has to show that the law has been complied with in some other way.

The Act imposes duties on all concerned with work activities (HSC, 1992a). The duties are imposed on individuals through to corporations. These are expressed in general terms so as to apply to all types of work. The principles of safety responsibility and safe working are explained in the general duties sections. Specific legal requirements are also laid down in earlier legislation, which is still in force. A number of duties set out in the Act are 'absolute' and have to be complied with, but many are written as 'so far as is reasonably practicable' (HSE, 1993a). 'Reasonably practicable' means that the degree of risk can be compared for a particular activity against the time, cost, effort and difficulty in avoiding the risk.

All employers must take measures which are reasonably practicable to ensure the health, safety and welfare of their employees at work. This includes measures such as the provision of safe plant, systems of work, safety information, training and supervision. Employees are required to take care for their own health and safety, and also that of others who may be affected by their acts or omissions at work, and to co-operate with their employers to enable statutory provisions to be complied with (Dewis, 1985; Stranks, 1992). Designers, manufacturers, importers and suppliers of articles and substances used at work also have duties under the Act. As far as is reasonably practical, substances supplied must be safe, and must be accompanied by information which makes users aware of the risks to health and safety.

The enforcement of the Act is the responsibility of the HSE via its inspectorate, with certain premises overseen by local authorities and the Fire Authority (Simpson, 1990). An inspector has a wide range of powers, including the right to inspect premises, to conduct interviews with employees and to seize articles, substances or documentation as evidence. If an inspector considers that a breach has occurred, or is likely to occur they may serve an Improvement Notice which requires that a contravention be rectified within a set period (Stranks, 1992). Where an inspector decides that an activity involves immediate risk of serious personal injury, he or she may serve a Prohibition Notice which requires that certain activities are not to be carried out unless the necessary corrective measures have been taken. Failure to comply with an Improvement or a Prohibition Notice can lead to prosecution. If a corporate body is found to have breached statute with the approval of a responsible employee, both the individual and the corporate body are guilty of that offence and are liable under the Act.

Safety representatives can be appointed by recognised trade unions to represent employees in consultations with their employers concerning health and safety, and in particular accident investigations (HSC, 1992a). The safety representatives also attend meetings of safety committees.

The Act imposes a duty on every employer of five or more persons to prepare a written statement of their safety policy and to make it available to employees (Stranks, 1992; HSC, 1992a). This may also be subject to revision (Stranks, 1992). The Policy should set out the employer's aims and objectives for improving health and safety at work (HSC, 1992a). The arrangements for ensuring that adequate levels of safety, health and welfare exist should also be set out, along with the procedures for their implementation.

2.3 Legislation passed through the Heath and Safety at Work Act 1974

There are more than a hundred health and safety regulations currently in existence. These have all been passed using the HASAWA. The principal regulations which relate to the management of workplace health and safety will be reviewed. Most of the regulations relate to specific work practices, and do not necessitate discussion in this study. Hence this section describes the main health and safety regulations passed under the HASAWA to date. These are summarised in Table 2.2:

Principal Regulations	Year
Health and Safety (First Aid) Regulations	1981
Reporting of Injuries, Diseases and Dangerous Occurrences Regulations	1985
Control of Substances Hazardous to Health	1988
Health and Safety (Information for Employees) Regulations	1989
Management of Health and Safety at Work Regulations	1992
Workplace (Health, Safety and Welfare) Regulations	1992
Provision and Use of Work Equipment Regulations	1992
Personal Protective Equipment at Work Regulations	1992
Manual Handling Operations Regulations	1992
Health and Safety (Display Screen Equipment) Regulations	1992
Chemicals (Hazard Information and Packaging) Regulations	1993

Table 2.2 Principal United Kingdom legislation concerned with health and safety at work

(a) The Health and Safety (First Aid) Regulations 1981

There is a duty for the employer to provide first aid arrangements, to inform his or her employees of these arrangements, and for the self-employed person to provide first aid equipment (Stranks, 1992). A suitable number of persons must be available to provide first aid. They must hold an appropriate first aid qualification and be trained adequately.

(b) The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985

The reporting of accidents, occupational diseases and dangerous occurrences has been a legal requirement for a long time (Stranks, 1992). The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985 (RIDDOR) came into effect in April 1986 (Carthy, 1992). Reporting accidents, diseases and dangerous occurrences allows the HSE to monitor accident trends and occupational diseases, to help it improve legislation. Failure to comply with the regulations is a criminal offence. Written reports for accidents involving fatalities, major injuries or illnesses requiring medical attention must be made under the regulation (Simpson, 1990). There is also a requirement to report certain diseases contracted through work. In addition dangerous occurrences must be reported to the enforcing authority, whether an injury has resulted or not (Stranks, 1992). They are specified as the types of incident where there is potential for fatal or major injury or for extensive property damage.

(c) The Control of Substances Hazardous to Health Regulations 1988

The Control of Substances Hazardous to Health (COSHH) provides one set of regulations to extend over occupational health risks, to set out principles to be followed in occupational health, and to make provision for future alterations to standards of control necessary to meet any new hazards. COSHH does not set out requirements for specific circumstances. It sets out a basic system for the management of risk to health (HSE, 1993b). The legal requirement is for a suitable and sufficient assessment. Employers must consider the properties of substances used at work, and have a duty to make health risk assessments, control exposures, carry out monitoring, and arrange for health surveillance (Stranks, 1992). The employer, manufacturer or supplier of substances must know about the potential for harm to employees or others of any substance used or supplied as part of their undertaking.

(d) The Health and Safety Information for Employees Regulations 1989

Information about health, safety and welfare matters has to be made available to employees through posters or leaflets in the form approved and published for the purposes of the regulations by the HSE (Stranks, 1992).

(e) Health and Safety at Work across the European Union

Under the Single European Act (1987), Article 118A was added to the Treaty of Rome. It was concerned with health and safety at work (Stranks, 1992). In the Article the European Union's (EU) member states resolved that health and safety legislation should become harmonised across the Union. Framework Directive 89/391/EEC allowed member states to ensure that their laws achieved the standards required by the EU (Carthy, 1992). In 1993 the UK Government issued six regulations through the HASAWA to comply with the framework directive (HSE, 1993a). The regulations implemented six EC directives on health and safety at work. They clarified the existing health and safety law, but there were some new aspects, particularly concerning health and safety management, manual handling and display screens. Some law was repealed by the new regulations.

(f) The Management of Health and Safety at Work Regulations 1992

The Management of Health and Safety at Work Regulations (MHSWR) of 1992 require employers to assess the risks to health and safety of employees and other people affected by their work activities through the identification of workplace hazards and the evaluation of the extent of the risks involved (HSC, 1992c). This allows preventative and protective measures to be identified. A risk assessment must be documented, periodically reviewed, and if necessary modified. Arrangements are needed to put the health and safety measures that follow the risk assessment into place (HSC, 1992c; HSC, 1992d). This includes planning, organisation, control, monitoring and review, i.e. the elements which are common to any management function.

(g) The Provision and Use of Work Equipment Regulations 1992

The Provision and Use of Work Equipment Regulations (PUWER) 1992 pulled together the fragmented laws governing specific types of equipment. The main objective of PUWER is to ensure the provision of safe work equipment and its safe use (HSC, 1992d). The general duties require that equipment is used only for operations for which it was intended, that sufficient information, instruction and training is administered, and that equipment complies with EU product safety directives.

(h) The Manual Handling Operations Regulations 1992

The Manual Handling Operations Regulations 1992 replaced fragmented and out of date legislation with a more ergonomic approach (HSC, 1992e). They apply to manual handling operations which may risk injury at work. These activities require identification through a risk assessment carried out under the MHSWR.

(i) The Workplace (Health, Safety and Welfare) Regulations 1992

The Workplace (Health, Safety and Welfare) Regulations 1992 replaced 38 pieces of law (HSC, 1992f). The regulations cover many aspects of health, safety and welfare in the workplace, many of which are only implied in the HASAWA. There is a requirement to assess the risks to health and safety associated with the general working environment and the provision of rest areas and hygiene, as well as housekeeping.

(j) The Personal Protective Equipment at Work Regulations 1992

The Personal Protective Equipment at Work (PPE) Regulations 1992 laid out principles for selecting, providing, maintaining and using personal protective equipment (PPE). PPE is equipment designed to be worn or held to protect against a risk to health or safety (HSC, 1992g). This included most types of protective clothing, and equipment such as safety harnesses and head protection.

(k) The Health and Safety (Display Screen Equipment) Regulations 1992

The Health and Safety (Display Screen Equipment) Regulations did not replace existing legislation but cover a new area of work activity. Employers are required to assess the layout and work tasks associated with display screen equipment (HSC, 1992h).

(l) The Chemicals (Hazard Information and Packaging) Regulations 1993

The objective of the Chemicals (Hazard Information and Packaging) Regulations (CHIP) is to assist in the protection of people and the environment from the ill effects of chemicals (HSE, 1994a). CHIP requires that chemicals be classified before any other action is taken, and requires safety data sheets for dangerous chemicals. CHIP obliges suppliers to identify the hazards, supply information, and to package the chemicals they supply safely.

2.4 Accident Statistics, Dangerous Occurrences and Enforcement Activity

(a) Accident and Dangerous Occurrence Figures

The HSC (1994) published accident and dangerous occurrence statistics based on the RIDDOR 1985. These figures can be used as one indicator of occupational health and safety performance in the United Kingdom. Table 2.3 shows injuries by severity reported to the HSE in recent years. The figures all result from work activities and include injuries to employees, the self-employed and members of the public.

Year	Fatal	Major	Over-3-day absence	Total
1986-87	499	35960	160040	196499
1987-88	558	33084	161011	194653
1988-89	730	33710	164622	199062
1989-90	681	33084	167109	200874
1990-91	572	31203	162888	194663
1991-92	473	29707	154338	184518
1992-93	452	28722	143283	172457
1993-94	379	28924	134841	164144

Table 2.3 Injuries by severity 1986-87 to 1993-94 (HSC, 1994, p.6)

The total number of injuries reported in 1993-94 fell for the fourth successive year and was the lowest number reported since the introduction of RIDDOR in 1986-87. The number of fatalities has fallen in each successive year in the 1990s. In 1993-94 there were 379 fatalities, 7% down from the previous year. Similar patterns can be seen for major injuries and injuries causing an employee to be absent from work for over three-days. The fatal injury rate fell from 1.3 per 100,000 employees in 1992-93 to 1.2 in 1993-94. The downward trend continues. Part of the decrease in the fatal injury rate has been due to changes in patterns of employment since the mid-1980s, with a growth in employment in services, and decline in the number of employees in the more hazardous sectors of energy, manufacturing and agriculture. The rate for fatal and major injuries combined fell slightly in 1992-93 from 82 per 100,000 employees to 79 in 1993-94. The 1993-94 rate is substantially below the average for the seven years from 1986-87. Figure 2.1. reflects the trend across several industrial sectors:

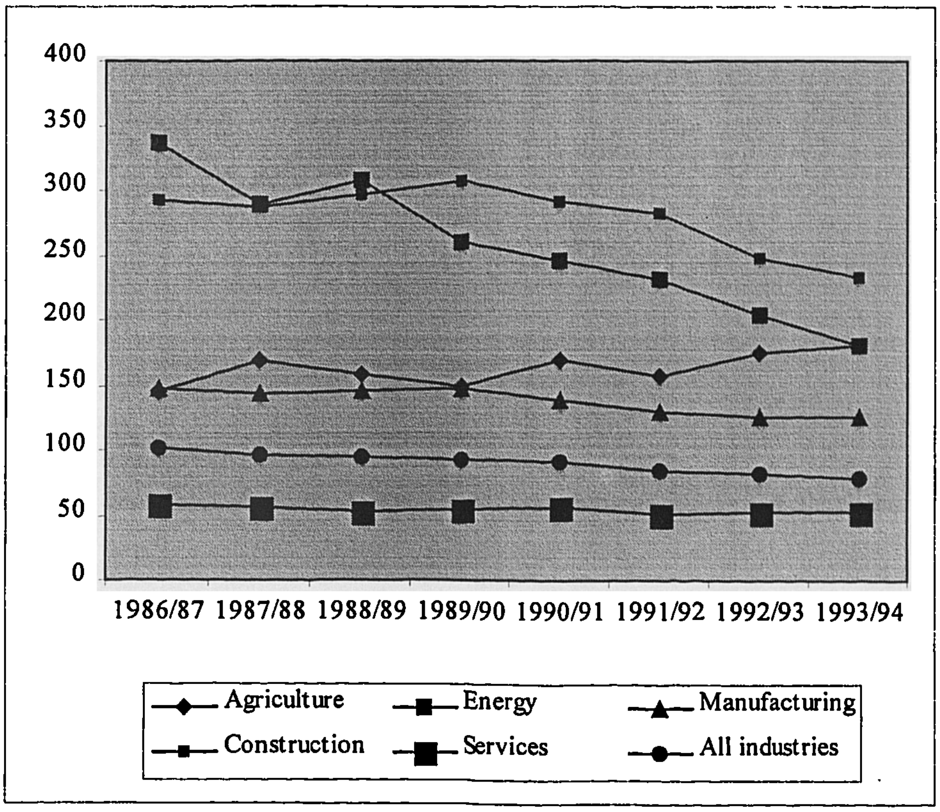

Figure 2.1 Fatal and major injury rate per 100,000 employees, 1986-87 to 1993-94 by sector (HSC, 1994,p.9)

Figures showing numbers of dangerous occurrences should be treated with caution, as not all reportable dangerous occurrences are reported. Figure 2.2 summarises the available statistics:

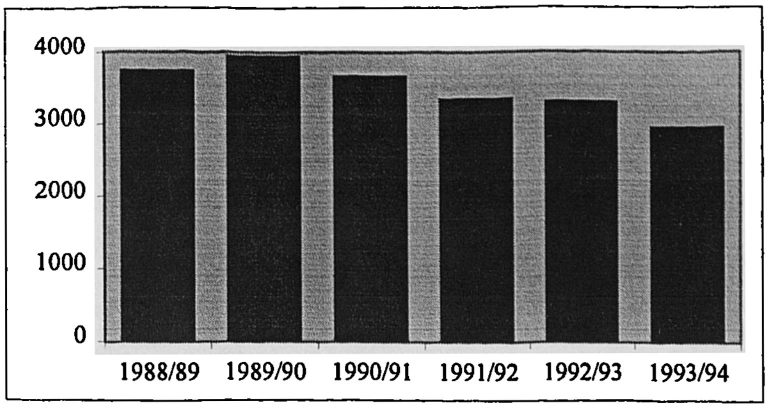

Figure 2.2 Dangerous occurrences reported to the HSE Inspectorates, 1989-90 to 1993-94

In 1993-94, just over 2,950 dangerous occurrences were reported to the HSE, the lowest number reported since RIDDOR came into force in 1986-87, more than 400 fewer than the average for the previous seven years.

(b) Health and Safety Enforcement Activity

As discussed in Section 2.2, under the HASAWA Act, the HSE was set up to ensure that employers complied with legislation relating to health and safety at work. In addition, local authorities were given the power to prosecute for contravention of the law. This section discusses the trends in occupational health and safety enforcement activity in recent years.

Just under 39,000 notices were issued by all enforcement authorities in 1992-93. This compares with 34,100 in 1991-92 and 14 529 in 1985-86. Figure 2.3 shows that there is an upward trend in the number of Enforcement Notices issued by the authorities. Just over 80% of all notices issued in 1992-93 were Improvement Notices and the other almost 20% were Prohibition Notices.

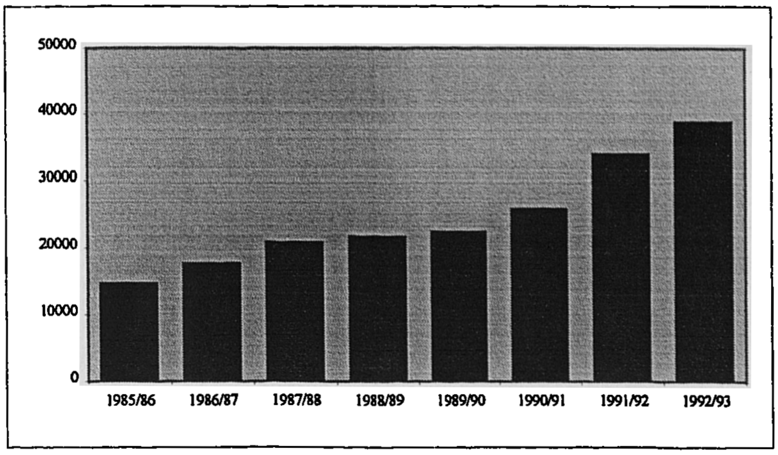

Figure 2.3 Enforcement notices issued by enforcement authorities, 1985-86 to 1993-94 (HSC 1994, p.107)

(c) <u>Prosecutions Brought about by the Enforcement Authorities</u>

Prosecution statistics are based on the informations which is evidence laid by inspectors before the courts. Each information laid relates to a breach of an individual legal requirement, and a case may involve more than one of these breaches. Figure 2.4 shows the number of informations laid by HSE inspectorates and HSC agencies compared to successful convictions for contravention of health and safety legislation from 1985 to 1994. The number laid in 1993-94 was 1,793, of which 1,507 were successful convictions. This represents a conviction rate of 84%. The trend shows a gradual decline in informations brought before the courts and subsequent convictions.

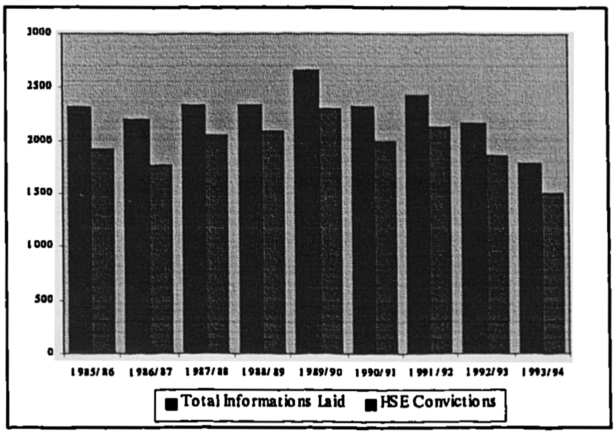

Figure 2.4 Successful proceedings instituted by enforcement authorities, 1985-86 to 1993-94 (HSE, 1994c, p.109)

(d) Fines Levied for Contravention of Health and Safety Legislation

Trends in average fines for contravention of health and safety legislation are complicated. This pattern is reflected in Figure 2.5 over the period from 1985 to 1994. The statistics are complicated by a small number of fines awarded against some companies in the higher courts. However, fines continue to rise with a marked increase from £1,390 in 1992-93 to £3,061 in 1993-94.

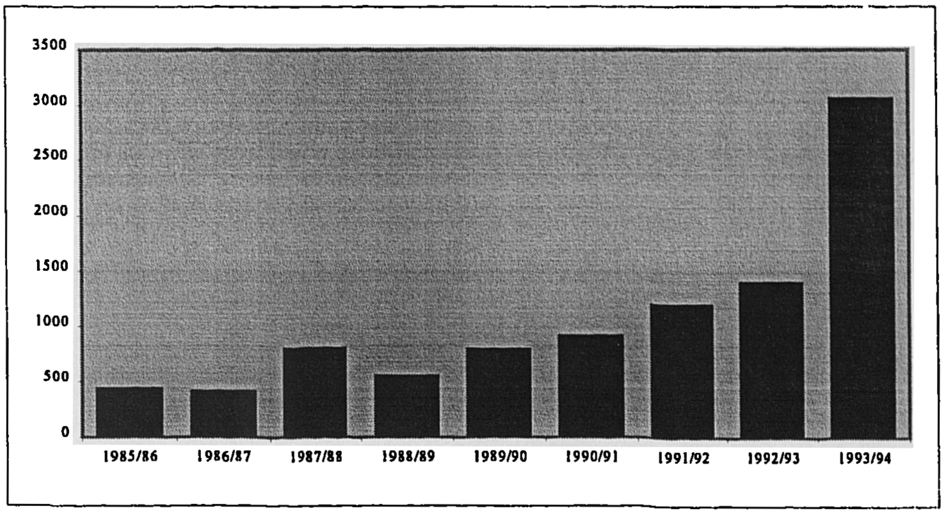

Figure 2.5 Average penalty fines per successful conviction, 1985-86 to 1993-94 (HSE, 1994b, p.109)

(e) Manslaughter Prosecutions

One could consider the denial of one's liberties as the potential cost of an accident (Dewis, 1992). There is scope in Section 37 of the HASAWA, which foreshadows prosecutions against corporate bodies for the offences of directors and the company board. The corporate body and individual directors can be charged under the Act. A company could be found guilty of manslaughter of an involuntary sort, and receive a fine or even imprisonment of directors.

2.5 The Costs of Occupational Accidents

All accidents, occupational diseases and dangerous occurrences result in losses to employers. The costs may be considered as direct or indirect (insured or uninsured). In the next chapter a fuller description of these types of cost will be given. The results of a study by the HSE (1993c) on the costs of accidents in five large companies revealed high financial losses. The accidents and work-related ill-health were calculated and applied to the national picture, and it was estimated that they were costing the United Kingdom up to £15 billion per annum, almost 3% of Gross Domestic Product.

The cost to employers of personal injury work accidents and work-related ill-health is estimated to be £1.5 billion per annum at 1990 prices, £900 million for injuries and £600 million for illness (HSE, 1994b). The loss caused by avoidable non-injury events is estimated to be in the range of £4 billion to over £9 billion per annum. This is equivalent to around 5% to 10% of all UK industrial companies' gross trading profits, averaging between £170 to £360 per person employed. The cost to the UK economy of work accidents including the avoidable non-injury accidental events and work-related ill-health is estimated to be between £6 billion and £12 billion per annum. This is equivalent to between 1% to 2% of total Gross Domestic Product (GDP). This includes the costs associated with property damage, loss of production, medical treatment and administration incurred by firms, along with expense for insurance companies and the taxpayer through the Department of Social Security.

Table 2.4 presents a summary of the costs incurred by employers from accidents and work-related illness. The total costs, excluding insurance and compensation to employers is estimated to be between £700 and £1000 million. The table shows that injuries cost more than illness, because of the larger number of workers affected and of days lost. Some of the costs associated with ill-health are due to the long-term effects of accidents in previous years. Adding a further £2.5 to £7.2 billion for non-injury events makes a total uninsured cost of between £3.2 and £8.1 billion. This shows that great costs come from accidents that frequently go unrecorded, and uninsured. This suggests that employers need health and safety systems which go beyond simply reducing the cost of injuries.

Cost	Injury Accidents (£m)	Non-Injury Accidents (£m)	Illness (£m)
Damage	15-140	2152-6499	-
Extra Production Costs	336	-	230
Administration	54	307-712	35
Recruitment	4-15	-	44-177
Total	409-545	2459-7211	309-442

Table 2.4 Total uninsured costs to employers of workplace accidents and work-related illness (HSE, 1994b).

In addition to the uninsured costs, the amounts that employers have to pay in insurance to cover compensation claims; both the compensation payments and legal costs should be added. During the 1970s employers liability (EL) and public liability (PL) was a very small part of most general insurance business (Waring, 1996). Since then, however, claims and payouts have risen dramatically to the extent that from 1987 to 1992 UK insurers made an underwriting loss of £588 million in EL. According to the HSE (1990) in 1986 over £300 million was paid out in employers' liability insurance claims for injury and ill-health. The number and size of claims has been rising sharply over the more recent years, and this trend for increasing claims and payouts is set to continue. This seems to reflect a social change in attitudes towards civil litigation claims concerning workplace accidents and ill-health. The factors include sharp increases in injury awards, long-term disease claims, a greater willingness for plaintiffs to take legal action, and improved diagnosis of work-related injuries and diseases (Waring, 1996).

At 1990 levels the average cost of EL insurance is around 1.7 pence per hour, making about £700 to £750 million in total (HSE, 1994b). Also, between 1989 and 1993, employers' liability insurers paid out £2.8 billion in claims for accidents and ill-health and dealt with about 690,000 claims (Association of British Insurers, 1995). In the light of these EL losses, indemnity capping has arrived (Waring, 1996). For example, the new limit in the UK for claims arising from any one occurrence is £10 million. The mechanisms of the insurance market have not provided sufficient incentives in the past for insurers to settle claims as economically as possible. Underwriters have been prepared to provide cover on the basis of minimal information. Now underwriters are placing policyholders under scrutiny and looking for evidence of risk assessments and clear safety management system documentation before deciding on their premium calculations.

The HSE (1994b) estimates the total cost to employers of workplace accidents and work-related illness is between £4.5 billion and £9.5 billion at 1990 prices, equating to between 5% and 10% of gross trading profits. This is shown in Table 2.5:

Type of Loss	Damage (£m)	Production Costs (£m)	Admin. (£m)	Insurance (£m)	Total (£m)
Injury	15-140	336	58-69	450	859-995
Illness	-	230	79-212	300	609-742
Non-injury	2152-6499	-	307-712	505	2964-7716
Total	2167-6639	556	444-993	1255	4432-9453

Table 2.5 Total costs to employers of workplace accidents and work-related illness including insurance (HSE, 1994b, p.46).

These figures can be looked at in another way, to show the cost per worker per accident. The total cost of work accidents and ill-health to employers equates to between £170 and £360 per worker employed. Each accident costs on average £90 to £200 and the average cost of an injury is £550 to £630. Also, each of the 1.5 million employees with work-related illness costs employers' £400 to £500 per year. Table 2.6 shows the typical costs of different types of accidents:

Cost	All Injuries (£)	Serious or Major (£)	Other Reportable (£)	Other Lost Time (£)	Non Injury (£)
Damage	45	45	45	45	104
Extra Production Costs	215	520	445	29	-
Administration	40	155	75	3	12
Insurance and Compensation	287	3782	-	-	12
Total	587	4502	565	77	128

Table 2.6 Typical costs of different accident types (HSE, 1994b, p.47).

The figures show that employers could minimise costs by reducing the number of workplace accidents. With better information on the costs of accidents at work there is a strong incentive for employers to introduce systems that will reduce the likelihood of accidents. In the case of ill-health there may be less incentive for employers to invest in preventative measures because of delays between cause and effect, making identification of the links more difficult.

2.6 Summary of Health and Safety Law, Accident Statistics, Enforcement Activity and Economic Costs

It can be seen from the review of the literature on health and safety that substantial legal changes to health and safety at work have occurred since 1974. There has been a move away from prescriptive health and safety legislation towards self-regulation within the boundaries of law enforcement. As a result of the HASAWA of 1974 and the six pieces of legislation of 1992, the onus now is on the employer to take practicable action to secure safe and healthy workplaces, along with systems to ensure their continuation.

From the mid-1980s to mid-1990s figures outlining trends in law enforcement activity show that enforcement notices issued have risen, that prosecutions for contravention of health and safety legislation have generally remained stable, and that there has been an upward trend in fines levied by the courts. Numbers of injuries and reported dangerous occurrences have also declined. These figures show that workplace health and safety has experienced continuous improvement. What can be concluded from the statistics presented is that there is still an important role for the enforcing authorities to ensure that accident rates are reduced further and act as a warning to employers who try to ignore their health and safety obligations.

The high costs associated with occupational accidents have been emphasised in this chapter. The changing nature of accident and ill-health costs must be noted. It has been shown that they have continued to rise upwards in recent years, mainly due to changes in attitudes to employers liability and partially through increased fines. Also the unanticipated gap between uninsured and insured costs appears to suggest why employers have invested less in occupational safety and prevention of ill-health than they should have.

It is clear from a review of health and safety legislation that in order to meet the 'duty of care' to provide a safe workplace, employers need to have thorough safety management systems in place. The national picture showing accident statistics and their associated costs further add to the justification for effective safety management. The next chapter seeks to identify the components of a workplace safety system which should help legislation to be adhered to and also benefit companies financially.

CHAPTER THREE

Occupational Safety Management Systems

3.1 Introduction to Safety Management Systems

This chapter reviews the systematic elements that are necessary for a safety management system (SMS) to operate. It aims to spell out the principles which successful occupational safety systems should be based upon. It starts by outlining the more recent changes in the way people work, and how these have necessitated a move away from the safety management approaches of direct supervision and control. It seeks to set out a framework for initialising, implementing, measuring the performance of and reviewing a continuous SMS. Where appropriate, additional background theory has been integrated into the work, particularly where human factors are discussed. The chapter illustrates that safety management is very diverse, and that synergistic benefits result from the integration of management, technological, psychological, ergonomic and medical principles. In this sense health and safety management is no different from other forms of management.

The use of wider management principles in the safety arena becomes all the more important when taking changes that have occurred in workplaces into account. Due to competitive pressures, more workplaces appear to be in a state of continuous change (Killimett, 1991). Killimett recommends that the answer to continuous change is continuous improvement in safety performance. This can be achieved by employing a safety approach that operates as a system or process, not a temporary programme. He also suggests that employee involvement is critical to this process, no matter what changes are brought about in products and equipment. Topf and Preston (1991) use a similar argument. They note that trends in industry have placed greater levels of responsibility on individual employees. A higher degree of unsupervised and independent working situations have led employers to seek innovative approaches to self-management, as well as the management of others. Topf and Preston point to the limitations of traditional behaviour modification strategies that often rely on third-party observation and correction of others behaviour. Often there is a brief change in behaviour and safety performance improves, but results can diminish when direct supervision or constant reinforcement is no longer present.

Chapter Three consists of eight sections. Section 3.2 of this chapter sets out the requirement of an overall safety policy. A description will ensue of the activities required to build and maintain a sound SMS. The principles of risk assessment and risk control are discussed in Section 3.3. Appropriate safety information, staff selection and training policies are reviewed in Section 3.4. In Section 3.5 the analysis of accident costs is then outlined. The chapter moves on in Section 3.6 to looking at how to conduct effective accident investigations. Section 3.7 examines a variety of measures of safety performance. Finally, in Section 3.8 the chapter is completed with a discussion of how to audit and review the SMS.

(a) A Description of Safety Management Systems

Many employers use the approach outlined in the HSE Guidance Document HS(G)65 *Successful Health and Safety Management* (1991) to assist them in setting up their SMS. The key elements of successful health and safety management are set out in Figure 3.1. In order for the SMS to be in a state of continuous improvement it should be moving continually between the various stages of the safety management model shown below:

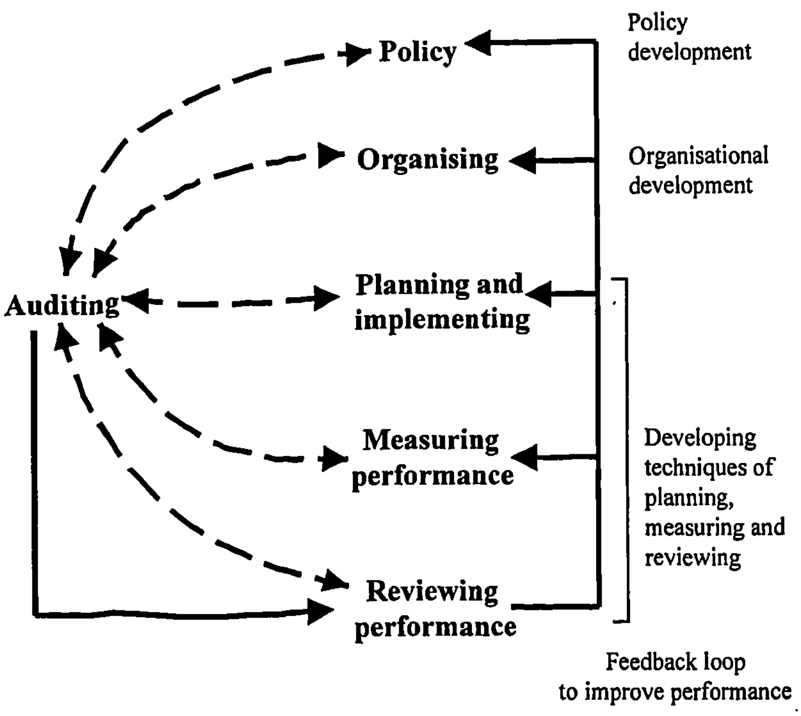

Figure 3.1 Key elements of successful health and safety management (HSE, 1991a, p.3)

An employer's Health and Safety Policy sets out its top management's beliefs, intentions, priorities and what they require from all employees. It states the objectives of the company, key responsibilities and wider practical arrangements for safety and health. Safety strategy emerges from the policy and its objectives (Waring, 1996). Obviously a firm must comply with the legal requirements set out in Sections 2.2 and

2.3 of Chapter Two, and this part of the SMS has to be suitably developed, else the whole system is likely to fail.

Good organisation is important for putting health and safety policies into practice (HSE, 1991a). A positive culture allows involvement and participation at all levels. Effective communication and the promotion of competence allows all employees to make contributions to the health and safety effort. Senior managers must be visible and active in order to develop and maintain a culture supportive of health and safety.

A planned and systematic approach to policy implementation is essential for any SMS. A range of different activities requires planning and resourcing. These include risk assessments, hierarchies of objectives, allocating responsibilities and accountabilities, establishing effective communication, and identifying information and training needs (Waring, 1996).

Health and safety performance can be measured. Failures of control are assessed through reactive monitoring which requires the investigation of any accidents, ill-health or incidents with the potential to do harm or cause loss (HSE, 1991a). More proactive measures can monitor safety before an accident has happened, through the use of safety inspections or training evaluation for example.

Learning from relevant experience and applying the lessons learned are important elements of health and safety management. Commitment to continuous improvement involves the continual development of policies, approaches to implementation and techniques of risk control. Periodic reviews can allow the results of monitoring and auditing activities to be assessed and remedial changes at the appropriate levels of the SMS to be made.

3.2 Safety Policy and Strategy

What actually happens in an organisation on a day-to-day basis underpins its safety policy and strategy, as it represents the actual beliefs and values of the management and workforce, as distinct from the beliefs and values which may be enshrined in the organisation's official documents (Waring, 1996). Organisations with a strong safety culture or climate have a close fit between the formal policy statements and what actually happens. Ford and Fisher (1994) regard a safety climate as consisting of employees' shared perceptions about the work environment that guide behaviour. Zohar (1980) suggests that safety climate varies greatly across companies. He describes a strong, positive safety climate as consisting of: strong management commitment, high priority given to safety matters, high status afforded to safety officers, emphasis on safety training, communication between management and workers, orderly plant operations, and strong safety promotion.

The safety policy statement should show the intentions of senior management towards health and safety (Waring, 1996). The policy should indicate recognition of issues and priorities for the organisation so that all employees understand clearly what is expected of them (Stranks, 1993). The Health and Safety at Work Act 1974 requires employers to prepare and revise their health and safety policy (Stranks, 1994a). Stranks suggested that a policy statement should start with a 'Statement of Intent', outlining the organisation's overall health and safety philosophy. Next, the organisation of people and their duties needs to be stated. It is necessary to outline the chain of command and responsibilities for health and safety management. In particular the policy statement should outline individual accountabilities, the system for monitoring implementation of the policy, and how safety committees and safety representatives are to function (Stranks, 1994a). Finally it is necessary to detail the arrangements for policy implementation.

Waring (1996) suggested that the presentation and dissemination of the safety policy is crucial to its practice. If it is to be acted on by all, it has to be communicated properly. This may be achieved through training, display on notice boards and in safety manuals for example (Waring, 1996; Stranks, 1994a). Some indication of long-term safety goals and broad objectives ought to be present in the safety policy statement (Waring, 1996). Waring suggests that long-term goals might include continuous improvement of the safety effort, reduction in risks through improved technology and a reduction in avoidable loss. The policy statement objectives should be used to help set the strategy to achieve safety. According to Veltri (1991) it was no longer acceptable for the safety function simply to control hazardous exposure and comply with mandates from governmental agencies and insurers. It should offer added strategic value and operating leverage to the firm's business performance through promoting a better understanding of the costs of accidents, and how these costs impact on profit.

Strategy may be seen as an overall framework or 'plan of plans' (Waring, 1996). To implement the safety strategy, it is necessary to go through a process of planning, which involves organising and resourcing. The safety objectives need translating into a systematically structured series of identifiable activities. It is necessary to resource the identified activities efficiently, and also to ensure that appropriate monitoring and control arrangements are carried out to the required standard set out in the plan. Performance standards for the measurement and control of hazards and risks are necessary in any SMS (HSE, 1991a). In order for this to be achieved the difference between a hazard and the risk attached, and their relation to accident causation should be understood. This leads on to an examination of risk assessment and control.

3.3 Risk Management Approaches

Waring (1996) warns that the focus of the safety strategy must be realistic and the stated objectives achievable. Strategies aimed at reducing accidents should be geared first to reducing the physical danger in the workplace, and second to increasing awareness of the risks at work (Boylston, 1990; Stranks, 1992). These two areas should feature strongly in an accident prevention programme. Waring (1996) suggests that as the strategy should ideally run over a long-term horizon, a balance has to be struck between a 'safe place' strategy and a 'safe person' strategy. These two complementary approaches will be reviewed in the following section.

(a) Accident Definitions

Several definitions of an accident have been suggested. Stranks offers a comprehensive definition of an accident as:

> An unexpected, unplanned event in a sequence of events that occurs through a combination of causes; it results in physical harm (injury or disease) to an individual, damage to property, a near miss, a loss, business interruption or any combination of these effects (Stranks, 1992, p.46).

A number of significant factors emerge from this definition. Generally, accidents are unforeseeable as far as the victim is concerned; unplanned, unintended, and unexpected. An analysis of accidents and their causes requires consideration of the events leading up to the accident. It is vital to know what to do after the accident, first to minimise the effects of the injuries, and second, to prevent a recurrence. The use of risk assessment can contribute to identifying these causes, and identify the remedial action required to prevent or reduce repetition.

(b) Risk Assessments

The risk assessment should enable an employer to check and improve the validity of their judgements about risks and the effectiveness of control measures (Mackmurdo, 1993). The risk assessment helps to ensure that health and safety policy is always effective, and provides easily updateable records which clearly show justification for the health and safety arrangements.

Before making a risk assessment the employer should know the difference between hazards and risks. A hazard is something with the potential to cause harm. This can include substances or machines, methods of work and other aspects of work organisation (HSC, 1992c). A hazard is associated with a degree of danger and is quantifiable (Bamber, 1990a). The risk expresses the likelihood that the harm from a particular hazard is realised, and also its severity. Risk can be conceptualised in terms of 'chance taking', or the probability of an accident occurring (Bamber, 1990a; HSC, 1992c). The extent of the risk covers the population which may be affected by a risk; that is the number of people who might be exposed and the consequences for them (HSC, 1992c). The relationship between hazard and risk must be understood (Bamber, 1990a). Inadequate control can create substantial risk, even from a substance with a low hazard; but with proper controls, the risk of coming to harm even from a very hazardous substance is reduced significantly.

Stranks (1994a) outlined the universally accepted stages of a risk assessment as the identification of all the hazards, evaluation of the risks, and implementation of measures to eliminate or control the risks. It is necessary to know the risk priorities in order to address safety and to plan. This may take the form of an initial risk assessment to identify the main risk categories and make some estimation of their level of risk, so as to help with strategic planning. Second, when planning or addressing particular parts of a safety programme, there may be a need for more detailed risk assessments. Thirdly, day-to-day circumstances are likely to warrant *ad hoc* risk assessments as a permanent part of the safety tools of managers, supervisors and the workforce.

Thinking solely of a risk as a likelihood that a hazard will cause harm does not allow for different degrees of harm or severity, or the fact that hazard exposures may differ significantly (Waring, 1996; Stranks, 1994a). Risk assessment approaches have been put forward by different safety writers (Waring, 1996; Stranks, 1994a; Mackmurdo, 1993; HSE, 1991a). Their methods of assessment vary in complexity. In order to account for consequences and exposure, formulas are commonly used throughout industry for risk estimation (Mackmurdo, 1993; Waring, 1996). Risk scores are obtained and can be ranked as a means of prioritising actions needed to reduce and control risks (Mackmurdo, 1993). This approach is especially useful where there are many identified hazards which are competing for limited resources. Once a risk score has been obtained, it can be transferred to a higher or lower priority category, depending on overriding factors. After a risk score is evaluated and categorised, for example high, medium or low, a decision is needed as to whether the risk is acceptable or not. Many companies use the 'as low as reasonably practicable' (ALARP) principle. As much effort as is reasonably practicable should be used to reduce the risks as far as possible down the inverted triangle. This will meet the requirements for risk assessment and control measures set out in the MHSWR, 1992. Figure 3.2 outlines the ALARP principle:

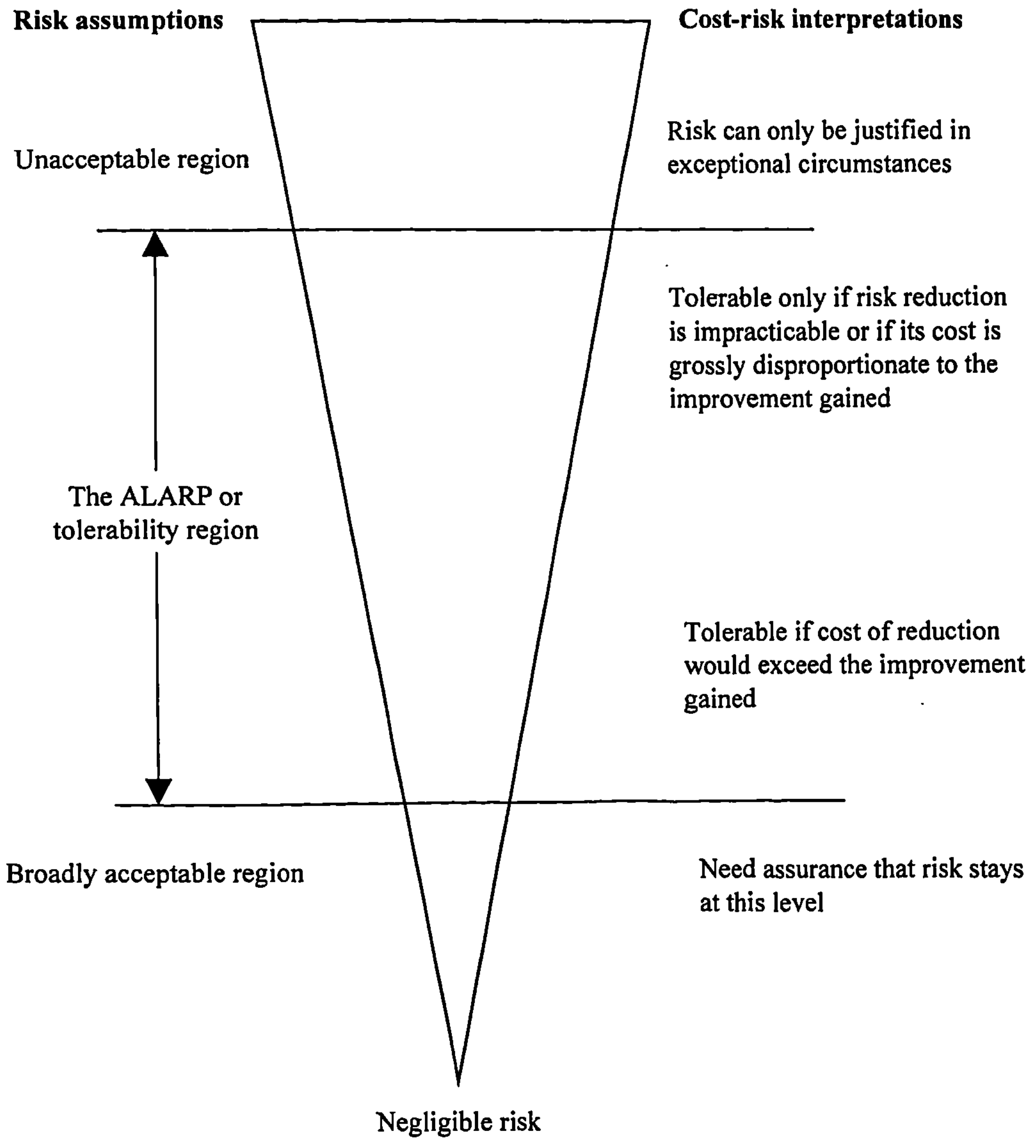

Figure 3.2 The 'as low as reasonably practicable' principle (Waring, 1996, p.96)

Once the risks have been assessed and the controls installed or implemented, then a number of additional safety practices or policies should be used (Waring, 1996). These include safety monitoring activities, preventative maintenance procedures and health surveillance. Once the risks have been identified and measured it is important to emphasise methods of risk control.

(c) A Safe Workplace

Safe place strategies are required under Section 2 of the HASAWA, 1974. A 'safe place' strategy seeks to reduce or eliminate objective dangers in the workplace through designing out hazards and any residual risks (Stranks, 1992; Waring, 1996). This can be controlled by engineering, organisational and procedural means. This strategy seeks to mitigate the effects of human error. This may be achieved through measures such as machinery guarding, improvements in the working environment or the design of 'safe systems of work' (Stranks, 1994a). Some examples of safe workplace strategies are to maintain safe premises, plant processes and materials, and safe systems of work.

There are general structural requirements for working premises, such as stability of buildings, soundness of floors and the load-bearing capacity of beams. Poor standards in the working environment are major contributing factors to many accidents (Stranks, 1992). A sound working environment will contain adequate lighting, ventilation and temperature control, in addition to the mitigation of environmental stressors such as noise, vibration and dust which can all be injurious to health. Risks can be combated at source by engineering controls (HSE, 1991a). If a hazard cannot be eliminated then control at source is the best approach, followed by control in the pathway between source and individuals at risk (Waring, 1996). Both these approaches emphasise attention to design, use of materials, construction, operation and maintenance. Assessing plant and machinery for hazards prior to acquisition or to make modifications can allow many hazards to be 'designed out' of the workplace (Stranks, 1994a). Maintenance and safety have much in common (Parmeggiani, 1983). Maintenance and cleaning systems should take into account the safety requirements of staff engaged in such operations. To keep machines, tools and equipment safe, a schedule of preventative maintenance can be set up which offers both a reduced accident rate, and efficient use of plant and equipment (Antion, 1979). All factors contributing to the operation of a specific process must be considered during process design and be subject to regular monitoring (Stranks, 1994a). Materials or substances used at work may be potentially hazardous. Adequate documentation on their correct use storage and disposal should be provided (Stranks, 1992).

The design and implementation of safe systems of work should feature highly in any 'safe place' strategy (Stranks, 1994a). Under the MHSWR 1992, safe methods of work should be in place to ensure that hazards are eliminated or risks minimised (HSE, 1992a). A safe system of work incorporates planning, training and designing out of hazards. It should set out a correct sequence of operations, a safe work layout, specification of safe practices and procedures, and reviews of systems of work and feedback to all concerned (Stranks, 1992; Bamber, 1990b). Safe systems of work are commonly designed through the use of a job safety analysis, which is based on task analysis (Stranks and Dewis, 1986). This requires assessment of specific job operations, hazards and risks associated with these operations, and the skills required to perform the task (Stranks, 1992). A permit to work (PTW) system is a formal safety control system, designed to prevent accidents; particularly when work with foreseeable high hazards is undertaken (Stranks and Dewis, 1986). The PTW is a document which lays out the work to be done and the precautions to be taken.

(d) Safe Person Strategies

'Safe person' strategies are used to protect the individual in situations where a 'safe place' strategy may not be appropriate or possible to implement. They rely on individuals conforming to certain prescribed standards. Some 'safe person' strategies include the use of PPE, care for the vulnerable, encouraging personal hygiene and maintaining awareness of danger.

The use of personal protective equipment (PPE) should only be considered as a last resort when all other prevention strategies have failed, or as an interim measure until an appropriate 'safe place' strategy can be implemented (Stranks, 1992). Accident prevention is reliant on the employee wearing the personal protection all the time that they are exposed to the hazard. It may be necessary to maintain a high level of supervision and control to ensure constant use of this equipment. Special consideration has to be afforded to certain groups of workers who may be regarded as vulnerable. Such groups include young people, whose experience of hazards may be limited, pregnant women, older and disabled people whose physical capability to perform certain tasks may be reduced, and 'accident repeaters' who have the same type of accident regularly. There may be the potential for occupational skin conditions or ingestion resulting from contact with certain substances (Stranks, 1994a). Facilities for maintaining good standards of hygiene should be provided. All employees should be aware of the risks in the workplace. These risks should be identified clearly in the

Statement of Health and Safety Policy along with appropriate precautions to be taken by workers to protect themselves from such risks.

3.4 Safety Information, Staff Selection and Training

(a) Provision and Communication of Safety Information

The employer's Statement of Health and Safety Policy should set good standards of safety supervision from the top downwards (Stranks, 1992). Duties relating to health and safety at all levels of management and workers should be identified clearly in the job description. The HASAWA, 1974 sets a legal duty on employers to provide information, instruction, training and supervision for all staff levels. Every employee is required to participate in some form of health and safety training. This requirement can be met through the application of induction training, on-the-job training and through specialised training. Training approaches will be reviewed extensively in subsequent sections.

It is important that information enters organisations from outside (HSE, 1991a). It is necessary to monitor new or proposed changes in public policy or legislation directed towards safety, and information about advances in knowledge about hazards and risks (Waring, 1996; HSE, 1991a). In addition, to learn lessons from accidents in other organisations, changes in design or operating specifications of plant and processes which have safety implications and developments in professional health and safety practice may be necessary. This information is particularly important for those engaged in policy making, planning, setting performance standards, measuring, auditing and reviewing performance (HSE, 1991a). The sources of information are extremely broad, ranging from law and engineering to sociology and psychology (Stranks, 1994a). Specific sources include Acts of Parliament (Statutes), regulations and codes of practice, HSE guidance notes, European Directives, British Standards, textbooks, periodicals and computer programs.

Key information needs to be communicated throughout organisations. Sources of internally generated information are also abundant. Existing written information may take the form of Statements of Health and Safety Policy, specific policies, regulations and codes of practice or job safety instructions. Other sources of information may be suppliers' product information; accident, illness and absence statistics; interviews and discussions, or direct observation. Internally generated safety information should be designed and distributed according to the needs of the recipients (Waring, 1996). Account should be taken of a number of factors: the processes and activities in which they are engaged, their responsibilities, hazards encountered and skill level. The most suitable media for communication should be considered, for example text, pictorial, or audio.

(b) Staff Selection and Safe Behaviour

The acts and omissions of every employee will affect safety. The demands of employees' jobs should not exceed their ability to carry it out without risk to themselves or other people (Stranks, 1993). Waring (1996) suggests that competence for a job require three main components: cognitive skills (adequate knowledge, behaviour and experience), good personality attributes (motivation and attitude to risks); and emotional stability (ability to cope under pressure and emergencies, and social style). Some physical attributes may also be essential for certain jobs. All the listed personal factors can interact with health and safety issues. For each job, the competence mix is likely to be different. This makes it important to ensure that the right kinds of employees are recruited, selected and trained to match the particular work that requires to be done. The use of techniques such as a job safety analysis can assist with identification of the particular safety needs of a job (Stranks, 1993). A job or task analysis may be able to assist with the developing and planning of training and resign of jobs in addition to hazard assessment (Waring, 1996). Petersen (1988) suggested that reducing accidents by staff selection assumes that those who will have accidents will be predicted, and that they as people are different in some identifiable way from those who do not have accidents. There are a number of recruitment approaches which some argue can help screen out potentially accident-prone staff.

'Accident proneness' describes a person who has significantly more accidents than others. Petersen (1988) and Sculzinger (1956) suggested that people who are consistently susceptible to accidents are small in number, and their contribution to the total accident problem is slight. The proneness theory indicates that these people can be identified and either appropriately trained in safety, or placed in low risk jobs (Minter, 1990). Some companies use personality tests for hiring staff. The tests are supposed to be predictive of whether a person would have a higher than average frequency of injuries. The concern with this approach is that it can result in labelling an employee as accident prone, when the root cause of the accidents lies in organisational and environmental arrangements. Petersen (1988) suggested that the cost of screening out such a small number of accident repeaters would have a very small impact upon accident rates and that it was not economically viable. Hansen (1988) argued differently, suggesting that by identifying and screening out job applicants with these ‘high risk’ personality characteristics, organisations should be able to reduce losses. Employees without these undesirable traits should also be more productive and easier to work with.

Personal factors of many kinds have been identified as having a bearing on accidents (Petersen, 1988). These may include factors such as age, physique, skill, qualifications and experience, aptitude, knowledge, intelligence and personality. Personnel selection policies and procedures should ensure that specifications are matched by the individuals (HSE, 1993d). Depending on the situation and the needs of the job, selection tests have been devised for many of these. There are a number of tests which can help to measure the functions and limits of the senses (Petersen, 1988; Stranks, 1994a). These may measure visual acuity, hearing, muscular co-ordination and reaction times. It is important to consider the appropriateness of the test in relation to the job requirement. Psychological tests can also help as predictors of accidents. Petersen (1988) suggested that intelligence might play a significant part in accident susceptibility, although except at extremes, intelligence is not associated with accidents to any significant degree. He concludes that using intelligence tests will not help predict accidents.

Personality and attitude may shape the way that an individual behaves based on generic factors, environmental or learned characteristics and situational factors (Hale, 1990). Petersen (1988) found evidence of a relationship between certain aspects of emotionality and accident frequency. Although personality questionnaires have been found inadequate for detecting accident susceptibility, some believe that accidents and poor adjustment are related (Dwyer, 1991; Cattell, 1965). Petersen (1988) stated that although poor adjustment is related to accident causation, it is difficult to use this knowledge well to predict or select since in the lion's share of cases it is not economically feasible to obtain a psychoanalytic evaluation for each applicant. There is no agreement on the usefulness of many of the psychological and sensorimotor tests' ability to predict accident-producing behaviour. The job to be filled will influence the job knowledge tools and skills tests that will be of value.

Background information and interviews have the potential to screen out unsafe applicants (Kamp, 1991). Interviewing is a universal staff selection device. It seems to be the most commonly used selection technique apart from initial shortlisting. Petersen (1988) argues that the interview selection process can often only be of limited value when trying to select safe working recruits. This is because the interview will often not furnish the type of information needed to make this type of decision, and particularly as the interviewer often makes their mind up about the candidate at the onset of the encounter.

(c) Health and Safety Training

A number of safety writers suggest that 60 to 95 percent of safety incidents are a result of unsafe behaviour (Perrow, 1984; Killimett, 1991; Krause *et al.*, 1990; Stranks, 1994b). For example, most of the major accidents that have occurred within process plants have been attributed to failures in human performance caused by problems in understanding, expectations, judgement, and decision-making (McGeorge *et al.*, 1994). Recognition of the role that human behaviour plays in the safe operation of work systems has led to the assessment of methods to improve human performance. One way of addressing this problem is to expand training programmes. Success depends on appropriate interventions and the subsequent assessment of their effectiveness. The Department of Employment defines training as:

> The systematic development of attitude, knowledge and skill patterns required by the individual to perform adequately a given task or job. It is often integrated with further education (Department of Employment, 1973, p.2).

Training has become a large budget item in occupational health and safety programmes (Everett, 1989). It is no surprise to learn that training typically accounts for more than 60 percent of an average safety management budget (Stegner, 1992). As partly a consequence of this it is becoming increasingly important to make sure that training gets results. The potential liabilities for ineffective training can be enormous. Lindell (1994) suggests that the purpose of safety training is to ensure that employees learn appropriate actions to take and how to perform them correctly. Training or education will help people to attain the skills, knowledge and attitudes to improve their competence in the health and safety aspects of their work (HSE, 1991a). This is achieved through the development of positive attitudes which encourages safe behaviour (Everett, 1989). This end can be reached through formal off-the-job training, instruction to individuals and groups, and on-the-job coaching and counselling (HSE, 1991a).

Topf and Preston (1991) warn that safety programmes which focus only on changing behaviour without addressing attitude and awareness often provide short-term results and little return on investment. Searle *et al.* (1994) take a different line and argue that knowledge is the focal point of health and safety training, especially its retention over time.

(d) The Training Process

Before any training process can begin, a decision should be made as to whether it is needed, as training should not be used to compensate either for inadequacies in other aspects of the safety system, such as systems of work or engineering (Everett, 1989; HSE, 1991a). However, it may be appropriate to use training as a temporary means of control, pending improvements. The remaining portion of this section will outline a systematic approach to attaining better workplace safety through training.

(e) Identification and Assessment of Training Needs

For training to be successful, it must be compatible with relevant selection and placement policies. The selection procedures must be capable of allowing the trainees to learn what is to be taught. A training needs analysis should take account of any relevant job analyses, hazard analyses and risk assessments (Waring, 1996). Wallerstein and Baker (1994) agree that needs assessment forms the foundation for the entire planning process. This should profile the target population, and should allow a broad set of questions to be answered. For example who would benefit from the training? What training has the target group already received? What knowledge and experience will the trainees bring to the process? The needs assessment can be based on a number of information sources such as questionnaires, review of documents, workplace observations, and interviews with employees.

Not only is a training needs analysis prudent, but it is also required by the MHSWR of 1992, which demand that training needs should be identified to cover three elements. The first is induction training for new recruits. The second requires orientation training of existing employees in instances such as changes of job, their exposure to new or increased risks, and prior to the introduction of safe systems of work. Third, refresher training directed at maintaining competence (HSC, 1992c).

(f) Gaining Support for Training

Wallerstein and Baker (1994) suggested that if participative training is to be successful, it is necessary to gain support from the target population before the educational objectives and course content can be set. This will require employee involvement in the planning process. Other key actors might be trade union representatives or even the HSE in an advisory capacity. The context of the job will be critical to transfer, either supporting or inhibiting training transfer. This includes factors such as managerial and co-worker support, workplace climate, and the constraints or opportunities for transfer of trained knowledge, skills and attitude to the job. Where there is a supportive climate for the training of skills, new knowledge is more likely to be applied to the job.

(g) The Development of a Training Plan and Programme

In the development of training plans, clear objectives need to be defined to suit current personnel needs (Stranks, 1994b). These can be derived from information gathered from the needs assessment or through job specifications or task analysis (Wallerstein and Baker, 1994; Stranks, 1994b). Such analysis helps to identify the specific training relevant to each job position.

Wallerstein and Baker (1994) suggested that an individual's knowledge, behaviour and attitude towards workplace health and safety needs to be based around a number of objectives. They proposed that there was a hierarchy to these objectives. The hierarchy of is outlined in Figure 3.3:

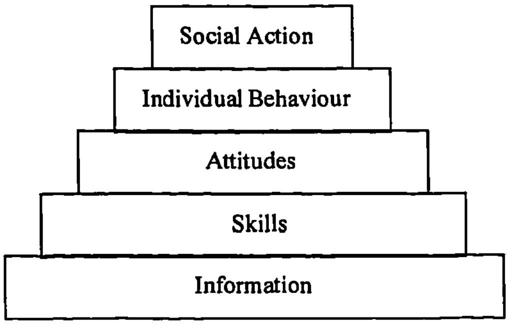

Figure 3.3 Hierarchy of training objectives (Wallerstein and Baker, 1994, p.313)

Knowledge objectives are the easiest to achieve; and skill objectives require more hands-on training to ensure that the necessary skills have been accomplished; but attitude objectives are more difficult because they may involve challenging ingrained beliefs. Individual behaviour objectives are achievable only if attitude barriers are addressed and if performance, practice, and on-the-job follow-up are built into the training. Social action objectives are most difficult to achieve, as education must prepare participants for collective action so that synergistic benefits can be obtained.

(h) The Selection of Education and Training Methods

The level of intensity and learning methods of health and safety training depend on how ambitious the objectives are, and the way that it is wished that people should learn (Wallerstein and Baker, 1994; Stranks, 1994b). Whatever methods are selected, the literacy and language profiles of employees must be considered. It is important to provide a good mix of methods to promote learning. A number of different learning mediums can be used to deliver safety training. They tend to split training into two broad types: active and passive (Petersen, 1988; Stranks, 1994b).

Everett (1989) suggested trainees tend to remember more when learning and experience occur through actual performance, simulating actual performance, participation in a task, viewing demonstrations of a task and the use of visual and audio material. The more active the trainee is, the more likely the retention of knowledge or skills. This is outlined in Figure 3.4.

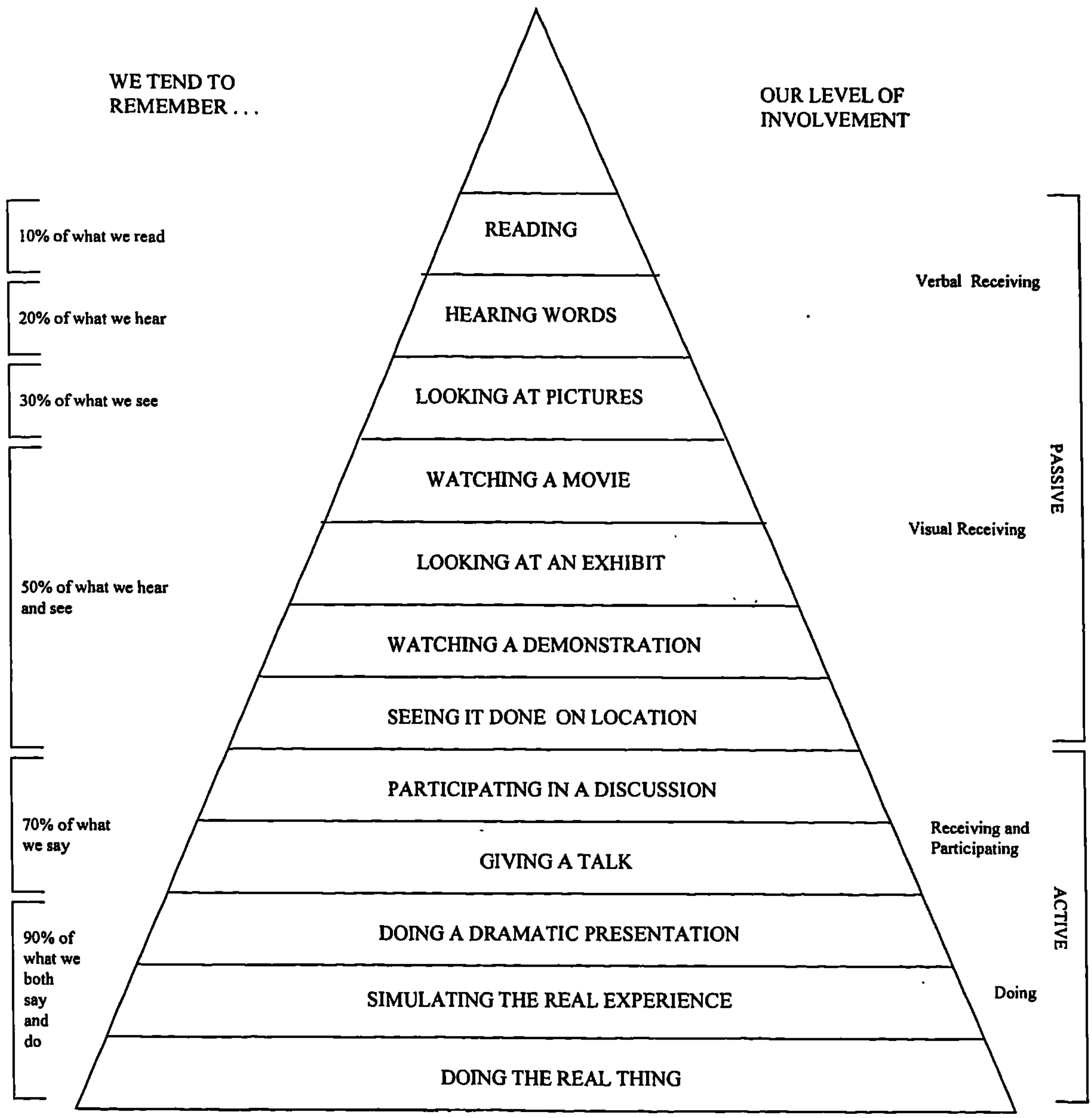

Figure 3.4 The cone of learning (Everett, 1989, p.36)

Table 3.1 shows the teaching methods available to the trainer, their pros and cons and the objectives that they achieve.

Teaching Method	Strengths	Limitations	Objectives
Lecture	Presents factual material in direct/logical manner. Can introduce a general survey or scope of a subject, set the scene for a demonstration, discussion or presentation, and illustrate the application of rules, policies and regulations. Contains experiences which inspire. Can set the scene for a demonstration, discussion or presentation. Suitable for large audiences.	Experts may not always be good teachers. Generally consists of one-way communication, with the instructor presenting information to a group of passive listeners. Little chance to clarify meanings, obtain any feedback, or account for individual differences. Group participation may only extend as far as questions at the conclusion. Learning difficult to gauge. Needs clear introduction and summary. Needs time and content limits to be effective.	Information skills
Demonstration	Instructor shows the trainees what to do and how to do it.	Similar limitations to lecturing. Usually needs to be combined with some other form of training.	Information skills
Worksheets and questionnaires	Allows people to think for themselves without being influenced by others in discussion. Individual thoughts can then be shared in small or large groups.	Can be used only for short period of time. Handout requires preparation time.	Information skills Attitudes/emotions
Brainstorming and discussion	Listening exercise that allows creative thinking for new ideas. Encourages full participation because all ideas equally recorded.	Can become unfocused. Brainstorming needs to be limited to 10-15 minutes. No best known or correct solution.	Information skills Attitudes/emotions
Audio-visual materials (films, slide shows, etc.)	Entertaining way of teaching content and raising issues. Keeps audience's attention. Effective for large groups.	Too many issues often presented at one time to have a focused discussion. Discussion will not have full participation.	Information skills
Audiovisuals as triggers	Develops analytical skills. Allows for exploration of solutions.	Discussion may not have full participation.	Social action skills Attitudes/emotions
Case studies (trigger)	Develops analytical and problem-solving skills. Allows for exploration of solutions. Allows students to apply new knowledge and skills. Active participation is encouraged. Trainees seek to find the best solution.	People may not see relevance to own situation as it lacks real-life pressures. Often regarded as being unable to teach general principles. Case and tasks for small group must be clearly defined to be effective.	Social action skills Attitudes/emotions
Role play session (trigger)	Attempts to simulate actual situations. Introduces problem-solving situation dramatically. Increase trainee involvement by introducing realism. Develops analytical skills and attitudinal change. Provides opportunity for people to assume roles of others. Allows for exploration of solutions.	People may be too self-conscious. Can be regarded as artificial situation where results do not count. Can be time consuming and expensive. Not appropriate for large groups.	Social action skills Attitudes/emotions
Report-back session	Allows for large group discussion of role-plays, case studies, and small group exercise.	Can be repetitive if each small group says the same thing. Instructors should prepare questions to focus discussion so not repetitive.	Social action skills Information skills
Prioritising/planning activity	Ensures participation by students. Provides experience in analysing and prioritising problems. Allows for active discussion and debate.	Requires a large area for posting. Posting activity should proceed at a lively pace to be effective.	Social action skills
Hands-on practice	Provides classroom practice of learned behaviour. Employees learn skills well by practising them.	Requires sufficient time, appropriate physical space, and equipment.	Behavioural skills

Table 3.1 Training methods chart (Wallerstein and Baker, 1994, p.316-317; Scherer *et al.*, 1993; Stranks, 1994b; Petersen, 1988)

This framework was built up from a number of literature sources, but it draws primarily on Wallerstein and Baker (1994). Passive learning systems use lecturers and visual materials. The basic objective is to impart knowledge. It can provide useful frameworks that can be used where large numbers of trainees are involved (Petersen, 1988). Active learning involves techniques such as group discussion, role-play or programmed field exercises such as safety inspections. Active learning methods reinforce what has already been taught on a passive basis and help to achieve attitudinal and social action objectives. Active learning systems are the most effective form of training once the basic framework is established and when there is plenty of time available in the training programme.

(i) The Implementation of the Training Plan

Decisions need to be made as to the extent of both active and passive learning systems to be incorporated into a programme (Stranks, 1994b). Once the plan is decided upon, the trainer simply needs to follow the plan. Safety training must affect the learning and transfer outcomes (Ford and Fisher, 1994).

(j) Evaluation and Follow Up

Evaluation of health and safety training is essential for several of reasons (Wallerstein and Baker, 1994). It allows the learner to judge their progress towards new knowledge, skills, attitudes or actions. It allows the trainer to judge the effectiveness of the training and to decide what has been accomplished, and whether this could have been achieved more effectively (Stranks, 1994b; HSE, 1991a). A further objective is to bring about a long-term change in attitude amongst the trainees leading to improved job performance (Stranks, 1994b). A decision as to whether training objectives have been met concerning attitudes or social action cannot be taken immediately or after a short time (Stranks, 1994b; Wallerstein and Baker, 1994). It may take several months before a valid evaluation can be made after continuous assessment of the trainees. In order to minimise the risk of providing inadequate training it is necessary to audit ongoing training programmes at their inception and on a regular basis thereafter, and. decide on the level of retraining required (Stegner, 1992; Everett, 1989).

It must be noted that evaluations of workplace outcomes, particularly those of injury and illness incidence rates can be deceptive (Wallerstein and Baker, 1994). For example promotional efforts linked to incentives for keeping accidents low can result in under-reporting of accidents. Conversely empowerment-orientated training encourages staff to recognise and report health and safety problems, and may result, at first, in an increase in reported injuries and illnesses even when health and safety conditions are improving.

3.5 Costing of Accidents

It is generally accepted that accidents at work cost money. This point was emphasised for employers as a whole across the United Kingdom in Section 2.5 of Chapter Two. To develop understanding of these costs the adoption of a total loss control approach to safety can ensure that underlying failures of management control are identified and eliminated irrespective of whether they lead to personal injury or not.

In Section 2.4 of Chapter Two the difference between direct and indirect accident costs was outlined. Heinrich as far back as 1931 distinguished between the costs of accidents covered by insurance, which he referred to as direct costs and all other associated accident costs which he termed as indirect. The iceberg in Figure 3.8 represents the total cost of accidents, but only the top fifth are visible or direct (HSE, 1994b). The other four-fifths require more detailed examination.

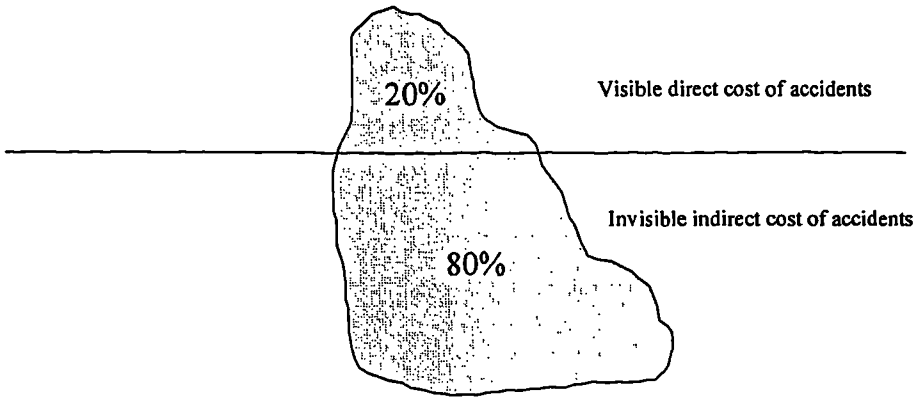

Figure 3.8 Heinrich's Iceberg (HSE, 1994b, p.5)

Direct costs are concerned mainly with the employer's insurance liabilities for staff and premises. Insurance premiums are calculated by underwriters who take account of the nature of the undertakings, previous claims histories, wage rates, safety culture and management commitment (Bamber, 1993). Other direct costs may be product liability claims or specific injury claims, which may be settled out of court (Stranks, 1992). Litigation costs and fines imposed by courts for breaches of legislation can also be included.

Indirect costs may be concealed in other costs, and not fully appreciated. These costs may be for the treatment of injured employees, lost time of employees, managers and first aid staff, lost output and damage. The cost of a fatality can run into hundreds of thousands of pounds. The costs associated with accident loss can be divided into a matrix as presented in Figure 3.9:

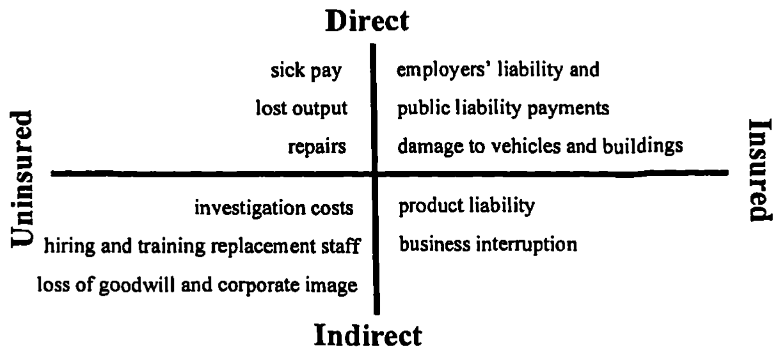

Figure 3.9 Insured and uninsured costs (HSE, 1994b, p.6)

The HSE (1991a) published in HS(G)96 an extensive accident costing methodology. A project management approach is recommended. To summarise, it suggested that the kinds of accidents to be costed are all incidents causing injury, ill-health, damage or loss to the business. The period chosen for the study should allow for a representative picture of the accident situation to emerge. The organising, planning and resourcing of the accident costing project team, data collection system, method of analysis, and presentation of the results needs to be set out. The implications of the results for the employer will also need consideration. These procedures account for the financial and opportunity costs arising from accidents. Examples of the costs which may be included where the accident occurred may consist of time costs of the injured person's absence from work, replacement labour costs, idle time costs and loss of raw materials or products (HSE, 1991a; Waring, 1996; Knutton, 1995).

Opportunity costs to employers which need consideration may be the time cost of the accident investigator(s) meeting with injured person(s) and other interested parties, re-engineering safety procedures or reorganising work programmes; and time spent on dealing with damage to material, and managing the replacement of plant and equipment.

There are a number of ways in which costs can be presented (Waring, 1996). These include mean cost per employee, mean cost per shift, week or month, or percentage of operating costs, gross profits or turnover. Being able to present the costs associated with specific accidents, accident types or accidents in general can provide a valuable measure of the performance of the safety system. Failures in management control can be identified and remedied through the channelling of resources to parts of the safety system in ways which should induce the most financial savings.

3.6 Accident Investigation

There are two main objectives for investigating accidents. The first is to ascertain their causes, and second to prevent a recurrence through the application of accident prevention principles (Saunders, 1992). There may be a need for immediate or planned remedial action so that legal compliance can be secured and to prevent further accidents of the same types. Adrian (1990) presented a useful plan to be used in the event of an accident. This is outlined in Figure 3.10 below (please refer to RIDDOR, 1985 for a full description of reporting requirements):

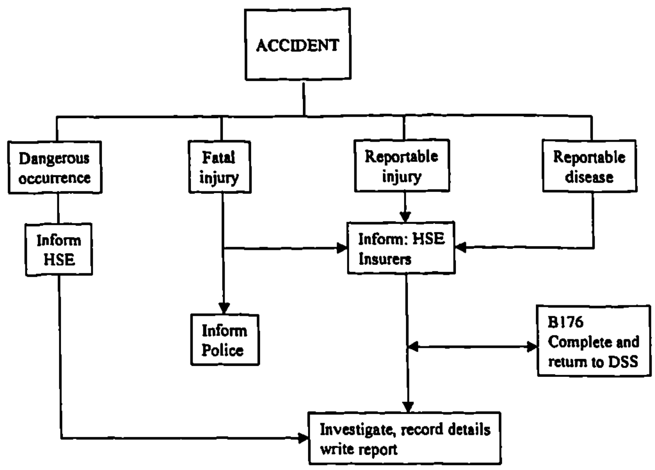

Figure 3.10 Diagram of action to be taken on learning of an accident (Adrian, 1990, p.205)

It should be recognised that it is not always practicable to investigate all accidents, with action limited to simple documentation of an incident. Stranks (1994a) recommended consideration of a number of factors when deciding which accidents should be investigated as a priority: accident type, injury type and severity, whether an accident falls into a trend of accidents, and the possibility of a breach of the law.

It is important to conduct an accident investigation as soon as possible after an accident (Adrian, 1990). Waring (1996) recommended a four-stage approach to accident investigation: establishing facts, analysing facts, establishing causes, and recommendations to prevent recurrence. These stages are summarised in Figure 3.11:

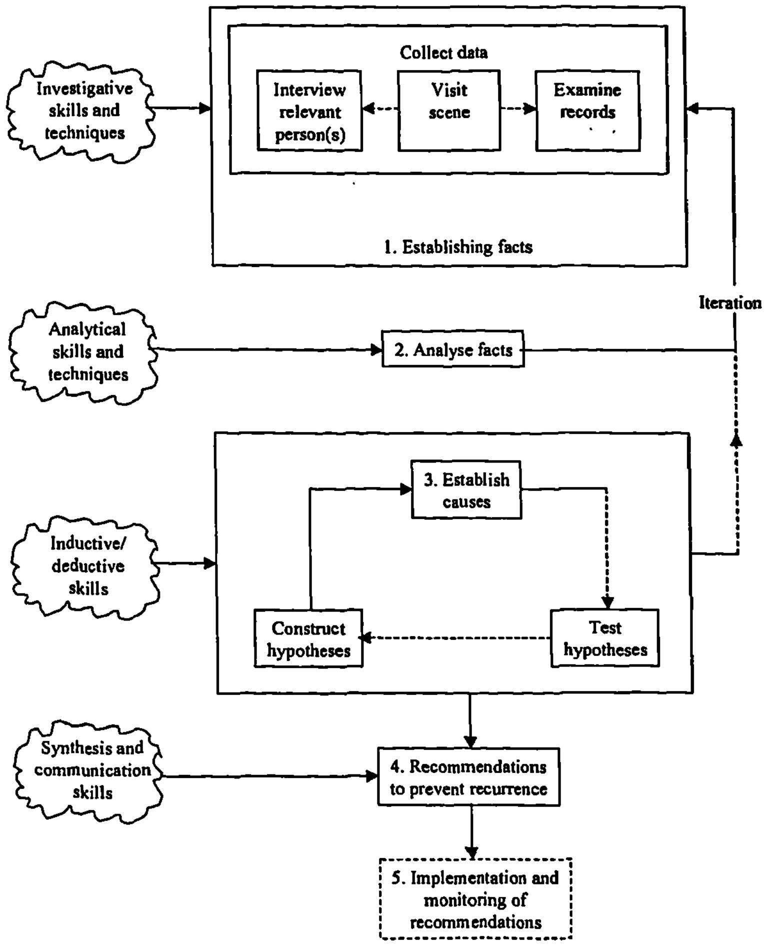

Figure 3.11 Flow diagram of accident investigation procedure (Waring, 1996, p.162)

Data is normally collected from accident record forms and other appropriate records; visiting the accident scene and through interviews. The investigator must decide how the accident arose. The wider factors such as organisational failures, safety culture or the decision-making process may need consideration. Once the cause(s) of an accident have been identified it is necessary to produce recommendations designed to help to prevent a recurrence (Stranks, 1994a). This should take the form of a written report, outlining the relevant shortcomings and appropriate remedial action (Waring, 1996).

3.6 Measuring Safety Performance

The control processes identified earlier in Section 3.4 of this chapter would be difficult to achieve without sufficient monitoring of safety performance. Measuring the extent of control against predetermined objectives forms an essential part of the safety monitoring process. Monitoring requires the detection of permanence or change in one or more parameters of the safety system. This may entail a casual consideration of day-to-day changes or regular systematic monitoring of safety parameters where results and actions are recorded. In order that safety performance can be monitored and measured, two types of system are needed. Reactive systems monitor accidents, ill-health, incidents and other evidence of problems in health and safety performance; and active systems monitor the achievement of objectives and the extent of compliance with standards (HSE, 1991a).

(a) Reactive Monitoring Systems

Reactive measures of safety performance are measures of past events (Waring, 1996). They require the recognition and reporting of injuries and ill-health, and other losses such as property damage, incidents which were potential loss events, hazards, or omissions in performance standards. This information should be evaluated, promptly in certain cases.

The most common examples of safety performance measurement are accident rates. Waring mentions that these are a negative measure of performance because they measure the failure of risk control, not its effectiveness. The HSE (1991a) agrees, warning that a low accident rate over a period of several years is no guarantee that risks are being effectively controlled and will not result in injuries, ill-health or loss in the future. Also the historical incidence of reported accidents could be an unreliable and misleading indicator of safety performance. Despite these points, Stranks (1994a) recommended that accident statistics are best used to measure safety performance in conjunction with other more positive indicators such as safety audits. However suitably analysed accident rates can be useful for comparing different time periods and employee groups. This can identify good and bad performers, assess risks, identify trends, predict future accident rates, and make comparison with similar companies (Waring, 1996). The HSE (1991b) describes how injury incidence and frequency rates are calculated in order to help with accident rate assessment.

The HSE's formula for calculating an annual injury incidence rate is:

$$\frac{\text{Number of reportable injuries in financial year}}{\text{Average number employed during year}} \times 100{,}000$$

This gives the rate per 100,000 employees and can be used for comparison against the national picture for a particular employment sector as published annually by the HSC.

An alternative measure of injuries is to calculate the injury frequency rates, usually per million hours worked. This method, by counting hours worked rather than the number of employees avoids distortions which may be caused in the incidence rate calculations by part and full-time employees and by overtime working. Frequency rates can be calculated for any period using:

$$\frac{\text{Number of injuries in the period}}{\text{Total hours worked during the period}} \times 1{,}000{,}000$$

Measures of injury rates can provide some indicators as to whether the safety performance of a firm is improving or deteriorating (HSE, 1991b). The simplest way to monitor accident trends is by plotting the measured data on a graph. Targets such as national industry averages may be plotted for comparative purposes.

(b) Proactive Monitoring Systems

Proactive measures of safety performance address present activities and are designed to prevent accidents and ill-health (Waring, 1996). Proactive measures should be more prominent than reactive measures because of their preventative nature. Their primary purpose is to measure success (HSE, 1991a). The various forms of proactive monitoring are broad, encompassing all the engineering, organisational, procedural, behavioural, and personal protective equipment (PPE) controls. The uses of safety inspections and safety tours will be considered in this sub-section.

Scheduled inspections of premises and working areas are used to assess the levels of legal compliance and observation of employers safety procedures (Stranks, 1992). The inspection may examine maintenance standards, employee involvement, working practices and housekeeping levels, and check whether work practices are followed according to employers procedures (Stranks, 1994a).

Safety tours are unscheduled examinations of work areas, often undertaken as group exercises involving line managers, safety specialists, safety representatives and safety committee members. They seek to assess compliance with safety requirements to ensure that, for instance, housekeeping is sufficient, fire protection measures are being observed and maintained, or PPE is being used correctly. For these tours to be effective, it is essential that any deficiencies be followed up immediately.

(c) Safety Audits

All control systems tend to deteriorate over time or become obsolete due to change (HSE, 1991a). This requires management systems to be audited intermittently. Safety auditing complements the planning and control cycle and is partly similar to financial auditing. It is an assessment of the reliability of the management planning and control system. It also measures the reliability, efficiency and effectiveness of policies, procedures, practices and programmes (HSE, 1991a; Saunders and Wheeler, 1991). All areas of an organisation's activities are examined critically with the aims of reducing accident potential and of increasing productivity (Stranks, 1993).

Present safety monitoring systems may only be measuring parameters relevant to an old situation (Waring, 1996). Safety auditing is a type of monitoring which can take a more holistic view of the SMS than the other approaches mentioned. Safety audits usually occur several years apart. They may require several days or weeks of site work, plus similar periods for analysis. A full safety audit should be able to examine three parts of the SMS. The first is the validity of the SMS design, for example whether it is capable of delivering the desired level of safety. The second is the extent to which the employer complies with its own safety policies, procedures and standards. Finally, the third is the level of compliance with external legislation and standards.

In order to maximise the benefit of an audit, a team approach should be taken, involving managers, safety representatives and employees (HSE, 1991a). Staff independent of the activities being examined should carry out auditing. External consultants or staff from outside the department or site under consideration may be used. Waring (1996) recommended that a safety audit report should be produced listing recommendations to build on the company's strengths and tackle any health and safety defects, whether in the SMS itself or its operation.

3.7 The Process of Revising Safety

There is much in common between auditing and reviewing, but some principal differences exist. Those who carry out the SMS reviews are not usually the same people who carry out safety audits. Auditors should always be independent of the company or part of the company being audited, whereas those conducting the review are responsible for the health and safety within the company. Auditing requires representative sampling, interviewing and data collection. Reviewing considers the implications of pre-existing information from within and without the company, including the audit report.

It is necessary to set suitable performance standards to identify the responsibilities, timing and systems of reviewing. Reviewing performance is based on information from measuring activities using both reactive and proactive monitoring, and from the auditing activities based around the whole SMS. Employers should decide on how often to review their SMS's and at what levels. Key performance indicators should be used to measure the performance and the management of improvements. These may include assessing the degree of compliance with performance standards, identifying areas where performance standards are inadequate, assessing the achievement of objectives; and analysing accident, ill-health and incident data. This process of reviewing is usually essential, not only for understanding the historical and current performance of the SMS, but the future adequacy of the SMS's design and operation (Waring, 1996).

3.8 Summary of Safety Management Systems

The need for a clear policy statement, its dissemination and practice across firms has been stressed. It is evident that the safety function has a much wider role in firms than merely controlling hazards and ensuring compliance with regulations. Safety has been shown to have strategic value.

Accident prevention through the strategies of a 'safe workplace' and 'safe person' have been considered. 'Safe workplace' approaches have shown to be more desirable, although given sufficient levels of supervision and control 'safe person' strategies can be effective. It is clear that if risk control is to be successful there is a need for adequate inspection, maintenance and monitoring procedures to be in place.

The safety training literature seems to suggest that employees should be treated as more than recipients of information. Rather, their role in preventing injury and ill-health in the workplace is enlarged through the use of participative education. A step-by-step approach to achieving the goal of occupational safety has been outlined. Training has been shown to be part of a proactive approach to safety. Success appears to stem from developing the knowledge, skills and attitudes of employees, so that there is a behavioural change towards safer working. It is clear that it is not a panacea for solving all safety problems. However it has shown to be an effective process for helping to achieve an employer's safety goals.

The importance of breaking down both the direct and indirect, insured and uninsured costs of accidents has been outlined. The reasons for and approaches to accident investigation have been described, with an emphasis on employers understanding how to identify the direct and indirect causes of accidents. The measurement of safety monitoring has been described. Reactive safety monitoring approaches based on the analysis of accident statistics were described first, followed by more proactive evaluation approaches. Auditing as a measure of a safety management systems performance has been presented as an important monitoring activity. Finally, the process of reviewing safety management systems was then outlined. It was important to identify as it allows performance standards to be set for further measurement of safety systems.

This chapter has shown that safety management is like other management functions, particularly the management of quality. Safety management was shown to be much broader than simply supervising safe working and measuring accident rates as the sole indicator of success. The concept of the SMS was introduced, along with a stepwise method to assist with its development. The knowledge of SMS introduced in this chapter should help with understanding the nature of safety in the case study to be considered in Chapter Five.

CHAPTER FOUR

Systems Thinking and System Dynamics and its Use in Occupational Safety

4.1 Introduction to Systems Thinking

The concept of a system has developed into a powerful intellectual device over the last half century (Checkland and Haynes, 1994). Systems thinking has been used in many different fields including engineering, ecology and management science (Checkland, 1981; Senge, 1990; Lane, 1994). Systems thinking contains a number of frameworks and methodologies which deal with the capture of insights and problem solving in both static and dynamic systems.

This chapter has six sections. Section 4.2 offers a brief discussion of the theory underpinning systems thinking, with emphasis on the work of Bertalanffy (1950). In Section 4.3 a systems taxonomy is introduced as a framework for differentiating between soft and hard systems thinking and its application to real world problem-solving. The work of soft systems theorists such as Checkland (1981) is examined along with harder operational research. The system dynamics methodology is discussed in Section 4.4 using a modelling framework suggested by Roberts *et al.* (1983, p.8) which listed the phases involved in building, testing and applying system dynamics models. The ideas of a number of prominent system dynamics modellers are used to help build up a picture of the modelling process (Forrester, 1961; Richardson and Pugh, 1981; Moffatt, 1991; Wolstenholme, 1990, 1993; Coyle, 1996). Despite the absence of literature integrating systems thinking and occupational safety, Section 4.5 outlines examples of the use of causality and more importantly systems thinking in occupational safety (Heinrich, 1959; Waring, 1990a, 1990b; Andersen et al., 1986; Crawford, 1991). The chapter is completed in Section 4.6 with a summary of the broad field of systems thinking, and more specifically the use of system dynamics as a suitable methodology with which to use to evaluate occupational safety strategies.

4.2 The Origins of Systems Thinking

(a) General Systems Theory

About 50 years ago a school of thought emerged in the biological sciences that argued against a reductionist approach (Checkland and Haynes, 1994). It advocated developing ideas relevant to what it took to be the unit of concern: the organism as a whole (Checkland, 1981; Checkland and Haynes, 1994). This group became known as the organismic biologists. One of them, Bertalanffy (1950, 1968) suggested that the theory could be related both to living organisms and social organisation. This led him to develop General Systems Theory (GST). A concept was developed around a system as a whole, built from requisite parts or sub-systems. It was also proposed that living organismic systems and social systems were similar in their emergent properties as a result of the central notions of open systems, feedback processes, and causality. One-way causality has been shown from Bertalanffy's work to be insufficient thinking hence the appearance across a number of fields of science the notions of wholeness and holism. Most importantly, GST promoted thinking in terms of systems of elements in mutual interaction, rather than separate elements.

A major criticism that can be levelled at GST concerns its generality and lack of content. Researchers in diverse fields have been reluctant to acknowledge GST as relevant to their particular problems (Checkland and Haynes, 1994). This overarching theory has ensured that it has little to do with solving any problem area in particular (Checkland, 1981). Despite or in spite of this, virtually all modern systems thinking appears to have stemmed from the principles of GST. In particular it was developed further by Churchman in the late 1960s.

(b) The Systems Approach

Churchman (1968) developed the Systems Approach to problem solving in organisational settings. His approach aimed to improve the performance of systems as a whole through setting the boundaries of the systems, determining the sub-systems which exist within them and measuring the resources they contain. Management control of the system is achieved through information feedback. The work is built on the ideas of the organismic biologists such as Bertalanffy, and strictly applies the open system rules to organisational problems. Emphasis is placed on the interdependence of systems, and on how they achieve dynamic behaviour through changes to components. Churchman wrote about measurement of system components and the whole system, but it is not clear how these dynamic changes can be traced (Checkland and Haynes, 1994).

Churchman, as with Bertalanffy, offered a philosophical analysis of enquiry systems. Despite this practical limitation, Mason and Mitroff (1981) developed the Systems Approach as a soft operational research (OR) tool called Strategic Assumption Surfacing and Testing, designed to encourage group debate where common values and goals are not evident. Systems thinking has become more prominent through its application to real world problems. This is evident in the following taxonomy of approaches.

4.3 The Boundary of Systems Thinking

(a) A Systems Thinking Taxonomy

Checkland (1981) presented a taxonomy to classify the strands of systems thinking. In particular, he wanted to show the systems approaches used to address real world issues. Figure 4.1 maps out what he call the 'Systems Movement':

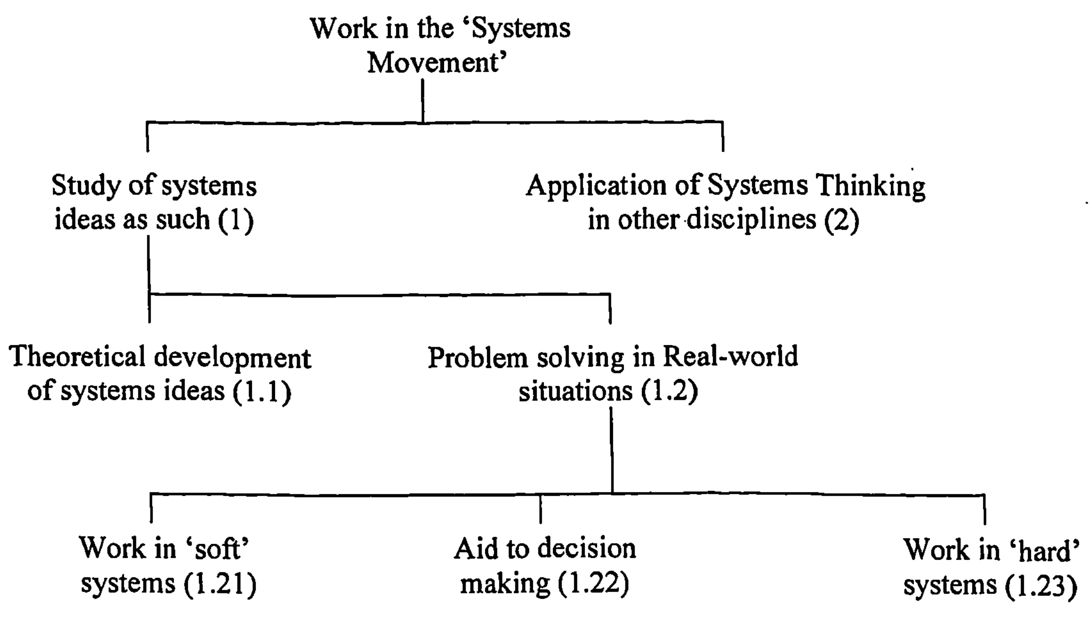

Figure 4.1 Varieties of systems thinking in the systems movement (Checkland, 1981, p.95)

Checkland's map consists of a layered structure, where (1) is the study of systems ideas as such; and (2) the application of systems thinking in other disciplines, such as geographical information systems. Category (1) is split into (1.1), that is theoretical developments such as cybernetics and GST, and (1.2) problem solving in real world situations. Category (1.2) is further divided into (1.21) work in 'soft' systems, (1.22) aids to decision making, and (1.23) work in 'hard' systems. Soft Operational Research (OR) and in particular soft systems methodology (SSM) can be categorised in (1.21) and are concerned with tackling ill-structured and messy problems or issues. Category (1.22) consists of RAND systems analysis, management science and classical operations research, which are systematic in their outlook rather than systemic. Category (1.23) contains systems engineering, computer systems analysis and it could be argued the original industrial dynamics, (Checkland and Haynes, 1994). It has emerged that there are three sub-sets of applied systems thinking. Given the above classification of applied systems thinking, it is no surprise that a number of formal definitions of systems thinking exist.

(b) Definitions of Systems Thinking

As one would expect, in a broad methodological area such as systems thinking, a variety of definitions have emerged. Forrester, coming from a simulation background, suggested that:

> ...systems thinking has no clear definition or usage ...some use systems thinking to mean the same as system dynamics (Forrester, 1994, p.251).

Richmond defined systems thinking in a much broader way as:

> ...the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure (Richmond, 1994, p.139).

Checkland and Haynes offered a definition which focuses on the human interaction:

> Systems thinking encompasses any use of the core idea of an adaptive whole to understand or intervene in the complexities of human affairs (Checkland and Haynes, 1994, p.189).

Senge suggested that systems thinking is dynamic:

> ...systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots' (Senge, 1990, p.68).

A number of key words emerge from the various definitions of systems thinking offered by the authors: complex(ities), emergent properties, whole, interrelationships, and understanding. Regarding systems thinking as looking at complex problems within the context of the adaptive whole should form a general definition. Checkland and Haynes may have been correct, and certainly diplomatic, when they simply suggested that:

> The different uses of the notion 'system' collectively constitute systems thinking (Checkland and Haynes, 1994, p.189).

Checkland's (1981) systems thinking taxonomy appeared to be extremely broad even where problem solving in the real world is concerned. Fortunately, an examination of the above definitions of systems thinking offered by prominent writers narrows down considerably the methodologies which can fit the label.

(c) Systems Thinking Methodologies and their Use in Solving Real World Problems

Using both Checkland's (1981) taxonomy and the above definitions of systems thinking, classical operational research (OR), soft OR, in particular soft systems methodology, and system dynamics will be examined to determine how suitable problem solving methodologies they might be.

(d) Traditional Operational Research

Traditional OR is concerned with the identification of problems, their objective, accurate descriptions, and then optimal solutions (Pidd, 1996). Problem formulation is in terms of a single objective and optimisation. There are often overwhelming data demands with the consequent problems of distortion, data availability, and data credibility (Ackoff, 1979). Models are opaque, frequently large and the stakeholders are assumed to be passive. Ackoff criticised this approach correctly by stating that managers did not have independent problems but were confronted with dynamic situations that consist of complex problems. Senge (1990) also noted that traditional OR was unable to deal effectively with dynamic complexity, prevalent in situations where cause and effect are subtle and where the effects over time of interventions are not obvious. OR models have a predictive function, whereas alternative systems thinking approaches allow the design of a system that is desired. Despite the argument by Churchman *et al.*, (1957) that OR concerns itself with as much of the whole system as it can given constraints of time and resources it clearly is not a systems thinking approach to problem solving (Checkland, 1981).

(e) Soft Systems Models

A number of soft systems (often referred to as soft OR) issue-structuring techniques have been developed. The principle ones are: Strategic Choice (Friend and Hickling, 1987), Critical Systems Heuristics (Ulrich, 1989; Flood and Jackson, 1991), Strategic Options Development and Analysis or SODA (Eden, 1990), Qualitative System Dynamics (Wolstenholme, 1990), and Soft Systems Methodology (Checkland, 1981). The last two will be reviewed in this section, as they tend to transcend more methodological boundaries than the others do. Before discussing soft systems methodology (SSM), another softer kind of methodology known as Qualitative System Dynamics (QSD) should be noted. It is a methodology which concerns itself with the front and back ends of the system dynamics modelling approach. The methodology follows the same sequence as that of the fuller quantitative models, with the exception of the actual simulation modelling and of its subsequent testing. It has been used by a number of modellers as a distinct and separate approach to problem solving (Senge, 1990; Wolstenholme, 1990), and acknowledged by others to be sufficient in instances where sufficient insight into a problem has been gained without the aid of simulation (Coyle, 1996).

SSM is an approach developed by Checkland (1981) to tackling complex problems. Checkland noted that in many management situations it is difficult to define the system or the area of concern thought to be problematic. He observed that in most management problem situations, the crucial need was to find accommodation between conflicting viewpoints and interests, rather than a consensus on goal seeking. SSM subjectively allows an enquiring process for expressing, challenging, and comparing the world views of various actors in their understanding of a problem situation through the building of a 'rich picture'. This allows a deep insight into a problem to be achieved (Lane, 1994). A comparison between 'ideal type' models and the 'real world' leads to accommodation amongst the relevant actors to change the problem situation in a way that is both desirable and feasible. Through the process of debate, knowledge can be captured and action can be taken (Checkland and Haynes, 1994). The systemicity lies in the process of inquiry rather than in the world, as distinct from harder systems thinking, which attempts to model the real world.

Soft OR techniques, are strongly interpretative in nature (Lane, 1994). SODA and SSM are based on subjective understanding and the use of cognitive maps and root problem definitions to express individual meaning and to negotiate world views. Strategic Choice also strongly emphasises the importance of the world views held by participants. The motivation for the methodologies is based on a subjective rather than objective view. QSD allows an appreciation to be built up of the feedback structure and delays contained within systems, and how these control behaviour. The advantage of soft systems models is that they are available to both the problem owners and professional practitioners (Checkland, 1985). Soft OR accepts the need to work with a plurality of world views, to pay attention to changes in perception which alter during the process of intervention, and to build consensus for change through discussion and debate (Jackson, 1994).

A major disadvantage of soft systems models is that they do not produce final answers and one has to accept that the inquiry is unending (Checkland, 1985). Another criticism of soft OR is that it seeks to elicit subjective viewpoints without considering the distortions they contain (Lane, 1994). Soft OR lacks a tool for examining the time-evolutionary behaviour of systems. Forrester (1994) and Sterman (1994) saw the need for simulation of systems due to this shortcoming. Sterman suggested that a mental model could not identify sufficiently well the elements of complexity which arise from feedback, time delays, accumulations and nonlinearities. Forrester was concerned that in lacking the identification of system accumulations or level variables, the causal loops of QSD fail to identify in full the systems elements which actually cause the dynamic behaviour. Another major problem of QSD is that there are many models explaining a specific problem, but without simulating the models with real data it is impossible to select the best model. Only when non-operational models of policy-making or strategic management are being discussed can QSD be of real use.

(f) Industrial Dynamics

According to Checkland and Haynes (1994), system dynamics in the form it was originally developed fell into the hard category. This could be disputed by a number of system dynamics modellers who might argue that certainly in today's form, system dynamics crosses all three types of systems approaches to real world problem solving (Forrester, 1961; Richardson and Pugh, 1981; Lane, 1994). In order to clarify this point, system dynamics needs to be described fully, as this is the chosen methodology for this work.

4.4 System Dynamics Modelling Methodology

System dynamics is a methodology used to assist in the understanding of complex problems (Forrester, 1961; Coyle 1977, 1996; Richardson and Pugh, 1981, Wolstenholme, 1990). System dynamics should be regarded as a rigorous approach to solving problems in complex systems, using the help of a computer simulation to identify equitable policy decisions that can be applied to control a dynamic problem or to alter undesired behaviour. An understanding of dynamic behaviour is achieved by focusing on the actual dynamic interrelationships in the complex system that causes the change.

(a) The Development of System Dynamics

Forrester (1961) first applied the principles of cybernetics and GST to industrial systems in *Industrial Dynamics*. He knew that control systems used in central heating systems relied on the feedback of information to regulate temperature through the use of policies or rules. He recognised a parallel in social systems. He noted that the ability to apply control theory concepts to business problems could be of great value if applied to business. The idea of designing policies to control the behaviour of a business temporally was developed (Coyle, 1996).

Forrester (1961) set out the concepts and methodology of a modelling technique which he termed industrial dynamics. He based industrial dynamics on the concept of information feedback control theory or servomechanisms. All systems whether they are biological, engineering or social, contain information feedback control loops. These systems are continuous and are driven by an adaptive process which leads to new decisions, keeping the system in continuous motion. He argued that the behaviour of these systems is governed by three characteristics: structure, delays and amplification. The structure describes how the parts of the system are related to one another. Delays exist between the availability of information and the taking of decisions based on the information. Amplification is common in many social systems, and he suggested that this is the most important characteristic determining the behaviour of information feedback systems. In a system with positive feedback loops a small change in an information input or policy often results in greater than anticipated amplification throughout that system.

Forrester took these three principles and was able to build a simulation model which integrated the functional areas of management within an industrial setting, and which demonstrated, through computer simulation modelling how policies could be designed to control a dynamic commercial system. Industrial dynamics was developed because many problem-solving methods, particularly those using management science approaches, were not providing useful insights into and a full understanding of strategic problems in complex systems (Wolstenholme, 1990; Coyle, 1996).

Later he began to apply his modelling approach to the problems of ageing urban areas and to the complex social issues surrounding them (Forrester, 1969), and population change and its effect on crowding, food, pollution and natural resource depletion in the context of world dynamics (Forrester, 1971). The term industrial dynamics was replaced by the more general one system dynamics (Richardson and Pugh, 1981). By the late 1970s and early 1980s the scope of system dynamics modelling had widened substantially to cover many social-economic issues, including evaluating policy in areas such as military planning, social policy, corporate strategy and environmental planning (Wolstenholme, 1990).

(b) Definitions of System Dynamics

A good number of definitions of system dynamics have been put forward. Forrester had defined industrial dynamics as:

> ...the investigation of the information-feedback character of industrial systems and the use of models for the design of improved organizational form and guiding policy (Forrester, 1961, p.13).

Coyle noticed that Forrester's definition did not state what type of models are involved, nor incorporate time or feedback. In order to retain the core concept of system dynamics and allow for the widening of the approach Coyle suggested that:

> System dynamics deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimisation (Coyle, 1996, p.10).

Although Coyle's definition is long it captures all the essential components of the system dynamics method. System dynamics is a suitable modelling approach where the problem under consideration is dynamic, i.e. its quantities change over time, and information feedback determines a system's behaviour. Wolstenholme (1990) suggested that system dynamics is concerned with controlling such undesirable behaviour through observing and identifying the problematic behaviour of a system over time and to create a valid representation of the system in a model form. This system must be capable of reproducing through computer simulation the existing system behaviour, and allowing the design of improved system behaviour through repeated experimentation using simulation.

(c) The Stages of System Dynamics Modelling

A number of authors have put forward frameworks for the use of system dynamics to solve problems (Richardson and Pugh, 1981; Roberts *et al.*, 1983; Coyle 1996). All three systems modellers offer a similar approach to the model building process. They all share the importance of problem identification, system conceptualisation, formulating the model both qualitatively and quantitatively, and policy testing and recommendation. The iterative process of model building is also common to all. Roberts *et al.* (1983, p.8) produced a detailed and rigorous overview of system dynamics modelling. They offer six stages to the building and use of system dynamics models. Following Roberts *et al's.* framework, the phases required for building a successful system dynamics model will be examined in a sequential order. Roberts *et al's.* approach is outlined in Figure 4.2.

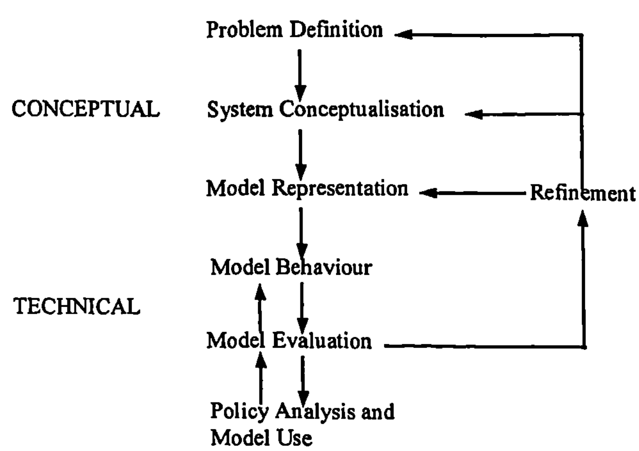

Figure 4.2 Phases in the model building process (Roberts et al., p.8)

Validation of the model is a continuous process, and through a number of structural, behavioural and policy tests, a model can be built which is a good representation of reality. The principal tests will be raised when appropriate throughout the stages of the modelling framework. The iterative cycles between the various model stages of the above framework are significant. In reality a typical system dynamics model is built from looping through adjoining stages several times, gradually progressing to the last stage of the model building process.

(d) Problem Definition

The first step in the model building process involves identifying the relevant problem. There are a number of criteria that the problem must meet in order for it to be successfully addressed using system dynamics. It needs to be capable of being analysed using a system. It has to be dynamic, that is to vary over time. Also, the forces causing this variability must be able to be described causally, and these causal influences must be able to be contained with a closed system of feedback loops. A model is regarded as valid if it fits a purpose of the study (Forrester and Senge, 1980; Richardson and Pugh, 1981). Defining a clear purpose serves to focus a study sufficiently and it assists in judging the validity of the results (Richardson and Pugh, 1981).

A number of variables can be pictured changing over time (Randers, 1980; Richardson and Pugh, 1981). Producing temporal graphs of principal model variables can assist with defining the problem and will lead to the formulation of structured, quantitative feedback models. These are often referred to as reference modes of behaviour. These can illustrate the actual or expected behaviour of the model against the desired behaviour. Doing so clarifies which variables must appear in the model. Two types exist: a historically observed reference mode, or if no empirical data exist, a hypothesised reference mode. The idea is that once the simulation model is built and calibrated, the model should be capable of reproducing the major dynamics of the reference mode. The validity of the system dynamics model is closely tied in with its ability to reproduce the reference modes (Richardson and Pugh, 1981). Moffatt (1991) showed how population dynamics can be modelled using system dynamics. He started the process with a simple reference mode of demographic behaviour as presented graphically in Figure 4.3:

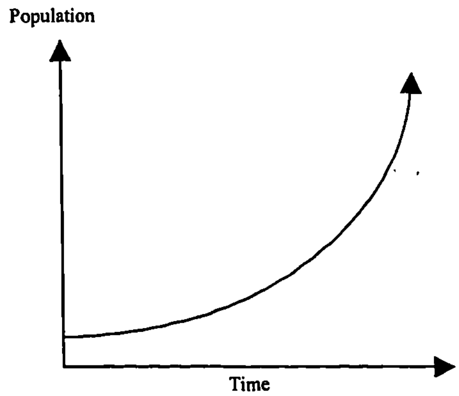

Figure 4.3 Exponential population growth (adapted from Moffatt, 1991, p.18)

The patterns depicted in the population growth curve may lead to the identification of a causal diagram as the modeller seeks to identify possible variables which explain the behaviour represented in the reference mode. For example, the causes of the exponential population change (see Figure 4.3) such as births, deaths and migration can be identified and modelled. From the reference mode of behaviour showing population dynamics a whole series of possible causal links can be drawn showing this behaviour. This helps to identify the principal variables surrounding the problem. Once these graphs are established, one can start to search for feedback structure between them, thus developing the models structure (Richardson and Pugh 1981).

(e) System Conceptualisation

Once the purpose of the study has been set, the problem identified, principal variables determined and reference modes defined; the interconnections between those variables should be explored. This involves both seeking out the cause-and-effect between the variables and forming them into feedback loops. The result is one or more causal-loop or influence diagrams. These are used to convey a picture of the system at the model conceptualisation stage, and often in final descriptions of model structure where it is necessary to give a simple overview of the model (Coyle, 1996). To build a valid representation of how the system functions, the model's structure needs to be compared to that of the real system (Forrester and Senge, 1980). Knowledge of the real system may be empirically based or purely hypothetical. It may be elicited from a number of sources such as the assumptions of the modeller, or from persons with a good knowledge of the real system, or through causal relationships found in appropriate literature.

Cause and effect can be displayed as either positive or negative according to the polarity of the relationship. A positive sign represents the variable at the opposite end of the arrow moving in the same direction, while a negative sign represents an inverse relationship. It is simple to convey a relationship using simple cause and effect. Figures 4.4(a) and 4.4(b) show positive and negative relationships respectively. It must be emphasised that a causal link between A and B assumes all the influences are equal. In a simple connection only A influences B, but when several factors influence an element the ceritus paribus clause applies. This assumption is very important when positive and negative loops are involved.

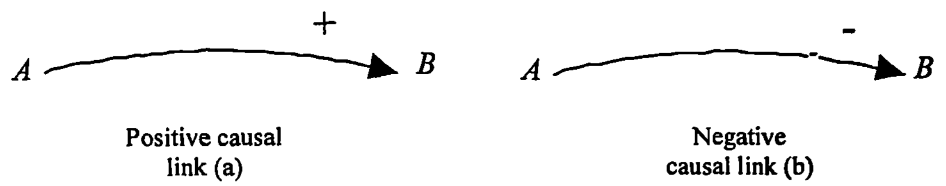

Figure 4.4 Causal link polarities (Richardson and Pugh, 1981, p.26)

As system dynamics is based on causality contained within feedback loops, these feedback loops need to be clearly understood. Feedback systems form loops of interconnections. These loops contain variables linked together through causes and effects. The causal feedback loops allow the changes which occur dynamically in the real world to be modelled. Two types of loop exist: goal-seeking or negative loops, and growth producing or positive loops (Coyle, 1996; Richardson and Pugh, 1981). The overall polarity of these feedback loops is determined from the sum of the individual polarities of the cause-effect links.

Figure 4.5(a) represents a positive feedback loop (Moffatt, 1991). Tracing around the loop it is evident that the greater the population; the more births there will be; the more births there are, the greater the population will become. The positive sign at each arrowhead defines the whole loop as being positive. It is also possible to read the loop as the smaller the population the fewer births there will be the fewer births there are, the fewer people will be added to the population. The positive sign in the parentheses indicates that the whole feedback loop is positive. Positive loops amplify disturbances around a loop (Richardson and Pugh, 1981). They are often associated with destabilising, disequilibrating, growth promoting or self-reinforcing behaviour.

The negative loop shown in Figure 4.5(b) shows that as the number of deaths increase, the population may decline. If this continued, the population would eventually die out. The polarities on the arrows show that there are both positive and negative influences working within the feedback loop. The negative sign in the parentheses shows that the overall structure of the feedback loop is negative. Negative feedback involves target-seeking behaviour. Where a disturbance is introduced the loop seeks a state of equilibrium. They are often used in control systems (Moffatt, 1991). All managed systems must contain at least one negative loop (Coyle, 1996).

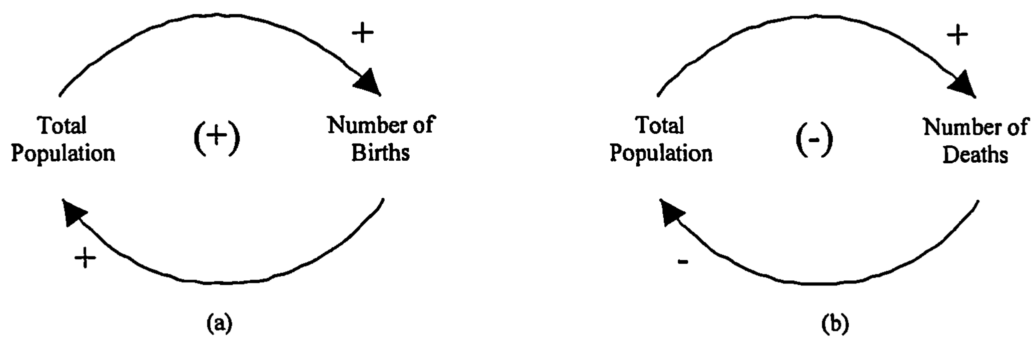

Figure 4.5 Causal diagrams illustrating positive and negative feedback loops (Moffatt, 1991, p.16)

System dynamics models invariably consist of several positive and negative feedback loops that integrate to form multi-loop systems. This is demonstrated in Figure 4.6 where the positive and negative loops shown in Figures 4.5(a) and 4.5(b) are interconnected to form a simple multiple feedback model of population dynamics.

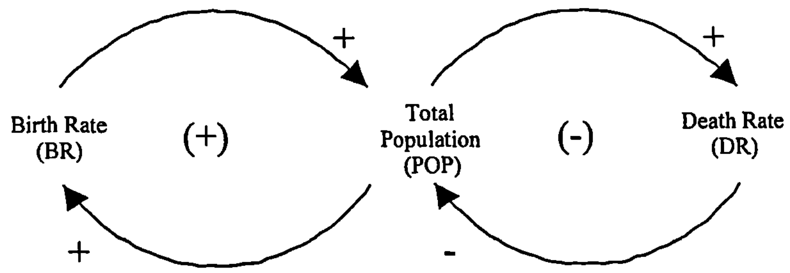

Figure 4.6 A population dynamics model (Moffatt, 1991, p.17)

Although only two feedback loops are connected in Figure 4.6, this may represent the full causal structure which would allow the reference mode of behaviour shown in Figure 4.3 to be replicated. The associated reference mode indicates exponential population growth. Under these circumstances the number of births will exceed deaths per unit of time. These two rates of change represent a positive and a negative feedback loop respectively. Total population (POP) is an accumulation in the system. It is a state variable or level which changes according to the two respective rates it interacts with.

Where several loops exist, the behaviour of systems of interconnected feedback loops often works counter to intuition and expectation, in spite of the fact that the dynamic behaviour of individual loops may be fully understood. The complex behaviour that emerges from a system containing feedback structure of a real problem can invariably only be traced using simulation (Richardson and Pugh, 1981). It is a relatively simple exercise to translate a causal diagram into a quantitative system dynamics model which can be simulated using computer modelling (Moffatt, 1991).

(f) Model Representation

In the development of the quantitative model, two phases are passed through. These consist of converting the causal diagram into a flow diagram, then transcribing this flow diagram into a suitable system dynamics computer language. The principles surrounding flow diagramming need to be understood.

(g) Flow Diagrams

A flow diagram allows the causal structure of the model to be translated into system dynamics equations. A number of commercial system dynamics packages exist, the pioneer was DYNAMO in 1960 (Coyle, 1996). Others include Stella/IThink, Vensim and Powersim. They all work to the same fundamental rules, but differ slightly in their representation of model constituents.

Moffatt (1991) offers a good example of how to arrive at a flow diagram from his model of population dynamics. Figure 4.7 shows Moffatt's causal loop diagram converted into a flow diagram. The diagram is built using Stella/IThink, which is the software package of choice for this thesis.

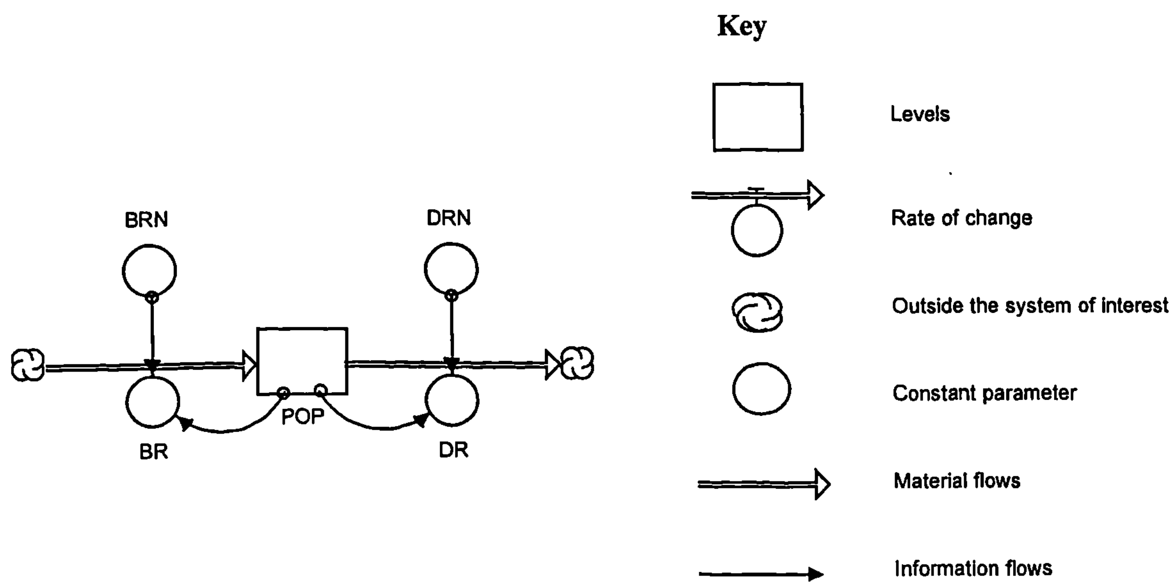

Figure 4.7 Flow chart of population dynamics, showing symbols for levels, rates and constant parameters (adapted from Moffatt, 1991, p.19)

The flow diagram has a key containing the symbols which are used to construct the diagram. Levels represent accumulations in a system, as with POP. The level may be compared to a liquid accumulation in a container. The feedback process involves a continuous fluid like movement within the system or model. In order for that to function, flows are introduced which increase and decrease a level. These are called rates, and BR and DR represent these. The circular symbols labelled BRN, birth rate normal and DRN, death rate normal represent constant parameters. In this instance the proportion of a population giving birth or dying over a period. The cloud symbols in Figure 4.7 represent sources and sinks for the material flowing into and out of the level (Richardson and Pugh, 1981). Their presence indicates that the real-world accumulations they represent lie outside the boundary of the system being modelled.

Material flowing out of a level will diminish that level, but information about it passing to other parts of the system will leave the level unaltered. Information feedback links are substantially different from physical or resource flows. Causal diagrams represent both types of links with the same sort of arrow, but flow diagrams differentiate between physical or material flows and information links. In the preceding figure, material flows are shown as the thicker transparent lines. They represent the rate of addition to the population through the birth rate and concurrently, the subtraction from the population through the death rate. The thin solid lines represent information flows. These can be thought of as decision variables, as they dictate the behaviour of the rates. In larger more complex systems these allow information feedback about the rate of change of the levels to occur.

Causal loop diagrams are invariably an aggregation of detail, used to picture the principal components and boundaries of the model. Flow diagrams allow the representation of the structural detail. There is a need, as with causal loop diagramming to ensure that the structure is representative of the real world. Additional confidence in a model's validity can be gained through comparing the form of the equations of the model with the relationships that exist in the real system (Barlas, 1996). This leads on to actually quantifying the model structure.

(h) Quantifying Flow Diagrams

A quantitative system dynamics model contains a set of equations (Coyle, 1996). It is created to represent the system and allowed to run forward in simulated time in an attempt to mimic the behaviour of the real system as it runs forward in real time. System dynamics simulation uses time step simulation. The model takes a number of steps along the time axis. A sufficient number of steps are taken in order to simulate to an acceptable level of accuracy the time period under consideration.

System dynamics uses numerical simulation based on difference equations to represent the process of accumulation (Wolstenholme, 1990). Using DYNAMO programming notation, the dynamics of the simulation can be explained using three points in time. These are conventionally labelled J, K and L, where K is defined as the current point in time, J as the past point in time and L as a future point in time. These are separated by DT which is the length of time or solution time elapsing between J and K, or K and L (Richardson and Pugh, 1981). The simulation moves one DT at a time. This concept is represented in Figure 4.8:

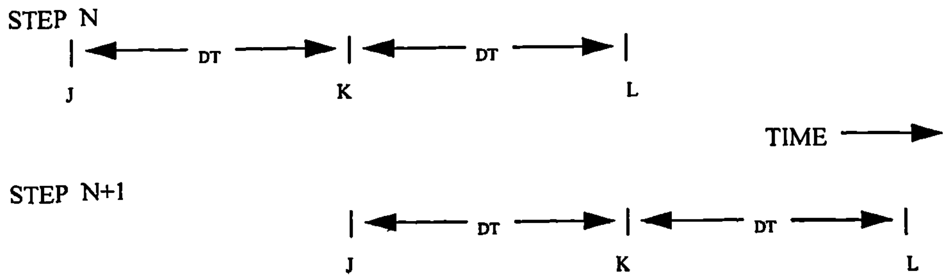

Figure 4.8 Time shift and re-labelling in simulation (Wolstenholme, 1990, p.49)

(i) Simulation Equations

DYNAMO is probably the clearest system dynamics programming language to understand from first principles, and will be used throughout the remainder of this chapter to demonstrate equation representation. There are several types of DYNAMO equation (Richardson and Pugh, 1981). Each equation is labelled on the left with a single letter to indicate its type. An L represents a level; R a rate, C a constant, N an initial value, A an auxiliary, and T a table function. All these equation types will be described in the remainder of this section.

Figure 4.7 contains one level, two rates, and two constants. In order to simulate, equations need to be specified for each of these variables. Moffatt's (1991) population dynamic flow chart can be written using the DYNAMO programming language. The level equation can be specified as follows:

L POP.K = POP.J + (DT) (BR.JK - DR.JK)

where L is a level equation, POP is the Population, BR is the Birth Rate, DR is the Death Rate, and DT is the Solution Time.

Levels are simply the integration of rates over a period of time (Coyle, 1996). They are calculated at the current time, and have the time subscript K (Wolstenholme, 1990).

They are based on the size of the level at the previous point in time, J, plus what has flowed into the level, less what has flowed out during the period JK. DT, the size of the time interval for the simulation, governs this period. Error is introduced when making discrete approximations of a continuous process. The smaller the DT, the closer the simulation to the actual. If DT is set too small then running the model may be time-consuming, whereas if it is too large, numerical instability may occur (Coyle, 1996). A number of authors have suggested loose rules for the selection of DT (Forrester, 1961; Richardson and Pugh, 1981; Wolstenholme, 1990, Coyle, 1996).

The level (POP) in Figure 4.7 is directly influenced by two rates, birth rate (BR) and death rate (DR). A rate equation sets the rate of flow into or out of a level (Moffatt, 1991). All levels are controlled by rate equations. A rate equation can be denoted by JK or KL. JK represents the previous time interval J to the present K, and KL the next time interval from K to L.

In Moffatt's demographic model the birth and death rates have the same structure. The birth rate can be written as:

$$\text{R} \quad \text{BR.KL} = \text{POP.K} \times \text{BRN}$$

where R is a rate equation, POP is the Population level at time K, and BRN is the Birth Rate Normal (a constant).

The death rate can be written as:

$$\text{R} \quad \text{DR.KL} = \text{POP.K} \times \text{DRN}$$

where DRN is the Death Rate Normal (a constant).

It is common to find three types of parameter in system dynamics models: constants, initial values of levels, and table functions (Richardson and Pugh, 1981; Moffatt, 1991). A table function is the only type of parameter to possess a time suffix, therefore it doubles as an auxiliary function and thus, will be introduced later in the section. It is important when setting up all constants and initial levels that these are based on the most accurate data or estimates of data possible. There are three alternatives available, either to match a historical situation, initialise the model in equilibrium, or for a set pattern of growth or decline (Richardson and Pugh, 1981).

The constant is normally fixed over the simulation period, hence they do not contain any time suffix (Moffatt, 1991). Constants can take many forms including conversion factors, information delays, adjustment times or proportions (Richardson and Pugh, 1981). Incidentally, BRN and DRN are proportions. BRN is a numerical value and is set in the program as:

C BRN = 0.001

where C is a constant equation, Birth Rate Normal (set in this instance at 1 birth per 1,000 people).

Moffatt (1991) suggests that initial value equations set for levels at the beginning of a simulation are also constants. The equation is written as the name of the level without the time suffix. The population level is set as:

N POP = 3,000,000

where POP is the numerical value of the level representing the population (set in this instance at 3 million people).

Auxiliaries are commonly used where the formulation of a level's influence on a rate involves one or more intermediate calculations (Roberts *et al.*, 1983). Auxiliaries are computations used to create the information feedback structures within the flow diagram and are more prevalent in complex models (Richardson and Pugh, 1981). Auxiliaries are always computed in the present, from the present values of other variables, be they levels, rates or other auxiliaries. The associated time-script is a K. Auxiliaries also allow the introduction of information delays into the feedback structure of a model, thus adding greater realism to the behaviour of the simulated model.

Models are refined and improved as a result of iterating through several of the model building stages. This is shown in Figure 4.2, Roberts *et al's* (1983, p.8) model building framework. New insights are often gathered at each stage of a model. A greatly increased understanding of the system problem can be developed even before any formal simulations have been run. In fact Wolstenholme (1990) and Coyle (1996) suggest that a problem may well become sufficiently understood simply through the process of describing the system. Moffatt (1991) shows in Figure 4.9(a) how a new population dynamics model could evolve from his basic model through the introduction of a further feedback loop containing two auxiliary variables. The new negative feedback loop assumes that as the carrying capacity of an area is approached, there is a substantial fall in the birth rate. In effect the model structure now represents a classic 'limits to growth' archetype as developed by Senge (1990). This causes a re-think about the reference mode, which may now take the logistical shape as outlined in Figure 4.9(b). Figure 4.10 shows a flow chart modified through the introduction of the new feedback loop. Two auxiliaries are introduced into the new loop: carrying capacity (CC) and a table function named infant survival multiplier (ISM).

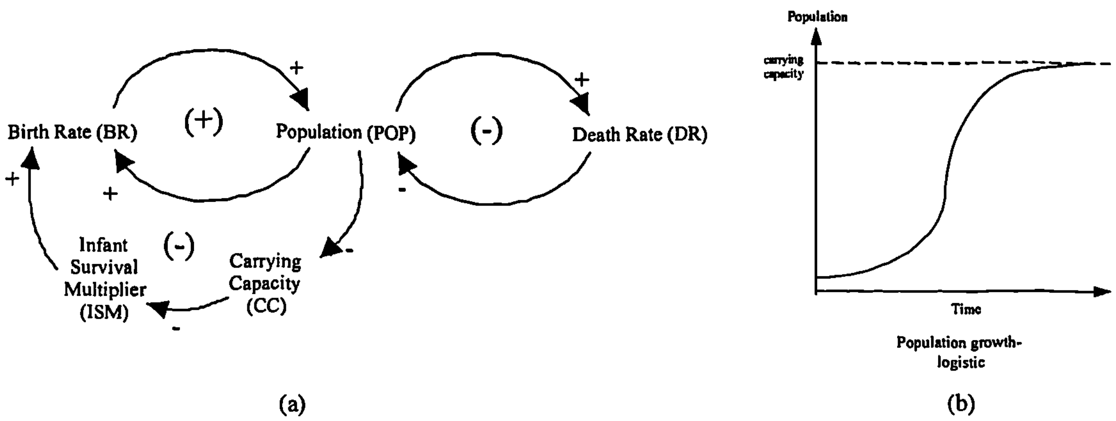

Figure 4.9 New causal loop model of population dynamics and associated reference mode (adapted from Moffatt, 1991, p.24; p.18)

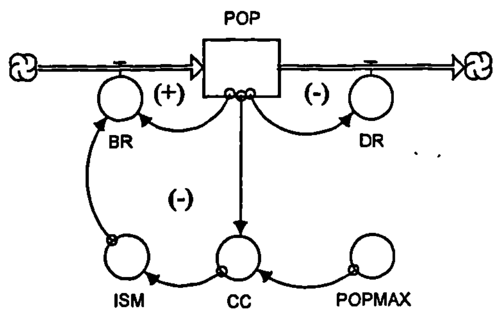

Figure 4.10 Flow diagram of the new model of population dynamics (adapted from Moffatt, 1991, 24)

The new flow chart shows that as POP increases, then the CC of the area is approached. This impacts on the ISM, which in turn reduces the BR. CC represents the total number of people that can be supported at a given level of material welfare. The limit of CC is constrained by the constant parameter (POPMAX). The equations for CC and POPMAX could be set up as:

A CC.K = (POPMAX - POP.K)/POPMAX
C POPMAX = 5000000

where A is an auxiliary equation, CC is the carrying capacity, POPMAX is a constant (set at 5 million people), and POP is the total population in the level.

A table function can represent either a linear or non-linear relationship between an independent and dependent variable plotted in a graph form. Coyle (1996) suggests the importance of these causal non-linear relationships in the modelling of managed systems. Table functions are constructed from either empirical data, particularly when injecting a historical pattern of data into a model, or purely from hypothetical relationships (Graham, 1980; Moffatt, 1991; Coyle, 1996). Most of these parameters are arrived at through the use of descriptive information.

In Moffatt's (1991) new model, the relationship between the ISM and CC can be set for a range of values:

A ISM.K = TABLE(ISM,CC.K,0,1,.25)
T ISM = 1.00/0.95/0.88/0.78/0.00

More recent system dynamics packages have the advantage over DYNAMO in that table functions can be drawn and modified with the use of a computer mouse, and are visible to the modeller as a simple cause-effect graph, rather than simply sets of co-ordinates. Moffatt's table function can be shown graphically in Figure 4.11:

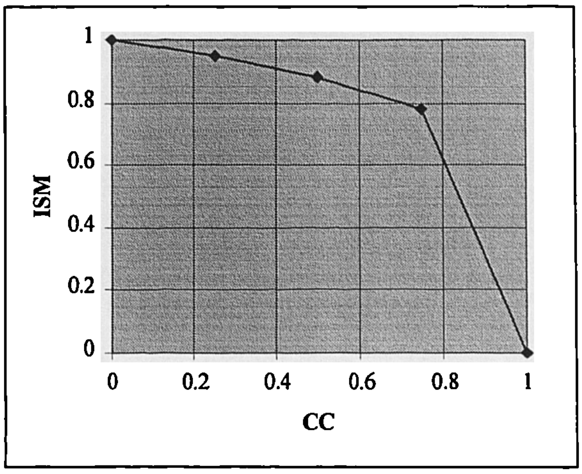

Figure 4.11 Graphical representation of simple table function

Coyle (1996) warns about the limitations of table functions, where the instance arises when the independent variable goes above or below the declared range. This can lead to a fatal error occurring. In addition, the accuracy of the table often depends on the use of small step sizes.

(j) Delays in Systems

Delays occur in most social and economic systems, and a system's behaviour over time is often strongly influenced by delays. (Richardson and Pugh, 1981; Roberts *et al.*, 1983). Delays can be divided into two types, those resulting from the time involved in processing physical materials, and those resulting from the time involved in perceiving and acting upon information (Roberts *et al.*, 1983). These are called material delays and information delays respectively. Both are represented as exponential delays. Two characteristics of a delay are important, the first being the delay time, and the second the transient response of the outflow to the inflow (Forrester, 1961).

In material delays outflow rates are simply calculated by dividing the level by the average delay. Higher order delays are represented by cascading a number of levels together, and dividing the delay by the number of levels used. The higher the order, the closer the output mimics the shape of the input. The delays represent the overall flow in the system, and not individual entities. This must be taken into account when choosing suitable delays. Lower order delays may be appropriate to use to model simple flows, and higher order delays for representing more complex flows (Richardson and Pugh, 1981).

Smoothing or averaging of information over time allows real trends in data to be detected (Richardson and Pugh, 1981). Often the smoothing out of randomness is required to obtain an accurate picture of behaviour. Where delays are applied to information flows, the idea of a level within an information flow is created (Wolstenholme, 1990). Delaying of information effectively represents smoothing of information. As with material delays, the order of the delay or averaging can be determined through the cascading of a number of levels together.

Although levels are used to represent both types of delay, it is vital to ensure that levels used in material delays are conserved, as they represent real material (Coyle, 1996). The levels used in information delays are not conserved, as it is not possible to contain real levels within an information flow.

(k) Parameter Verification and Dimensional Consistency

Model parameters can be compared against observations from the real system in order to determine whether they correspond conceptually and numerically to real life. (Forrester and Senge, 1980; Barlas, 1996). Numerical confirmation requires the numerical values of the parameters to be estimated with sufficient accuracy (Barlas, 1996). In addition, Hamilton (1980) sets out estimation techniques for lengths and orders of delays in system dynamics models. A dimensional analysis of a model's rate equations (Forrester and Senge, 1980) is important for building confidence in a model. The dimensions of the state variables and parameters must be consistent (Moffatt, 1991; Coyle, 1977)

(l) Model Behaviour

Once the structure of the flow diagram has been set, a model is ready for computer simulation (Roberts *et al.*, 1983). The fourth stage of the modelling process can begin. The computer simulation is run to determine how all the variables within the system will behave over time. At the qualitative level, the model may be verified through comparing the correspondence of the reference mode of behaviour or state variables(s) with the behaviour or hypothesised behaviour of the real system (Moffatt, 1991).

(m) Model Evaluation

In stage five, parameter sensitivity tests and calibrations are performed on the model. These are often accompanied by statistical validation tests of behaviour replication (Roberts *et al.*, 1983; Moffatt, 1991).

The behaviour sensitivity tests focus on the sensitivity of model behaviour to changes in parameter values. The test can indicate whether shifts in model parameters can cause plausible model behaviour. They can also help the modeller to identify where the sensitive model parameters might lie (Moffatt, 1991). Tank-Neilsen (1980) recommended that sensitivity testing can help determine if a model's sensitivity accords with the real world or the anticipated real world, and if the model is sensitive to the same changes as the real system.

If the simulation output is able to replicate the actual behaviour of the system under study, be it a historical or a hypothetical pattern, then this is a strong contribution to the overall validity of the model. A number of behaviour reproduction tests can be used to evaluate system dynamics models. They are used to determine the closeness of the match between model-generated behaviour and the real system. The behaviour reproduction attempts to replicate the magnitude, turning points and periodicity of state variables in the system under study (Moffatt, 1991). Tests include replication of reference modes, frequency generation, relative phasing, multiple mode, behaviour characteristic and the application of an overall summary statistic (Forrester and Senge, 1980; Richardson and Pugh, 1981; Sterman, 1984).

(n) Policy Analysis and Model Use

Finally, the sixth phase of the modelling process involves testing alternative policies that might be implemented in the system under study. Sudden policy changes can be made, and their effects upon the system behaviour examined. An invaluable insight into the reasons for the behaviour of a real system can be derived from building a system dynamics model. Often the purpose of modelling a system is to not only to evaluate system behaviour but also actually to suggest the implementation of policies which will mitigate undesirable behaviour and improve its operation (Forrester, 1961; Richardson and Pugh, 1981; Wolstenholme, 1990; Coyle, 1996).

Alternative policies can be tested through either parameter and/or structural analysis (Richardson and Pugh, 1981; Coyle, 1996). Both involve changing the ways in which decisions are made. Testing policies through the modification of parameter values simply consists of changing the value of a parameter in rerun mode, running the model and then comparing the resulting behaviour to that of the base or original simulation run. Policy parameters can be classified as those whose values are to some extent within the control of the real system owners (Wolstenholme, 1990). Testing a model's sensitivity to the value of a policy parameter may also test the sensitivity of the real system to the corresponding policy change (Richardson and Pugh, 1981). A sensitive policy parameter may be able to identify for the modeller a leverage point in the real system. It is not sufficient to know that a policy improves model behaviour. The reason why the model behaviour improved must be understood. The understanding should be compared to what is known or expected about the real system. Only at that point can a model based policy analysis contribute fully towards decisions about policy implementation in a real system.

Structural changes are usually greater determinants of system behaviour over time (Richardson and Pugh, 1981; Coyle, 1996). Policy improvements in system dynamics studies often involve the addition of new feedback links that represent new ways of using information. Additional model equations can be used to represent new policy options that alter the feedback structure of a system. The addition of new parameters can assist in experimentation with policies. To decide on an alternative structure, guidance must come from familiarity with both the real system and the model. The addition of a link that creates a positive loop may have the potential to destabilise model behaviour, while a new link, which creates a negative loop, has the potential to add stability. For example, if instability is a problem in the system, a way to address the problem is to introduce one or more new minor negative feedback loops in order to dampen behaviour.

System dynamics has traditionally relied on the use of intuition and experience by the system modellers and users to test policies for better system behaviour over time (Wolstenholme, 1990). To make this more objective, simulation by optimisation using system dynamics has been developed in recent years (Coyle, 1985, 1996; Mohapatra and Sharma, 1985; Wolstenholme and Al-Alusi, 1987; Dangerfield and Vapenikova, 1987; Kleijnen, 1995). The approach uses computer software in its model analysis. An examination of this approach to policy testing is beyond the scope of this study, particularly as only three commercial system dynamics packages support optimisation (DYSMAP, COSMIC and Vensim).

According to Richardson and Pugh (1981), the modeller must consider the validity of the recommendations, and whether they can actually be implemented. A system dynamics model may be able to indicate trade offs between alternatives. It is used as a tool to test different management policies, and the policy recommendations which result. A policy remains robust if it remains a good choice despite variations in parameters, different exogenous conditions and reasonable alternatives. It must also be realised that the real system will always contain aspects, which are not captured by the model. Finally, when considering implementation of the set of policy recommendations, the users of the model must be convinced as to the value of the recommendations, and consideration must be given as to how the real system would respond to the process of implementation.

4.5 The Literature on the Causes of Accidents and on the Application of Systems Thinking to Occupational Safety

(a) Simple Accident Causation Models

In order to investigate accidents, an understanding of the mechanism by which accidents occur is a prerequisite. A number of theories of accident causation have been put forward. Heinrich (1959) developed the 'Domino Theory'. It is based on the theory that a chain or sequence of events can be given in a chronological order up to the accident event (Bamber, 1990b). The theory is shown in Figure 4.12:

Ancestry and social environment → Fault of person → Unsafe act and/or mechanical or physical hazard → Accident → Injury

Figure 4.12 The five factors in the accident sequence (Heinrich, 1959, p.14)

Heinrich likens these five stages to five dominoes standing on edge in a line next to each other, so as the first domino falls it knocks down its neighbour and so on. Removal of any of the first four factors will break the sequence, thus preventing the injury. The injury is caused by an accident, and the accident is in turn always the result of the factor that immediately precedes it. Heinrich recommends that the key to accident prevention is to remove the middle of the sequence: an unsafe act of a person, or a mechanical or physical hazard.

Bird and Germain (1987) extended the 'Domino Theory' to include the influence of management in the cause of accidents and the effect of wastage of assets. They emphasised loss control. Their model is presented in Figure 4.13. This modified sequence can be applied to all accidents, whether they are injury or non-injury.

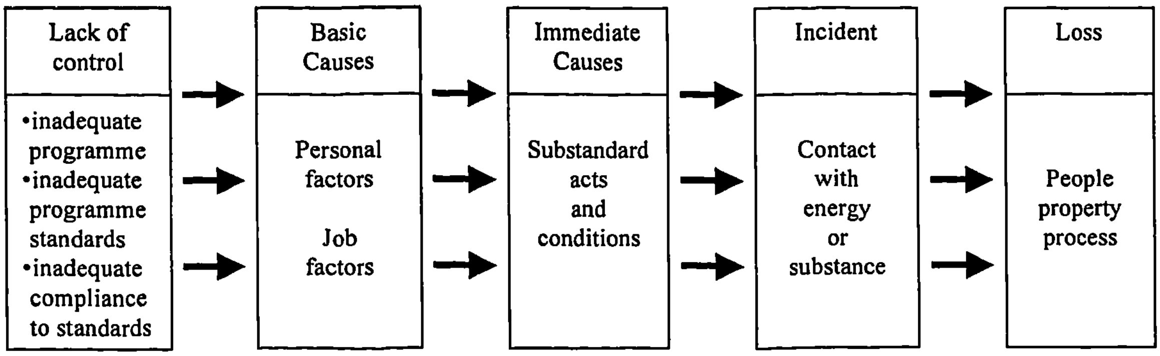

Figure 4.13 The loss causation model (Bird and Germain, 1987, p.22)

Multi-causality refers to the fact that there may be more than one cause to any accident (Bamber, 1990b). Figure 4.14 represents several accident causes:

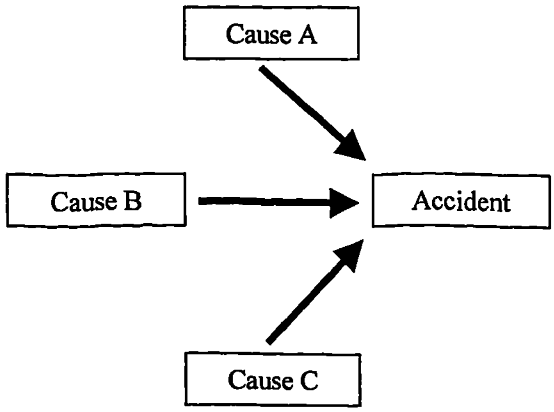

Figure 4.14 Multiple causation theory (Bamber, 1990b, p.154)

Bamber suggested that each of these multi-causes was equivalent to the third domino in the 'Domino Theory' and could represent an unsafe act, condition or situation. Each of these can itself have multi-causes and the process of following each branch back to its root is called a fault tree analysis. The theory of multi-causation consists of the contributing causes combining together to result in an accident.

Petersen (1988) suggested that often in accident investigations one unsafe act and/or unsafe condition is sought out. This seems very logical when applying the principles expressed by the 'Domino Theory'. However, he warned that interpretation of the theory could be too narrow. It may not be enough to look for a single act and/or condition as the factors affecting the sequence may be multi-causal. When looking only at the act and the condition only symptoms are identified, not root causes. This can result in the root causes remaining to cause another accident. Root causes often relate to the management systems policies and procedures, supervision, and training. He concludes that Heinrich's theory fails to deal sufficiently with situational variables and complexities.

(b) <u>The Search for Strategic Models of Occupational Safety</u>

A review of the occupational safety literature indicated that studies concerned with forecasting or modelling safety strategy or policy-making were almost non-existent. The literature search consisted of a number of strands. Library bookshelves were examined (health and safety, management science, and operational research books). Manual searches of abstracts were conducted (Health and Safety Science Abstracts, Computer and Control Abstracts, Management Science Abstracts). On-line and CD-ROM search engines were used (Bath's Information and Data Services, ABI-INFORM, Occupational Safety and Health CD-ROM, INSPEC Electronics and Computing CD-ROM). A total of thirteen literature sources were identified.

The search indicated that safety decision-making models have been developed that looked at operational or process based problems in specific industries, particularly those which involved high-risk technologies (Perrow, 1984). Most of the safety literature discussed the application of probabilistic models in the diagnosis of occupational safety systems (Amendola, 1988; Heino *et al.*, 1992; Lehto and Salvendy, 1991; Bamber, 1990a, 1990b). These were diagnostic rather than interpretative, and were neither dynamic nor strategic in nature. Veltri (1991) elicited opinion from safety experts using the Delphi inquiry system on the maximisation of the safety function. Although Veltri's study was enlightening it failed to suggest what types of outcome could be achieved. Bhattacherjee *et al.* (1994) conducted a time-series analysis of mining accident rate behaviour. They suggested that mine accidents occur as a result of both natural conditions and management decisions, and that an analysis of injury experiences would reveal the underlying trends that are the results of these complex interactions. Reading on, it is evident that this may not be a suitable approach for basing safety policy on. This may stem from four factors. First, the need in time-series modelling to assume that system variables remain fixed when clearly in reality they do not, second basing future outcomes purely on past events. Third, the blindness of the model to causal influences, and finally, a single variable output, such as the accident rate is only a downstream measure of safety.

No suitable harder operational research models were found in the literature search. This may be because OR models are essentially concerned with optimisation and exact prediction, rather than the design of a system that is desired.

The field of occupational health and safety appears not to have been a subject of interest for system dynamics modellers and systems thinkers. Very little work appears to be in the public domain. There were only two instances of the discussion of softer systems and safety (Waring, 1990a, 1990b), and only two publications evidencing the application of system dynamics modelling applied to occupational safety (Andersen *et al.*, 1986; Crawford, 1991).

(c) Systems Thinking and Occupational Safety

Waring (1990a) argued that systems thinking and practice are essential tools for better safety management. The difficulty arises in the variation in perception of what constitutes a system and how reductionist the content should be. He warns that an accident is often attributed to human error and/or technical failure. The fact that accidents have more than one cause is well established, and although human error and technical failure may form part of the explanation, they are essentially symptoms of more fundamental causes. He suggested that human error and technical failures, along with the accident are emergent properties of a system that has failed. Some errors are due to the inadvertent behaviour of humans, although many may be a result of receiving inadequate information, instructions or training. Functions such as selection, training, design engineering and maintenance need to be examined. A systems approach to failures probes not only the technical and individual human aspects but also the organisational precursors of signs and symptoms of failure. Waring suggested that systemic approaches to safety systems involve anticipation and prevention of failures. It requires understanding of the system concerned and of how it works. He criticises the hard systems view towards safety strategy of writers such as Veltri (1989), who espouse the link between investment and safety performance. He questions Veltri's isolation of the causality between the effects of safety investments from other variables (Waring 1990b). He argued that accidents alone cannot be taken as a reliable measure of safety performance, because there is no direct cause and effect relationship between investment and safety. He acknowledged that there is a relationship, but it is very hard to predict what the relevant returns will be.

Waring made a case for an interpretative systemic approach to tackling the safety function using SSM. He was forceful in his premise that there were both direct and indirect causes of accidents. These causes could be examined from a systems viewpoint to allow an understanding of the systems properties which lead to failure. He suggested that both soft and hard factors should be accounted for when examining safety issues, but he did not offer a unified systems thinking approach for integrating the measurable hard objective factors and the more subjective soft factors into one safety model. From Waring's description of occupational safety as being holistic with direct and indirect causality, and his acknowledgement that safety performance should be measured beyond accident rates in the management functions, a mental picture emerges as to the possible structure of a system dynamics model of occupational safety. Waring proves to be a useful aid when it comes to conceptualising a safety system.

(d) A System Dynamics Model of Regulation and Safety in Industrial Firms

Andersen *et al.* (1986) developed a system dynamics model to determine whether safety inspections by the United States Occupational Safety and Health Administration (OSHA) had an effect on occupational accident rates. OSHA has a similar remit of responsibility and structure to that of the HSE in the United Kingdom. Designers of regression-based evaluations of health and safety had concluded that OSHA's regulation had failed to increase either the level of safety, or safety-related investment by firms. However, case studies and analyses of other less aggregated data had suggested that regulation did increase both. Andersen *et al.* developed a system dynamics model as an approach that could bridge both the qualitative and quantitative research elements associated with the regulation of safety. Their model simulates accident generation within firms, generates synthetic data from variations in the model and evaluates the sensitivity of regression methods to variations in the model. This was achieved through the introduction of a Monte Carlo type simulation of synthetic data. Crawford (1991), one of Andersen's original co-authors, later developed a more extensive set of results based on additional sensitivity test runs.

Andersen *et al.* (1986) suggested that the discrepancy between the case study and regression analysis results may have been a result of the limitations of regression models. Such models can fail to incorporate a credible theory of how such regulatory systems work. Crawford (1991) suggested that the evidence from less aggregated studies and from case studies indicated that negative feedback processes were at work to regulate safety, regardless of OSHA inspections. She pointed to the presence of endogenous feedback loops that could be influencing the effects, or measurement of the effects of OSHA's actions.

The principal causal structure within the model is displayed in Figure 4.15. Two negative feedback loops operate between the level of accidents within a firm, and the safety equipment and safety programme levels of that firm. This facilitates the operation of a negative feedback system, with the endogenous effects between accidents, safety programmes and safety equipment, thus regulating the total number of accidents that occur within the system. Therefore, an increase in the level of accidents within a firm will raise the levels of safety equipment and safety programmes. This leads to a reduction in accidents within the firm, producing a self-regulated system.

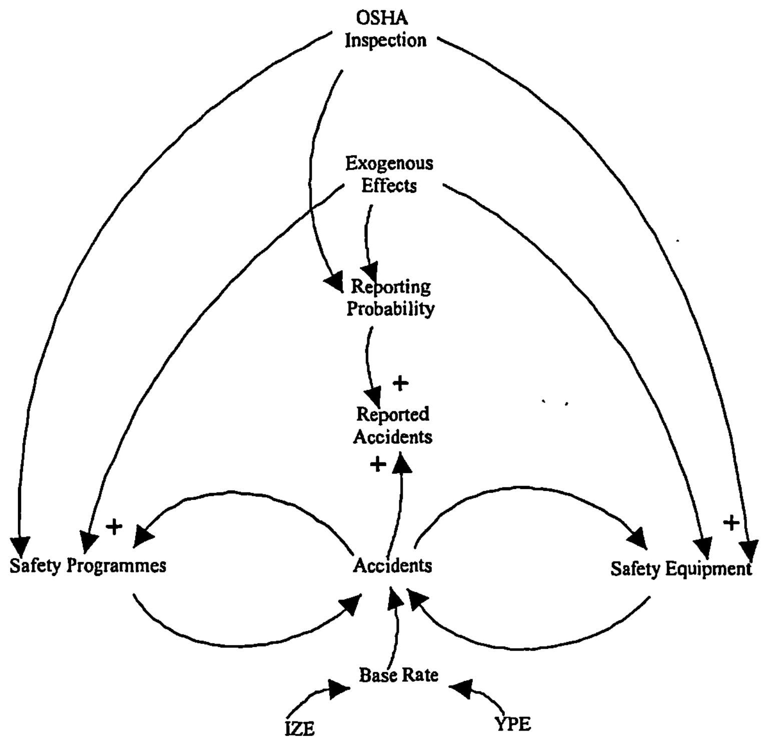

Figure 4.15 Principal causal structure within the simulation model (Andersen *et al.*, 1986, p.228)

The results of the simulations suggest that OSHA inspections do have an effect upon the safety effort, increasing the safety programmes and safety equipment levels. Andersen *et al.* (1986) argue that the results differ from those of the regression analyses because much of the theoretical richness of the case study has been retained in the model through the integration of hard and soft effects. In addition, the simulation model, unlike in the case studies or regression analysis, contains a mathematically explicit causal structure which forces the analyst to define explicitly the causal hypotheses on which the policy system operates.

The safety regulation model contains some useful ideas about the high level causal structure of an occupational safety model and the idea that the negative feedback loops serve to self-regulate the safety system. This model offers a useful insight into where to start looking for appropriate structural relationships and system behaviour.

4.6 Summary of Systems Thinking and System Dynamics

The origins of systems thinking have been discussed in this chapter, and Checkland's (1981, p.95) taxonomy of systems thinking has been examined in relation to its application to tackling real world problems. There appears to be a broad spectrum of ideas about the boundaries of systems thinking. The diversity and commonality of a number of systems thinking approaches have been considered. System dynamics appears to transcend all three of Checkland's systems approaches to problem solving in the real world. This indicates that its potential application to problem solving is very broad. The review of prominent authors in the system dynamics field has revealed that system dynamics has emerged as a successful problem solving methodology over the last four decades. It is evident that system dynamics is appropriate to use where the problem is dynamic and complex and where the forces causing the behaviour can be contained within a closed loop feedback structure. The building and testing of system dynamics models is shown to be robust, as validation is carried out at every stage of the model building process. The case for applying system dynamics successfully to the complex problem of occupational safety appears from the survey of literature to be strong. The stepwise approach to system dynamics modelling discussed in Section 4.4 of this chapter will be used over the next three chapters to build a model of occupational safety, validate it with real world data from a firm, and evaluate its use to aid policy decision-making and learning.

CHAPTER FIVE

The Generic System Dynamics Model of Occupational Safety

5.1 Introduction to the Generic Occupational Safety Model

It is evident from the health and safety literature that occupational safety is a complex phenomenon. It has been examined by a number of model builders, but only Andersen *et al.* (1986) and Crawford (1991) have noted that a realistic strategic model of occupational safety must contain causal feedback loops, be non-linear in its behaviour, and be likely to contain material and information delays. This is sufficient reason for evaluating occupational safety decisions using system dynamics modelling.

The first three chapters have been concerned with the literature on occupational safety and systems modelling. This chapter is the first of three which outline the development, testing and evaluation of a quantitative system dynamics model of occupational safety. The purpose of this chapter is to develop an abstract or generic system dynamics model of occupational safety containing the structure which will allow replication of safety system behaviour in typical employing organisations. Once the plausibility of the generic occupational safety model is established, Chapter Six will reveal how the model is calibrated with information derived from the records, experiences and opinions of a participating manufacturing firm. Chapter Seven will elicit opinion on the model's suitability as a policy-making and learning aid. The continuous validation of the occupational safety model as a good structural and behavioural representation of real world occupational safety dynamics is important if users are to have confidence in its outputs. The stages involved in building a system dynamics model as identified by Roberts *et al.* (1983, p.8) and outlined in Section 4.4 of Chapter Four is broadly followed throughout Chapters Five, Six and Seven. The contents of Chapter Five equate to the model representation and model behaviour stages of Roberts *et al.'s* framework.

A model of occupational safety is only useful for learning or for aiding decision-making if it is representative of the real world domain. Chapter Five is sub-divided into seven sections. The issues surrounding the validation of a model built to evaluate occupational safety is discussed in Section 5.2. The importance of validating the model at every phase of the model building process is highlighted. Section 5.3 outlines the application of Roberts *et al's.* 'problem definition' phase. The problem of occupational safety is explained through identifying the principal actors in the wider occupational safety system, setting an adequate system boundary for the safety model, and identifying appropriate reference modes of behaviour for accidents. In Section 5.4 the important influences believed to be operating in an occupational safety system are conceptualised with the aid of a causal loop diagram. The structural validity of the diagram is justified using evidence from literature sources, and through logical deduction. This section ties in with Roberts *et al's.* 'system conceptualisation' phase. Next, in Section 5.5, a detailed influence diagram of the occupational safety model is constructed and translated into a flow diagram. This section relates to Roberts *et al's.* 'model representation' phase of their modelling framework. The model structure is broken down into more manageable model sectors. For all sectors the levels, rates, auxiliary equations and constants are validated. Each equation and parameter is analysed to ensure that it is both dimensionally consistent and structurally representative of a real occupational safety system. The levels and constants are initialised so as to set the 'base run' of the simulation model in a state of equilibrium. Attention is paid to parameter sensitivity testing in Section 5.6 of the chapter. The need to identify sensitive model parameters is justified. A number of behavioural tests are performed in order to assess the robustness and internal consistency of the model to parameter modifications. Finally, in Section 5.7 the process of building the generic occupational safety model is summarised. The plausibility of the model as representative of a firm's safety performance, based on all the validation tests is thus determined.

5.2 The Problem of Validation and the Approaches Taken to Resolve It

There is an ongoing debate amongst systems modellers as to what constitutes the validation of a model and what constitutes its verification (Pidd, 1996; Brooks, 1999). For the purpose of this study, verification is associated with corroborating the consistency and internal logical structure of a model, whilst validation seeks to prove the correctness of a model's behaviour against that of the real world.

Roberts *et al.* identified the 'model evaluation' phase in their framework as model validation testing. Examination of other system dynamics literature and the logic of the model building process dictate that validation is necessary at every phase of the model. In Section 4.4 of Chapter Four the importance of a number of tests of model structure, behaviour and policy implication was emphasised. Despite these three clear categories, prominent system dynamics modellers accept that there are no universally agreed set of tests that can fully validate a model (Forrester and Senge, 1980; Richardson and Pugh, 1981; Sterman, 1984). Indeed Barlas (1996) noted that no single definition of model validity even existed.

System dynamics has had criticism levelled at it because of its more informal, subjective and qualitative validation procedures. The criticisms have been levelled by people more familiar with hard input-output models where statistical measurement of model output is the principal determinant of model confidence (Sterman, 1984; Eberlein and Wang, 1985; Moffatt, 1991; Eberlein and Peterson, 1994). Forrester and Senge simply describe validation of system dynamics models as:

> ...the process of establishing confidence in the soundness and usefulness of a model ...the ultimate objective of validation in system dynamics is transferred confidence in a model's soundness and usefulness as a policy tool (Forrester and Senge, 1980, p.210, 211).

Whether the ultimate objective of validation may be to inspire confidence in a model's use as a policy tool it can be argued that tests of model validation are also equally important. Tests of validation are strongly emphasised in all the subsequent sections of this chapter, and throughout Chapters Six and Seven. Bearing this in mind, the success of the occupational safety simulation will be judged on the extent to which the model passes a number of formal and informal validation tests, and also the level of confidence the managers of the host firm have in the model. At the structural level, any model validation tests should be able to justify the causes and effects present in the safety model. The chosen parameters and structural equations should confidently represent the strategic issues surrounding workplace accidents and the financial costs of safety management. The Generic Occupational Safety Model's (GOSM's) behaviour is to be examined through extensive simulation testing. This will involve exploring parameter changes to determine which ones the model exhibits sensitivity to. It will also be necessary to determine whether the conditions generated by these changes are plausible in a real workplace. Calibrating the GOSM with real world data and replicating the historical behaviour of the host firm's safety further adds to the plausibility of the model. The final aspects of model validity are the opinions of the host firm's managers and the policy implication tests, which will involve examining alternative policy scenarios.

5.3 Problem Definition and the Focus of the Modelling Study

Problem definition was the first phase of Robert's *et al's.* modelling framework. They suggested that the problem under study must vary over time, the forces causing the variability need to be described causally, and the important causal influences can be contained within a closed system of feedback loops. Randers (1980) suggested that conceptualisation of a model starts by establishing the focus of the study through developing its general perspective and time horizon. In addition to this, a number of authors suggest a boundary adequacy test to consider the relationships between attributes necessary to satisfy a model's purpose (Forrester and Senge, 1980; Richardson and Pugh, 1981; Moffatt, 1991). The boundary is set when the important interactions within the feedback structure of the model reflect the behaviour of the real world system. It should be noted that there is a danger of overextending the boundary of the model to include structure from the real system not necessary to fulfil the model's purpose (Richardson and Pugh, 1981). It is also important to set the model's structural boundary to inhibit seeing the behavioural outputs only as a consequence of external factors, and thus to ensure that model behaviour is generated endogenously.

Addressing two questions can help to fix the purpose of the study and to set an adequate model boundary. First, who cares about occupational safety (Coyle, 1996)? Second, why do they care? In the literature review of Chapter Two the need for robust health and safety policies within companies was introduced from both a legal, financial and moral perspective. Chapter Three described many of the policies that are necessary to operate a successful occupational SMS. Occupational safety is broad and contains many groups with vested interests. This immediately raises the danger of overextending the structure of the safety model. If this is to be averted it is necessary to identify who has an influence over workplace safety and how strong their impact is. Table 5.1 offers a summary of the types of groups who participate in the broad field of occupational safety and their vested interests. These groups or stakeholders listed have a mixture of altruistic and economic motives for being involved in health and safety. All would wish the achievement of zero accident workplaces. In reality, this will not be possible, so they act to ensure that reasonable and practicable measures are taken to make workplaces safer.

As the onus for safe workplaces appears to be on employers, they may be seen as the 'gatekeepers' to successful health and safety at work. Only the employees in most industries will be at the receiving end of accidents. Managers have a vested interest in health and safety from moral, financial and legal viewpoints. It is ethically unacceptable to allow people to work in dangerous environments without allowing employees adequate protection from danger (Petersen 1988). Managers can be prosecuted in cases where there is gross failure to maintain a safe workplace, and empirical evidence strongly links successful occupational safety to good business sense (HASAWA 1974; HSC, 1992c; HSE, 1991a, 1994b). It would appear that employers and employees are the strongest stakeholders in occupational safety as they have the greatest control over accidents. Limiting the boundary of the GOSM to the workplace will make it easier to generate safety behaviour endogenously.

Group	Vested Interest
European Union	Setting of appropriate Directives concerned with Health and Safety at work in order to allow the maintenance of social welfare and a single European market (HSE, 1993a).
United Kingdom Government	Setting of legislation which will seek to improve and maintain health and safety at work practice (HSE, 1993a; HSC, 1992b).
HSC	Responsible for proposing health and safety law and standards to ministers of Government, and developing Codes of Practice to assist employers with legal compliance (HSC, 1992b).
HSE	Responsible for advising the HSC on policy, research and publication of material to assist employers with safety practice, and enforcing health and safety law and standards (HSC, 1992b).
Trade Unions	Protecting the welfare at work of its members through lobbying politicians for improved legislation and enforcement activity, and encouraging employers to comply with legislation and maintain safe workplaces (Waring, 1996).
Insurance Companies	Through underwriting PL/EL for employers they seek to encourage employers to maintain safe workplaces, so that indemnity insurance claims are minimised (Bamber, 1993).
Employers	Seek to comply with health and safety regulations to avoid prosecution, and minimise accidents to employees from moral and financial perspectives through the maintenance of safe workplaces (HSE, 1991a; Stranks, 1994a; Waring, 1996).
Employees	Seek to preserve their own health and the health of others through safe work practice (HSE, 1991a; Stranks, 1994a; Waring, 1996).

Table 5.1 The vested interests in the broad occupational safety system

The focus of this thesis consists of occupational accidents and the costs of maintaining safety management. The GOSM should be able to reflect variable occupational accident rates based on repeated policy experimentation. It should also reflect the potential differences in safety management costs associated with alternative safety strategies.

Randers (1980) recommended that in conceptualising a system dynamics model one should identify and describe developments over time, and then proceed to identification and description of the underlying causes. It was decided to plot a chart showing the dynamic behaviour of a temporal accident pattern. The health and safety statistics published by the HSC show the national accident picture in the United Kingdom. This was a good source of data to set a general reference mode to focus the model building around. It was only possible to obtain figures based on 'all reported accidents', that is those which were classified under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations, 1985 as 'over three-day injuries' upwards to 'fatalities'. The chart was used as the initial reference mode of behaviour for the study. It would be necessary at a later stage for a quantitative simulation model to be able to reproduce this and other reference modes. In Figure 5.1 recent accident reference modes across United Kingdom industry is compared. This sets out the problem or symptom for study.

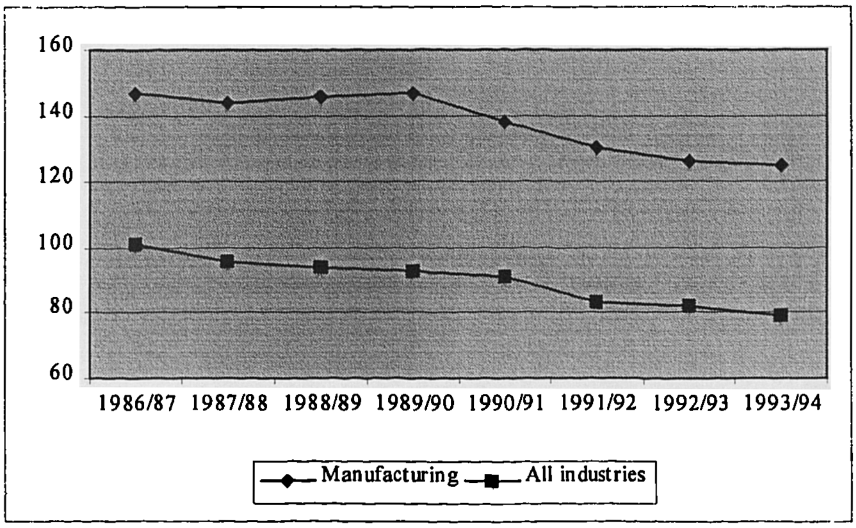

Figure 5.1 Fatal and major injury rate per 100,000 employees, 1986-87 to 1993-94 by industrial sector (HSC, 1994, p.9)

The accident pattern observed in the national statistics (1986-87 to 1993-94) showed a downward trend across industries, specifically manufacturing. Despite this movement, serious workplace injuries were still unacceptably high. In manufacturing there was a temporary upturn in accidents which is of some concern. The range of occupational accident and ill health statistics published by the HSC show that there is still a great need for employers to improve their management of occupational health and safety.

The principal variables that explained the accident reference mode in manufacturing needed to be identified so that causal links could be made. If any of these variables lay outside of the typical organisation then this would result in a re-evaluation of the initial model boundary. In order to maintain a crisp and clear view of the problem, only three were nominally noted: hazards, accident reporting and safety knowledge, skills and attitude. Simple sketches of these dynamic safety variables are made in Figure 5.2. These outputs are derived by simple logical deduction. Lower accidents result in less accident reports being processed. Accidents are determined by the risks associated with workplace hazards, and the less active the hazards, the lower the accidents. Good safety knowledge, skills and attitude do prevent the likelihood of accidents. These three attributes may have improved across workplaces in recent years. These suggestions are hypothetical causes of the accident reference mode. The extent of their contribution to the national accident picture would be very hard to determine. Despite this limitation they are useful in clarifying some of the important structure which will need to be included in a model which seeks to generate plausible safety behaviour.

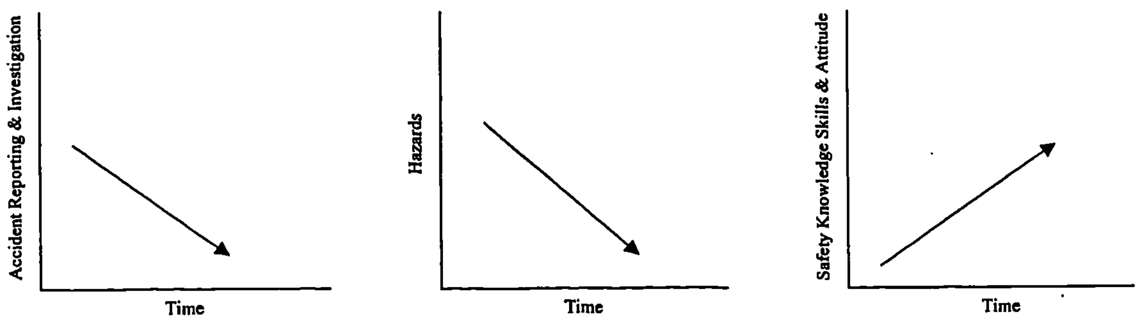

Figure 5.2 Hypothesised modes of behaviour for likely safety model variables

Next it was necessary to consider the time horizon over which the safety simulation would run. The statistics presented in Figure 5.1 show the need to be careful when selecting the time span for the simulation. Depending on the chosen time slice, the trend identified for both sets of accident data can be different. It was decided that a model containing a time horizon of three years would be adequate for examining the dynamics of safety system behaviour, as it would not be unduly influenced by any short-term fluctuations. Evaluating safety performance over any longer period may cause the model user to raise questions about the accuracy or suitability of the model for predicting behaviour over such a time frame. At the level of the firm, it is evident that some safety policy decisions made, particularly those related to training will not have immediate effects. In fact it can take several months before the overall effects of changes are realised (Stranks, 1994b; Wallerstein and Baker, 1994).

The problem based on the historical reference mode for accidents in the United Kingdom had been plotted in a chart (Figure 5.1), and a three-year time frame for the model selected. The downward accident trend in manufacturing would not necessarily be representative of the host organisation's accident picture. As a result, a successful GOSM will need to be able to replicate the mode of behaviour of accidents in a host organisation when calibrated.

The next stage of the modelling process was to construct a causal feedback loop diagram which drew in other important safety variables. This helped to set more of the additional system attributes necessary to generate possible alternative modes of model behaviour.

5.4 Conceptualising the Structure of the Safety Model

The second phase of Robert's *et al's.* (1981, p.8) modelling framework involves identifying the important influences working within a system. The main route by which a system dynamics model is conceptualised is via the construction of causal loop diagrams. A causal loop diagram was developed to represent the occupational safety system for two reasons. First, it would help with understanding the complex safety behaviour emerging from the feedback structure in organisations. Second, at a later date it could be used as a suitable medium to communicate the system dynamics model to clients in the host organisation. The causal loop diagram needs to represent the problem of safety, rather than the whole safety system. If the quantitative simulation model was to be useful as a learning and strategic decision-making tool then it had to contain sufficient detail, whilst at the same time capture the complexity of the dynamics of an organisation's safety.

(a) <u>The Causal Feedback Loops of the Generic Occupational Safety Model</u>

Forrester and Senge (1980) suggest that verifying the structure of a system dynamics model involves comparing the structure of the model to that of the real system. To build a model reflective of the real world one or more of the following sources of information need be consulted: safety literature, opinions of persons familiar with occupational safety, and the personal assumptions of the model builder. A simple causal loop diagram was constructed, primarily from safety literature to represent the underlying structure of the safety problem. Safety KSA is a pneumonic for safety knowledge, skills and attitude. This is outlined in Figure 5.3:

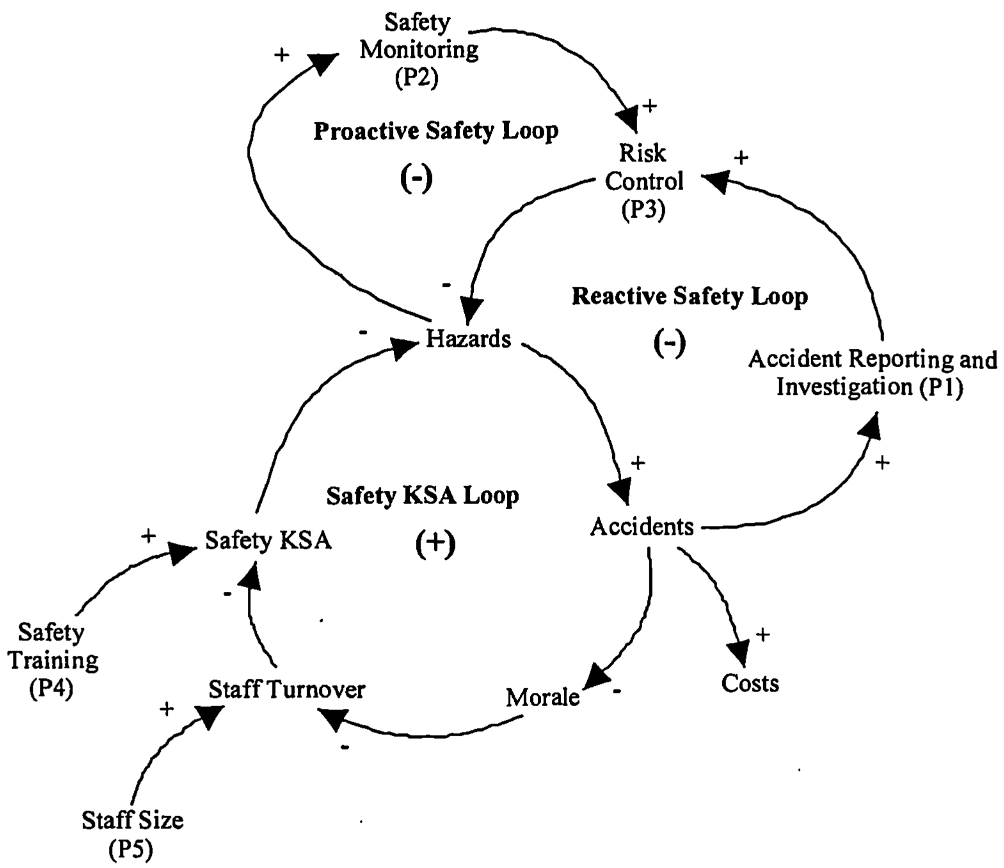

Figure 5.3 The basic causal feedback loop structure of the generic occupational safety model

Three feedback loops exist, one reinforcing and two balancing. A total of five potential policy areas are also identified as change parameters (P1-P5). Three of the five policies appear to be embedded within the feedback structure of the model. This is because the causal model has been built with the intention of distilling and communicating ideas about initial high-level model structure and feedback. All the policies can be regarded as aggregations of potential system parameters and variables. The policies and other attributes of the causal feedback loops will be structurally verified with the assistance of literature sources and logical deduction.

(b) Descriptions of the Causal Feedback Loops

Each feedback loop contained in the GOSM needs to be traced through to verify its causal relationships and to describe its operation.

(c) The Reactive Safety Loop

A good place to start may be with a description of a hazard and its relationship to accidents. A hazard may be regarded as something which has the potential to do harm (HSC, 1992c; Bamber, 1990a). In order to put a workplace hazard in context the term risk must be understood. The risk is the likelihood that a particular hazard can cause harm. It can be thought of as the probability that an accident will occur. Inadequate control of a hazard can create substantial risk, even with a low hazard; but with proper controls even the risk of coming to harm from a very hazardous substance, for example, can be greatly reduced (Bamber, 1990a).

An accident can be regarded as an unexpected and unplanned event which results in harm to a person(s), damage to property, a near miss, or some kind of loss. For an accident to occur a hazard has to be present, with some form of risk attached. This results in a positive causal relationship between hazards and accidents, as the more active hazards are present, the more accidents occur.

Accidents need following up to consider their causes and prevent recurrence. The Accident Reporting and Investigation Policy has been discussed in the previous section. The causal relationship between accidents and the accident reporting and investigation policy is positive, as the more accidents that occur, the more accident reports have to be made, and thus accident causes are identified.

Once the causes of accidents have been established, and/or the risks responsible for creating active hazards have been identified, then control measures can be taken to minimise the risk of hazards causing harm. There is a positive causal relationship between accident reporting and investigation and risk control, as the more accident reports made; the more risk controls are taken.

The causal relationship between risk control and hazards is negative, as the more risk control measures taken, the fewer active hazards are present in the workplace. This description completes the trace around the Reactive Safety Loop. The overall polarity of the loop is negative. This is not surprising, as balancing loops are invariably target seeking or regulatory. In this instance the loop is reacting to accidents occurring.

(d) The Safety Knowledge Skills and Attitude (KSA) Loop

Working around the loop from the hazard, this causes the accident. It is well known that workplace accidents have a detrimental effect on employee morale (Stranks, 1994a; Waring, 1996; HSE, 1991a). The causal relationship between accidents and employee morale is negative, as more accidents contribute towards lower morale.

Safety morale may be regarded as a very important contributor to staff turnover. Maslow studied the factors significant in the motivation of successful people and what gave them satisfaction in their work (Stranks, 1994b). Maslow proposed that people wish to satisfy needs. He categorised these needs and ranked them in order of importance, producing a hierarchy of needs. Referring to Maslow's (1954) hierarchy of needs, safety and security needs are very near the bottom of his hierarchy, that is they should be satisfied before higher needs can be addressed. On this basis, the causal relationship between morale and staff turnover is negative, as the higher the morale, that is satisfaction with safety and security, the lower the staff turnover will be. Staff turnover will also be affected by staffing policies such as recruitment and layoffs of staff. The causal relationship between staff size and staff turnover is regarded as positive, as the greater the size of the workforce, the higher staff turnover will be.

Staff turnover will have direct impact upon safety knowledge, skills and attitude (KSA). Schulzinger (1956) postulated that there is a direct link between accident risk, and age and experience of employees. His research found that industrial accidents reduce from a peak at the age of 21 and continue to decline through to ages over 60. This indicates that the causal relationship between staff turnover, that is losing older and more experienced staff and safety KSA is negative.

The link between safety training and KSA has been made in Chapter Three. The causal relationship between these attributes is a positive one, as engaging in effective training for sufficient durations improves KSA.

Hazards can either be active or inactive depending upon the measures taken to mitigate risk. As already discussed in the Section 3.4 of Chapter Three on risk control, if it is not possible to remove the hazard at source or enclose it, then safe systems of work can be followed or hazards can de dealt with through the use of personal protective equipment (PPE). These latter two measures will only be successful if employees have a sufficient level of KSA about safety. This suggests that the causal relationship between KSA and hazards is a negative one, as hazards need not become active dangers provided that they are worked with properly.

(e) The Proactive Safety Loop

The causal link between workplace hazards and safety monitoring activity is positive. Whether this link should be built directly into the quantitative model needs consideration. If the contribution to the overall mode of behaviour of the safety model was to be understood then a direct causal link between hazards and safety monitoring would not be suitable. The user would not be able under those circumstances to explore the effect that safety monitoring has on safety performance. In the flow diagram it was decided to set safety monitoring as a policy parameter rather than a variable. Richardson and Pugh can justify this when they suggested that:

> ...the modeler must to some extent become part of the system to simulate accurately a policy change ...the modeler acts as the missing feedback links, changing other parameters manually, as it were, to simulate whatever far-reaching effects the policy change involves (Richardson and Pugh, 1981, p.326).

The modeller may be involved in observing the resulting behaviour and taking action to change the test inputs in order to bridge the link between information and consequences (Coyle, 1996). There is also a positive causal relationship between safety monitoring activities and risk control, as the more active hazards that are identified; the more risk control measures are taken.

(f) Other Causal Structure Considerations

Costs are shown to be an output of the structure. As discussed in Section 3.6 of Chapter Three there are direct and indirect financial costs associated with accidents (HSE, 1994b; HSE, 1993c; Stranks, 1994a; Waring, 1996). A fuller representation of the financial costs resulting from safety is not shown in this simple causal diagram. Any safety activity, such as training or risk control, will be a separate cost centre. These causal links are not included, as doing so would add to the visual complexity of the causal loop diagram. The fact that a link is shown between accidents and costs merely highlights the cost centre most likely to be the highest.

The causal loop diagram of the GOSM has been structurally justified. The overall polarity of the model is negative. This is essential if the behaviour of the subsequent quantitative GOSM is to be stable enough to be managed or controlled.

(g) Accident Reporting and Investigation Policy

Accident reporting and investigation has two objectives. The first is to determine the cause(s) of the accident, and the second is then to prevent recurrence through the gathering and documentation of sufficient information in order that the accident prevention principles related to risk control can be implemented (Stranks, 1996). This policy represents the process of reporting accidents to the appropriate authority within the workplace, invariably the safety manager or officer. Under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations of 1985, all injury accidents, no matter how minor, have to be logged in accident reports. Whether the injury is of a serious nature or not, details of the accident type, injury type and severity, how it occurred, and whether there was the possibility that it breached the law must as a minimum be documented (Stranks, 1994a). An accident investigation must be conducted at least at some nominal level. Obviously the level of activity is proportional to the seriousness of the accident. When an accident is of a serious nature, or had the potential to be more serious, or if it fell into an identified trend then a full investigation would be needed.

(h) The Safety Monitoring Policy

This policy can be considered to be an aggregation of any measures of safety performance, both reactive and active. Risk control is difficult to achieve without sufficient monitoring of safety performance (Waring, 1996). Monitoring seeks to detect either permanence or change in the safety system.

The principal measure of reactive safety performance is accident rates. These can certainly be good measures of whether safety performance in a firm is improving or deteriorating (HSE, 1991b). More proactive measures of safety address the present activities designed to prevent accidents (Waring, 1996). The following measures may be regarded for the purpose of the model as active monitoring actions: risk assessments of all work activities, safety inspections and safety tours, safety audits and safety committee meetings.

(i) Risk Control

Safety monitoring and accident reporting and investigation are policies which can be used to analyse and assess risks and accident causes. Once the facts about risks have been established then risk control measures are taken. The HSE (1991a) recommended a preferred hierarchy of control principles. First eliminate the risk by using a less hazardous substance, either through substituting machinery and/or by avoiding the use of certain processes. Second combating the risk at source by engineering controls through separating the operator from exposure to the hazard, by protecting the dangerous parts of the machine, and/or by designing machinery that is remotely operated. Third minimising risk by the design of suitable systems of working; and finally minimising the risk through the use of PPE as a last resort.

The first two points are related to safe workplace strategies and the third and fourth are safe person strategies. In dealing with many hazards often one or more of the above controls are concurrently in use, therefore, the model should treat all risk control in an aggregated way.

(j) Safety Training

Safety training and education of employees can be one of the most proactive safety measures an employer can take. It is well known that somewhere between 60% and 95% of safety incidents result from unsafe behaviour (Killimett, 1991; Krause *et al.*, 1990; Stranks, 1994b). That is not to say that employees are wholly responsible, as the underlying causes invariably lie at the hands of the managers. Successful safety training is achieved through improving the KSA relevant to safety. This was discussed in Section 3.5 of Chapter Three. Training will only be successful if all three are improved (HSE, 1991a; Everett, 1989).

Training can take three forms: formal off-the-job training, instruction to individuals and groups, or on-the-job coaching (HSE, 1991a). Stranks (1994b) suggests that training should occur at three various stages of people's employment in an organisation. The first experience is through induction training of new staff. The second may be orientation training following promotion or where changes to work are introduced. The third instance is refresher training which should be repeated periodically to ensure continued competence.

Any training whether it is off or on-the-job, used as induction, orientation, or in refreshing skills is to be aggregated in the model, with the intention of showing the effects of training as one attribute of safety. Any training that enhances the safety KSA of employees is useful in reducing the likelihood of accidents.

(k) Staff Size

Staffing policies are associated with maintaining a target number of staff. They principally concern staff recruitment and wastage. A number of authors have offered evidence that using careful criteria for staff selection based on physical and mental job requirements, personality tests and interview checks can result in less accident prone staff being recruited (Petersen, 1988; Minter, 1990; Hansen, 1988; HSE, 1993d; Stranks, 1994a; Kamp, 1991). It is beyond the feasibility of the model to measure this array of factors, but there is the potential to emphasise the effects of better staff recruitment.

(l) Bridging the Gap between the Causal Loop Structure of the Problem and Constructing the Full Flow Diagram

The basic causal feedback loop structure of the generic occupational safety model was useful for illustrating the aggregated structure thought to be the cause of accidents. Instead of building a causal loop diagram, many system dynamics modellers start to conceptualise the structure which contributes to a dynamic problem by identifying immediately what they believe to be the most important levels and rates. Forrester (1994) states that he never starts to build a flow diagram from a causal loop diagram. He warns that a causal loop diagram lacks the identification of level variables, resulting in a failure to identify the systems elements which actually cause the dynamic behaviour. Another problem with causal loop diagrams is that they ignore the difference between information and resource flows. Coyle (1996) on the other hand recommends developing flow diagrams not from causal loop diagrams, but influence diagrams as in this diagrammatic form, level variables, information flows and resource flows can be differentiated.

Choosing to develop the full structure of the system dynamics model using levels and rates was the personal choice of the modeller due to the above reasons mentioned by Forrester (1994). A jump between the basic causal loop structure to an influence/full flow diagram was obviously not feasible. The full flow diagram was built up incrementally. This process was of an iterative nature. From the causal loop diagram, many of the important levels, rates and policy parameters needed to build the flow diagram could be determined. The important levels and rates for the model were first identified. These were the bones of the flow diagram.

The next stage was to introduce the information links which carried information about changes in levels around the model. This involved the gradual introduction of auxiliaries, constants and delays. Concurrently, as the structure of the model grew, it became necessary to introduce equations to the rates and auxiliaries and select numerical values for the parameters. This allowed the model to be simulated, and through simulation the structure of the model could be more readily developed to represent real world occupational safety. The model's validity was also tested throughout its development through using two methods. The first was to verify each of the equation's structure and the plausibility of every parameter. The second was to determine whether the model's behavioural outputs were representative of the real world. The full approaches to these structural and behavioural tests will be discussed in Sections 5.5 and 5.6 of this chapter respectfully.

As the model grew in size, examining its structure became more cumbersome. A number of distinct modules or sectors began to emerge within the model. These were used to group together functionally related portions of structure such as for example, the constants and variables representing staff recruitment and turnover. This made the task of refining the functional structure far easier.

In summary, moving from the causal loop diagram to the full flow diagram was an incremental process. The increase in model complexity continued through the addition, subtraction and modification of structure. This was based on the goal of introducing a sufficient level of structure which would not only facilitate the simulation of the right behaviour, but for the right reasons. The process of structural modification could be never ending, but one has to be pragmatic and stop its refinement when a sufficient amount of rigour has been expended on verifying the internal consistency of the system dynamics model. The full methods by which the GOSM was developed and tested will be detailed in the remainder of this chapter.

5.5 Representing the Structure of the Generic Occupational Safety Model

The third stage of Roberts *et al's.* (1981, p.8) framework is model representation. If a successful qualitative GOSM were to be constructed, three tests of structural validity would need to be passed before any simulation experiments be conducted. These involve structure verification, dimensional consistency and parameter verification. The backgrounds to each of these tests are briefly explained.

The structural verification would continue. To pass the structural verification test the assumptions contained within the feedback structure of the model must be consistent with the structure of the real world (Moffatt, 1991). Barlas (1996) suggested that using empirical information means comparing the form of the equations of the model with the relationships that exist in the real world system. As well as verifying the realism of these structural equations, they have to be checked to ensure that the dimensions of the rate equations, parameters and state variables are consistent. Moffatt (1991) suggested that failure to pass the dimensional consistency test would indicate the inclusion of parameters with little or no real world meaning. These, he noted should be weeded out at the parameter verification stage. Parameter verification involves comparing model constants against real world observations to determine whether they correspond conceptually and numerically to real life (Forrester and Senge, 1980; Barlas, 1996). Conceptual parameter consistency is important in the GOSM.

In the model representation phase, the causal diagram was disaggregated, and converted into a full influence diagram. The full detail of the GOSM's influence diagram is revealed in Figure 5.4. The diagram is rich in detail and clearly shows the state variables, rates and auxiliaries, resource and information flows, and system delays. The influence diagram was easily translated into a flow diagram, as shown in Figure 5.5. The flow diagram shows the integration of the model parameters and variables clearly. In order for the simulation to operate and for meaningful insights about workplace safety to be gathered, the structural equations for the model had to be set. Translating the causal loop diagram into a detailed flow diagram in one step is difficult. Hence it was decided to construct the diagram piecemeal. A total of six model sectors were chosen.

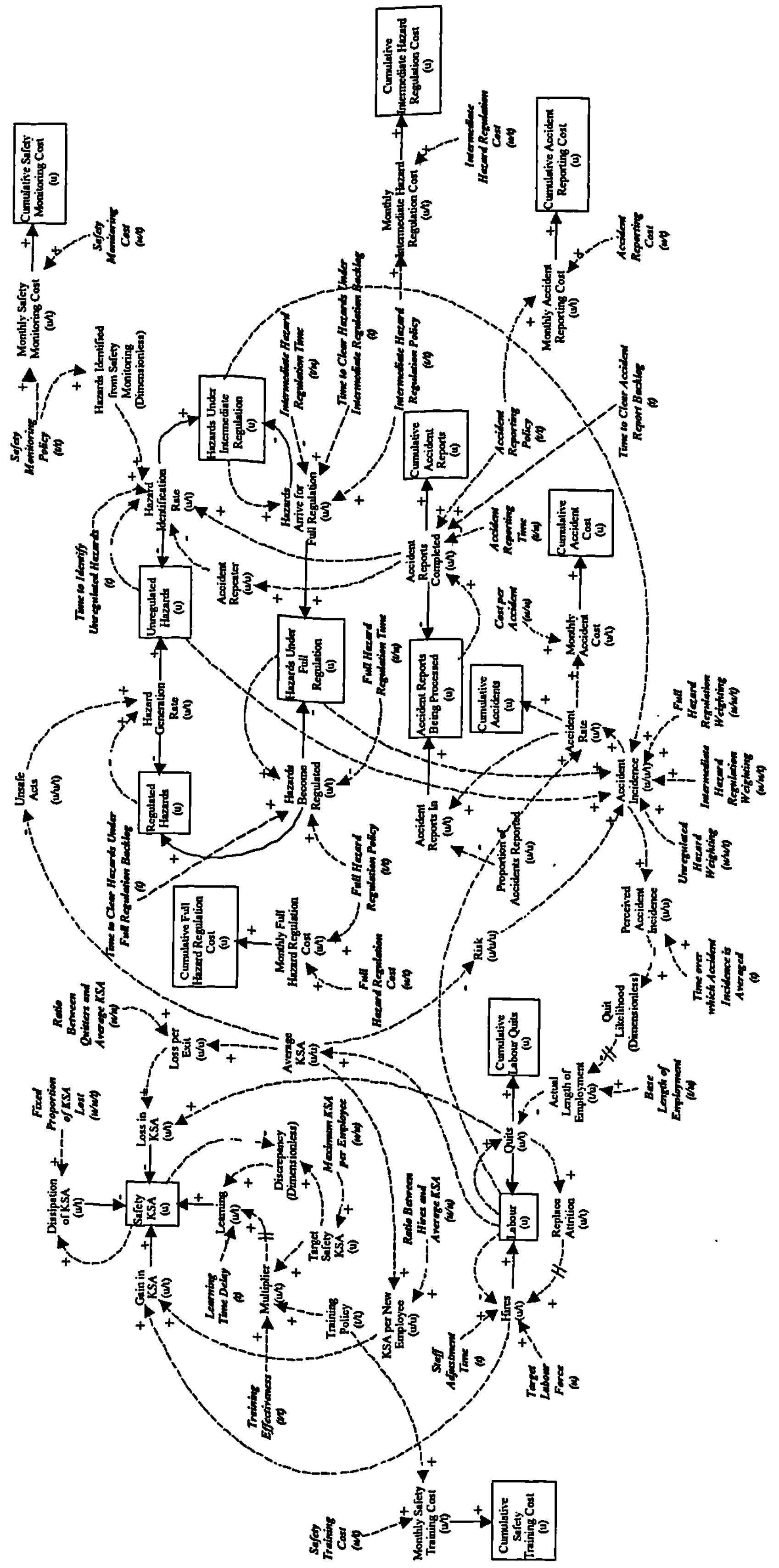

Figure 5.4 The generic occupational safety model's influence diagram

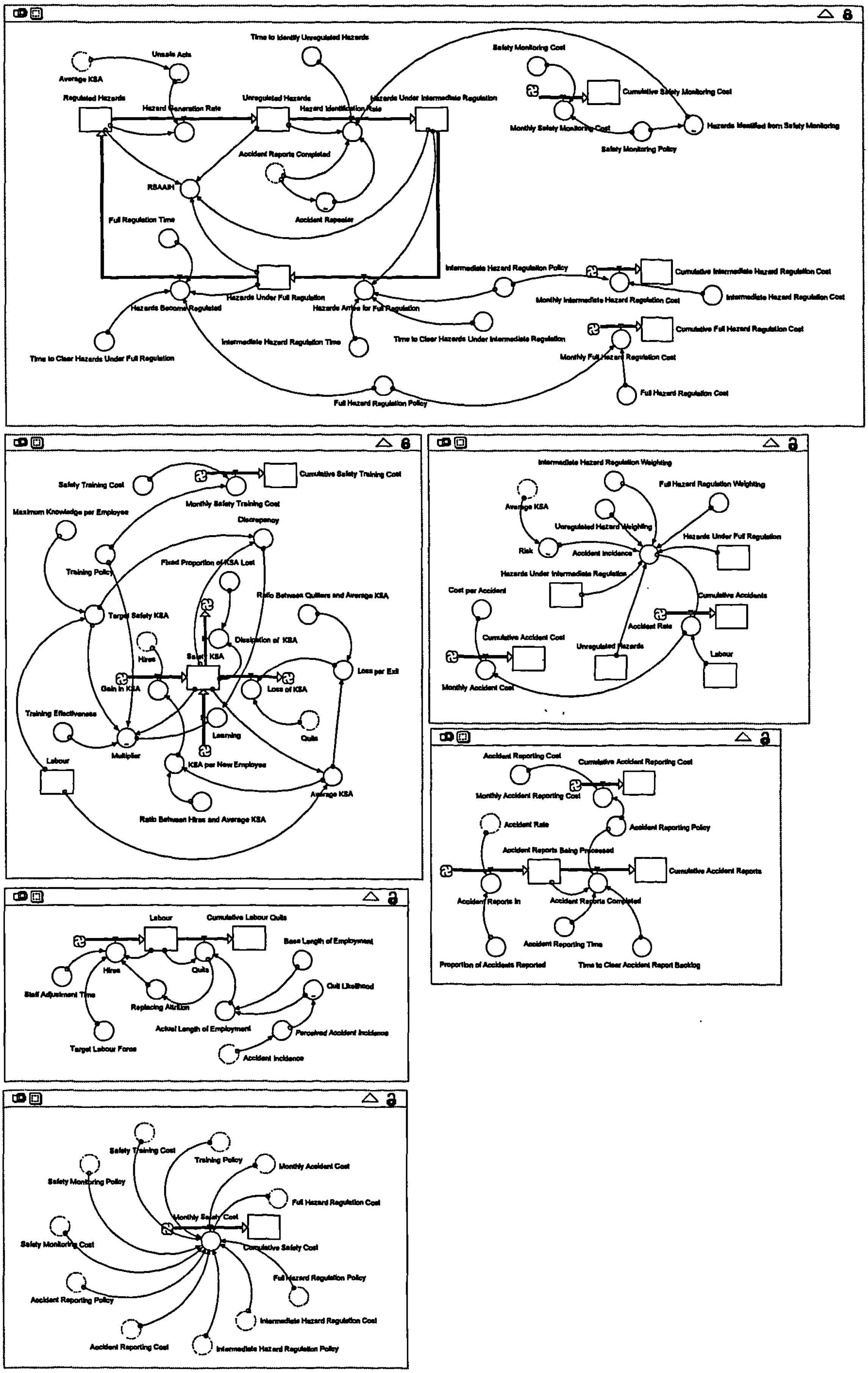

Figure 5.5 The generic occupational safety model's flow diagram

Within each one of these sectors the detail of the influence diagram was set out, then translated into a flow diagram. The sectors were then linked together to allow the subsequent simulation of the quantitative GOSM.

A total of 51 parameters are present in the occupational safety model; of which 29 are constants, 16 are levels, and 6 are table functions. Thirty-one variables are also contained in the model, of which 19 are rates and 12 are auxiliaries. All the model components are endogenous to the system under study. Thirty-nine feedback loops are present in the full system dynamics model. This is broken down into 13 reinforcing loops and 26 balancing loops. The dominance of balancing feedback loops in line with the causal loop diagram is shown by these statistics. This suggests that controlling the behaviour of the GOSM through policy parameter modification will be possible. The solution interval or DT was set at 0.25. The full Ithink model run time and initialisation equations are listed below and also in Appendix L. Detailed equation descriptions will follow in Section 5.5(a) to (h).

<u>A Full Listing of the Generic Occupational Safety Model Equations (Written in Ithink ©High Performance Systems Inc.)</u>

Accident_Reports_Being_Processed(t) = Accident_Reports_Being_Processed(t - dt) + (Accident_Reports_In - Accident_Reports_Completed) * dt
INIT Accident_Reports_Being_Processed = 2.06

Accident_Reports_In = Accident_Rate*Proportion_of_Accidents_Reported
Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Cumulative_Accident_Reporting_Cost(t) = Cumulative_Accident_Reporting_Cost(t - dt) + (Monthly_Accident_Reporting_Cost) * dt
INIT Cumulative_Accident_Reporting_Cost = 0

Monthly_Accident_Reporting_Cost = Accident_Reporting_Policy*Accident_Reporting_Cost
Cumulative_Accident_Reports(t) = Cumulative_Accident_Reports(t - dt) + (Accident_Reports_Completed) * dt
INIT Cumulative_Accident_Reports = 0

Accident_Reports_Completed =
MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Accident_Reporting_Cost = 100
Accident_Reporting_Policy = 25
Accident_Reporting_Time = 10
Proportion_of_Accidents_Reported = 1
Cumulative_Accidents(t) = Cumulative_Accidents(t - dt) + (Accident_Rate) * dt
INIT Cumulative_Accidents = 0

Accident_Rate = Accident_Incidence*Labour
Cumulative_Accident_Cost(t) = Cumulative_Accident_Cost(t - dt) + (Monthly_Accident_Cost) * dt
INIT Cumulative_Accident_Cost = 0

Monthly_Accident_Cost = Accident_Rate*Cost_per_Accident
Accident_Incidence =
((Unregulated_Hazards/Unregulated_Hazard_Regulation_Weighting)+(Hazards_Under_Intermediate_Regulation/Intermediate_Hazard_Regulation_Weighting)+(Hazards_Under_Full_Regulation/Full_Hazard_Regulation_Weighting))*Risk
Cost_per_Accident = 100
Full_Hazard_Regulation_Weighting = 2
Intermediate_Hazard_Regulation_Weighting = 1.5
Unregulated_Hazard_Regulation_Weighting = 1
Risk = GRAPH(Average_KSA)
(0.00, 0.05), (0.5, 0.049), (1.00, 0.0473), (1.50, 0.0383), (2.00, 0.021), (2.50, 0.017), (3.00, 0.0138), (3.50, 0.0105), (4.00, 0.007), (4.50, 0.003), (5.00, 0.00)
Cumulative_Full_Hazard_Regulation_Cost(t) = Cumulative_Full_Hazard_Regulation_Cost(t - dt) + (Monthly_Full_Hazard_Regulation_Cost) * dt
INIT Cumulative_Full_Hazard_Regulation_Cost = 0

Monthly_Full_Hazard_Regulation_Cost =
Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost
Cumulative_Intermediate_Hazard_Regulation_Cost(t) =
Cumulative_Intermediate_Hazard_Regulation_Cost(t - dt) +
(Monthly_Intermediate_Hazard_Regulation_Cost) * dt
INIT Cumulative_Intermediate_Hazard_Regulation_Cost = 0

Monthly_Intermediate_Hazard_Regulation_Cost =
Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost
Cumulative_Safety_Monitoring_Cost(t) = Cumulative_Safety_Monitoring_Cost(t - dt) +
(Monthly_Safety_Monitoring_Cost) * dt
INIT Cumulative_Safety_Monitoring_Cost = 0

Monthly_Safety_Monitoring_Cost = Safety_Monitoring_Policy*Safety_Monitoring_Cost
Hazards_Under_Full_Regulation(t) = Hazards_Under_Full_Regulation(t - dt) +
(Hazards_Arrive_for_Full_Regulation - Hazards_Become_Regulated) * dt
INIT Hazards_Under_Full_Regulation = 1.36

Hazards_Arrive_for_Full_Regulation =
MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Hazards_Become_Regulated = MIN(Hazards_Under_Full_Regulation/
Time_to_Clear_Hazards_Under_Full_Regulation,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazards_Under_Intermediate_Regulation(t) = Hazards_Under_Intermediate_Regulation(t - dt) +
(Identification_Rate - Hazards_Arrive_for_Full_Regulation) * dt
INIT Hazards_Under_Intermediate_Regulation = 1.36

Identification_Rate =
MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Hazards_Arrive_for_Full_Regulation =
MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Regulated_Hazards(t) = Regulated_Hazards(t - dt) + (Hazards_Become_Regulated - Hazard_Generation_Rate) * dt
INIT Regulated_Hazards = 85

Hazards_Become_Regulated =
MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation_Backlog,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Unregulated_Hazards(t) = Unregulated_Hazards(t - dt) + (Hazard_Generation_Rate - Identification_Rate) * dt
INIT Unregulated_Hazards = 1.36
Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Identification_Rate =
MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Full_Hazard_Regulation_Cost = 10
Full_Hazard_Regulation_Policy = 15
Full_Hazard_Regulation_Time = 10
Intermediate_Hazard_Regulation_Cost = 10
Intermediate_Hazard_Regulation_Policy = 5
Intermediate_Hazard_Regulation_Time = 2
RBAAIH =
(Unregulated_Hazards+Hazards_Under_Intermediate_Regulation+Hazards_Under_Full_Regulation)/Regulated_Hazards
Safety_Monitoring_Cost = 10
Safety_Monitoring_Policy = 20
Accident_Repeater = GRAPH(Accident_Reports_Completed)
(1.00, 0.00), (2.00, 0.01), (3.00, 0.02), (4.00, 0.03), (5.00, 0.04), (6.00, 0.055), (7.00, 0.07), (8.00, 0.085), (9.00, 0.1), (10.0, 0.125), (11.0, 0.165), (12.0, 0.215), (13.0, 0.265), (14.0, 0.32), (15.0, 0.365), (16.0, 0.425), (17.0, 0.49), (18.0, 0.545), (19.0, 0.6), (20.0, 0.68)
Hazards_Identified_from_Safety_Monitoring = GRAPH(Safety_Monitoring_Policy)
(0.00, 0.00), (10.0, 0.125), (20.0, 0.325), (30.0, 0.575), (40.0, 0.925), (50.0, 1.53), (60.0, 3.15), (70.0, 4.35), (80.0, 4.73), (90.0, 4.93), (100, 5.00)
Unsafe_Acts = GRAPH(Average_KSA)
(0.00, 0.1), (0.5, 0.099), (1.00, 0.098), (1.50, 0.096), (2.00, 0.089), (2.50, 0.074), (3.00, 0.038), (3.50, 0.022), (4.00, 0.016), (4.50, 0.012), (5.00, 0.009)
Cumulative_Labour_Quits(t) = Cumulative_Labour_Quits(t - dt) + (Quits) * dt
INIT Cumulative_Labour_Quits = 0

Quits = Labour/Actual_Length_of_Employment
Labour(t) = Labour(t - dt) + (Hires - Quits) * dt
INIT Labour = Target_Labour_Force

Hires = ((Target_Labour_Force-Labour)/Staff_Adjustment_Time)+Replacing_Attrition
Quits = Labour/Actual_Length_of_Employment
Actual_Length_of_Employment = Base_Length_of_Employment*(1-Quit_Likelihood)
Base_Length_of_Employment = 120
Perceived_Accident_Incidence = SMTH3(Accident_Incidence,3)
Replacing_Attrition = Quits
Staff_Adjustment_Time = 4
Target_Labour_Force = 100
Quit_Likelihood = GRAPH(Perceived_Accident_Incidence)
(0.00, 0.00), (0.1, 0.001), (0.2, 0.003), (0.3, 0.006), (0.4, 0.014), (0.5, 0.028), (0.6, 0.08), (0.7, 0.0915), (0.8, 0.096), (0.9, 0.098), (1, 0.1)

```
Cumulative_Safety_Cost(t) = Cumulative_Safety_Cost(t - dt) + (Monthly_Safety_Cost) * dt
INIT Cumulative_Safety_Cost = 0

Monthly_Safety_Cost = Monthly_Accident_Cost+(Safety_Monitoring_Policy*Safety_Monitoring_Cost)+(Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost)+(Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost)+(Accident_Reporting_Policy*Accident_Reporting_Cost)+(Training_Policy*Safety_Training_Cost)
Cumulative_Safety_Training_Cost(t) = Cumulative_Safety_Training_Cost(t - dt) + (Monthly_Safety_Training_Cost) * dt
INIT Cumulative_Safety_Training_Cost = 0

Monthly_Safety_Training_Cost = Training_Policy*Safety_Training_Cost
Safety_KSA(t) = Safety_KSA(t - dt) + (Learning + Gain_in_KSA - Loss_of_KSA - Dissipation_of__KSA) * dt
INIT Safety_KSA = 400

Learning = DELAY(Multiplier*Discrepancy,3)
Gain_in_KSA = Hires*KSA_per_New_Employee
Loss_of_KSA = Quits*Loss_per_Exit
Dissipation_of__KSA = Safety_KSA*Fixed_Proportion_of_KSA_Lost
Average_KSA = Safety_KSA/Labour
Discrepancy = 1-(Safety_KSA/Target_Safety_KSA)
Fixed_Proportion_of_KSA_Lost = 0.01
KSA_per_New_Employee = Average_KSA*Ratio_Between_Hires_and_Average_KSA
Loss_per_Exit = Average_KSA*Ratio_Between_Quitters_and_Average_KSA
Maximum_KSA_per_Employee = 5
Proportion_of_Accidents_Reported = 1
Ratio_Between_Hires_and_Average_KSA = 0.7
Ratio_Between_Quitters_and_Average_KSA = 1.3
Safety_Training_Cost = 10
Target_Safety_KSA = Labour*Maximum_KSA_per_Employee
Time_to_Clear_Accident_Report_Backlog = 1
Time_to_Clear_Hazards_Under_Full_Regulation_Backlog = 1
Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog = 1
Time_to_Identify_Unregulated_Hazards = 1
Training_Effectiveness = 0.75
Training_Policy = 200
Multiplier = GRAPH((Training_Effectiveness*Training_Policy)*(IF(Safety_KSA<Target_Safety_KSA)THEN(1)ELSE(0)))
(0.00, 0.00), (50.0, 10.0), (100, 20.0), (150, 30.0), (200, 40.0), (250, 50.0), (300, 60.0), (350, 70.0), (400, 80.0), (450, 90.0), (500, 100)
```

(a) The Sectors of the Occupational Safety Model

The six chosen sectors are Accident Reporting, Accidents, Hazard Processing, Labour, Safety Costs and Safety KSA. An influence diagram and flow diagram represent the structure of each model sector. The influence diagram can be scrutinised to assess causal links and their polarity, and also to distinguish between the units, time and dimensions of the attributes. The flow diagram allows the parameter and equation structure to be examined. Both diagrams also show the important causal linkages to and from other model sectors. A full description of the function and workings of each model sector is offered.

The model is parameterised to run in equilibrium as a 'base run'. The parameter values selected are partly chosen to minimise the transient start-up period of the simulation. This is necessary for subsequent assessment of parameter sensitivity, as described in Section 5.6 of this chapter. As a result, for every sector, a list of all Ithink equations and parameters is set out in an appendix. The Ithink equations and parameters are converted from Ithink notation into DYNAMO. DYNAMO modelling is a simulation language developed in the 1960's to describe the difference equations used in system dynamics. In Ithink, symbolic icons are used to draw the diagrams, from which some of the equations are written automatically, whereas in DYNAMO, equations are written using a text editor. In this form it is easier to analyse the time suffixes and dimensions of the equations and parameters.

Two structural measures of validation were necessary. Detailed structure and parameter verification tests were performed. The structure of each equation and parameter is verified with empirical evidence, or more commonly, against the assumptions about relationships thought by experts to be present in real world occupational safety.

The results of a detailed dimensional consistency test are also contained in each appendix. The units in which a variable or parameter is measured are called its dimensions (Coyle, 1977). Each model equation must be able to transform the numerical values for the quantities on the right hand side into a numerical outcome on the left hand side; and to transform the individual dimensions on the right hand side into a resultant dimension for the left hand side quantity. If this is not possible then the equation is dimensionally inconsistent. The convention for showing dimensions is to place them in square brackets and use abbreviations. Also negative exponents are used to represent division by another dimension. These are called compound dimensions. A number of dimensionless quantities such as ratios or multipliers are present in the occupational safety model equations. Where these appear on the right hand side of an equation they are ignored. Where they appear on the left-hand side of an equation, the dimensions of the variables on the right hand side are shown to cancel out. As the table function is a dimensional transformation, then despite often appearing to be dimensionally inconsistent, the equation is acceptable. The abbreviations for the GOSM dimensions are shown in Table 5.2.

Accident Reports	[AR]
Accident	[A]
Cost	[C]
Employee (Labour)	[E]
Hazard	[H]
Knowledge, Skills and Attitude (KSA)	[K]
Time	[T]

Table 5.2 Generic occupational safety model dimension abbreviations

(b) <u>The Accident Reporting Sector</u>

The Accident Reporting Sector provides a simple representation of the accident reporting and investigation sub-system. The infrastructure of both the influence and flow diagram is contained in Figures 5.6 and 5.7. The sector is driven by one input, the Accident Rate, and contains one output, the Accident Reports Completed.

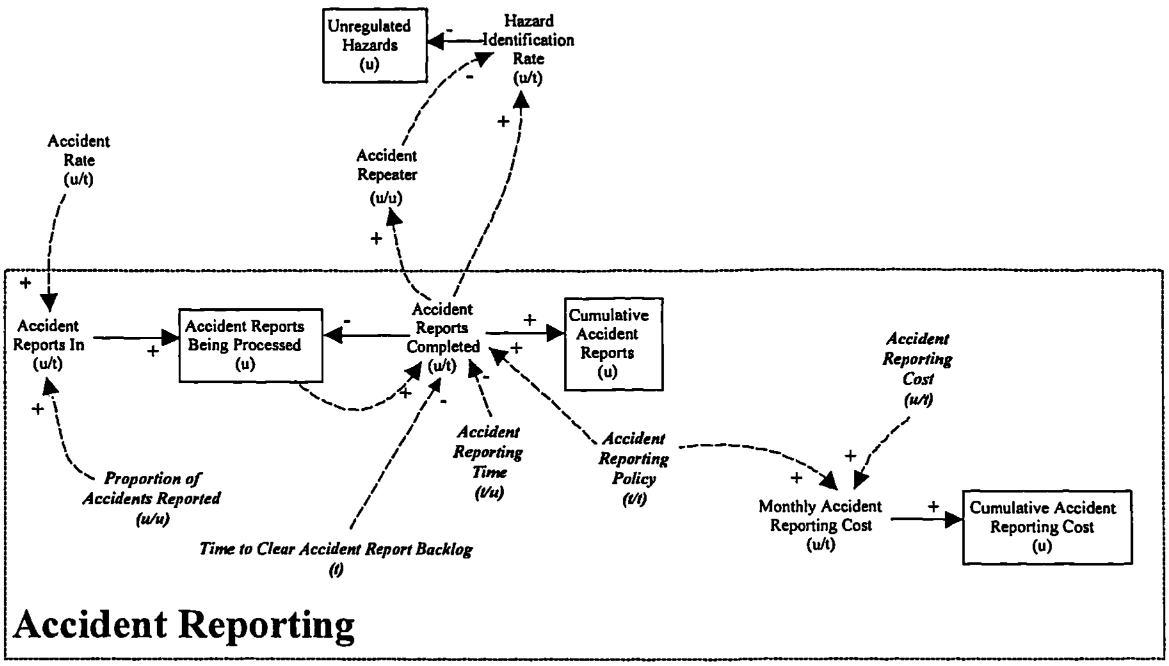

Figure 5.6 Accident reporting sector influence diagram

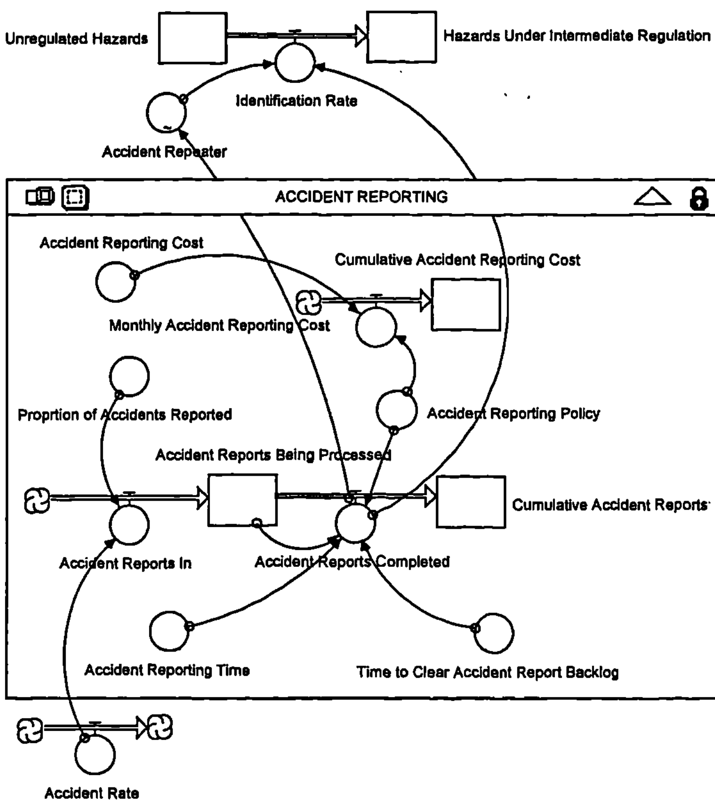

Figure 5.7 Accident reporting sector flow diagram

The Accident Rate is an input to the sector. Accidents occur, and accident reports are subsequently written as standard procedure. This is a coincident flow (or rate on rate calculation), and according to High Performance Systems (1994, p.72) is acceptable, as accident reports run in parallel to accidents. Depending upon the seriousness of the accident, an investigation may follow. Accident Reports Completed are outputs of the sector. They will help in identifying the nature of the hazard contributing to the accident situation. The rate at which accident reports are completed may be important to the overall performance of the firm's safety, as backlogging uncompleted reports may lead to hazards remaining active for longer, thus resulting in further accidents. The Cumulative Accident Reports may be a good indicator of the performance of the sector if it is compared directly with Cumulative Accidents. If Cumulative Accidents exceed Cumulative Accident Reports then the accident reporting and investigation system of a firm may not be working to its full potential.

High costs are associated with accident reporting and investigation, as often there is a need to involve many employees in the process. The sector contains the structure that allows scorekeeping of the Monthly Accident Reporting Cost and Cumulative Accident Reporting Cost. The sector's equations, numerated parameters and dimensions are verified in Appendix A.

(c) The Accidents Sector

The Accidents Sector shows the mechanism by which accidents occur. The infrastructure for accident generation and its consequences is presented as an influence diagram in Figure 5.8, and in Figure 5.9 for additional clarity as a flow diagram.

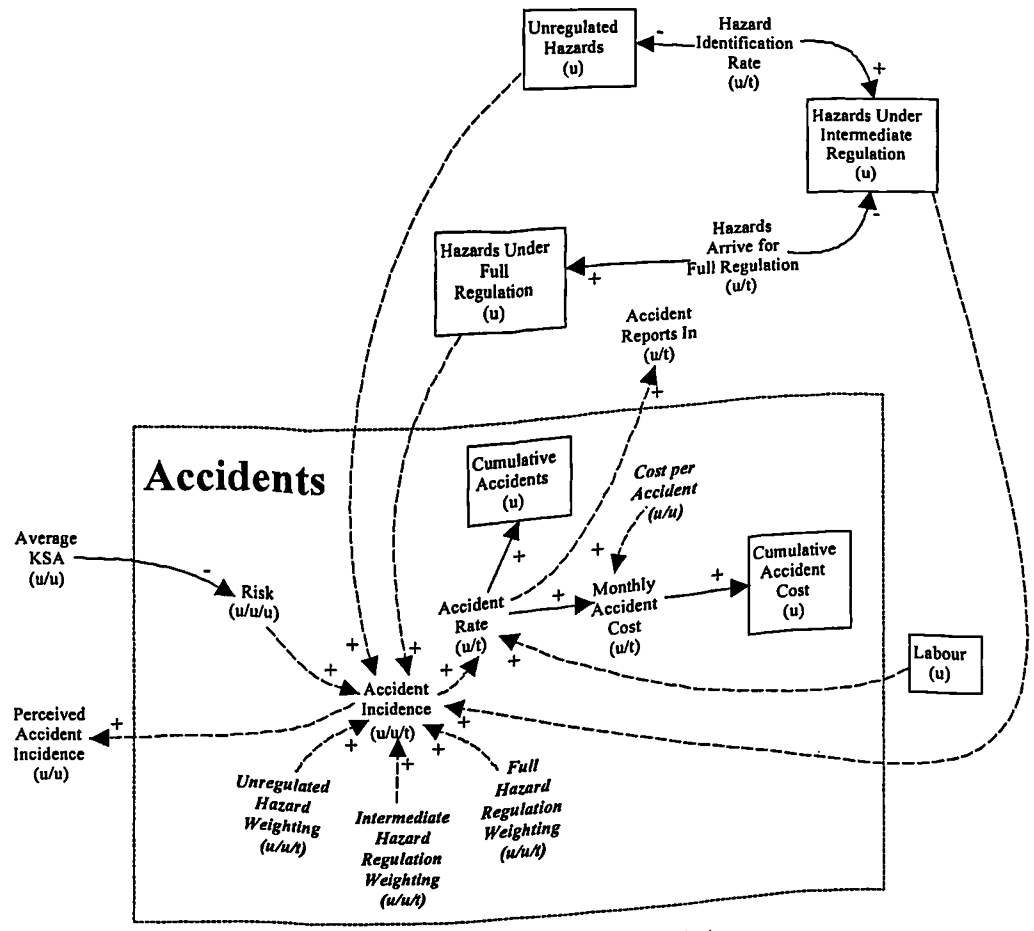

Figure 5.8 Accident sector influence diagram

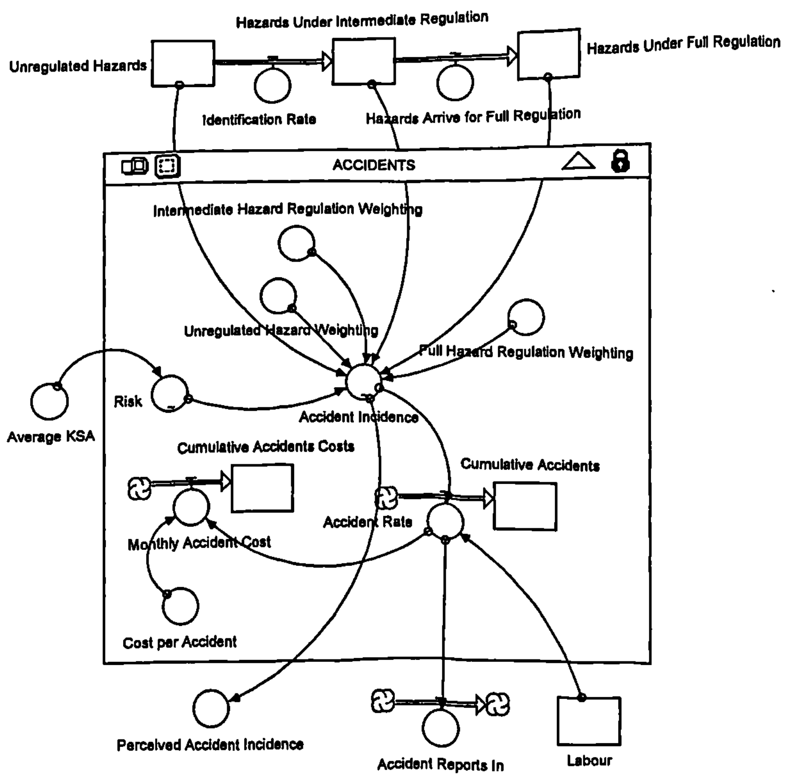

Figure 5.9 Accident sector flow diagram

Accidents are generated as a result of hazards and risk coinciding. If both are high then so too are accidents. Accidents cannot occur unless active hazards are present in the workplace which have a risk attached to them (Bamber, 1990a). Active hazards can be present in the workplace in three states: unregulated, intermediately regulated or under full regulation. These active hazards are sector inputs. A fuller description of hazard states and their associated affect upon safety is given in Section 5.4. With each of these sequential hazard states, their contribution to accidents lessens due to their weighting.

For accidents to occur, people must be involved, so the labour force is represented as an input to the sector. This assists with computation of the Accident Rate, and the Cumulative Accidents. The average safety KSA of the current labour force is another input. It determines the risk or likelihood that an active hazard will result in an accident, that is it governs the way that people work with hazards.

The Accident Incidence is a significant output of the sector. It has a direct impact upon the safety morale of the employees, in the form of their Perceived Accident Incidence. Another output is the Accident Rate which necessitates accident reporting and investigation. Accidents are a very important measure of the safety performance of a company. They are the most tangible and obvious measure. Despite this, they are a downstream measure of safety, and should not be taken in isolation to represent safety performance (HSE, 1991b; Waring, 1996). The sector does allow the monthly and cumulative scorekeeping of accidents and the costs of safety activities. The sector's equations, numerated parameters and dimensions are verified in Appendix B.

(d) The Hazard Processing Sector

The infrastructure of the Hazard Processing Sector provides a generic representation of the states through which workplace hazards move, the activities which facilitate their movement, and their associated costs. The full structure of the sector is presented as an influence diagram in Figure 5.10, and a flow diagram in Figure 5.11 A full listing of the sector's equations, their description and dimensional verification can be found in Appendix C.

The key to the behaviour of this sector, and indeed the whole model lies in the hazard resource loop. Hazards move through a continuous self-renewing life cycle. They lie in a regulated state where they are inactive, that is they do not have the capacity to cause an accident. They can move through three active states, unregulated, being intermediately regulated and being fully regulated, before returning to a regulated state. The frequency and duration over which hazards move around the loop from active to inactive is determined by a number of key activities. These are the Accident Reporting Policy, Safety Monitoring Policy, and two hazard regulation policies. The sector has Safety KSA and Accident Reports Completed as inputs, and active hazards as outputs. A measure of how effective the policies contained within the sector can be determined by analysing the Ratio Between Active and Inactive Hazards (RBAAIH's). A high value is an indication that the management policies addressing active hazards are not sufficiently resourced.

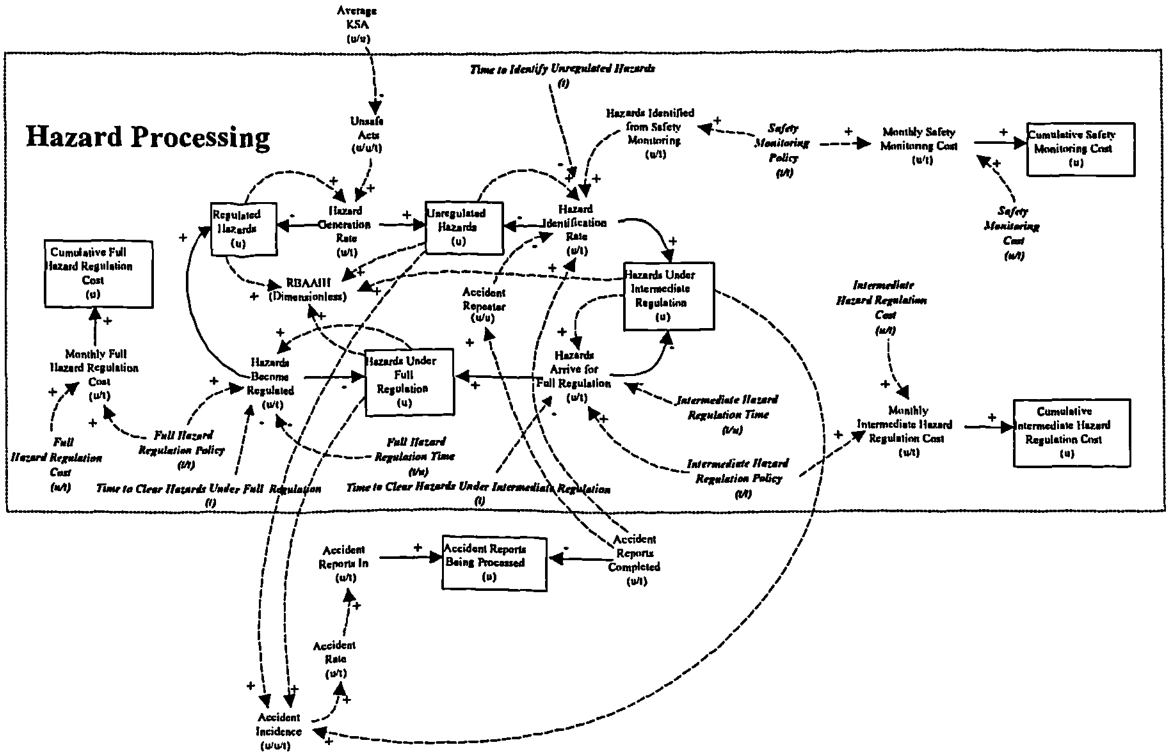

Figure 5.10 Hazard processing sector influence diagram

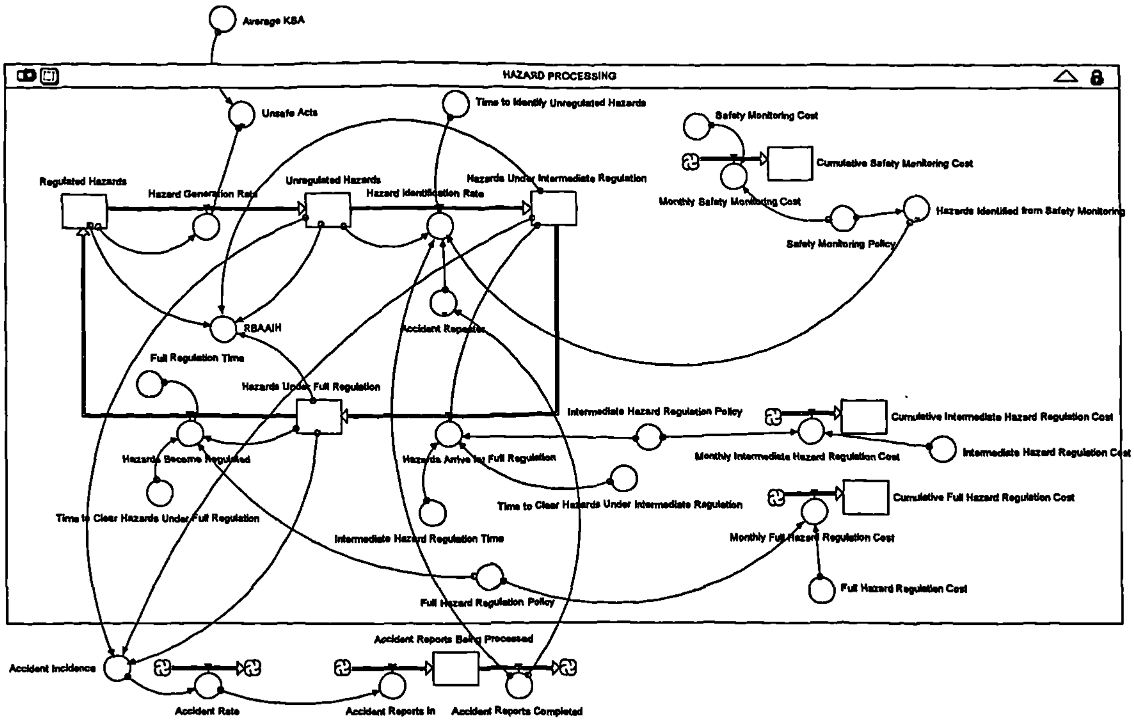

Figure 5.11 Hazard processing sector flow diagram

An analogy can be used to explain how the hazards move through the various states. The hazard can be regarded as a lion. If the lion is locked in the cage, it is inactive, and does not have the ability to cause harm (Regulated Hazard). Under circumstances where the KSA of the lion tamer (Average KSA) is lacking, then the likelihood that the cage door is left open is high (Unsafe Acts). If the cage door is left open then the lion can escape and it becomes a danger (Unregulated Hazard). The lion tamer will learn that the lion has escaped through one of two activities. Either they are injured by the lion, that is be party to an accident and make a quick mental accident report! (Accident Reporting Policy) or they will be constantly aware of the possibility of an escape and intermittently check the cage to ensure that the lion is still locked away (Safety Monitoring Policy). On realising that the lion has escaped, the lion tamer may carry out a number of protective activities which will both reduce the possibility of being injured, and force the lion back into the cage. With the help of a whip and a stool the lion can first be kept at a safer distance (Intermediate Hazard Regulation Policy). A reduction in the threat of injury can quickly ensue (Hazard Under Intermediate Regulation). Then the lion can be guided using the whip and stool back towards the cage (Hazards Under Full Regulation). Finally, the lion is forced back into the cage (Full Hazard Regulation Policy) where once again it no longer has the ability to cause harm (Regulated Hazard).

To summarise the hazard life cycle, Regulated Hazards can become Unregulated Hazards due to Unsafe Acts. Unsafe Acts depend upon an input to the sector, the Average KSA of the workforce. Accident reports and/or safety monitoring allows Unregulated Hazards to be identified, and this facilitates the partial and full regulation of the active hazard, sending it back into a regulated and inactive state.

There are many costs associated with dealing with active hazards. This sector contains the structure which will allow the full extent of the monthly and cumulative costs of hazard processing to be measured.

The levels in the sector have been initialised to show that the majority of hazards (85%) are regulated, i.e. inactive. To distribute the hazards evenly over the four hazard stages would be far from representative of a range of typical firms. Under the HASAWA of 1974, an employer has a duty of care for the safety of its employees, and under the MHSWR of 1992, managers must take suitable and sufficient action to mitigate the risk of injury. If the HSE inspectorate visited a workplace where the majority of hazards were active then it would be certain that improvement notices at least, and more likely prohibition notices, would be issued, preventing further work activity, and prosecution for ignorance of duty of care would follow. It would be rare to find employers who would be foolhardy to this extent.

(e) The Labour Sector

This sector is very straightforward in structure. Its core is based on a human resource infrastructure suggested by High Performance Systems (1994, p.90). The infrastructure is presented as an influence diagram in Figure 5.12 and a flow diagram in Figure 5.13. The sector shows a simple representation of staff hiring and attrition flows. It facilitates the turnover of labour in the firm. Goal-seeking behaviour is in operation. When employees leave the firm, then the labour stock drops, and they are replaced by new employees.

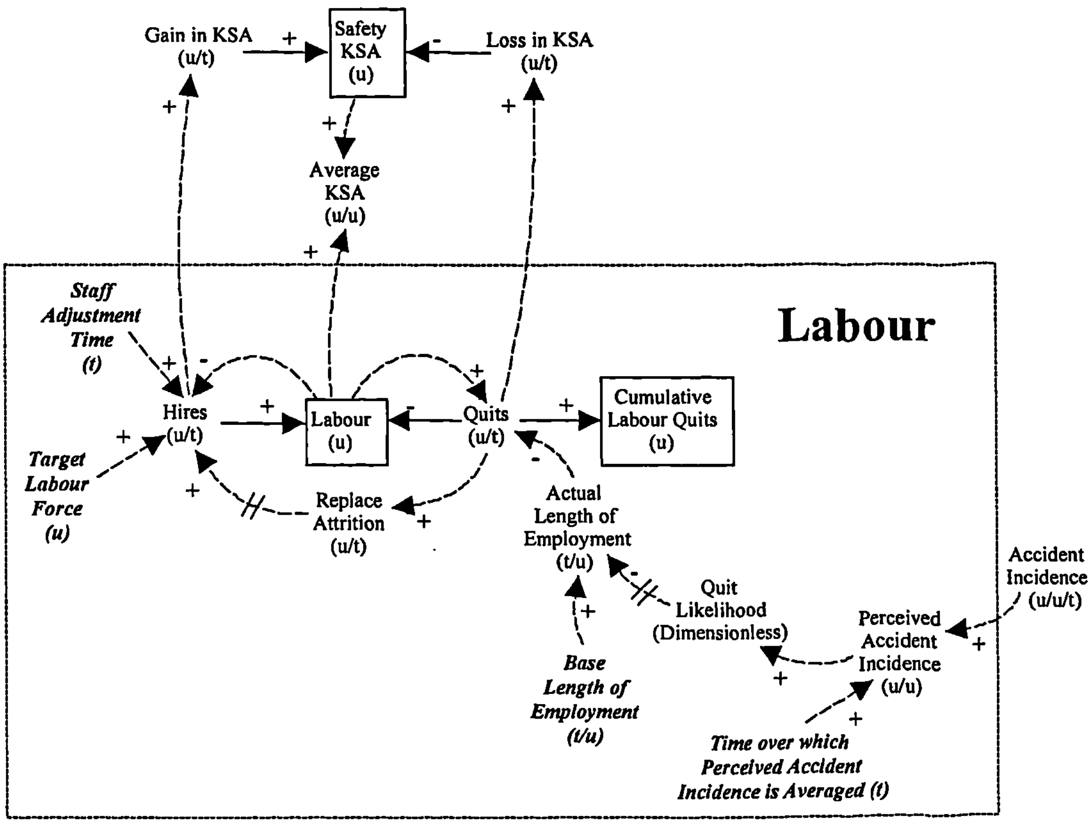

Figure 5.12 Labour sector influence diagram

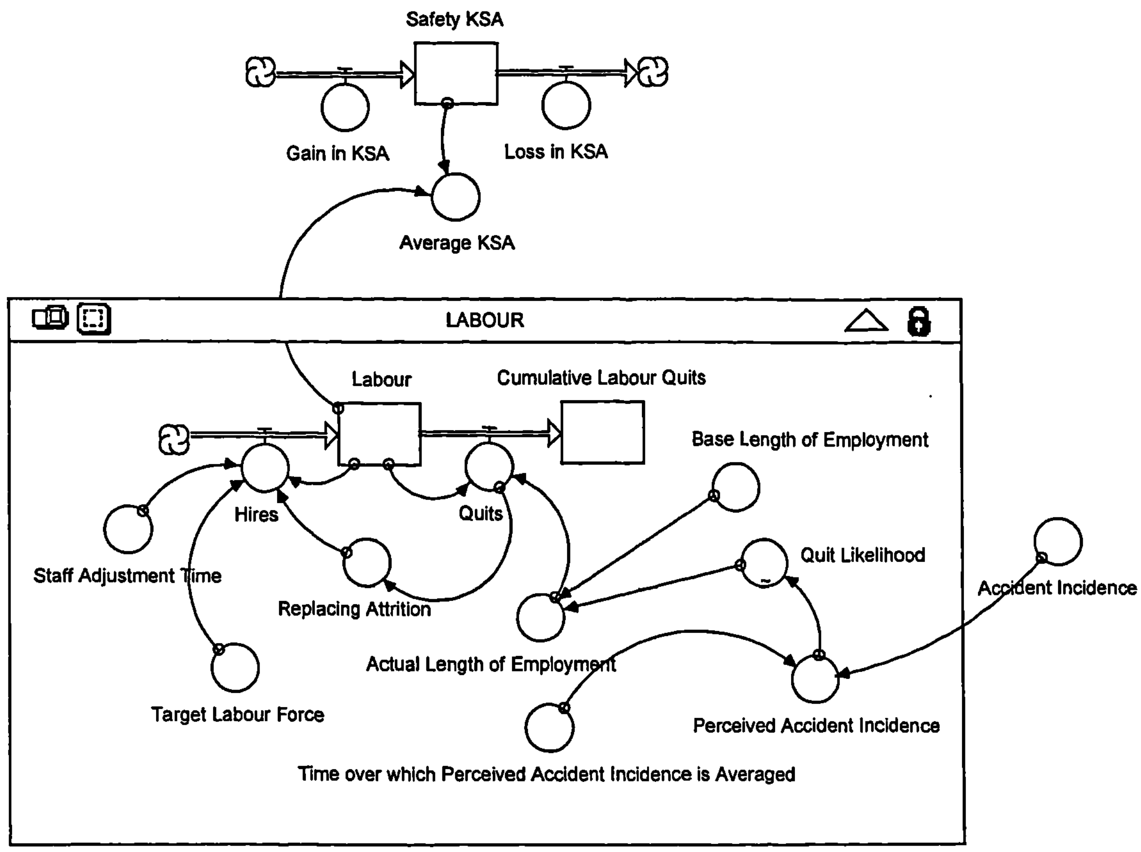

Figure 5.13 Labour sector flow diagram

The Labour level represents the current size of the workforce. The Target Labour Force regulates Labour turnover. This is a human resource policy. The Labour size will move towards the target or desired level through replacing staff Quits with new Hires. A delay in recruitment is introduced to represent the expected lag between quitters and their replacements. Natural wastage of labour is built into the sector. This is based on the average time management expect an employee to be part of the workforce. The Base Length of Stay or the average duration of employment determines this.

The influence of accidents is added to the labour turnover infrastructure. Accident Incidence is the only input into the sector. There will be a threshold where the effect of Accident Incidence begins to drive staff turnover, rather than natural wastage, through depleted safety morale. This is governed by how the Perceived Accident Incidence, that is how the employees regard the underlying accident situation. This will determine the likelihood of them leaving the firm as a result of depleted safety morale. The Quit Likelihood will influence the Actual Length of Employment of the average employee. The influence of the labour turnover can have repercussions for the behaviour of safety in the firm. The labour turnover can be regarded as an output of the sector, directly affecting the growth, retention and loss of Safety KSA in the firm, and having repercussions for the performance of safety metrics in the wider model. A full description of the sector's equations and dimensional analysis can be found in Appendix D.

(f) <u>The Safety Costs Sector</u>

The Safety Costs Sector contains the structure which allows the whole safety effort of the firm to be costed for a given month or cumulatively. An influence diagram was not thought to add any clarity to the understanding of the sector's structure so it was precluded. The structure of these calculations is shown as a flow diagram in Figure 5.14. For every hour of safety activity or management policy, or for every accident there are direct and indirect costs (Stranks, 1994b; HSE, 1991a). These costs are fully represented in the sector. A full description of the sector's equations and a dimensional analysis can be found in Appendix E.

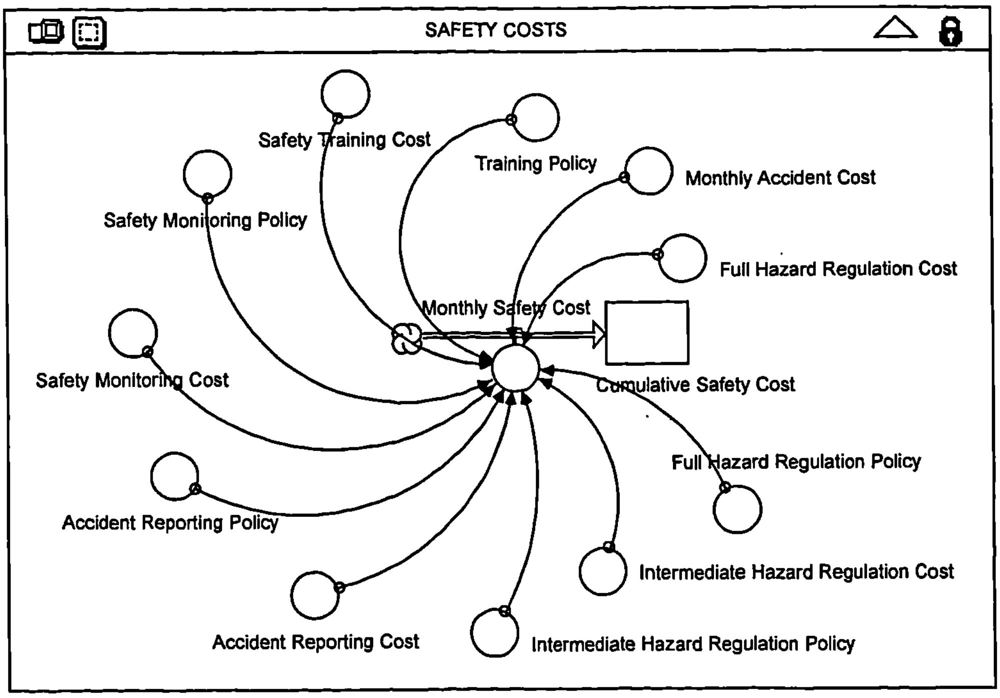

Figure 5.14 Safety costs flow diagram

(g) The Safety Knowledge, Skills and Attitude Sector

The infrastructure of the Safety KSA Sector represents the process of employee safety knowledge, skills and attitude (KSA) acquisition, retention and loss. The sector is set out as an influence diagram in Figure 5.15 and as a flow diagram in Figure 5.16.

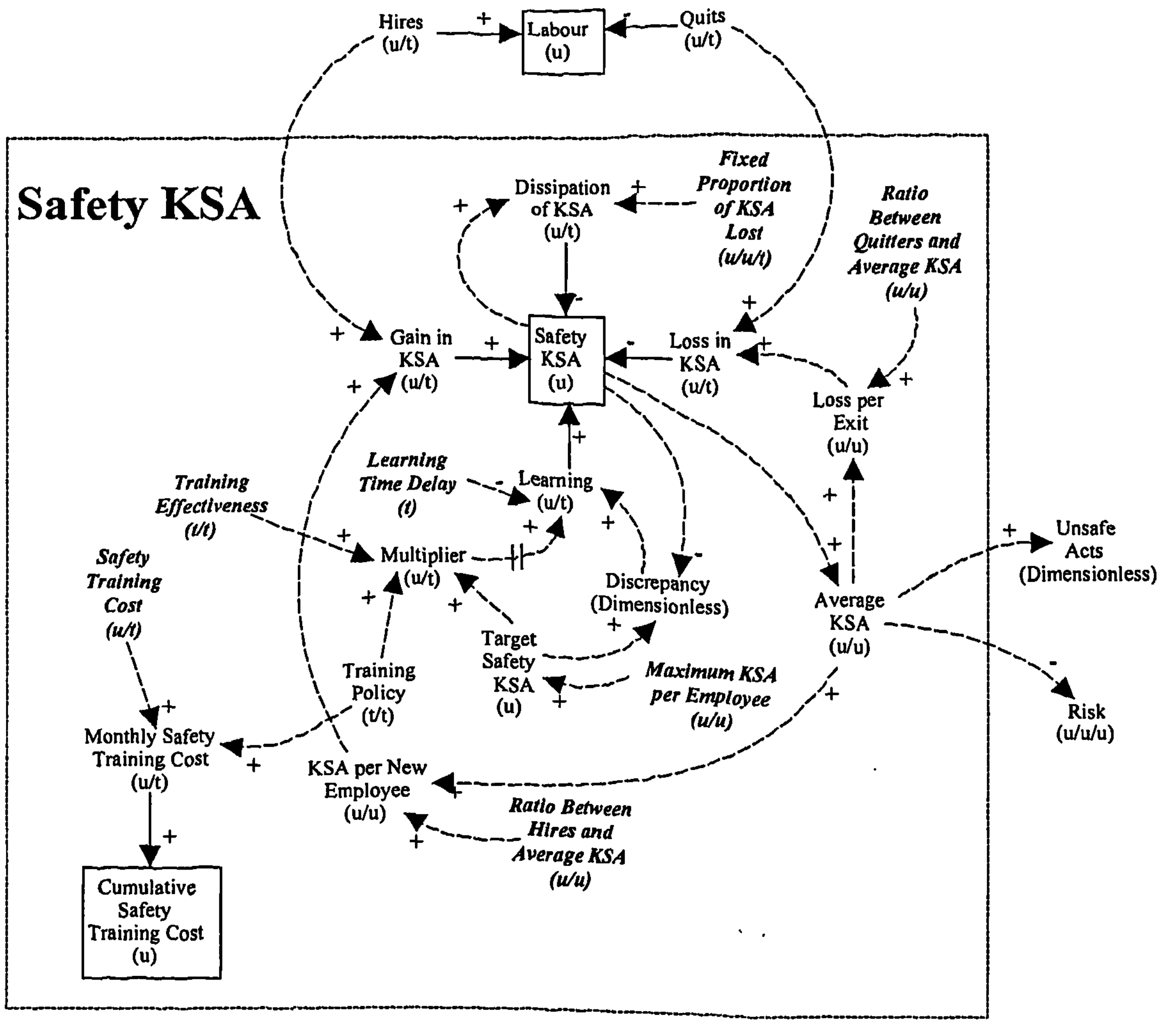

Figure 5.15 Safety knowledge, skills and attitude sector influence diagram

The core structure of the sector is based on a generic infrastructure developed by High Performance Systems (1994, p.92). It exploits the use of two coincident flows (rate on rate equations) which are used to represent a process which runs in parallel with a primary process (High Performance Systems, p.72). There are two inputs into the model, Hires and Quits, and two outputs, Unsafe Acts and Risk.

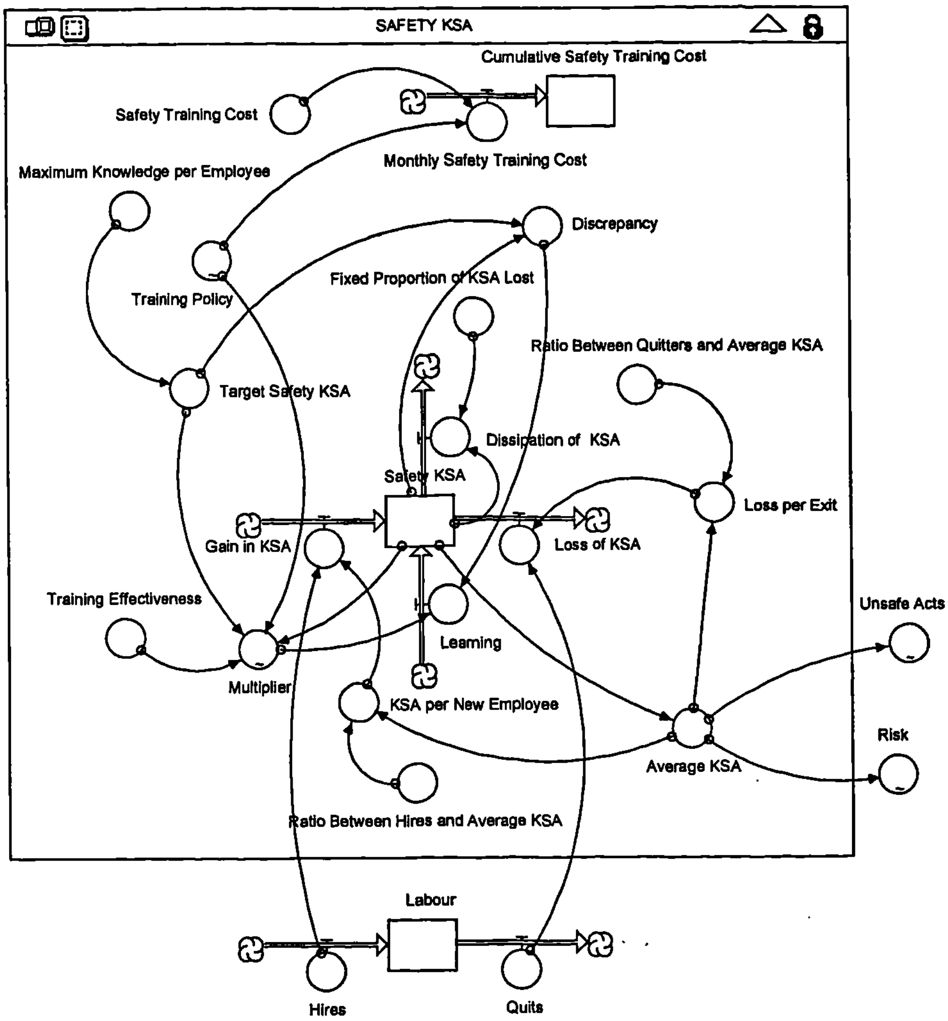

Figure 5.16 Safety knowledge, skills and attitude sector flow diagram

The Safety KSA level represents the current KSA possessed by the workforce. It is driven through two inputs, the KSA that new employees bring to the firm and Learning of KSA through safety training. The level is diminished as a result of KSA dissipation or in simple terms, forgetfulness, and also the KSA that employees leaving the firm take away with them.

The sector inputs and outputs work to balance each other. Hires bring KSA to the workplace, and quitters remove it. Unfortunately, the employer who assumes that new will balance out old will be disappointed because Safety KSA grows with both training, experience and age (Petersen, 1988; Stranks, 1994a).

The average safety KSA of an employee is essential to the safety performance of the firm. As mentioned by a number of safety authors, 60% to 95% of accidents are thought to emanate directly from human error (Perrow, 1984; Killimett, 1991; Krause *et al.*, 1990; Stranks, 1994b). If this human error can be reduced or even ideally removed then it is suspected that huge dividends in terms of accident statistics and their associated costs can be reaped. Two outputs, both Unsafe Acts and Risk represent human error. Unsafe Acts cause employees to work inappropriately with inactive hazards, and Risk increases the likelihood that an active hazard will result in an accident.

Appropriate structure is present in the sector to represent the monthly and cumulative costs of safety training. A full description of the sector's equations and a dimensional analysis can be found in Appendix F.

(h) Summary of the Structure of the Generic Occupational Safety Model

The full structure of the GOSM has been presented as an influence and flow diagram. The model has been broken down into six sectors. The infrastructures and mechanism by which each operates have been described in detail. Appendix A to Appendix F shows the structure of the model attributes and their dimensions to be consistent with those present in the safety system of a typical employer. Having the boundary of the model set to keep the structure endogenous to the firm will ensure that future policy implication tests will allow system behaviour to be generated by the policy decisions of the user, rather than coming from an external source. Importantly, the model simulations are under the full control of the user.

5.6 Analysis of the Behaviour of the Generic Occupational Safety Model

The confidence building tests of Section 5.5 concentrated on the GOSM's structural validity. Some tests to further evaluate the validity of the model structure were required. An analysis of the model's behaviour generated by its structure is achieved through a group of tests identified by authors as behavioural tests. A number of confidence building approaches were available such as behaviour reproduction and prediction tests. These would only be possible in an operational model when real world data were available. The results of these tests are outlined in Chapters Six and Seven respectively. Two suitable sets of behavioural tests were available. The first, extreme conditions or policy tests could be used to determine whether the GOSM would behave reasonably under extreme conditions or policies (Richardson and Pugh, 1981). If these tests were passed then the second set of behavioural tests measuring the sensitivity of the model to a range of parameter changes could be made. The GOSM was parameterised for the base run to simulate in a state of equilibrium. This would reduce the likelihood of an unanticipated shift in loop dominance, and also allow the exact effect of each parameter change to be measured clearly.

(a) Extreme Conditions Testing

Forrester and Senge (1980) suggested that introducing extreme conditions into the model would help to further determine whether a system dynamics model has a valid structure. This process consists of testing the model beyond its normal operating limits to help identify any flaws in the model structure, and also gives the opportunity to analyse policies which may force the system to operate outside its historical operating regions (Moffatt, 1991). Forrester and Senge (1980) suggest that the effects of minimum and maximum values for a level or combination of levels needed to be tested.

In the case of the generic occupational safety model, as it was not calibrated for any particular employment sector it was decided to test only the minimum numerical values for significant state variables or levels, and when appropriate, close off the rates which governed their values. High values could not be tested in the generic model as these values could only be ascertained when the model was verified with real world data.

The range of extreme behaviour tests chosen included setting the labour level and target labour force to near zero and observing the accident incidence. It also consisted of initialising all the four hazard levels to zero and measuring the accident incidence; and setting the Safety KSA level and Training Policy to zero and observing the Average KSA.

Forrester and Senge (1980) also identified extreme policy tests which are concerned with altering policy statements in an extreme way, running the model and noting the consequences. The test would be successful if it was believed that the model would replicate the behaviour of a real system faced with the extreme policy circumstances. The extreme policy tests conducted on the occupational safety model consisted of setting all the policies concerned with hazard regulation to zero and noting the accident incidence. It also involved setting the Base Length of Employment to near zero and examining the accident incidence; and switching the training policy off and examining the Average KSA.

(b) Extreme Conditions and Policy Test Results

The results of the extreme conditions and policy tests can be found in Tables 5.3 and 5.4 respectively. Note that some parameters were set to near zero, as this would avoid a division by zero.

Extreme Behaviour Test	Parameter(s)	Initial Value	Resulting Model Behaviour
Does setting the labour force level to near zero result in near zero accidents?	Labour Target Labour Force	0.01 0.01	Accident Incidence runs at zero throughout simulation.
Does setting all the hazard levels to zero result in zero accidents?	Regulated Hazards Unregulated Hazards Hazards Under Intermediate Regulation Hazards Under Full Regulation	0 0 0 0	Accident Incidence runs at zero throughout simulation.
Does setting the Safety KSA level and Training Policy to zero result in zero Safety KSA?	Safety KSA Training Policy	0 0	Safety KSA runs at zero throughout simulation.

Table 5.3 Extreme behaviour tests

Extreme Policy Test	Parameter(s)	Initial Value	Resulting Model Behaviour
Does setting the Training Policy to zero result in a drastic increase in accidents as compared to the base run?	Training Policy	0	Accident Incidence greatly increases compared to the base run. Its growth is logistical in shape.
Does setting the Base Length of Employment to near zero result in a drastic increase in accidents as compared to the base run?	Base Length of Employment	0.01	Accident Incidence drastically increases compared to the base run, then temporarily reverses before reaching equilibrium. The output is polynomial in shape.
Does setting all the policies concerned directly with hazard regulation to zero result in a drastic increase in accidents compared to the base run?	Safety Monitoring Policy Accident Reporting Policy Intermediate Hazard Regulation Policy Full Hazard Regulation Policy	0 0 0 0	Accident Incidence greatly increases compared to the base run. Its growth is logistical in shape.

Table 5.4 Extreme policy tests

Both the extreme behaviour and policy tests appear to show plausible model behaviour given the exaggerated parameter changes made. The test results show that initialising key levels to zero, and shutting off input rates results in sensible model outputs. The tests appear to have been passed.

(c) Parameter Sensitivity

According to Forrester (1969) sensitive parameters are examined in system dynamics models to see if they affect the validity of proposed policy changes. Whilst many policy analysts may agree with such a proposition, the vast majority of model builders would not. Most model builders view parameter sensitivity tests as confirming whether a small perturbation to a parameter's numerical value results in a significant change in the model's behaviour. If this happens, then that parameter is identified as a sensitive parameter. In the GOSM it was sufficient to identify sensitive parameters, and to then test the plausibility of their impact further in the calibrated model of the host firm.

Two broad tests of sensitivity exist, namely structural and parameter tests (Forrester, 1961; Richardson and Pugh, 1981; Coyle, 1996). In the occupational safety model only parameter sensitivity tests were performed, although it was acknowledged that there are certain situations where structural changes have the greatest effect on model behaviour. As the purpose of the study was to build a generic occupational safety model using system dynamics and calibrating it to fit a given firm, it was not deemed necessary to concentrate on testing any behavioural outputs brought about by structural changes to the model.

Behaviour sensitivity tests are conducted by experimenting with different parameter values and assessing their effects on behaviour (Forrester and Senge, 1980). It was necessary to know where the sensitive parameters may lie in the occupational safety model. The sensitivity tests aimed simply to identify whether the GOSM was sensitive to certain parameter changes such as training or labour force size, and whether the numerical and behavioural changes exhibited by the model would be acceptable in the system under study.

It is widely known that system dynamics models are insensitive to most parameter changes, but are sensitive to a few parameters in a model of a system (Tank-Neilson, 1980; Richardson and Pugh, 1981). System behaviour will not be greatly affected by quite large variations in the values of most parameters, and in these instances it is not so important that the values assigned to them are highly accurate (Coyle, 1977; Moffatt, 1991).

Three types of parameter were tested for sensitivity: constants, initial values and table functions. Initial values are simply the values with which all levels in the model are initialised (Richardson and Pugh, 1981). There was little point in testing all the parameters in the model. Indeed, all the parameters which were not contained within, or did not affect any of the feedback structure of the model were discounted from the sensitivity analysis.

Moffatt (1991) suggested that it is difficult to perform sensitivity tests on non-linear models especially when a large number of parameters are evident. Coyle (1977) suggests that it is impractical to run a sensitivity analysis on a trial and error basis because of the almost limitless possibilities to be simulated. As the objective of the sensitivity analysis was simply to identify the sensitive parameters rather than to give a detailed mathematical account of each, a range of easily analysed tests were needed.

It was important in the design to account for some of the major limitations associated with parameter sensitivity analysis. Ithink did not contain any kind of optimisation software. This created an immediate practical limitation as the number of manual changes to the parameters' values could not be extensive, otherwise the time taken to prepare the tests would become problematic. Only single parameter changes were made at a time so that each parameter's effect could be assessed. There was a limitation to this approach as Forrester (1969) had warned, when testing the sensitivity of his Urban Dynamics model, that one parameter modification could change the sensitivity of the model to other parameters. This is another reason why the base run was set to simulate in a state of equilibrium, besides the need to measure the effect of a single parameter change clearly.

Forrester (1969) suggested that a system dynamics model can be insensitive to some parameters, but to others the system may show sensitivity of one type but not another. For example a model may exhibit numerical but not behavioural sensitivity (Richardson and Pugh, 1981). To counteract this it would be necessary with some of the sensitivity tests to measure final values of simulation runs as well as behaviour across the whole run. Measuring a number of output metrics will allow a more representative picture of model behaviour and performance to emerge than simply using a single metric such as accident incidence. As mentioned by Waring (1996) and the HSE (1991a) accident rates are simply a downstream measure of a safety system. More proactive measures such as hazard states are noted as equally important measures.

Coyle (1978) published the idea of producing a performance index (PI) to measure system dynamics models. He suggested that a PI could be useful when comparing one simulation run with another. A PI is usually a single number summarising the whole performance of a model run. This allows easy presentation of conclusions and also gives a uniform comparison of one run with another. It is most useful in the instance where differences between runs are not greatly evident from examining graphical output. He also identifies problems with this approach. The main problem is in selecting the base run, which will have quite an effect on how the other runs perform. The overall measure can also be dimensionally suspect as using several model outputs will invariably involve different dimensions. The advantages and disadvantages of Coyle's method were considered and it was decided that it would be suitable for classifying the parameters according to sensitivity. A total of six model outputs were selected as performance metrics, one from each model sector. Each output assumed equal weighting when used to analyse the overall PI or sensitivity. As the sensitivity measurements for the set of parameter tests varied, so did the output metrics. A number of methods were used to assess the parameters. The most common involved comparing the percentage change in outputs with the percentage change in input, referred to in this study as gearing ratios. The changes in output were always measured against the base run for the model. From the separate gearing ratios a grand mean was calculated to represent a measure of overall sensitivity. The greater the overall gearing ratio the more sensitive the model to parameter change.

Forrester (1969) offered more advice when examining parameter sensitivity. He suggested that it is very important to identify the parameters that both affect the system condition and can be changed or controlled. He also suggested that a sensitive parameter that cannot be controlled or effectively measured is of no interest unless it affects the overall policy recommendations. This gives justification to the purpose of the tests, that is to simply identify the sensitive parameters. In the real world calibrated model, if they affect the model behaviour in a plausible way and can be controlled all well and good. If they affect the model output and cannot be measured or controlled (in the case of many table functions) then as long as the calibrated real world model behaves in a realistic way, then the fact that they are sensitive should be of little concern.

(d) Constant Parameter Tests

Two types of constant parameter can be found in the occupational safety model. These are the policy parameters which carry a constant value on any one occasion, and constants which are invariant throughout the simulation, such as delays and proportions. Two sets of sensitivity tests were performed on the constants, and three measures of sensitivity were calculated. The first consisted of a fixed constant modification test, where a fixed change was made to a constant at the outset of a simulation run, and the final value of the output noted. The second test involved equilibrium disturbance, and with two measures of sensitivity: settling time back to equilibrium and maximum absolute point value achieved. It was the intention of using these tests to obtain an overall rank for the sensitivity of the constants and determine whether there was some correlation between the three performances of sensitivity.

A total of twenty constants impact directly on the feedback structure of the occupational safety model. Of these nineteen were tested for sensitivity. The exception being 'Maximum KSA per Employee' as this was truly invariant and needed to remain set at a value of five.

(e) Fixed Constant Modification Parameter Tests

The fixed constant modification sensitivity tests were carried out in order to show the numerical sensitivity of the model to single parameter changes. The six output metrics, one from each model sector, were Cumulative Accidents, Average KSA, Average Length of Employment, Cumulative Accident Reports, RBAAIH (Ratio Between Active and Inactive Hazards) and Cumulative Safety Costs.

It was decided to test constant values over a wide range. Forrester and Senge (1980) suggest that a model will be improved in the normal operating regions if any results of extreme behaviour tests can be incorporated into the model. Richardson and Pugh (1981) agreed as they stress the need to test whether the behaviour of the model is plausible under extreme conditions.

The base run for the model was set for a duration of 50 time units (months). At the finish of the base run the values of the six output metrics were noted. The outputs brought about by the parameter changes would be measured against the outputs from the base run to assess sensitivity levels. Table G1 in Appendix G shows these final values. For each parameter, the test range was plus 100% to minus 100%. In the instances where division by zero would occur the lower end of the range was set to minus 99%. Each constant was varied by 25% for each new simulation run. The percentage change from the base run value was called the 'Adjustment Fraction'. Therefore, a total of eight sensitivity runs were performed on each constant, producing 48 final value outputs. The final values for all the output metrics are set out in Appendix G under Tables G2 to G20.

A unified index was needed to summarise the overall sensitivity of each constant given that an array of results had been obtained for each one. It was decided to first calculate a gearing ratio based on percentage changes, as a percentage change is a simple measure of a system's performance. Absolute values were used to calculate the gearing as the polarity of the result was of no consequence. Gearing is simply a ratio between what is put in and what comes out. Gearing was calculated as:

$$\frac{\Delta \text{Output}}{\Delta \text{Input}}$$

Where;

$$\Delta \text{Output} = \left(\frac{\left| (\text{New Run Final Value} - \text{Base Run Final Value}) \right|}{\text{Base Run Final Value}} \right)$$

$$\Delta \text{Input} = \text{Adjustment Fraction}$$

The magnitude of the gearing is a good indicator of the model's sensitivity to parameter change. A total of 48 gearings were collated for each constant tested. These are shown in Tables G21 to G39 in Appendix G. From these values for each constant a mean gearing was calculated. The mean gearings are shown in Table 5.5 ranked from most to least sensitive.

These results show that there a small number of constants which have a significant effect and conversely a number which have little or no effect. Note that the most sensitive constants, Base Length of Employment and Training Policy are both policy parameters, and are also associated with human resources rather than inanimate objects. Surprisingly, the Safety Monitoring Policy and Staff Adjustment Time showed themselves to be very insensitive to change. This may have resulted from the initialisation values used to set the base run, and the fact that only single parameter changes were made to the model. These two constants' sensitivities will be re-examined further in the next chapter where they are involved in the behaviour replication and prediction tests with the real world calibrated occupational safety model.

Parameter	Mean Gearing
Base Length of Employment	4.69
Training Policy	2.53
Training Effectiveness	2.51
Full Hazard Regulation Policy	1.76
Unregulated Hazard Regulation Weighting	1.19
Intermediate Hazard Regulation Policy	1.06
Intermediate Hazard Regulation Weighting	0.79
Full Hazard Regulation Time	0.78
Accident Reporting Policy	0.76
Full Hazard Regulation Weighting	0.62
Ratio Between Quits and Average KSA	0.40
Fixed Proportion of Knowledge Lost	0.39
Ratio Between Hires and Average KSA	0.19
Intermediate Hazard Regulation Time	0.04
Accident Reporting Time	0.03
Safety Monitoring Policy	0.01
Learning Delay	0.00
Staff Adjustment Time	0.00
Perceived Accident Incidence Smooth	0.00

Table 5.5 Ranking of constants according to mean fixed constant change gearing

(f) Equilibrium Disturbance Tests

Coyle (1977) proposed the use of a number of tests to validate system dynamics models. Two in particular appear to be useful for analysing the sensitivity of the occupational safety model when faced with temporary equilibrium disturbance. The settling time is a measure of the time for the variable to settle back to equilibrium. This is what Coyle classifies as a time domain test or behavioural measure. An alternative indicator of sensitivity may be the maximum value achieved in a simulation run. This is a straightforward numerical measurement. These two measures were chosen as complementary measures of parameter sensitivity to equilibrium disturbance. An appropriate disturbance function needed to be chosen to examine the robustness of the model to temporary input change. The pulse function was considered but dismissed, as it was too instantaneous and not reflective of many real world changes. The step function was selected for this purpose as it is more representative of real life situations. A different six model outputs were selected as performance metrics as cumulative measures could obviously not be used to find settling times. The measures taken from each model sector were, Accident Incidence, Accident Reports Being Processed, Actual Length of Employment, Average KSA, Monthly Safety Cost, and Ratio Between Active and Inactive Hazards (RBAAIH). The new base run output metrics were noted. Table G40 in Appendix G shows their final values.

(g) Settling Times

Single parameter changes were used to measure sensitivity. A step input with a duration of ten time steps was introduced into the simulation run, and then stepped back to its original value. For each parameter the step test range was plus 100% to minus 100% with the usual proviso that division by zero had to be avoided, and with an 'Adjustment Fraction' in increments of 25%. The settling time in the simulation for each output metric was noted after every run. The settling times for all the output metrics are shown in Appendix G under Tables G41 to G59. The sensitivity measure was simple to arrive at. The longer the settling time to equilibrium, the more sensitive the parameter. A total of 48 settling times were collated for each constant. These are shown in Tables G41 to G59 in Appendix G. From these values, a mean settling time for each constant was calculated. These are shown in Table 5.6 ranked from most to least sensitive. The results show that the same policy parameter constants as in the fixed constant modification tests were high up in the sensitivity rankings. As in the previous test, the Staff Adjustment Time was totally insensitive to change.

Parameter	Mean Settling Time (months)
Base Length of Employment	172.63
Unregulated Hazard Regulation Weighting	51.77
Training Effectiveness	48.23
Training Policy	48.02
Ratio Between Quits and Average KSA	38.73
Fixed Proportion of Knowledge Lost	37.88
Intermediate Hazard Regulation Weighting	35.02
Ratio Between Hires and Average KSA	32.85
Full Hazard Regulation Weighting	25.21
Full Hazard Regulation Policy	24.50
Intermediate Hazard Regulation Policy	17.33
Accident Reporting Policy	13.48
Full Hazard Regulation Time	10.85
Perceived Accident Incidence Smooth	7.60
Safety Monitoring Policy	1.83
Accident Reporting Time	1.19
Intermediate Hazard Regulation Time	0.71
Learning Delay	0.00
Staff Adjustment Time	0.00

Table 5.6 Ranking of constants according to mean settling time

(h) Constant Maximum Absolute Point Values

The maximum point values for the outputs are shown in Tables G60 to G78. The maximum absolute point value was read off and used to calculate a gearing ratio. The gearing ratio was calculated as:

$$\frac{\Delta \text{Output}}{\Delta \text{Input}}$$

Where;

$$\Delta \text{Output} = \left(\frac{|(\text{Maximum Absolute Value} - \text{Base Run Value})|}{\text{Base Run Value}} \right)$$

$$\Delta \text{Input} = \text{Adjustment Fraction}$$

A total of 48 gearings were calculated for each constant. These are shown in Tables G79 to G97 in Appendix G. From these values a mean gearing for each constant was calculated. The higher the gearing, the more sensitive the constant. The results of the maximum point values are shown in Table 5.7, ranked from most to least sensitive.

Parameter	Mean Point Value Gearing
Base Length of Employment	31.48
Accident Reporting Policy	13.48
Unregulated Hazard Regulation Weighting	11.10
Intermediate Hazard Regulation Weighting	7.31
Full Hazard Regulation Weighting	5.70
Full Hazard Regulation Policy	3.03
Intermediate Hazard Regulation Policy	1.97
Training Policy	1.40
Training Effectiveness	1.34
Full Hazard Regulation Time	1.02
Ratio Between Quits and Average KSA	0.45
Fixed Proportion of Knowledge Lost	0.37
Accident Reporting Time	0.22
Ratio Between Hires and Average KSA	0.13
Intermediate Hazard Regulation Time	0.01
Safety Monitoring Policy	0.01
Learning Delay	0.00
Perceived Accident Incidence Smooth	0.00
Staff Adjustment Time	0.00

Table 5.7 Ranking of constants according to mean maximum point value gearing

(i) Summary Analysis of Constant Parameter Tests

Spearman's Rank Correlation coefficient was used to test the level of association between the constant parameters for the fixed constant changes, settling time and point value sensitivity rankings. The full methodology, calculations and results are shown in Section G1 of Appendix G. Table 5.8 summarises the parameter sensitivities. A simple grand mean sensitivity was calculated from the three performance measures for each constant.

The grand mean rankings are useful if the constant sensitivities are to be classified ordinally, but this sensitivity exercise sought to identify sensitive and insensitive parameters. A classification of the constants according to high, medium or low sensitivity would show which of these parameters needed to be set more accurately with real world data, and also allow the most likely leverage points in the real world occupational safety system to be identified. Table 5.9 shows an appropriate classification of sensitivities according to the range of the grand mean rank. As few parameters in a system dynamics model are sensitive, then only the highest ranking from the table could be regarded as sensitive.

Parameter	Mean Fixed Const. Rank	Mean Settling Time Rank	Mean Point Value Gearing Rank	Grand Mean Rank	Overall Rank Order
Accident Reporting Policy	9	12	2	7.67	7
Accident Reporting Time	15	16	13	14.67	14
Base Length of Employment	1	1	1	1.00	1
Fixed Proportion of Knowledge Lost	12	6	12	10.00	11
Full Hazard Regulation Policy	4	10	6	6.67	6
Full Hazard Regulation Time	8	13	10	10.33	12
Full Hazard Regulation Weighting	10	9	5	8.00	8=
Intermediate Hazard Regulation Policy	6	11	7	8.00	8=
Intermediate Hazard Regulation Time	14	17	15.5	15.50	15
Intermediate Hazard Regulation Weighting	7	7	4	6.00	5
Learning Delay	18	18.5	18	18.17	18=
Perceived Accident Incidence Smooth	18	14	18	16.67	17
Ratio Between Hires and Average KSA	13	8	14	11.67	13
Ratio Between Quits and Average KSA	11	5	11	9.00	10
Safety Monitoring Policy	16	15	15.5	15.50	15
Staff Adjustment Time	18	18.5	18	18.17	18=
Training Effectiveness	3	3	9	5.00	4
Training Policy	2	4	8	4.67	3
Unregulated Hazard Regulation Weighting	5	2	3	3.33	2

Table 5.8 Spearman's rank correlation coefficient test summary constant rankings

Forrester (1969) suggested that a sensitive parameter that cannot be controlled, and often cannot be measured is of no interest unless it affects the selection or use of other parameters which are employed to improve the system. A total of five such invariant constants were identified and tested for sensitivity: Unregulated Hazard Regulation Weighting, Intermediate Hazard Regulation Weighting, Full Hazard Regulation Weighting, Perceived Accident Incidence Smooth and Learning Delay. The latter two were insensitive to change and are unlikely to have any great impact on the model's behaviour. Unregulated Hazard Weighting is the only such invariant constant that shows a high sensitivity, with the other two hazard weightings being of more moderate sensitivity. These parameter's weightings will affect the selection and use of policy parameters. The justification for their level of sensitivity stems from the description of the hazard life-cycle. In Section 5.5 unregulated hazards are described as the type of hazards that are most likely to contribute to an accident. As management action is taken at subsequent stages of the hazard life cycle to reduce the hazard's propensity to cause harm, it becomes safer. This is in line with the fact that the Unregulated Hazard Weighting should be more sensitive than the other hazard weightings as that is representative of the real world. Table 5.9 identifies the sensitivities of all the constants.

Constant Parameter	Sensitivity
Accident Reporting Policy	Medium
Accident Reporting Time	Low
Base Length of Employment	High
Fixed Proportion of Knowledge Lost	Medium
Full Hazard Regulation Policy	Medium
Full Hazard Regulation Time	Medium
Full Hazard Regulation Weighting	High
Intermediate Hazard Regulation Policy	Medium
Intermediate Hazard Regulation Time	Low
Intermediate Hazard Regulation Weighting	High
Learning Delay	Low
Perceived Accident Incidence Smooth	Low
Ratio Between Hires and Average KSA	Medium
Ratio Between Quits and Average KSA	Medium
Safety Monitoring Policy	Low
Staff Adjustment Time	Low
Training Effectiveness	High
Training Policy	High
Unregulated Hazard Regulation Weighting	High

Table 5.9 Aggregated ranking of constant parameter sensitivities

Table 5.10 shows only the policy parameter constants, with the top third rankings being taken as highly sensitive, the middle third as having medium levels of sensitivity and the bottom third as having low sensitivity. Base Length of Employment, Training Effectiveness, Full Hazard Regulation Policy and Training Policy are policies which should receive the most attention when both testing alternative occupational safety scenarios and calibrating the occupational safety model with real world data. Of surprise is the insensitivity of the Safety Monitoring Policy. This may result from the limitations of performance measurement associated with using a particular base run as identified by Coyle (1977). Although this parameterisation problem may have reduced the validity of the results, the overall approach to constant sensitivity measurement appears to be sound. The results are clear and easy to interpret.

Constant Parameter	Sensitivity
Base Length of Employment	High
Full Hazard Regulation Policy	High
Training Effectiveness	High
Training Policy	High
Accident Reporting Policy	Medium
Fixed Proportion of Knowledge Lost	Medium
Full Hazard Regulation Time	Medium
Intermediate Hazard Regulation Policy	Medium
Ratio Between Hires and Average KSA	Medium
Ratio Between Quits and Average KSA	Medium
Accident Reporting Time	Low
Intermediate Hazard Regulation Time	Low
Safety Monitoring Policy	Low
Staff Adjustment Time	Low

Table 5.10 Final ranking of policy parameter constants sensitivities

(j) Sensitivity Testing Using Initial Values

The initial value tests involved measuring the robustness of the model against changes in initial values of levels. Little guidance is to be found in the relevant literature about this formal sensitivity test of state variables or levels. Indeed no formal method of initial value sensitivity analysis was found in the literature review. Moffatt (1991) suggested that initial values should be based on the most accurate data available.

Richardson and Pugh (1981) simply experiment by varying initial values for levels as a means to determine whether a parameter is sensitive or insensitive to change.

The purpose of the initial values test was to produce a taxonomy of initial value sensitivities based on low, medium or high sensitivity. A total of seven levels are contained within the feedback structure of the model. The initial value sensitivity testing consisted of single parameter changes, followed by measurements of output against the base run. As with the previous constant parameter tests, mean gearings were used to summarise the whole performance of a model run.

Six model outputs were selected as performance metrics, one from each model sector: Accident Incidence, Accident Reports Being Processed, Actual Length of Employment, Average KSA, Monthly Safety Cost and RBAAIH. Each one of these assumed equal importance. A full range of values for each initial value were tested as in previous tests. The base run for the model was simulated in a state of equilibrium over a duration of 50 time units (months) and the final values were noted. These are evidenced in Table H1 of Appendix H. The sensitivity of the initial value changes was measured using two different numerical criteria as previously used in the constant sensitivity tests. The criteria used were the final output values and the maximum absolute point value. It was decided to test the effect of initial value changes over a wide range. For each parameter, the test range was plus and minus 100%, with an 'Adjustment Fraction' of 25% introduced to the parameter for each run. The final values were noted.

(k) Initial Value Parameter Modification Final Values

As with the previous final value tests, 48 outputs were produced for each level. The final values for all the output metrics are set out in Appendix H under Tables H2 to H8. Again, a gearing ratio was devised. Absolute values were used to compute the gearings. Gearing was calculated as:

$$\frac{\Delta \text{Output}}{\Delta \text{Input}}$$

Where;

$$\Delta \text{Output} = \left(\frac{|(\text{New Run Final Value} - \text{Base Run Final Value})|}{\text{Base Run Final Value}} \right)$$

$$\Delta \text{Input} = \text{Adjustment Fraction}$$

The larger the gearing, the higher sensitivity exhibited by the output metrics. Again, a total of 48 gearings were calculated for each level. These are shown in Tables H9 to H15 in Appendix H. From these values, a mean gearing for each level was calculated. The mean gearings for the levels are ranked from most to least sensitive in Table 5.11.

Parameter	Mean Initial Value Final Value Output Gearing
Labour	98.98
Safety KSA	44.75
Regulated Hazards	8.98
Accident Reports Being Processed	0.00
Hazards under Full Regulation	0.00
Hazards under Intermediate Regulation	0.00
Unregulated Hazards	0.00

Table 5.11 Ranking of initial values according to mean final value gearing

The gearings show that only three of the initial values exhibited any sensitivity over the model's output. Interestingly, the two most sensitive levels are associated with people rather than actual hazards themselves.

(I) <u>Initial Value Parameter Maximum Absolute Point Values</u>

The maximum absolute point value was also noted and used to produce a gearing ratio. Gearing was calculated as:

$$\frac{\Delta \text{Output}}{\Delta \text{Input}}$$

Where;

$$\Delta \text{Output} = \left(\frac{|(\text{Maximum Absolute Value - Base Run Value})|}{\text{Base Run Value}} \right)$$

$$\Delta \text{Input} = \text{Adjustment Fraction}$$

A total of 48 gearings were collated for each level. These are shown in Tables H16 to H22. From these values a mean gearing for each constant was computed. Again, the higher the gearing, the more sensitive the level. The results of the maximum point values are shown in Table 5.12, ranked from most to least sensitive.

Parameter	Mean Initial Value Maximum Point Value Output Gearing
Labour	101.78
Safety KSA	49.75
Regulated Hazards	11.13
Unregulated Hazards	0.18
Accident Reports Being Processed	0.17
Hazards under Intermediate Regulation	0.13
Hazards under Full Regulation	0.09

Table 5.12 Ranking of initial values according to mean maximum point value gearing

As with the final values, only three of the initial values exhibited any real sensitivity over the models output. Interestingly, the two most sensitive levels are associated with people rather than actual hazards themselves. Labour was the most sensitive parameter. A variation to the number of employees causes the model to exhibit very high sensitivity in the instance where the Safety KSA level remained unchanged. The result being that as the number of employees decreases markedly, the KSA per employee will increase massively. This has had the effect of giving an unrealistic change in sensitivity. Here is a good example of what Forrester (1969) wrote about changes in one parameter have a drastic effect on the impact of other parameters.

(m) Summary Analysis of Level Initial Value Sensitivity Tests

Spearman's Rank Correlation Coefficient was again used to test the level of association and its statistical significance. The full methodology, calculations and results are shown in Section H1 of Appendix H. Table 5.13 is a summary of the parameter sensitivities. The results show a grand mean sensitivity calculated from the two performance measures for each level.

Parameter	Mean Initial Value Output Gearing Rank	Mean Initial Value Point Value Output Gearing Rank	Grand Mean Rank	Overall Rank Order
Accident Reports Being Processed	5.5	6	5.75	5=
Hazards under Full Regulation	5.5	7	6.25	7
Hazards under Intermediate Regulation	5.5	6	5.75	5=
Labour	1	1	1.00	1
Regulated Hazards	3	3	3.00	3
Safety KSA	2	2	2.00	2
Unregulated Hazards	5.5	4	4.75	4

Table 5.13 Spearman's rank correlation coefficient test summary initial value rankings

From the above results the ordinal ranking of the levels sensitivities is clear. Although, a classification of parameters according to low, medium or high sensitivity is more useful when both identifying the levels of accuracy needed when initialising the levels, and in identifying the parameters which have the greatest effect on the GOSM's behaviour. As before, the top third were taken as being the most sensitive. The full classification of all levels is shown in Table 5.14. The initial values for all the levels contained within the feedback structure of the occupational safety model are under the control of the modeller. The most sensitive levels are Labour and Safety KSA. These levels concern the ways in which people carry out their work. These results are in keeping with the constant parameter tests which showed that employees were the most sensitive factors. The initial values for hazards were of low to moderate sensitivity and the actual level of accident reports insensitive. From these results it could be suggested that the numbers employed and their levels of ability will have more influence over accidents than the numbers of hazards present in the workplace. Again, the type of base run selected may inhibit the results.

Initial Value Parameter	Sensitivity
Accident Reports Being Processed	Medium/Low
Hazards under Full Regulation	Low
Hazards under Intermediate Regulation	Medium/Low
Labour	High
Regulated Hazards	Medium
Safety KSA	High
Unregulated Hazards	Medium

Table 5.14 Aggregated ranking of initial value parameter sensitivity

(n) Table Sensitivity

According to Richardson and Pugh (1981), table functions, as with other parameters, must be investigated for sensitivity. The effects of reasonable alternative table functions should be tested in the model. They suggest comparing the behaviour of a model in its base run with its behaviour in a simulation using an alternative table. It is recommended to test at first only the extremes of the likely alternatives. If there is no significant change in the resulting model behaviour, then the conclusion would be that changes to a particular table function would result in the model being insensitive to that change. However, if significant changes were found then that may call into question the structural formulation of the model, or if there was empirical evidence that suggested a sensitive causal relationship, then the inclusion of the table could be justified.

In the GOSM all the table functions are based on hypothesised relationships. The basis for these relationships has been stated clearly in the structural validation of the model. In order to justify the output of the model as a consequence of some of the hypothesised relationships, a number of sensitivity tests needed to be performed. Richardson and Pugh recommend that the sensitivity of table functions should be measured in two ways, the first to change the slope, and second to change the shape of the table from its original co-ordinates. These changes will test alternative assumptions about the structure of the model. The alternative assumptions made about the table functions for the purpose of the sensitivity tests are described in Appendix I.

A balance had to be struck between spending endless time running simulations and obtaining a representative sample of output results. There was also the danger that an unsatisfactory range for the table functions would be tested, so producing misleading results. The three most sensitive constant parameters as identified in previous tests were used in order to mitigate the likelihood that the table functions would act as pseudo constants. In addition, they would put a reasonable limit on the number of simulation runs necessary to identify table function sensitivity. The three policy parameters used were Base Length of Employment, Training Policy and Training Effectiveness.

In the first set of tests the slope of the original table was halved. The value of the chosen parameter was varied over the usual $\pm 100\%$ range, and the final value was noted for each of the six outputs: Cumulative Accidents, Average KSA, Actual Length of Employment, Cumulative Accident Reports, RBAAIH and Cumulative Safety Costs. These procedures were then repeated for the other two parameters. In the second set of tests the shape of the table function was modified and the above procedures were followed. The whole set of tests were then repeated on the next table. Each test was run over 50 time periods (months) and it should be noted that only one parameter change was effected for each test.

The table function settings are recorded in Appendix I in Tables I1 to I6 or, for additional visual clarity in Graphs I1 to I6, along with the alternative assumptions made about their slope and shape for the purpose of the sensitivity test. The results of the base run simulation is shown in Table I7. The full output results are listed for both sets of tests in Appendix I under Tables I8 to I45.

The results of the sensitivity tests had to be converted into some kind of meaningful sensitivity measurement. It was decided to compare the percentage change for the new outputs with those of the base run. Percentage change is calculated as:

$$\left(\frac{|(\text{New Run - Base Run Value})|}{\text{Base Run Value}}\right)\times 100$$

The percentage changes in sensitivity brought about by modifications to the table functions are listed in Appendix I under Tables I46 to I81.

(o) <u>Summary Analysis of Table Function Sensitivity Results</u>

A different approach to classifying the level of sensitivity for table functions was needed, as table functions are polynomials or collections of parameters as distinct from constants and initial values which are system parameters. Comparing the rank sensitivities for the table functions based on slope and shape changes using Spearman's Rank Correlation Coefficient is not appropriate because changes in slope cannot be compared to changes in shape, the difference being too fundamental. The summary percentage changes in outputs brought about by table function modifications are shown in Tables 5.15 and 5.16.

Table Function Parameter	% Change Base Length of Employ.	% Change Training Policy	% Change Training Effective.	Grand Mean % Change
Accident Repeater	1.00	1.00	1.00	1.00
Hazards Identified from Safety Monitoring	1.00	1.00	1.00	1.00
Multiplier	87.00	55.00	55.00	65.67
Quit Likelihood	1.00	1.00	1.00	1.00
Risk	14.00	13.00	13.00	13.33
Unsafe Acts	26.00	26.00	26.00	26.00

Table 5.15 Grand mean % changes in output metrics resulting from table function slope changes

Table Function Parameter	% Change Base Length of Employ.	% Change Training Policy	% Change Training Effective.	Grand Mean % Change
Accident Repeater	1.00	1.00	1.00	1.00
Hazards Identified from Safety Monitoring	1.00	1.00	1.00	1.00
Multiplier	81.00	45.00	44.00	56.67
Quit Likelihood	1.00	1.00	1.00	1.00
Risk	53.00	63.00	62.00	59.33
Unsafe Acts	15.00	19.00	19.00	17.67

Table 5.16 Grand mean % changes in output metrics resulting from table function shape changes

The results in Table 5.15 indicate that only one table is sensitive to slope change namely the Multiplier, with Unsafe Acts and Risk being moderately sensitive. Table 5.16 shows Risk and Multiplier to be sensitive to table shape change, with Unsafe Acts being moderately sensitive. Interestingly, the sensitive tables as with the two previous set of parameter tests are all associated with employees and modifications to the ways in which people work. These are important to the behaviour of the model.

The sensitive table functions in the model have been determined. As stated previously, all the table functions have hypothetical relationships. The causalities and polarities of each have been suitably justified in the appendices. The next stage of the model building is to calibrate the model with real world data from a firm. What will be important, as Coyle (1996) suggests, is to produce the right model behaviour for the right reasons. It is important to select the correct parameters within the sensitive tables. However, this selection may not be absolutely criticised and provided that the real model replicates an actual or plausible behaviour pattern, the parameters are acceptable.

The obvious limitations of this approach to testing table function sensitivity are due to three possibilities. The first that the results are determined by the base run. The second is the limited number of changes made to the table parameters. Lastly the possibility that a wide enough numerical range for each table may not have been tested.

(p) Summary of Parameter Sensitivity Tests

The behavioural sensitivity tests for the three types of parameter: constants, levels and table functions have been used to discover which parameters have a bearing on the overall model sensitivity. The tests have identified a number of sensitive parameters. The range of sensitivities exhibited by the parameters appears to be plausible as they fit a definite pattern. The study could now concentrate on carefully setting those parameters which have been shown to be most significant. The policies most likely to offer the greatest leverage over the safety performance in the host firms are now also known. This should aid the search for effective policy decisions.

5.7 Summary of the Generic Occupational Safety Model

Chapter Five has described the building and testing of a quantitative system dynamics model of occupational safety. The model is generic in nature, and can potentially be verified with the safety data gathered from any employer. As no similar system dynamics model has been found to exist, particular effort has been placed on validating the structure and behaviour of the model. The literature on system dynamics methodology describes validation in very general terms, although some authors do offer good specific examples of validation tests. No system dynamics modellers appear to have detailed a stepwise approach to validation of a model from conception to completion. This may be why validation is still a rather contentious subject and why modellers hold to the view that there is no specific set of tests for validating system dynamics models. Hence, the approach taken to validation, particularly the thorough parameter sensitivity analysis may have contributed to the development of the system dynamics methodology. It could be argued that this chapter has over-emphasised the approach to validation. In response to this assertion, validation is a continuous effort, both formal and informal, and both implicit and explicit to the model. If the GOSM had failed to pass any one test then the need to address an earlier stage of the model development would be paramount. Fortunately, this was not shown to be the case.

Starting with a reference mode of behaviour showing temporal accidents statistics across the United Kingdom, the organisational boundary of the GOSM and some of the important variables influencing the reference mode were identified. A causal loop diagram was constructed to explain the important causal linkages in an occupational safety system. The inclusion of all parameters and variables was verified using safety literature. The overall reinforcing nature of the system suggested that building a successful quantitative system dynamics model was possible. The structure of the model has been shown to be a good representation of safety in a real firm both descriptively and dimensionally. The full model equations and parameters have been validated. The behavioural tests have identified plausible model outputs given the extreme nature of the decisions instigated. Also, the sensitivity tests have identified the sensitive model parameters. The most sensitive parameters are associated with employment policies, those concerned with staff recruitment, retention and turnover; and the knowledge, skills and attitude of staff. This also adds to plausibility of the model (in particular see Chapter Three, Section 3.4 for justification).

In Chapter Five the feasibility of an empirical study has been addressed. A number of careful measures have been taken to ensure that the model replicates the structure and to a lesser degree, the behaviour of a real occupational safety system. At this stage of the study, the main limitation to verifying the plausibility of the model is the absence of real world data. Chapter Six will address this shortfall. It offers an approach to verifying the occupational safety model with real world data in order to replicate the safety behaviour in an employing organisation.

CHAPTER SIX

The Real World System Dynamics Model of Occupational Safety

6.1 Introduction to the Real World Calibrated Safety Model

If an operational system dynamics model is to be accepted by employers and managers of a host firm as a policy analysis tool they will often expect the model to replicate the past behaviour of the proposed system under study (Lyneis, 1999). They may wish to compare how well the model-generated behaviour matches the observed behaviour of the real system (Forrester and Senge, 1980).

Homer (1996) warned about the limitations of gathering insights from an exploratory model without stopping to evaluate its validity. System dynamics is a scientific approach to modelling, and as such its models should contain a wide range of empirical detail about a system based on both data and experience. This would allow the model to produce predictions with levels of confidence and insights greater than those of an exploratory model. The generic occupational safety model, being an exploratory one based on experiential data, can offer an insight into the problem of occupational safety. Without empirical detail and sufficient calibration it would be difficult to get the managers of a real organisation to even think about making specific safety policy decisions based on these insights. Sterman (1984) suggests that when building empirically based system dynamics models, parameters should be estimated from below the level of aggregation of the model. He mentions interviews, engineering data, surveys and other disaggregate studies that draw on the knowledge of the system's structure, rather than its aggregate behaviour. This approach will be used throughout this chapter.

Chapter Six is concerned with model evaluation, as outlined in Phase Five of Roberts *et al's.* modelling framework (1983, p.8). It describes the conversion of the generic occupational safety model (GOSM) from an exploratory model to an empirically based operational one. This is achieved by using safety data and experience derived from a host manufacturing firm and by developing a three-year historical representation of the key behaviour of their safety management system. Two phases in the development of an empirically validated real world occupational safety model (RWOSM) are described.

The first phase is the more substantial (Sections 6.2 to 6.6), and involves the measurement and validation of all numerical parameter values in the model. Section 6.2 describes the criteria which a firm would have to fulfil in order to participate in an empirical test of the safety model The background to the host firm chosen for developing the real world occupational safety model (RWOSM) with is outlined in Section 6.3. In Section 6.4 the terms of reference agreed with the managers of the host firm for the empirical study are outlined. The data requirements for the validation of the RWOSM are set out in Section 6.5.

Section 6.6 is the most substantial in this chapter. The process of validating all the model parameters and important comparative outputs is described. The level of objectivity of the parameters determined the process by which numerical values were arrived at for each parameter. Hard data was collected from the firm's records and more descriptive data was elicited through direct discussion and a questionnaire survey of employees. How well these facts and opinions were analysed would determine the ease with which the model could be parameterised and calibrated to achieve a level of correspondence between simulated output and historical data. Many of the policies were found to be dynamic and numerical time-series data played an important role in achieving a close historical match between model and reality.

The second phase is set out in Section 6.7. It consists of an explanation of how the RWOSM was calibrated to replicate the past safety behaviour of the host firm by tuning the less measurable parameters to achieve correspondence between real and simulated safety. The important outputs of the behaviour replication efforts are outlined and the possible reasons for such behaviour are discussed. The closeness of fit between important simulated output and past data from the host firm is then tested. The size of the error and its composition is assessed to determine whether the correspondence between model outputs and historical data is acceptable. If these tests were passed this would allow a more confident safety policy analysis to be conducted with the host firm.

Finally, Section 6.8 is a summary of the process of data elicitation and model parameterisation within the firm. It also indicates the level of success in replicating historical safety behaviour using the validated RWOSM.

6.2 Criteria for Selection of a Host Firm

Information about occupational safety and accident statistics is for many organisations very sensitive. Many employers do not wish to have their occupational safety records examined closely by outside parties. If the RWOSM were to be calibrated to replicate a good historical fit against real safety data, a number of criteria would need to be met for this partnership to be successful. The host would have to allow sufficient access to company records and contact with staff. The research would have to guarantee both compliance with the Data Protection Act, 1984 and respect of staff confidentiality. To evaluate the appropriateness of such an empirically based occupational safety model, managers of the firm would need to be interviewed so as to elicit their views of the model's value.

6.3 Background to the Host Firm

Due to a confidentiality arrangement with the host employer, the identity of the firm and the full details of its work are not revealed in this thesis. The host firm was internationally owned and the site where the study took place was the largest of three manufacturing plants in the United Kingdom. Low and medium density fibreboard was manufactured from raw timber on site. The firm's products are supplied to most of the large furniture manufacturers in the UK and many in Europe. A total of 450 people were employed on the site.

Work activities on the site were of a high-risk nature. As a consequence, health and safety was afforded a high priority. The health and safety information system in operation was highly structured and well documented. Most safety and personnel records were contained within a computer networked relational database.

It was agreed with the safety managers that to examine safety across the whole of the firm would be very time-consuming. In the event, it was decided to examine a large department in the plant, the 'Finishing Department', which had recently bucked the firm's downward accident trend despite the efforts of safety and production management. There were two sections, Finishing End One (F1) and Finishing End Two (F2). The department was responsible for cutting batches of low and medium density fibreboard to size and sending them for storage. A total of 57 employees worked in both finishing ends. From an initial tour of the works and inspection of the accident statistics it was evident that many injuries were lacerations brought about by trips, slips and falls. Fortunately, these are the types of injury that are relatively easy to prevent at an affordable price if appropriate remedial action is taken. The most serious danger was fire, and fire prevention was high on the list of priorities.

6.4 Agreeing on the Criteria for Calibrating the Real World Occupational Safety Model

One of the objectives of the study was to 'apply the generic workplace safety model to a real world industrial setting' (see Chapter One, Section 1.3 for full thesis objectives. For guidance on group model building with clients as an alternative route to developing system dynamics models (see Vennix 1996,1997). It was hoped that all the extensive work carried out to develop and subsequently test the validity of the GOSM would be worthwhile. It was evident that the hurdle to progression of the work lay in convincing the firm's managers that the model structure was broadly representative of safety in their workplace. If this was not to be the case, two options were open. The first was to seek an alternative host firm, and the second was to modify the structure of the model. As the GOSM had been deliberately designed in order to represent the broad problem of occupational safety through the development of a structure common to most employers, the modeller was confident that the host firm would accept the model as it had been built.

The Safety managers readily agreed to help calibrate the model. In return, they hoped its output would fit the past observed safety behaviour. In their eyes, having the simulation model produce a good historical fit was probably the most important test of the model's credibility. The extent to which the model would mimic the past behaviour of safety in the firm would depend on both how representative the model's structure was of the real safety system and the accuracy of the data collected for model parameterisation. It was evident that the managers were concerned as much about the costs of safety as actual accidents. They were interested in seeing how improved safety policies might both reduce accidents and the cost of operating the workplace safety system. A model that showed certain desirable safety scenarios could be a useful bargaining counter when asking for additional resources.

(a) The Time Horizon for Matching the Historical Fit of Model with Reality

The safety records had been fully computerised for more than three years. It was agreed that a suitable time horizon for the behaviour replication was three years. This is a sufficiently long period for identifying any underlying trends in the safety system. Most of the firm's safety data was documented on a monthly basis, so this remained the time interval for the simulation.

(b) Setting the Objectives for Model Calibration

The firm supported the study not only by offering access to safety documents but by forming a small team to assist in collecting both formal and informal data for model parameterisation. The team consisted of the safety manager, safety officer, fire officer and Finishing Department manager. For the team to work together efficiently in the research, a clear set of calibration objectives had to be agreed by all. It was agreed to:

- Examine the generic occupational safety model (GOSM) to ensure that the necessary structure to replicate the past behaviour of the safety system in the department was present.
- Ensure that the most accurate informal and formal data be made available. It was obvious that the inaccurate setting of parameters could lead to errors in the difference between observed and simulated safety, calling the validity of the whole real world occupational safety model (RWOSM) into question.
- Arrive at the cost-benefit for alternative choices. A model based on empirically derived cost centres would help the managers understand where best to allocate safety efforts. It was agreed that a substantial portion of the model calibration should involve the costing of both accidents and safety policies. This would allow the cost-benefit of different scenarios to be understood.

(c) Explaining the Full Model Structure to the Management Team

Building the manager's confidence in the GOSM was achieved through introducing the basic causal feedback structure of the model first to the team (see Chapter Five, Figure

5.3). The fact that there were two principal balancing loops and one reinforcing loop governing the behaviour of the system was explained. The team understood that accidents were generated by the reinforcing Safety knowledge, skills and attitude (KSA) feedback loop and controlled by the balancing Proactive and Reactive safety loops. Once this was understood, the GOSM was introduced.

At first, only the most important system parameters were explained to the group. The group examined and then raised questions about various equations and policy parameters. Their queries were satisfied, and the team moved their attention to the model's simulated outputs.

The group wished to explore the robustness of the model by carrying out a number of extreme behaviour tests. They decided that the best way to examine the plausibility of the model was to exaggerate some of the policy decisions. The major model policies such as safety training were taken to exaggerated highs and lows and the behaviour of a number of model outputs compared. They were pleased to see that the model output showed very problematic behaviour when certain policies were shut off. At the other extreme they noticed that arbitrarily setting policies with high levels of resources only served to push up the costs of safety to an unsustainable level without showing any significant improvement in accident rates. The team was introduced to the aspects of the model structure which were thought to cause the behaviour under study. To connect the system's behaviour to the underlying structure of the model, frequent reference was made to the causal loop diagram. After playing out a range of safety scenarios, the team was convinced that the model's structure was sound and the capture of a historical replication of the behaviour of safety in the Finishing Department feasible.

The modeller was aware that the firm's managers were becoming involved in the model building process at its half way stage. As a result of them not being involved in developing the GOSM one could argue that they may have had a far from perfect understanding of the model's mechanism. On the other hand, just because the team did not seek changes to any of the model structure does not automatically suggest that they did not understand essentially how the GOSM's structure and parameterisation determined its simulated outputs.

6.5 Host Firm Data Requirements

Calibration of the model would require a substantial effort due to the array of model parameters and their dimensions. For the RWOSM to generate a historical mode of behaviour, the model parameters would have to be validated accurately using hard data derived from the firm's database and manual records and more descriptive data obtained from discussions with managers and survey of employees to validate the softer parameters.

Before any data could be collected and analysed it was important to identify every parameter needing numerical validation. These parameters were policies and levels. Changes to the less easily measured invariant constants and table functions would not be performed until the detailed calibration stage following the validation of the policies and levels. The dimensional analysis showed that there were a total of seven different dimensions contained within the structure of the model. The level of objectivity varied across all the dimensions. It was decided to categorise the parameters according to their objectivity, and then to determine the processes by which the data would be captured.

The categories chosen were objective, where exact values could be collected; semi-objective, where good estimates of values could be determined; and subjective, which would cover softer parameters not traditionally measured quantitatively.

The parameter sensitivity tests had highlighted, in rank order, the level of sensitivity that the GOSM exhibited to single parameter changes. The level of accuracy for which each parameter would need to be validated was noted. The effort placed in deriving data for each parameter was to be commensurate to the results of the previous sensitivity tests performed on the GOSM. A summary of the data needs for the parameters to be validated are set out in Table 6.1 and Table 6.2.

Parameter	**Objective, Semi-Objective or Subjective?**	**Accuracy Required**
Accident Report Cost	Semi-Objective	-
Accident Reporting Policy	Semi-Objective	Medium
Accident Reporting Time	Semi-Objective	Low
Cost per Accident	Semi-Objective	-
Full Hazard Regulation Cost	Semi-Objective	-
Full Hazard Regulation Policy	Semi-Objective	High
Full Hazard Regulation Time	Semi-Objective	Medium
Intermediate Hazard Regulation Cost	Semi-Objective	-
Intermediate Hazard Regulation Policy	Semi-Objective	Medium
Intermediate Hazard Regulation Time	Semi-Objective	Low
Safety Monitoring Cost	Semi-Objective	-
Safety Monitoring Policy	Semi-Objective	Low
Base Length of Employment	Objective	High
Perceived Accident Incidence	Subjective	Low
Staff Adjustment Time	Semi-Objective	Low
Fixed Proportion of KSA Lost	Subjective	Medium
Ratio Between Hires and Average KSA	Subjective	Medium
Ratio Between Quitters and Average KSA	Subjective	Medium
Safety Training Cost	Semi-Objective	-
Training Effectiveness	Subjective	High
Training Policy	Objective	High
Training Delay	Subjective	Low

Table 6.1 Validation needs for policy parameters

Note that in Table 6.1, the required accuracy for the financial policy parameters is not specified. This is because these constants are not contained within any part of the feedback loop structure of the model, and could not previously be tested for sensitivity. Obviously, the more accurately the parameters are calibrated, the more likely the RWOSM is to replicate observed behaviour.

Table 6.1 clearly shows that the vast majority of policy parameters are semi-objective in nature. These could be estimated confidently through discussions with the management team. The most difficult parameters to set would be those which were both subjective in nature and required accurate setting. Fortunately, only Training Effectiveness fitted this bill.

Parameter	Objective, Semi-Objective or Subjective?	Accuracy Required
Accident Reports Being Processed	Objective	Medium/Low
Hazards under Full Regulation	Objective	Low
Hazards under Intermediate Regulation	Objective	Medium/Low
Regulated Hazards	Objective	Medium
Unregulated Hazards	Objective	Medium
Labour	Objective	High
Safety KSA	Subjective	High

Table 6.2 Validation needs for levels

Table 6.2 shows that all apart from one of the levels which needed to be calibrated is objective in nature. The only subjective level is Safety KSA, a sensitive parameter which needs to be accurately set.

As well as setting the parameters, a number of measures of the safety system's past behaviour or output metrics had to be generated by the model for comparison with historical data. The two variables needed for comparison were Accident Rate and Actual Length of Employment.

6.6 Host Firm Data Collection and Analysis

Data was collected from April 1993 to March 1996, a period of 36 months. Every sector of the model contained either policy parameters or levels that needed to be validated with real world data.

(a) Validating the Accident Rate

The Accident Rate represents the number of accidents occurring in a month (see Appendix B for fuller details). For the purpose of the model this acts as a variable and as an important performance output. The number of monthly accidents, their severity, and the resulting number of lost working days were collated for the three-year period.

Tables J1 to J3 in Appendix J show the host firm's monthly injury statistics for the year's 1993/94 to 1995/96. The accident figures are classified according to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations, 1985 as Over-3-Day, Under-3-Day, and Minor injuries. An Over-3-Day injury causes an employee to be absent from work for over three days, an Under 3-Day injury for absence of three days or less, and a minor injury does not cause an employee to be absent. Where appropriate, the man-days lost for each month are shown.

The monthly accident statistics are prone to a great deal of short-term fluctuation. The annual figures suggests that there was an upward trend in accidents with 51 injuries in 1993-94, 68 in 1994-95 and 72 in 1995-96. These figures are the observed output of the firm's safety system. The RWOSM would need to replicate the monthly Accident Rate if a successful historical match was to be achieved. In addition to being used as a historical performance measure of the safety system the figures would help to estimate the Accident Reporting Policy, Accident Reporting Time and Accidents Reporting Cost.

(b) Validating the Accident Reporting Time

Accident Reporting Time is a policy parameter which represents the amount of time that it takes to process each accident report (see Appendix A for fuller details). This parameter is semi-objective in nature and requires estimation. A discussion with the management team rendered details about who might be typically involved in the accident reporting process, what their roles were, and most importantly for numerical validation, the duration of their participation. Tables J4 to J6 outline the findings of these discussions. The estimates show that total number of man-hours dedicated to dealing with an Over-3-Day injury was 16.5 hours. For an under-3-Day injury it was 10.5 hours, and for a minor injury it was 1.5 hours. In order to arrive at a measure of the average Accident Reporting Time, a breakdown of the injury severities is also required. Table J7 in Appendix J is a summary of the injury statistics in the firm over the three-year period. The Accident Reporting Time can be calculated as follows.

$$\text{Accident Reporting Time} = \frac{(\text{Minor} \times \text{Hours}) + (\text{Under - 3 - day} \times \text{Hours}) + (\text{Over - 3 - day} \times \text{Hours})}{\text{Total injuries}}$$

Where:
Minor = minor injuries
Under - 3 - day = under - 3 - day injuries
Over - 3 - day = Over - 3 - day injuries
Hours = Time needed to process accident report

$$\text{Accident Reporting Time} = \frac{(99\times 1.5)+(18\times 10.5)+(74\times 16.5)}{191}$$

$$= 8\text{hours}$$

The Accident Reporting Time parameter is set at 8 hours.

(c) Validating the Accident Reporting Policy

The Accident Reporting Policy is a parameter representing the man-hours in a month dedicated to monthly accident reporting (see Appendix A for full details). It is semi-objective in nature as it is arrived at through estimation. It is a policy parameter which largely depends upon the Accident Rate. This parameter would vary over time and need to be set using time-series data. To vary this policy on a time scale of anything less than one year would not be representative of the real safety system, as business functions tend only to review their resource needs on an annual basis. Having the Accident Reporting Policy remaining invariant for twelve-month periods would be a good representation of the real system. The short-term increases in accidents would create a situation where temporary backlogs of unprocessed accidents would arise, a trait not unusual in any firm.

The accident trend was upwards with the figures for the three-years being 51, 68 and 72 accidents respectively. The Accident Reporting Time has been calculated as 8 hours. From these two sets of data, the Accident Reporting Policy can now be found.

$$\text{Annual Accident Reporting Policy} = \frac{\text{Annual accidents} \times \text{Accident Reporting Time}}{12}$$

Where:
12 = No. of months per annum

$$\text{Annual time-series Accident Reporting Policy} = \frac{51 \times 8}{12}, \frac{68 \times 8}{12}, \frac{72 \times 8}{12}$$

$$= 34,45,48$$

The Accident Reporting Policy parameter is set at 34+STEP(11,13)+STEP(3,25) hours.

(d) Validating the Workplace Hazards

Workplace hazards move between four states (for further details refer to Appendix C). These are objective in nature as their occurrence can be quantified accurately. The firm's database contained extensive results of the risk assessments and risk control measures taken dating back over an eighteen-month period. Although this did not cover the whole three-year history for which the model would replicate behaviour, the time over which the records dated back was sufficiently long for the model to arrive at a fair representation of the assessment and control of workplace hazards. Detailed records of every workplace hazard were accessible. Hazards were classified according to whether they were related to the work environment or to specific work activities. The risk assessment records showed that 102 hazards were present in the workplace at the time of the study. The 41 relating to specific work activities were quantitatively assessed for risk. The remainder were environmental hazards such as walkways and lighting and were qualitatively assessed.

(e) Validating the Initial Hazard Levels

From the risk assessment records an average hazard distribution across the four states could be produced. Month by month the records were examined and the hazards categorised according to their present states. This distribution is an average spread of hazards, and would be used to initialise the hazard values in the model and for historical comparisons against the simulated hazard distribution. Table J8 in Appendix J shows this distribution over the eighteen-month period. The figures show that at any one time the vast majority of hazards were in a regulated state. This is what would be expected for a firm that had a competent occupational safety system. If the opposite had been the case, the firm's safety system would be out of control. The initial hazard values can be determined through calculating the average distribution for the hazards. As the hazard distribution data for the first half of the historical study are not available, it is inevitable that the initial values set are unlikely to match those of the real historical system too closely.

$$\text{Average Regulated Hazards} = \frac{\text{Total Regulated Hazards}}{\text{Number of Months Available}}$$

$$= \frac{1727}{18}$$

$$= 96$$

$$\text{Average Unregulated Hazards} = \frac{\text{Total Unregulated Hazards}}{\text{Number of Months Available}}$$

$$= \frac{9}{18}$$

$$= 0.5$$

$$\text{Average Hazards Under Intermediate Regulation} = \frac{\text{Total Hazards Under Intermediate Regulation}}{\text{Number of Months}}$$

$$= \frac{79}{18}$$

$$= 4.5$$

$$\text{Average Hazards Under Full Regulation} = \frac{\text{Total Hazards Under Full Regulation}}{\text{Number of Months}}$$

$$= \frac{21}{18}$$

$$= 1$$

Regulated Hazards is set at 96, Unregulated Hazards at 0.5, Hazards Under Intermediate Regulation at 4.5, and Hazards Under Full Regulation at 1.

(f) Validating the Hazard Regulation Times

The Intermediate Hazard Regulation Time and Full Hazard Regulation Time represent the time it takes to regulate a hazard intermediately or fully (see Appendix C for full details). The policy parameters are semi-objective in nature. Discussions with the management team produced estimates of the time spent processing each hazard. From these figures, average times to process intermediate and full hazards were determined. Table J9 in Appendix J details the results of those discussions. Numerical estimates of the time afforded to hazard regulation by the line managers, line employees and safety managers is shown for the 41 quantitatively assessed records. Where no risk control action was taken, the duration of intermediate and full action taken was zero. From the estimates of these durations, the average time taken to intermediately and fully regulate a hazard could be determined. Of the 41 hazards, 27 received intermediate regulation and 19 full regulation.

$$\text{Intermediate HazardRegulation Time} = \frac{\text{Hours spent on intermediate hazard regulation}}{\text{Number of Hazards Acted Upon}}$$

$$= \frac{57}{27}$$

$$= 2.1$$

$$\text{Full Hazard Regulation Time} = \frac{\text{Hours spent on full hazard regulation}}{\text{Number of Hazards Acted Upon}}$$

$$= \frac{432}{19}$$

$$= 22.7$$

Intermediate Hazard Regulation Time is set at 2.1 hours, and Full Hazard Regulation Time at 22.7 hours.

(g) Validating the Hazard Regulation Policies

The Intermediate Hazard Regulation and Full Hazard Regulation Policies represent the man-hours dedicated to intermediate and full hazard regulation in a month (for a full description see Appendix C). They are semi-objective in nature, as they are arrived at through estimation. As the hazard data was only available for the previous eighteen-month period then it seemed plausible to set the policies as invariant for the purpose of the simulation.

The hazard regulation policies are averages, and can be determined by dividing the total time spent on hazard regulation by the time over which the hazard data was collected.

$$\text{Intermediate Hazard Regulation Policy} = \frac{\text{Total Time Spent on Intermediate Hazard Regulation}}{\text{Time Period Over Which Hazard Data was Collected}}$$

$$= \frac{57}{18}$$

$$= 3.2$$

$$\text{Full Hazard Regulation Policy} = \frac{\text{Total Time Spent on Full Hazard Regulation}}{\text{Time Period Over Which Hazard Data was Collected}}$$

$$= \frac{432}{18}$$

$$= 24$$

The Intermediate Hazard Regulation Policy is set at 3.2 hours per month, and the Full Hazard Regulation Policy set at 24 hours per month.

(h) Validating the Safety Monitoring Policy

The Safety Monitoring Policy represents the time in a month dedicated to activities associated with measuring the performance of the safety system (see Chapter Three, Sections 3.4 and 3.7 for theoretical background; and Appendix C for a full description of activities). This parameter is semi-objective in nature. A discussion with the managers allowed a picture to emerge of the activities associated with safety monitoring. The managers were queried about the dates on which these activities were introduced to the safety management system, the number of persons involved in them and estimates of the time spent. New activities were introduced periodically over the three-year period. This required the parameter to be set up using time-series data. Tables J10 to J13 in Appendix J show a summary of the time spent on safety monitoring activities. The tables show that at the start of the three-year period only three safety monitoring activities were operated, increasing to six three years later. The total time dedicated to the policy grew, from only 18 man-hours per month to 50 man-hours in the space of three years.

The Safety Monitoring Policy is set at 18+STEP(23,15)+STEP(2,28)+STEP(7,35) hours per month.

(i) Validation the Base and Actual Length of Employment

The Base Length of Employment is a parameter which represents the average period over which a member of staff would be expected to remain employed by the firm assuming that their safety morale was running at a maximum. The Actual Length of Employment is a variable. It represents the actual time a person is employed, and is influenced by the level of safety morale in the workforce (see Appendix D for a full description of both). In order to calibrate the model to represent the Actual Length of Employment, the Base Length of Employment needed to be set higher to represent staff turnover resulting from the accident situation.

Actual Length of Employment is objective in nature and easily quantifiable. The firm's database contained details of the starting dates for each employee. From these figures, an average for the Actual Length of Employment could be easily computed. This parameter is calculated using the figures presented in Table J14 in Appendix J.

$$\text{Actual Length of Employment} = \frac{\text{Total Months Employed}}{\text{Number of Employees}}$$

$$= \frac{5808+1495}{42+15}$$

$$= 128$$

The Base Length of Employment was arrived at through careful calibration of the Base Length of Employment. This required some minor changes to the numerical values of the Base Length of Employment. Although there had been a steadily growing number of accidents in the department the figures suggested that the safety system was still far from being out of control. The assumptions in the model equations are that a moderate accident rate will only have a small effect on staff turnover. In order to for the model to replicate an Actual Length of Employment of near to 128 months, the Base Length of Employment was set to 129 months. This allowed the RWOSM to replicate a good approximation of the real employment duration.

The Base Length of Employment is set at 129 months.

(j) Validating the Training Policy

The Training Policy is objective in nature and represents the amount of safety training given to the employees of the Finishing Department (see Appendix F for further details). The database contained comprehensive records dating back over a number of years detailing the safety training activities which employees had engaged in. Three classifications of training existed in the firm. These were on-the-job, in-house and external. The rich data on training allowed the Training Policy to be set using numerical time-series data.

The development and delivery of on-the-job training was the responsibility of each departmental manager and their supervisors. Quite a large portion of their staff development time was spent delivering intensive safety induction and refresher training. The refresher training was used to both reaffirm the more formal training and to maintain and develop a positive attitude towards safe working practices. All these records were manual and required the Finishing Manager to make good estimates of the durations of each individual training session that they had delivered over the three-year period. The development of training material was the responsibility of the Safety Department. The safety management did not train the workforce directly but developed the training material. Managers with specific safety knowledge delivered this training. Only forklift truck training was identified from the database as in-house. External training was classified as any training delivered by an outside organisation. This information was also stored on the database. Six types of training were identified from records. Four different organisations were used to deliver this training. External training included first aid, woodworking machine use, chainsaw use, risk assessment, safety management and fire safety.

A number of different training types, mediums and deliverers have been mentioned. The volume of data relating to safety training across the Department was substantial. This data had to be aggregated to put it in a form suitable for parameterisation of the Training Policy. All types of training contribute towards the development of KSA. It would be very difficult to assess the individual contribution of a piece of training to the development of employee's KSA. A time–series reflecting the training given over the previous three-year period was determined. The man-hours spent on safety training over the three-year period is presented in Table J15 in Appendix J. This table shows that the Training Policy did fluctuate somewhat, although the underlying trend was fairly static.

The Training Policy is set up as GRAPH(TIME) (0.00, 7.50), (1.00, 52.5), (2.00, 22.5), (3.00, 30.0), (4.00, 0.00), (5.00, 7.50), (6.00, 195), (7.00, 15.0), (8.00, 45.0), (9.00, 15.0), (10.0, 15.0), (11.0, 90.0), (12.0, 60.0), (13.0, 150), (14.0, 90.0), (15.0, 52.5), (16.0, 105), (17.0, 105), (18.0, 143), (19.0, 15.0), (20.0, 30.0), (21.0, 7.50), (22.0, 15.0), (23.0, 0.00), (24.0, 0.00), (25.0, 113), (26.0, 113), (27.0, 37.5), (28.0, 60.0), (29.0, 37.5), (30.0, 60.0), (31.0, 22.5), (32.0, 22.5), (33.0, 240), (34.0, 22.5), (35.0, 7.5) man-hours per month.

(k) Validating the Training Delay

Training Delay represents the time lag between training being delivered and its benefits becoming evident. This is subjective in nature, and would be very difficult to measure accurately. There would be obvious differences between individual trainees and the types of training undertaken. Fortunately, the sensitivity analysis on the GOSM had indicated that changes in this delay has very little effect over the model's behaviour. Stranks (1994b) and Wallerstein and Baker (1994) suggest that it can take several months before a valid evaluation of the impact of safety training can be made. In line with the literature the arbitrary delay of three months set in the GOSM remained in the RWOSM.

The Training Delay was set at three months.

(l) Validating the Perceived Accident Incidence

Perceived Accident Incidence represents how the workforce perceives the underlying accident incidence. The Accident Incidence is smoothed using a third-order smoothing (see Appendix D for further details). The smoothing time is subjective in nature and difficult to measure. Fortunately it was identified as very insensitive in the GOSM. Therefore, the need to accurately validate it was low. The smoothing time of three months, set in the GOSM was retained as basing the underlying accident perception as medium term, is not an unreasonable assumption.

Perceived Accident Incidence smooth is set at three months.

(m) Validating the Staff Adjustment Time

Staff Adjustment Time represents the time it takes to replace staff leaving the firm (for fuller details see Appendix D). This is semi-objective in nature. In the GOSM this was set at four months. Sensitivity tests revealed that this parameter was very insensitive, so attempting to validate this accurately was unnecessary. The management team agreed that this figure was a good approximation of the recruitment time.

Staff Adjustment Time is set at four months.

(n) Validating the Safety Costs

A total of five cost parameters needed to be numerically validated in the RWOSM. These were the Accident Report Cost, Cost per Accident, Full Hazard Regulation Cost, Intermediate Hazard Regulation Cost, Safety Monitoring Cost and Safety Training Cost. These parameters differ from the other model parameters in that they do not affect the feedback structure of the model. This is not to say that they are any the less important. They are essential for helping arrive at the cost-benefits of alternative strategies. All are semi-objective in nature and are a mixture of direct and indirect costs (see Section 3.5 of Chapter Three for fuller details). These costs would be arrived at through a mixture of hard financial data, estimates provided by the managers and HSE published statistics. Most of the data used to calculate these financial parameters relate to the cost of labour.

The management team agreed to divulge the wage rates of the line employees. This amounted to £311 per week or over a 37.5-hour week, £8.29 per hour. They did not wish to disclose their own salaries. It was decided to multiply the line employees' wage by one and a half to arrive at an estimate of a supervisor's and fire officer's wages (£12.44 per hour) and by two for a safety or the department manager (£16.58 per hour).

(o) Validating the Accident Reporting Cost

The Accident Reporting Cost is the man-hour cost of the Accident Reporting Policy (see Appendix A for fuller details). Material costs are negligible and are not included in the calculation. Using the accident reporting data from Tables J4 to J6 and wage rates, the hourly cost of accident reporting can be determined. The time employees are involved in processing an average accident report is multiplied by relevant wage rates and then divided by the total hours over which employees are involved in processing accidents.

$$\text{Accident Reporting Cost} = \frac{\text{Total cost of processing an accident report}}{\text{Total hours spent processing an accident report}}$$

Where:

Total cost of processing an accident report = line management time × relevant wage + line supervisors time × relevant wage + safety management time × relevant wage + line employees time × relevant wage

$$\text{Hourly cost of accident reporting} = \frac{(8.5 \times 16.58) + (4.25 \times 12.44) + (4.75 \times 16.58) + (11 \times 8.29)}{28.5}$$

$$= £12.76$$

The Accident Reporting Cost is set at £12.76 per hour.

(p) Validating the Intermediate and Full Hazard Regulation Costs

The intermediate and full hazard regulation policies are essentially the same in composition, with full regulation being more comprehensive. The hazard regulation costs represent the average man-hour cost of processing hazards (see Appendix C for further details). The cost of hazard regulation is split between the labour input and materials. A reasonable estimate of the labour cost could be arrived at, but the cost of the materials used to mitigate hazards is not included in these calculations. This has probably introduced an underestimate of the true cost of hazard regulation. Despite this, the majority of these costs would be wage-related, and the cost of materials would be insignificant by comparison.

A discussion with the line management team revealed that the line manager and three supervisors were involved in both intermediate and full hazard regulation activities. The line management cost equates to the manager's wage at £16.58 per hour plus the supervisors' wages at £12.44 per hour. Using the data from Table J9 and relevant wage rates, the hourly costs of hazard regulation can be determined.

$$\text{Hourly cost of intermediate hazard regulation} = \frac{\text{Total cost of regulation}}{\text{Time spent on regulation}}$$

Where:
Total cost of regulation = safety management time × relevant wage rate +
line management time × relevant wage rate + line employee time × relevant wage rate

$$\text{Hourly cost of intermediate regulation} = \frac{(1 \times 16.58) + (32 \times 13.48) + (24 \times 8.29)}{57}$$
$$= £11.35$$

$$\text{Hourly cost of full hazard regulation} = \frac{\text{Total cost of regulation}}{\text{Time spent on regulation}} (£/\text{hour})$$

Where:
Total cost of regulation = safety management time × relevant wage rate +
line management time × relevant wage rate + line employee time × relevant wage rate

$$\text{Hourly cost of full regulation} = \frac{(13 \times 16.58) + (28 \times 13.48) + (391 \times 8.29)}{432}$$
$$= £8.87$$

The intermediate and full hazard regulation costs are set at £11.35 and £8.87 per hour respectively.

(q) Validating the Safety Monitoring Cost

The Safety Monitoring Cost represents the average man-hour cost of the Safety Monitoring Policy (see Appendix C for fuller description). Tables J10 to J13 show the time spent by different types of employee on safety monitoring activities over the three-year period. Using this data, and relevant wage rates, the hourly cost of safety monitoring can be determined.

$$\text{Hourly cost of safety monitoring} = \frac{\text{Total cost of safety monitoring}}{\text{Time spent on safety monitoring}}$$

Where:

Total cost of safety monitoring = line management time × relevant wage + line employee × relevant wage + safety management time × relevant wage + fire officer time × relevant wage

Table 6.3 shows the changes in the total safety monitoring costs for the three-year period.

Months	**Safety Monitoring Activities**	**Total Man Hour Cost (£)**
1-15	Fire inspections and Safety committee	12.84
16-28	Fire inspections and Safety committee, Risk assessment, Safety monitoring	12.57
29-35	Fire inspections and Safety committee, Risk assessment, Safety Monitoring, Guard inspections	12.49
35-36	Fire inspections and Safety committee, Risk assessment, Safety monitoring, Guard inspections, Safety tours	12.60

Table 6.3 Changes to the hourly cost of safety monitoring over the three-year period

Despite radical changes to the safety monitoring activities, the man-hour cost remained fixed. The Safety Monitoring Cost can be rounded to £13 per hour.

(r) Validating the Labour

Labour represents the total number of employees working in the department. At the start of the three-year period, there were 57 employee in the Finishing Department. Labour was therefore set at 57.

(s) Validating the Accident Reports Being Processed

Accident Reports Being Processed represents the backlog of accident reports awaiting attention. For further details see Appendix A. The model was relatively insensitive to this parameter, therefore as there was only one accident in the first month of the period, Accident Reports Being Processed was set at 1.

(t) Validating the Safety Training Cost

The Safety Training Cost represents the hourly cost of an aggregation of on-the-job, in-house and external training. See Appendix F for fuller descriptions. In order to arrive at a cost for the training, the training would have to be split into on-the-job training as one cost centre, and in-house and external training as a second cost centre. The on-the-job training cost is based on wage rates, and the in-house and external training costs based on wage rate and the fixed cost of training delivery. The average hourly cost of safety training is determined monthly for the three-year period, then an average is taken to represent the hourly cost of safety training.

The Finishing Department manager was responsible for administering all on-the-job training. The training was normally provided by the manager for five employees at a time, i.e. for every hour of training delivery there are five man-hours of training benefit. The training cost equates to the manager's wage at £16.58 per hour plus the employees' wages at £8.29 per hour. This averages out at £11.60 per man-hour. Using the training data from Table J15 and relevant wage rates, the hourly cost of on-the-job training can be determined. Table J16 in Appendix J shows the cost of in-house training over the three-year period.

$$\text{Hourly cost of on-the-job safety training} = \frac{\text{Total cost of safety training}}{\text{Time spent on safety training}}$$

$$\text{Hourly cost of on-the-job safety training} = \frac{11310}{975}$$

$$= £11.60$$

In-house and external training was delivered to all employees of the firm, rather than being arranged purely for the benefit of Finishing Department employees. All training was delivered in blocks of at least 7.5 hours, as opposed to the short periods of on-the-job training. The cost of this training is greater than on-the-job training as it includes both the fixed cost of running the training plus the labour costs of the participants. The fixed cost per trainee needs to be calculated for each form of training. Using the training data from Table J15 and relevant wage rates, the hourly cost of a combination of in-house and external training can be determined. Table J17 in Appendix J shows the cost of this training over the three-year period.

$$\text{Hourly cost of in-house and 'external' safety training} = \frac{\text{Total cost of safety training}}{\text{Time spent on safety training}}$$

$$\text{Hourly cost of in - house and external safety training} = \frac{16958}{1080}$$

$$= £15.70$$

The hourly cost of safety training can be found by taking an average cost for on-the-job, and in-house plus external training.

$$\text{Hourly cost of all training} = \frac{\text{Cost of on - the - job training} + \text{Cost of in - house and external training}}{\text{Total time spent on training}}$$

$$\text{Hourly cost of all training} = \frac{11310 + 16958}{975 + 1080}$$

$$= £13.75$$

Safety Training Cost is set at £13.75 per hour.

(u) Validating the Cost per Accident

Cost per Accident represents a number of direct and indirect costs associated with an accident (see Appendix B for fuller details). To arrive at a final cost, a number of sub-costs needed to be summed.

$$\text{Cost per Accident} = \text{indemnity insurance} + \text{first - aid cost} + \text{absenteeism} + \text{overtime costs} + \text{damage costs}$$

The indemnity insurance cost is based on the nature of the industry, the numbers of employees in the firm, and its accident statistics. Due to lack of sufficient detail, the contribution of the indemnity insurance per accident can only be based on the overall premium cost, the proportion of the firm's employees working in the Finishing

Department and the accidents occurring in that department. Using the 1995 statistics a cost can be estimated.

$$\text{Indemnity insurance cost per accident} = \frac{\text{Indemnity contribution}}{\text{No. of accidents in Finishing department}}$$

Where :

$$\text{Indemnity insurance cost per accident} = \text{Indemnity insurance cost} \times \frac{\text{Finishing department employees}}{\text{Total firm employees}}$$

$$\text{Indemnity insurance cost per accident} = \frac{400000 \times \frac{57}{450}}{72}$$
$$= £704$$

This figure of £704 insurance cost per accident reflects the high-risk insurers attach to work in such a hazardous industry as timber and furnishing. A discussion with the line managers revealed that there were two costs associated with first aid. These were the labour and materials costs.

$$\text{First - aid cost} = (\text{first - aider's time} \times \text{wage rate}) + \text{material cost}$$

$$\text{First - aid cost} = (0.5 \times 8.29) + 10$$

$$= £14$$

The wage costs resulting from work absence can be high. Tables J1 to J3 show the lost man-days resulting from accidents over the three-year period. Using these statistics and the relevant wage rate, an estimate of the cost of absence resulting from an accident can be determined.

$$\text{Cost per accident of absence from work} = \frac{\text{Total lost working days} \times \text{conversion to hours}}{\text{Total accidents}} \times \text{relevant wage cost}$$

$$\text{Cost per accident of absence from work} = \frac{1072 \times 7.5}{191} \times 8.29$$

$$= £349$$

In order to maintain the necessary high volume of production, workers from other shifts were required to cover for colleagues away from work due to injury. This work was paid at time and a half. Therefore, if the cost of absence for an injured employee is £349, then the cost of overtime to cover that employees work is one and a half times greater at £524.

No figures were available to make a good estimate of the lost production costs. The HSE (1994b) in their Labour Force Survey, estimated that where a typical injury accident occurs, the cost of property damage incurred is £45. This seems to be a low estimate, and it is likely that this is an underestimation of the real cost in this firm. Despite this, £45 is added onto the cost of every accident to account for this damage. The Cost per Accident can now be determined.

$$\text{Cost per Accident} = \text{indemnity insurance} + \text{first-aid cost} + \text{absenteeism} + \text{overtime costs} + \text{damage costs}$$

$$\text{Cost per accident} = 704 + 14 + 349 + 524 + 45$$

$$= £1636$$

This figure only accounts for the injury accidents. Many accidents occur where there is property damage but no injuries. Therefore, the overall monthly costs the model may suggest are likely to be an underestimation of the true costs.

The Cost per Accident is set at £1636.

(v) Validating Parameters Concerned with Safety Knowledge, Skills and Attitude

Safety KSA is a level which represents the sum of the safety knowledge, skills and attitude possessed by the workforce. See Appendix F for more detail. It is subjective in nature and has been identified as a sensitive parameter, so the level of accuracy when validating the parameter needed to be high. There are a number of policy constants which dictate the rate of change of this level. See Appendix F for more detail. These are the Fixed Proportion of KSA Lost, Ratio Between Quitters and Average KSA, Ratio Between Hires and Average KSA, and Training Effectiveness. All are also subjective in nature, with the first four having exhibiting a medium level of sensitivity and the latter one a high level in the GOSM tests. The Fixed Proportion of KSA Lost represents the 'forgetfulness' of the workforce, or the proportion of KSA dissipating in a given month. The Ratio Between Quitters and Average KSA and Ratio Between Hires and Average KSA represent the difference between the KSA of the average employee and that possessed by those leaving or being recruited to the firm respectively. Training Effectiveness represents how good the training given to the workforce is.

Validating parameters that were both soft and exhibited medium to high sensitivity would not be an easy task. Safety KSA is rather amorphous and imprecise, but it is evident from analysis of literature and the results of GOSM's sensitivity tests that it plays an important role in generating the dynamics of the safety system. The parameters associated with Safety KSA need to be set with internally consistent values so as to allow the model to yield historically observed results. Due to the inevitable error introduced in the measurement of these soft factors, some of the final parameter values would be incrementally set through detailed numerical calibration. A method was needed to capture a measure of these soft factors that would have an acceptable margin of error. The easiest way to validate the Safety KSA and related parameters was through a form of workforce survey. This was the method of data collection chosen for validation of these parameters.

(w) The Survey Method Used to Measure the Aspects of Safety Knowledge, Skills and Attitude of the Workforce

A survey is a commonly used method of data collection for research (McCormack and Hill, 1997). It is used to make inferences about the behaviour, attitudes and opinions of a population from whom a sample is taken. Survey questionnaires or interview schedules are used to ask identical questions of often quite large numbers of individuals. The collective responses to the postal questionnaire or interview questions are analysed and conclusions drawn. A survey has to be designed so that a reasonably accurate reflection of a population's views can be gathered. It must be reliable and also internally valid. A rigorous stepwise approach to the design, dispatch, analysis and interpretation of a survey was developed, based on an approach offered by McCormack and Hill. A total of seven stages were followed en route to the final calibration of these soft parameters.

Step 1 - Understanding the Data Requirements

The general aim of the survey was to elicit facts and opinion about safety knowledge, skills and attitudes in the Finishing department from its workers. The objectives of the survey were to ask direct and indirect questions about the nature of safety in the

Department; ensure that the questions would be easy to understand, inoffensive and guarantee confidentiality; and capture broad numerical measures of Safety KSA suitable for statistical analysis.

Step 2 - Data Collection Method

The Finishing Department consisted of 57 employees, of which there were 53 workers, three supervisors and one manager. Face-to-face interviews were discounted due to the danger of respondents not answering questions in an anonymous fashion. It was decided, principally on the basis of this political sensitivity, to use the most basic type of survey, the self-administered survey. Questionnaires could be distributed to the workforce and collected without the involvement of an interviewer. If the questionnaires were left in a prominent place in the rest area, the whole department would have the opportunity to participate in the survey and to remain anonymous. A serious disadvantage of this approach lies in the fact that people choose themselves whether to complete the questionnaire.

Step 3 - Identify an Appropriate Sample

The population of interest was the 53 non-supervisory employees of the Finishing Department. It was unlikely that all the staff would respond to a self-administered questionnaire. If the actual response rate to the questionnaire were low, then the survey would not be entirely random and unlikely to be totally representative of the workforce. It was acknowledged that some systematic error or bias would be introduced to the results as a consequence. This was a price worth paying to minimise other introductions of bias.

Step 4 - Designing the Questionnaire

The questionnaire is the means by which data is collected. The quality of the findings is determined by the form in which the questions are presented and the clearness of the instructions. Two different types of question, behavioural and attitudinal, would be contained in the survey. Behavioural questions would seek to elicit factual information about the staff's safety actions and intentions, whilst attitudinal questions would try to find out what the staff actually thought about safety in the firm. Closed questions were chosen to limit respondents to a pre-determined selection of alternative answers, thus avoiding many of the difficulties associated with interpretation of open-ended questions. Using scaled questions the range of responses could be easily compared and statistically analysed, as well as offering guidance to the respondents (Gill and Johnson, 1991). A limitation of such questions concerns the use of intervals along the scale (McCormack and Hill, 1997). Scaled questions introduce two problems. The first concerns translation of perception into visual representation, and the second concerns the intervals across the range, which are equally spaced, when this may not be the case in reality. Despite these limitations this was the chosen question style of the survey.

Both questions and statements would be used to build up the measure of Safety KSA amongst the workforce. The participants would be asked to ring one answer category in response to a question, indicating their intensity of attitude or opinion; or indicate their level of agreement or disagreement with a statement using a Likert scale. The scale for both the questions and statements was set between one and five. Each point on the scale was assigned a value, with a one representing a very poor response and five a very favourable one. A number of questions and statements were similar in nature. This was a deliberate ploy to ensure the internal consistency of responses. If some questions were actually similar in content but received varying responses, then the validity of some of the survey questions would be queried at the data analysis stage. If the questionnaire were to reveal clear patterns associated with Safety KSA then the questions would have to be relevant to the theme, easily answerable, unbiased, relatively short and unambiguous in style. Longer questions could put off respondents so that they then failed to complete the questionnaire.

A total of 23 scaled questions were included in the final questionnaire. A well-sequenced questionnaire encourages all the questions to be completed. It was decided to keep the safety themes raised in the questionnaire grouped together, for example 'use of safe systems of work' as a set of questions. As safety in the workplace can be an emotionally sensitive matter, the questions moved from being more factual at the beginning of the questionnaire to questions requiring more value judgements towards the end.

Throughout the survey process, close consultation with the management team responsible for safety in the Finishing Department was important. The sensitivity of the subject matter and the possible consequences of asking certain questions of the workforce may have been unacceptable to the managers. For reasons of courtesy and to maintain a good working relationship, the proposed workforce questionnaire and a guide to its aims, potential danger points, relevance and structure was passed to the managers for inspection. The full outline is presented in Section J1 of Appendix J. The managers were happy with the questionnaire and gave permission to have it dispatched to all Finishing Department employees. Due to the limited size of the population, a pilot survey was not conducted although the rigorous evaluation of the questionnaire by the management team may have compensated for this omission.

In the case of self-completion questionnaires, the questionnaire's layout and the clarity of its instructions may largely determine the response rate. A letter copied on to University notepaper accompanied the questionnaire. In this letter the purpose of the overall study was provided, along with an estimate of the time the questionnaire would take to complete. A confidentiality clause was also offered to appease any political sensitivity. Clear instructions on exactly how to fill out the questions was provided, along with an example of how to ring a response to a scaled question. The questions were well spaced to reduce the perception of complexity in the mind of the respondents.

Step 5 - Data Collection

The response rate to the survey was favourable. A total of 26 staff returned the completed questionnaire. Unfortunately, two of the questionnaires had to be deemed void as they were filled in incorrectly. This still left a valid response rate of over 49%, high for self-administered questionnaires.

Step 6 - Data Processing

The most widely used software package for analysing data collected from a survey is what is now called Statistical Products and Service Solution (SPSS). Processing the data using SPSS comprised two main elements. The first was its transfer from the questionnaire into the computer and the second was identifying statistical relationships between the answers.

Based on the accurate answers, an objective inference of the Safety KSA parameter could be made through calculating a grand mean score for all statistically significant questions. Validation of values for the four parameters relating to Safety KSA was achieved by calculating a mean from blocks of responses relating to specific safety themes within the questionnaire and also to information beyond the survey results.

As all the questions asked used a continuous scale the levels of significance between the responses indicate strength of relationship. The 10% level of significance was thought to be a strong enough measure of accuracy between responses. Using SPSS all the question responses were cross-tabulated and compared against each other and the correlation coefficients and their levels of significance were computed. The matrix of results is shown in Section J2 of Appendix J.

Step 7a - Calculation of Safety KSA

The matrix in Section J2 shows that all the questions except three had at least a 10% level of significance against at least one or more questions when cross-tabulated. The three that did not were considered not to be valid for the purpose of calculating the numerical parameter value for Safety KSA as they did not fit the pattern of responses given. The grand mean score calculated for Safety KSA was 3.75. This represented the Average KSA for the employees. As there were 57 employees then multiplying the two numbers together would set the Safety KSA at 213.75. This value is probably less than it ought to be because managers and supervisors will have a higher individual Safety KSA than line employees. However, their Safety KSA was not evaluated so the 3.75 value was used for them also.

Step 7b - Calculation of the Policy Parameters Associated with the Safety KSA

The remaining four policy parameters governing the Safety KSA level could not be assessed so precisely as they were more difficult to measure using the survey than the overall Safety KSA. The responses to the questionnaire would simply guide the calibration of these parameters rather than be used to calculate exact figures. Each will now be considered in turn.

The Fixed Proportion of KSA Lost is based on the results of the sections of the questionnaire concerned with the use of safe systems of work and safety awareness (questions 4 to 9, and 12 and 13). SPSS was used to compute a grand mean score for the responses to the six related questions. The output averaged out at a high value of 4.0, suggesting that safe working practices were generally followed. This may indicate that the attitude to safety was positive and enthusiasm for safe working high. As a result the dissipation of good work practice brought about by training may be slow. After some sensitive calibration runs of the model, the parameter was set at 0.02, which indicates that 2% of Safety KSA is lost through forgetfulness in every month.

Ratio Between Hires and Average Safety KSA is calculated from the section of the questionnaire related to recruitment (questions 20 to 22). The mean score for the responses to the three questions was 3.03. Ratio Between Quits and Average Safety KSA was determined from the section of the questionnaire concerned with staff wastage (question 23). Unfortunately only one question was related to this attribute. The mean score arrived at was 3.17. The mean score relating to the quitter's KSA was higher than that for the hires, but surprisingly by not a great deal. This may result from an unintended bias where many employees may have claimed their KSA was very high when recruited and could go no higher! It was evident though that the parameterisation would involve setting the ratios fairly close to one, so as not to distort changes in the workforce's Safety KSA brought about by staff turnover. After a number of calibration runs and fine-tuning of the model, the Ratio between Hires and Average KSA was set to 0.85, and Ratio Between Quits and Average KSA was set to 1.01.

Training Effectiveness is a parameter which would be difficult to justify solely on the evaluation of the trainees, particularly as the employees, not being safety experts may not be in an appropriate position to measure the training quality accurately. The section of the questionnaire relating to the use of safety training (questions 10 and 11) was used to arrive at a mean response for training effectiveness. This was lower than anticipated, at only 2.96. This prompted an examination of the firm's training documentation. The records showed clear documentation relating to the nature of the on-the-job, internal and external training. A sizeable proportion of the training led to recognised health and safety certificates with competent training organisations such as the Royal Society for the Prevention of Accidents and a regional college.

Rather than set the Training Effectiveness parameter at only 59% effectiveness, the proportion was raised after some model calibration to 0.75, representing 75% effectiveness.

(x) Validating the Time to Clear Accident Report Backlog

Time to Clear Accident Report Backlog is a time constant which represents the management policy or intention to turn around an accident report in a given time. Data relating to safety management was collected and analysed on a monthly basis. The

Safety Committee met on a monthly basis and progress on matters such as the findings of accident reports were discussed. It is not unreasonable to ensure that accident reports be turned around in a month.

The Time to Clear Accident Report Backlog is set at one month.

(y) Validating the Time to Clear Hazards Under Full Regulation Backlog

Time to Clear Hazard Under Full Regulation Backlog is a time constant which represents the management policy or intention to turn around or fully regulate a hazard in a given time. Data relating to hazard regulation was collected and analysed on a monthly basis. The Safety Committee met on a monthly basis and progress on matters such as hazard regulation were discussed. It is not unreasonable to ensure that hazards waiting to be fully regulated be turned around in a month.

The Time to Clear Hazards Under Full Regulation Backlog is set at one month.

(z) Validating the Time to Clear Hazards Under Intermediate Regulation Backlog

Time to Clear Hazard Under Intermediate Regulation Backlog is a time constant which represents the management policy or intention to turn around or intermediately regulate a hazard in a given time. Data relating to hazard regulation was collected and analysed on a monthly basis. The Safety Committee met on a monthly basis and progress on matters such as hazard regulation were discussed. It is not unreasonable to ensure that hazards waiting to be intermediately regulated be turned around in a month.

The Time to Clear Hazards Under Intermediate Regulation Backlog is set at one month.

(aa) Validating the Time to Identify Unregulated Hazards

Time to Identify Unregulated Hazards is a time constant which represents the management policy or intention to locate an unregulated hazard in a given time. Data relating to risk assessment exercises and safety tours was collected and analysed on a monthly basis. The Safety Committee met on a monthly basis and progress on matters such as how many hazards had become unregulated (unsafe) were discussed. It is not unreasonable to ensure that unregulated hazards are spotted and earmarked for action within a month of becoming unregulated.

The Time to Identify Unregulated Hazards is set at one month.

6.7 The Calibrated Real World Occupational Safety Model

Calibration of the real world occupational safety model (RWOSM) was an iterative process. It consisted of setting all the measured parameters derived from the firm, running the simulation, and comparing its outputs to those of the actual safety system. It was a process of adjusting some model parameter values in order to achieve a better correspondence between simulated and actual historical data. The efforts concentrated on adjustment to the less easily measurable constants such as Fixed Proportion of Knowledge Lost, Ratio Between Hires and Average Safety KSA, Ratio Between Quitters and Average KSA and the hypothetical table functions. A close visual fit was eventually achieved between the actual and observed accident rate. Also, a reasonable visual fit between actual and observed hazards was accomplished. These correspondences would need to be statistically measured to identify whether the sources of error between observed and actual data and their composition would be acceptable.

The simulation was calibrated to show the gradual increase in accidents over the three-year period. More resources had been allocated to dealing with problem hazards, resulting in an arrest but not reversal in accidents. Time-series data had been used to reflect these policy changes. The only feasible explanation for the declining performance of the safety management system was that the Safety KSA of the workforce had been in decline. This was the reason strongly suspected by managers as they had been frustrated by the apparent ineptitude of their safety monitoring, hazard regulation and accident reporting efforts. As a result the model was parameterised to reflect a gradual decline in the Safety KSA of the workforce. The full Ithink RWOSM run time and initialisation equations are listed below and also in Appendix M.

<u>A Full Listing of the Real World Occupational Safety Model Equations (Written in Ithink ©High Performance Systems Inc.)</u>

Accident_Reports_Being_Processed(t) = Accident_Reports_Being_Processed(t - dt) + (Accident_Reports_In - Accident_Reports_Completed) * dt
INIT Accident_Reports_Being_Processed = 1
Accident_Reports_In = Accident_Rate*Proportion_of_Accidents_Reported
Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Cumulative_Accident_Reporting_Cost(t) = Cumulative_Accident_Reporting_Cost(t - dt) + (Monthly_Accident_Reporting_Cost) * dt
INIT Cumulative_Accident_Reporting_Cost = 0

Monthly_Accident_Reporting_Cost = Accident_Reporting_Policy*Accident_Reporting_Cost
Cumulative_Accident_Reports(t) = Cumulative_Accident_Reports(t - dt) + (Accident_Reports_Completed) * dt
INIT Cumulative_Accident_Reports = 0

Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/ Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Accident_Reporting_Cost = 13
Accident_Reporting_Policy = 34+STEP(11,13)+STEP(3,25)
Accident_Reporting_Time = 8
Proportion_of_Accidents_Reported = 1
Cumulative_Accidents(t) = Cumulative_Accidents(t - dt) + (Accident_Rate) * dt
INIT Cumulative_Accidents = 0

Accident_Rate = Accident_Incidence*Labour
Cumulative_Accident_Cost(t) = Cumulative_Accident_Cost(t - dt) + (Monthly_Accident_Cost) * dt
INIT Cumulative_Accident_Cost = 0

Monthly_Accident_Cost = Accident_Rate*Cost_per_Accident
Accident_Incidence =
((Unregulated_Hazards/Unregulated_Hazard_Regulation_Weighting)+(Hazards_Under_Intermediate_Regulation/Intermediate_Hazard_Regulation_Weighting)+(Hazards_Under_Full_Regulation/Full_Hazard_Regulation_Weighting))*Risk
Cost_per_Accident = 1636
Full_Hazard_Regulation_Weighting = 2
Intermediate_Hazard_Regulation_Weighting = 1.5
Unregulated_Hazard_Regulation_Weighting = 1
Risk = GRAPH(Average_KSA)
(0.00, 0.05), (0.5, 0.049), (1.00, 0.0473), (1.50, 0.0383), (2.00, 0.021), (2.50, 0.017), (3.00, 0.0138), (3.50, 0.0105), (4.00, 0.007), (4.50, 0.003), (5.00, 0.00)
Cumulative_Full_Hazard_Regulation_Cost(t) = Cumulative_Full_Hazard_Regulation_Cost(t - dt) + (Monthly_Full_Hazard_Regulation_Cost) * dt
INIT Cumulative_Full_Hazard_Regulation_Cost = 0

Monthly_Full_Hazard_Regulation_Cost =
Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost
Cumulative_Intermediate_Hazard_Regulation_Cost(t) =
Cumulative_Intermediate_Hazard_Regulation_Cost(t - dt) +
(Monthly_Intermediate_Hazard_Regulation_Cost) * dt
INIT Cumulative_Intermediate_Hazard_Regulation_Cost = 0

Monthly_Intermediate_Hazard_Regulation_Cost =
Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost
Cumulative_Safety_Monitoring_Cost(t) = Cumulative_Safety_Monitoring_Cost(t - dt) +
(Monthly_Safety_Monitoring_Cost) * dt
INIT Cumulative_Safety_Monitoring_Cost = 0

Monthly_Safety_Monitoring_Cost = Safety_Monitoring_Policy*Safety_Monitoring_Cost
Hazards_Under_Full_Regulation(t) = Hazards_Under_Full_Regulation(t - dt) +
(Hazards_Arrive_for_Full_Regulation - Hazards_Become_Regulated) * dt
INIT Hazards_Under_Full_Regulation = 1

Hazards_Arrive_for_Full_Regulation =
MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Hazards_Become_Regulated =
MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazards_Under_Intermediate_Regulation(t) = Hazards_Under_Intermediate_Regulation(t - dt) +
(Identification_Rate - Hazards_Arrive_for_Full_Regulation) * dt
INIT Hazards_Under_Intermediate_Regulation = 4.5

Identification_Rate =
MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Hazards_Arrive_for_Full_Regulation =
MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Regulated_Hazards(t) = Regulated_Hazards(t - dt) + (Hazards_Become_Regulated -
Hazard_Generation_Rate) * dt
INIT Regulated_Hazards = 96

Hazards_Become_Regulated =
MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Unregulated_Hazards(t) = Unregulated_Hazards(t - dt) + (Hazard_Generation_Rate -
Identification_Rate) * dt

INIT Unregulated_Hazards = 0.5

Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Identification_Rate =
MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Full_Hazard_Regulation_Cost = 9
Full_Hazard_Regulation_Policy = 22.7
Full_Hazard_Regulation_Time = 16
Intermediate_Hazard_Regulation_Cost = 11
Intermediate_Hazard_Regulation_Policy = 3.2
Intermediate_Hazard_Regulation_Time = 2.1
RBAAIH =
(Unregulated_Hazards+Hazards_Under_Intermediate_Regulation+Hazards_Under_Full_Regulation)/Regulated_Hazards
Safety_Monitoring_Cost = 13
Safety_Monitoring_Policy = 18+STEP(23,15)+STEP(2,28)+STEP(7,35)
Accident_Repeater = GRAPH(Accident_Reports_Completed)
(1.00, 0.00), (2.00, 0.01), (3.00, 0.02), (4.00, 0.03), (5.00, 0.04), (6.00, 0.055), (7.00, 0.07), (8.00, 0.085), (9.00, 0.1), (10.0, 0.125), (11.0, 0.165), (12.0, 0.215), (13.0, 0.265), (14.0, 0.32), (15.0, 0.365), (16.0, 0.425), (17.0, 0.49), (18.0, 0.545), (19.0, 0.6), (20.0, 0.68)
Hazards_Identified_from_Safety_Monitoring = GRAPH(Safety_Monitoring_Policy)
(0.00, 0.00), (10.0, 0.125), (20.0, 0.325), (30.0, 0.575), (40.0, 0.925), (50.0, 1.53), (60.0, 3.15), (70.0, 4.35), (80.0, 4.73), (90.0, 4.93), (100, 5.00)
Unsafe_Acts = GRAPH(Average_KSA)
(0.00, 0.1), (0.5, 0.099), (1.00, 0.098), (1.50, 0.096), (2.00, 0.089), (2.50, 0.074), (3.00, 0.038), (3.50, 0.022), (4.00, 0.016), (4.50, 0.012), (5.00, 0.009)
Cumulative_Labour_Quits(t) = Cumulative_Labour_Quits(t - dt) + (Quits) * dt
INIT Cumulative_Labour_Quits = 0

Quits = Labour/Actual_Length_of_Employment
Labour(t) = Labour(t - dt) + (Hires - Quits) * dt
INIT Labour = Target_Labour_Force

Hires = ((Target_Labour_Force-Labour)/Staff_Adjustment_Time)+Replacing_Attrition
Quits = Labour/Actual_Length_of_Employment
Actual_Length_of_Employment = Base_Length_of_Employment*(1-Quit_Likelihood)
Base_Length_of_Employment = 129
Perceived_Accident_Incidence = SMTH3(Accident_Incidence,3)
Replacing_Attrition = Quits
Staff_Adjustment_Time = 4
Target_Labour_Force = 57
Quit_Likelihood = GRAPH(Perceived_Accident_Incidence)
(0.00, 0.00), (0.1, 0.001), (0.2, 0.003), (0.3, 0.006), (0.4, 0.014), (0.5, 0.028), (0.6, 0.08), (0.7, 0.0915), (0.8, 0.096), (0.9, 0.098), (1, 0.1)
Cumulative_Safety_Cost(t) = Cumulative_Safety_Cost(t - dt) + (Monthly_Safety_Cost) * dt
INIT Cumulative_Safety_Cost = 0

Monthly_Safety_Cost =
Monthly_Accident_Cost+(Safety_Monitoring_Policy*Safety_Monitoring_Cost)+(Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost)+(Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost)+(Accident_Reporting_Policy*Accident_Reporting_Cost)+(Training_Policy*Safety_Training_Cost)
Cumulative_Safety_Training_Cost(t) = Cumulative_Safety_Training_Cost(t - dt) + (Monthly_Safety_Training_Cost) * dt
INIT Cumulative_Safety_Training_Cost = 0

Monthly_Safety_Training_Cost = Training_Policy*Safety_Training_Cost
Safety_KSA(t) = Safety_KSA(t - dt) + (Learning + Gain_in_KSA - Loss_of_KSA - Dissipation_of_KSA) * dt

INIT Safety_KSA = 213.75

Learning = DELAY(Multiplier*Discrepancy,3)
Gain_in_KSA = Hires*KSA_per_New_Employee
Loss_of_KSA = Quits*Loss_per_Exit
Dissipation_of_KSA = Safety_KSA*Fixed_Proportion_of_KSA_Lost
Average_KSA = Safety_KSA/Labour
Discrepancy = 1-(Safety_KSA/Target_Safety_KSA)
Fixed_Proportion_of_KSA_Lost = 0.02
KSA_per_New_Employee = Average_KSA*Ratio_Between_Hires_and_Average_KSA
Loss_per_Exit = Average_KSA*Ratio_Between_Quitters_and_Average_KSA
Maximum_KSA_per_Employee = 5
Proportion_of_Accidents_Reported = 1
Ratio_Between_Hires_and_Average_KSA = 0.85
Ratio_Between_Quitters_and_Average_KSA = 1.01
Safety_Training_Cost = 14
Target_Safety_KSA = Labour*Maximum_KSA_per_Employee
Time_to_Clear_Accident_Report_Backlog = 1
Time_to_Clear_Hazards_Under_Full_Regulation_Backlog = 1
Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog = 1
Time_to_Identify_Unregulated_Hazards = 1
Training_Effectiveness = 0.75
Training_Policy = GRAPH(TIME) (0.00, 7.50), (1.00, 52.5), (2.00, 22.5), (3.00, 30.0), (4.00, 0.00), (5.00, 7.50), (6.00, 195), (7.00, 15.0), (8.00, 45.0), (9.00, 15.0), (10.0, 15.0), (11.0, 90.0), (12.0, 60.0), (13.0, 150), (14.0, 90.0), (15.0, 52.5), (16.0, 105), (17.0, 105), (18.0, 143), (19.0, 15.0), (20.0, 30.0), (21.0, 7.50), (22.0, 15.0), (23.0, 0.00), (24.0, 0.00), (25.0, 113), (26.0, 113), (27.0, 37.5), (28.0, 60.0), (29.0, 37.5), (30.0, 60.0), (31.0, 22.5), (32.0, 22.5), (33.0, 240), (34.0, 22.5), (35.0, 7.5)
Multiplier =
GRAPH((Training_Effectiveness*Training_Policy)*(IF(Safety_KSA<Target_Safety_KSA)THEN(1)ELSE(0)))
(0.00, 0.00), (50.0, 10.0), (100, 20.0), (150, 30.0), (200, 40.0), (250, 50.0), (300, 60.0), (350, 70.0), (400, 80.0), (450, 90.0), (500, 100)

(a) <u>The Results of the Calibrated Real World Occupational Safety Model</u>

The reasons why the performance of the firm's historical safety system had been less than desired may be explained through comparing the changes made to safety policies with the turning points in the behaviour of the principal outputs of the RWOSM. The resources dedicated to intermediate and full hazard regulation had remained fixed. Changes were made to the accident reporting, safety monitoring and safety training policies. As more accidents were occurring, more time had to be dedicated to processing accident reports. In an effort to assess problematic hazards there had been increases in safety monitoring. Safety training fluctuated greatly on a month by month basis but the underlying trend was static, averaging out at 56 man-hours per month.

As noted, the system had been characterised by a fairly sharp growth in accidents, followed by a stabilisation. The simulation reflected these changes. Figure 6.1 shows how the simulation produced a reflection of these changes in the real system. The safety policies implemented by the mangers had failed to arrest and to reverse the long-term upward accident trend.

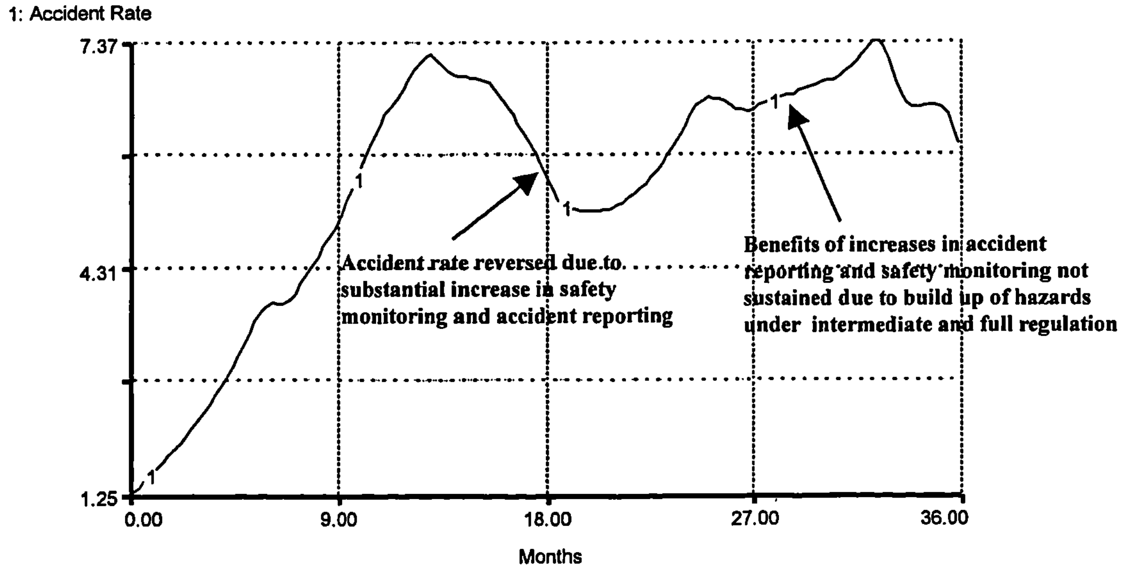

Figure 6.1 Changes in the accident rate over the three-year period

The close match between the costs of running the safety management system and the costs of accidents is evident in Figure 6.2. It is evident that most of the safety costs are attributed to accidents. The firm's managers had made some cost-effective decisions in the shorter term by increasing efforts to identify hazards but in the longer term it was evident that the hazard problem was simply pushed into another part of the safety system.

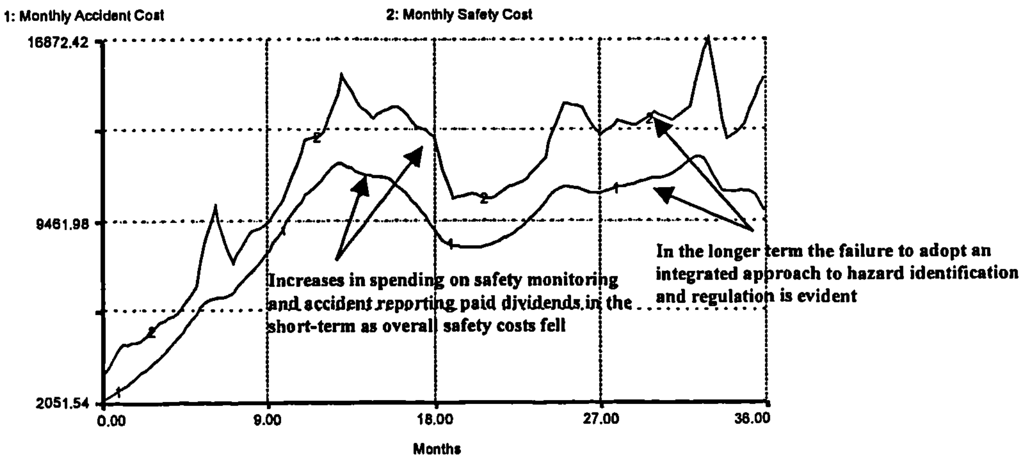

Figure 6.2 Changes in the costs of accidents and running the safety management system over the three-year period

Figure 6.3 shows the simulated changes in the hazard distribution for the three-year period. The graph shows that there was a slow decline in the proportion of regulated hazards. This it is suspected strongly contributed to the accident problem. The short-term benefits of increased safety monitoring and accident reporting are evident along with the longer-term increases in hazards under intermediate and full regulation.

Figure 6.4 shows that the cumulative accident output of the model was 197, close to the observed total of 201. It also reveals that the cost of running safety in the department was high, averaging over £135,000 per annum.

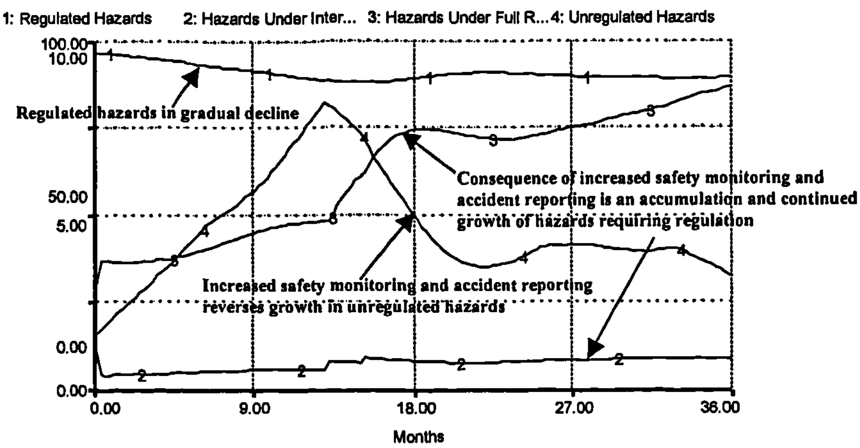

Figure 6.3 Changes in the distribution of hazards over the three-year period

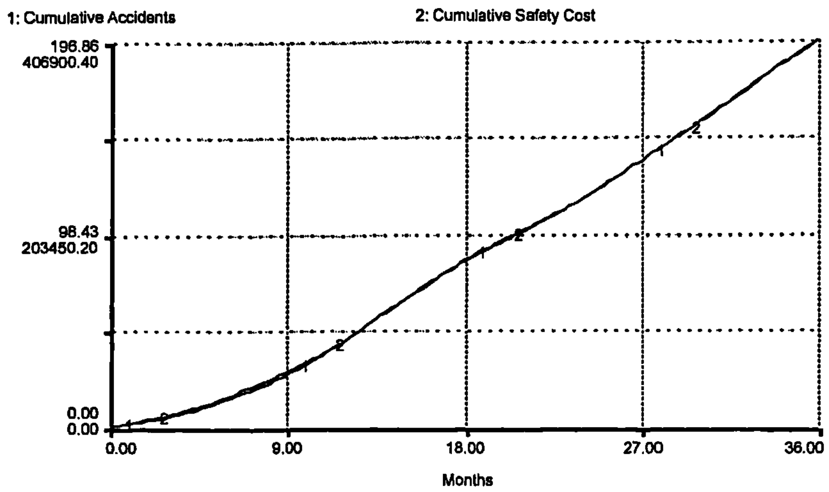

Figure 6.4 Cumulative accidents and safety management system costs over the three-year period

Figure 6.5 shows the potential root cause of the safety problem. Average Safety KSA in the department is seen to be in gradual decline. It is evident from the fluctuations in Safety KSA that training could have quite a substantial impact upon the performance of the safety system. There was also a small increase in staff turnover resulting from the underlying accident rate. This may have had a minimal impact on loss of KSA across the workforce, but not enough for this to be considered as a strong cause. This is represented by the decline in the Actual Length of Employment.

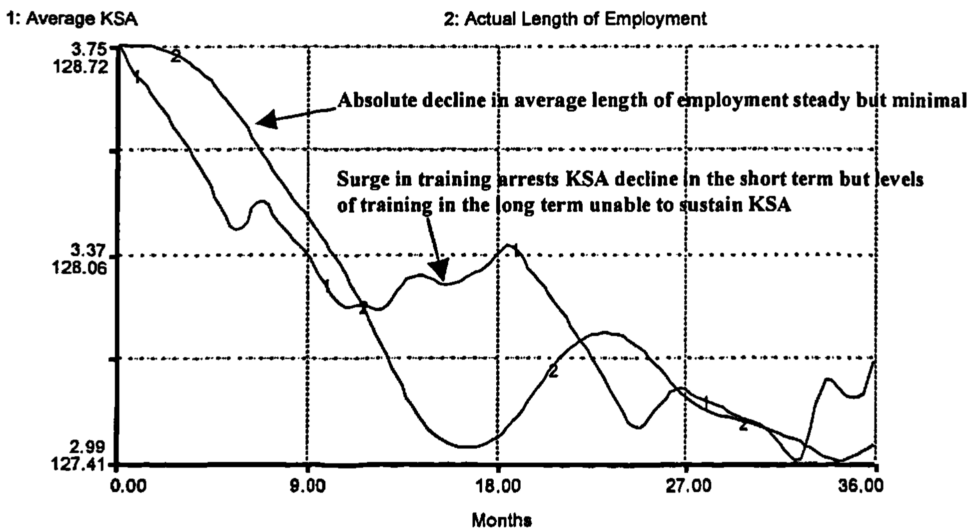

Figure 6.5 Changes in the average safety knowledge, skills and attitude and actual length of employment over the three-year period

(b) Interpretation of the Results of the Calibrated Real World Occupational Safety Model Using the Basic Causal Loop Diagram of Safety

Using the causal loop diagram of the safety system outlined in Figure 5.4 of Chapter Five, the performance of the system can be explained. Over the three-year period the accident rate had risen steadily. The response of the firm was to attempt to arrest this trend by allocating more and more resources to control of active workplace hazards through increased safety monitoring, accident reporting and hazard regulation. These actions are represented in both the proactive and reactive safety loops of Figure 5.4. The strategy appeared to have been one of controlling the accidents through increasing the dominance of these loops over the system's behaviour. This strategy had met with limited success. The accident rate had been arrested, but not reversed. This suggests that they were not able to offset the influence that the reinforcing Safety KSA loop had over system behaviour. In fact they had largely ignored the potential leverage points on the Safety KSA loop that exerted influence over the outputs of the safety system. In an effort to manage accidents through increased engineering controls and more rigorous accident reporting and hazard control, they had overlooked the benefits of improved training and recruitment as a means to help ensure that fewer accidents occurred. If employees could through training be encouraged to work more safely with hazards then this may be the answer to reversing the undesirable accident trend and its high associated financial cost. Thus, shifting the possible loop dominance from the control loops to the reinforcing Safety KSA loop could be the answer to better safety in the future. This is a scenario which will be explored in Chapter Seven.

(c) Measurement of Error and the Composition of Error Between Simulated and Observed Outputs

Appropriate output metrics generated by the model would have to match those in the real system. The selected outputs would have to capture the underlying past behaviour of the real system and be easily measurable. A total of three data sets came to mind. These were the Accident Rate, Hazards and Actual Length of Employment. As staff turnover was very low in the department it was decided that comparing the simulated Actual Length of Employment to the actual would not be necessary. Attention was focused towards replicating the changes in accidents and hazard states.

(d) The Use of Summary Statistics to Validate the Real World Occupational Safety Model's Correspondence to Historical Safety Data

Analysis of the historical fit of a model to data is concerned with behaviour reproduction testing (Sterman, 1984). The test does not seek to compare the correspondence of simulated and actual data on a point-by-point basis. Rather it concentrates on the character of the simulated data. It seeks to measure whether the simulated data exhibit the same modes, phases, amplitudes and variability as the real data. Calibrating an operational model to gain a good historical fit can be important in building confidence in the model with a client (Lyneis, 1999). They can be reluctant to place confidence in the model unless its historical fit is measured by some form of summary statistics (Sterman, 1984).

Sterman noted that the sum of the squared error over the range of available data is higher in system dynamics models than regression models between simulated and actual data. This results from the fact that most single equations are broken by the multi-loop, non-linear nature of the model's complex feedback systems. Despite this he suggests that a system dynamics model may capture the behaviour of a system without matching the historical data on a point-by-point basis. In fact, the total error may be large, even if the model matches the relevant mode of behaviour very well. As a result of this, using the coefficient of determination to measure goodness-of-fit may be inappropriate for system dynamics models. He suggests an alternative, measuring the mean squared error (MSE) and root mean squared percentage error (RMSPE) to assess the goodness of fit between simulated and observed data.

MSE is defined as:

$$\frac{1}{n}\sum_{t=1}^{n}(S_t - A_t)^2$$

where;
n = number of observations (t = 1, ... n)
S_t = Simulated value at time t
A_t = Actual value at time t

and RMSPE is defined as:

$$\sqrt{\frac{1}{n}\sum_{t=1}^{n}\left[\frac{(S_t - A_t)}{A_t}\right]^2}$$

It important not only to identify the size of error, but also identify its sources. Theil's inequality statistic is one method by which error can be resolved into systematic and random portions. Theil's inequality statistic is derived from a decomposition of MSE. The statistic identifies the proportion of MSE that is attributable to bias (U^M), unequal variance (U^S), and unequal covariance (U^C).

A fit between the historically observed and simulated data can be compared to determine the size of error and its composition using RMSPE and Theil's inequality statistic. The RMSPE shows a normalised measure of the magnitude of the error, i.e. it is the proportional difference between the simulated and observed, as a proportion of the observed, averaged over the time frame. The MSE and inequality statistics shows a measure of the total error, and where the error breaks down proportionately into bias, unequal variation and unequal covariation. By dividing each of the components of the error by the total mean square error, the inequality proportions are derived:

$$U^M = \frac{(\bar{S} - \bar{A})^2}{\frac{1}{n}\sum (S_t - A_t)^2}$$

$$U^S = \frac{(s_S - s_A)^2}{\frac{1}{n}\sum (S_t - A_t)^2}$$

$$U^C = \frac{2(1-r)s_S s_A}{\frac{1}{n}\sum (S_t - A_t)^2}$$

As $U^M + U^S + U^C = 1$, so U^M, U^S, U^C reflect the fraction of the MSE due to bias, unequal variance, and unequal covariance, respectively.

(e) Interpretation of the Error Between Simulated and Observed Accident Rates

Figure 6.6 shows the historical behaviour of accident rates alongside the simulated version of the same data. The actual accident rate is characterised by short-term fluctuations. This is of no great surprise, as one would not expect too many accidents to arise on a monthly basis from a total of 57 departmental employees.

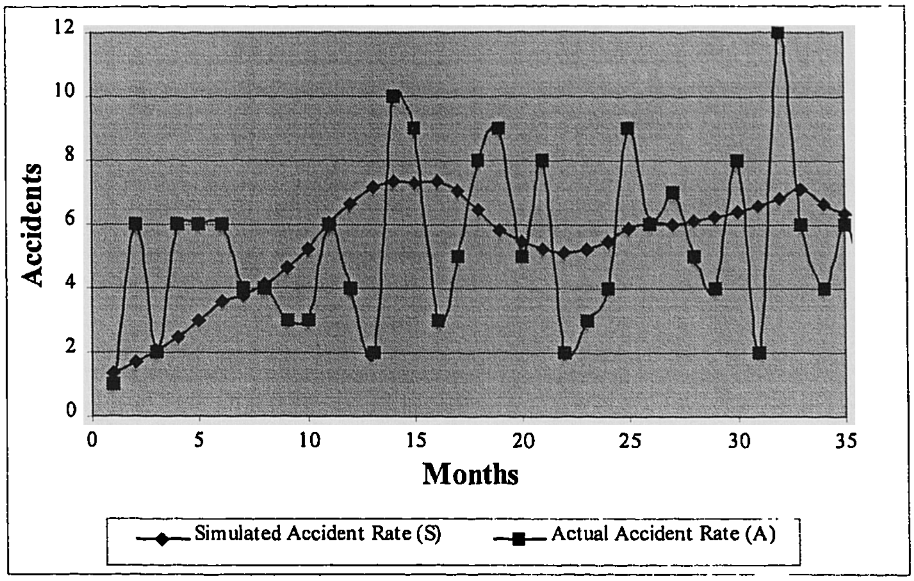

Figure 6.6 Simulated versus observed accident rate

As a result of the short-term variability evident in the actual accident rate it is difficult to visually determine whether the simulated accident rate captures the underlying behaviour of the actual accident rate. Smoothing out the actual accident rate can provide an estimate of the underlying accident rate, thus allowing a more meaningful visual comparison for the data set. Figure 6.7 shows the exponentially smoothed underlying accident rate alongside the simulated accident rate. The simulated accident rate appears to match the behaviour of the underlying accident rate.

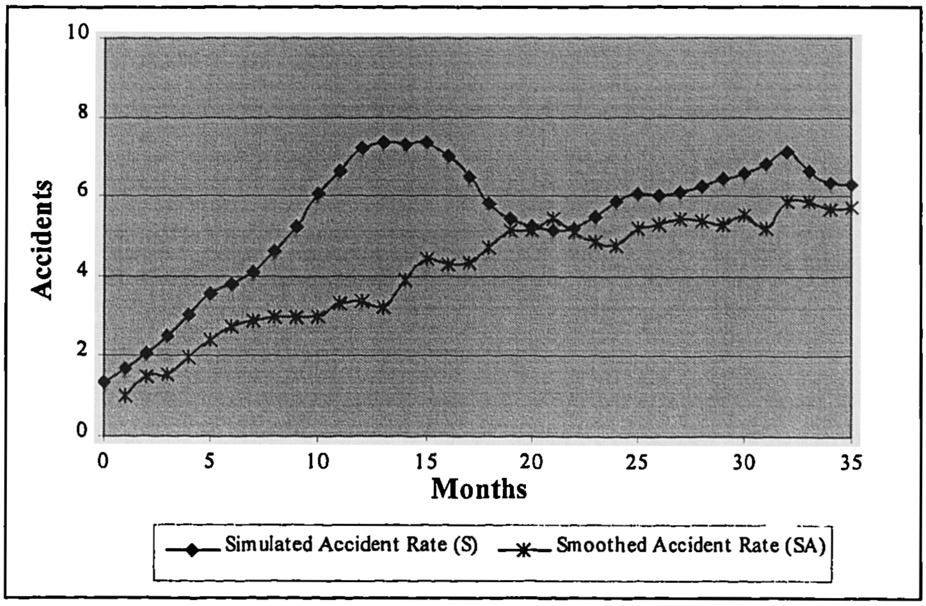

Figure 6.7 Simulated versus underlying accident rate

To visually determine whether the degree of fit is close enough is not sufficient. It is necessary to measure where the error lies in the comparative data. Measuring the error and its composition between the underlying accident rate and the simulated accident rate may be misleading. As a result of smoothing the actual accident rate the data points are no longer independent. The data set, it could be argued is artificial or contrived. It is more appropriate to measure where the error lies between the simulated accident rate and the actual accident rate.

The RMS, RMSPE and error composition can be determined for this data set. The results of these computations are shown below in Table 6.4. An examination of the historical fit of the accident rate reveals that the RMSPE is 111%. This is the value of the average squared difference between observed and simulated and exceeds 100%. This is a high figure. The error may be due partly to the limited assumptions made in the model about the causes of the accident pattern. The model was not built and calibrated to replicate short-term fluctuations in the system. Therefore, for the purpose of this model the fact that the RMSPE of the model is high does not necessarily invalidate the results. Taking a more pessimistic line, it could be suggested that the model is internally inconsistent or the structure controlling the accident rate is incorrect.

$\sum(S_t - A_t)^2$	238.71	$\bar{A}$	5.33	U^M	0.0021
$\sum\frac{(S_t - A_t)^2}{A_t}$	44.23	s_S	1.64	U^S	0.1209
MSE	6.63	s_A	2.54	U^C	0.8770
RMSPE	1.11	r	0.30	$U^M + U^S + U^C$	1.0000
$\bar{S}$	5.45				

Table 6.4 Summary statistics measuring level of correspondence between the simulated and observed accident rate

Decomposing the error may throw more light on the problem. Although the RMSPE is 111%, less than 1% of the mean squared error is attributable to bias. Only 12% of the error results from unequal variation, leaving nearly 88% of the error attributable to unequal covariation. This indicates that there is very little systematic error in the results. The simulated accident rate tracks the underlying trend almost perfectly, simply diverging on a point-by-point basis. The fact that the RMSPE is high is of little consequence and does not compromise the purpose of the model.

(f) Interpretation of Error Between Stochastically Simulated and Observed Accident Rates

It could be argued that accidents are the function of chance, and that the events which lead to them are to some extent beyond the control of the firm. The accident causation models set out in Chapter Four, Section 4.5(a) invalidate this extreme argument. In addition, the evidence that the majority of accidents result from human failure, either attributed to the employee or more often an inadequate management system further refutes this proposition (Perrow, 1984; Killimett, 1991; Krause *et al.*, 1990; Stranks, 1994b). The remaining minority of accidents result from technical failure or 'Acts of God'. For the purpose of this model these could be regarded as legitimate stochastic events as, according to Perrow (1984) these types of accidents can not easily be anticipated, nor their causes identified until after the event.

System dynamics is a form of deterministic modelling and it is unusual for stochastic elements to be introduced into the simulation. To show that the structure of the real world model is robust when noise is introduced it was decided to randomly generate a portion of the accident rate. This was to test whether the introduction of random accidents would make any difference to the underlying behaviour of the model. Figure 6.8 shows the effect of adding a series of random numbers between ± 1.36 to the simulated Accident Rate. The 1.36 value was chosen as it represents the lowest simulated accident rate in the firm's three-year time-series. It introduces a plausible random effect without causing the accident rate to fall below zero. This is not simply an arbitrary randomness but introduces the maximum range of variation.

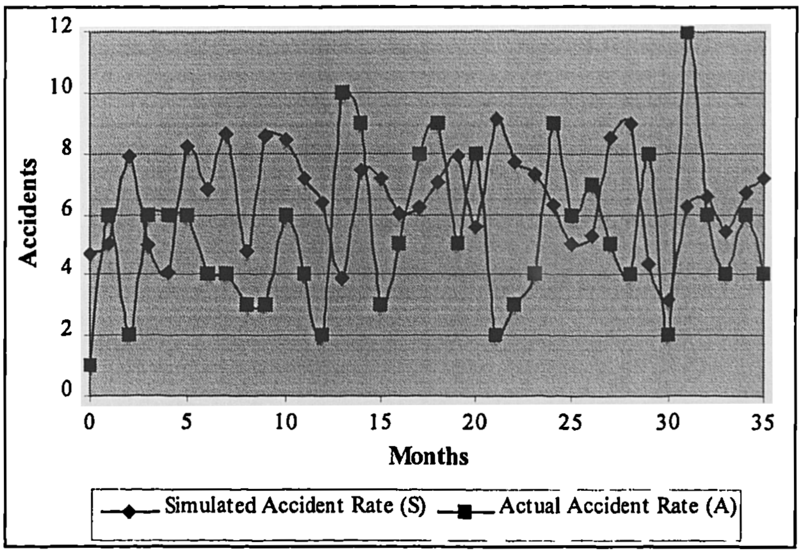

Figure 6.8 Addition of stochastically simulated output versus observed accident rate

Table 6.5 shows that RMS and RMSPE is higher than in the deterministic model, with the RMSPE at 138%.

$\sum(S_t - A_t)^2$	264.95	$\bar{A}$	5.33	U^M	0.0040
$\sum\frac{(S_t - A_t)^2}{A_t}$	68.13	s_S	1.75	U^S	0.0848
MSE	7.36	s_A	2.54	U^C	0.9112
RMSPE	1.38	r	0.25	$U^M + U^S + U^C$	1.0000
$\bar{S}$	5.50				

Table 6.5 Summary statistics measuring level of correspondence between the added stochastically simulated output and observed accident rate

This is not surprising, as error has been deliberately introduced into the carefully calibrated model. Despite this, the majority of the error still lies with unequal covariation between the two data sets. This suggests that introduction of stochastic influences on accidents does not overtly change the numerical or behavioural output of the model.

An alternative way of interpreting a chance element in the model involves multiplying the accident rate by a stochastic element. In this case Figure 6.9 shows the effect of introducing a series of uniformly distributed random numbers between ± 2 and multiplying this by the simulated Accident Rate. This represents a random influence along a range $\pm$ 200% for the simulated Accident Rate in the time series.

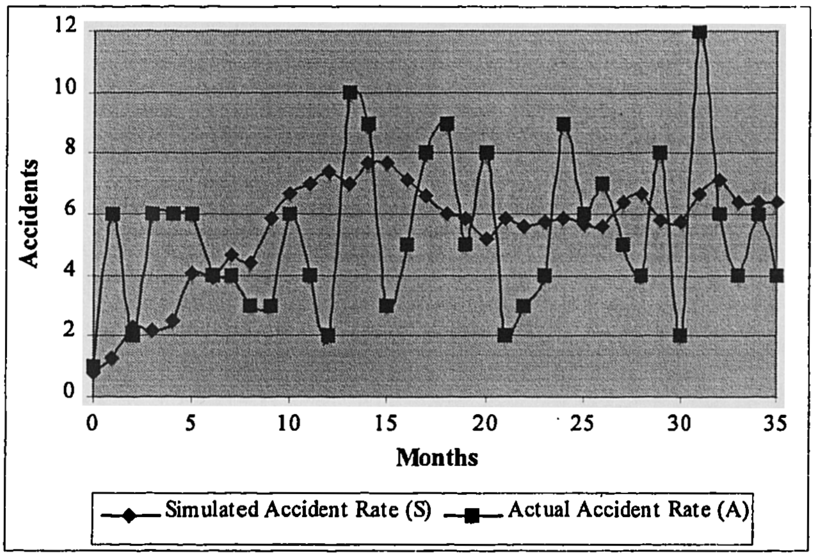

Figure 6.9 Multiplication of stochastically simulated output versus observed accident rate

Table 6.6 shows that RMS and RMSPE is higher than in the deterministic model.

$\sum(S_t - A_t)^2$	336.26	$\bar{A}$	5.33	U^M	0.0005
$\sum\frac{(S_t - A_t)^2}{A_t}$	97.87	s_S	2.16	U^S	0.0153
MSE	9.34	s_A	2.54	U^C	0.9841
RMSPE	1.65	r	0.16	$U^M + U^S + U^C$	1.0000
$\bar{S}$	5.40				

Table 6.6 Summary statistics measuring level of correspondence between the multiplied stochastically simulated output and observed accident rate

As with the previous example, similar behaviour results from the introduction of stochastic elements to the model.

These tests show that if random factors are introduced into the simulation to affect the output of the accident rate, this results in moderate changes to the numerical output of accidents but not the underlying behaviour. It can be concluded then that with or without plausible stochastic model inputs the same policy decisions would be taken.

(g) Interpretation of the Error Between Simulated and Observed Hazards

Actual hazard statistics were only available for the last 18 months of the study. This made it harder to attain a good historical match between simulated and observed hazards. An examination of the distribution of the records showed several instances of months where for a particular hazard state the value was zero. Using these figures to calculate the RMSPE would result in an invalid interpretation, as division by zero would be apparent. An examination of the records showed that in any one month the numbers of actual Regulated Hazards was always well above one. Therefore, it was decided to measure the error between actual and simulated Regulated Hazards. Figure 6.10 shows the historical correspondence. It is evident from a visual examination of the graph, the error is evident, and appears mostly to lie in the difference between the means.

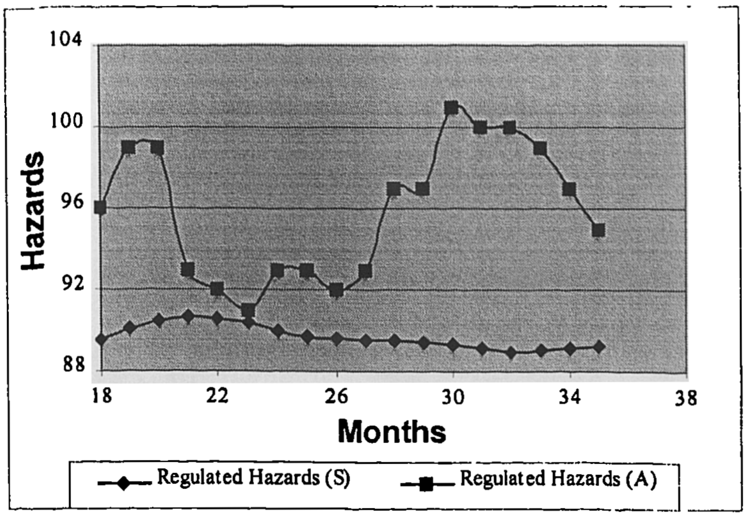

Figure 6.10 Simulated versus observed regulated hazards

The RMS, RMSPE and error composition can be determined for the data set. The results of these computations are shown below in Table 6.7. The RMSPE for the historical fit was 72%. This is quite a high figure, and confirms the difficulties experienced in calibration of the model. Decomposing the error will show whether this error is largely systematic or non-systematic in nature. Seventy-six percent of the mean squared error is attributable to bias. This unfortunately is high and suggests that there is a systematic difference between the model and reality. Only 14% of the error resulted from unequal variation.

$\sum(S_t - A_t)^2$	497.22	$\bar{A}$	95.95	U^M	0.7624
$\sum\frac{(S_t - A_t)^2}{A_t}$	5.03	s_S	0.54	U^S	0.1354
MSE	27.62	s_A	3.17	U^C	0.1022
RMSPE	0.72	r	-0.54	$U^M + U^S + U^C$	1.0000
$\bar{S}$	89.7				

Table 6.7 Summary statistics measuring level of correspondence between the simulated and observed regulated hazards

The fact that the magnitude of the error around the means is low is encouraging. Ten percent of the error is attributable to unequal covariation. This type of error is unsystematic. Unfortunately, little of the error lies here.

There are a number of possible reasons why the compositions of the error was less favourable than that found for the Accident Rate. The error may be due to the incomplete hazard data set attributable to inaccuracies in the firm's records, the limited structural assumptions in the model about hazard behaviour and the fact that continuous data is being compared to discrete data.

Figure 6.10 showed that there was a great deal of short-term variability within the observed data, a pattern which any system dynamics model would find difficult to replicate. Again, for the purpose of this model the fact that the RMSPE is quite high does not necessarily invalidate the results. Despite these potentially gloomy findings, the simulated Regulated Hazards are able to track the underlying trend adequately, but not able to capture convergence between the means. Extensive model calibration failed to capture a close match between the means for actual and simulated hazards but in a serendipitous way the simulation may actually be nearer to reality than the firm's records. In Section 3.3 of Chapter Three, the principles of risk control were outlined. Safe workplace and safe person strategies were described. The workplace strategies involve engineering controls and development of safe systems of work whereas the safe person strategies rely on employees working safely with hazards for them to be successful. A hazard can be perfectly safe if an employee uses the correct working procedures. For example, in the course of their work, the moment they discard the personal protective equipment provided for them the hazard becomes active. The means by which these hazards are passed around the life cycle may be more discreet than the documented safety management system suggests. The reality is that more hazards are active than the safety management anticipate. They may be rendered safe on a more informal basis through line managers or other employees insisting that colleagues follow correct work procedures. In reality hazards may be more transient than suggested in the records, i.e. the simulation may capture reality better than the documented records.

As a result of this situation it is likely that much of the error between the observed and simulated hazards lies in the inaccuracies of only collecting formal hazard data, ignoring the more subtle undocumented elements of the hazard system. Another source of error may be in the assumptions of the model. Dissagregation of hazards into different types may have eased the difficulties of replicating hazard behaviour but this may have been at the expense of model clarity. In conclusion, although the model has failed to capture a close historical fit, it has still shown the movement of hazards around the life-cycle. This behaviour is fundamental to functioning of the model. So for the purposes of this modelling effort the quantity and nature of the error is acceptable.

6.8 Summary of the Real World Occupational Safety Model

The process of selecting a suitable host firm and specifying the terms for validating the RWOSM with its relevant managers has been discussed. The unhindered access to both detailed documentation and descriptive information has proved to be important in accurately parameterising and testing the model. A rigorous and detailed approach to numerical validation of all model parameters was presented. A large volume of dissagregated data was collected and aggregated into a suitable form for setting the numerical values of the model parameters. Some difficulties arose through having an incomplete data set but these problems were resolved through making sensible assumptions about the real safety system.

The iterative process by which the model was calibrated has shown to be successful in allowing the simulation to replicate the observed past three-year behaviour of both accidents and hazards. The reasons why the safety system may have behaved in a certain way are explained using a range of output metrics. Using MSE and Theil's inequality statistic, the size and nature of the error arising between the observed and simulated data has been shown to be acceptable.

The purpose of validating the RWOSM and then replicating historical behaviour was not only to understand why the firm's safety system behaved in a certain way but to build the manager's confidence in the model as a plausible means of exploring future safety decisions. It was not the intention to show how certain behaviour could have been avoided but to arrive at an empirically validated model to show how the management might act differently in the future to avoid undesirable accidents and costs. This is analysis of policy and will receive attention in Chapter Seven.

CHAPTER SEVEN

Evaluation of the Uses and Policy Analysis in the Real World System Dynamics Model of Occupational Safety

7.1 Introduction to Model Evaluation and Policy Analysis

The generic occupational safety model (GOSM) was built and subsequently validated with real data from a host firm with the intention of developing a means of improving insights into the real world problems of occupational safety. These insights could be brought about by learning about the effects of safety decisions or through designing policies to improve safety system behaviour. Chapter Seven is concerned with model evaluation, as outlined in Phase Five of the modelling framework of Roberts *et al.* (1983, p.8). This chapter seeks to show the level of utility and effectiveness of the real world occupational safety model (RWOSM) as a policy-making and learning tool. This relates to the 'policy analysis and model use' phase of Roberts *et al.* (1983, p.8) system dynamics modelling framework. A strong measure of its success will lie with whether the model actually generates new insights or improves existing understanding about the nature of safety in the firm.

Section 7.2 of this chapter describes the gathering of opinion on the model's uses from a group of managers from within the host firm. The views of this group as to the efficacy of both the RWOSM and its usefulness in developing insights into the running of an occupational safety management system are outlined. The findings of this discussion, outlined in Section 7.2, essentially determine whether the research aims and objectives for the whole study had been met. Section 7.4 is concerned with safety policy analysis using the simulation. The model is used to replicate some of the alternative scenarios raised by the management team when they explored the RWOSM's behaviour. In addition to exploring policies, the final scenario is concerned more with improving the performance of the RWOSM through designing a mix of policies to optimise safety costs and accidents. The common thread to the alternative scenario tests is the search for a set of robust policies that both improve safety system behaviour and can be feasibly implemented within the safety management system of the firm. In Section 7.5 the interview findings and policy analysis results are drawn together and summarised.

7.2 The Development and Application of an Interview Method to Capture Client Opinion of the Real World Occupational Safety Model

A group of managers from within the firm agreed to be interviewed in order to gather their opinions on the suitability of the RWOSM as a policy-making or pedagogic aid to understanding occupational safety. An interview framework needed to be developed that would lead to meaningful insights being gathered as to the uses of the model. The framework developed was unique to the study although many more standard aspects were based on the interview approaches recommended by Easterby-Smith *et al.* (1991) and Saunders *et al.* (1997). The model would be introduced to the interviewees. They would experiment with the simulation and in a discussion setting, comment on aspects of its uses within occupational safety management. Before this could be developed the most suitable interviewing approach needed to be chosen.

(a) Choice of Interview Style

Interviewing is often claimed to be the best method of gathering qualitative information. Interviews can be highly formal and structured, or very informal and unstructured conversations. Structured interviews are very standardised and use a set of pre-determined questions, whereas semi-structured and unstructured interviews tend to be non-standardised (Saunders *et al.*, 1997). Structured interviews are based on asking a set of predetermined questions with pre-coded answers. It was felt that this would be too restrictive, limiting the richness of the responses and the range of possible insights. Unstructured interviews are non-directive, with the direction of the interview partly determined by the interviewees. The two problems associated with this approach are the possibility that the general question being asked might ultimately not be answered and, given the group's limited knowledge and experience of system dynamics modelling, it could quickly run out of comments.

A semi-structured interview format was chosen for three reasons. This was due to the ability to pre-set themes for discussion, the opportunity to ask probing questions, and the freedom where necessary to introduce an acceptable level of bias in to the discussion. The boundaries of the discussion could be set clearly. These boundaries are the educational and policy-making aspects of the RWOSM. Within these boundaries, a list of themes and questions to be covered could be used to increase the likelihood of arriving at a meaningful outcome to the discussion. This would allow the general direction of the interview to be guided by the interviewer whilst allowing, at the same time, a rich picture about the use of the RWOSM to emerge. Semi-structured interviews provide an opportunity to probe answers given and allow interviewees to explain and build on their responses. This it was felt would be necessary to generate relevant and enriching responses. The fact that a semi-structured interview is based on general themes allows much of the information to be generated by the interviewees rather than by the continuous intervention of the interviewer. As a result, the likelihood that the interviewer implicitly or explicitly introduces bias through leading questions may be reduced.

(b) The Backgrounds of the Interviewees

The interviewees consisted of three managers from the host firm. None of them were involved in developing the structure of the model, although one had helped with the collation of data for it.

The first, and most dominant interviewee, was the safety manager (Safety Professional). He was a graduate engineer with some twenty years experience in engineering and occupational safety. He had a strong background in database management systems and some knowledge of spreadsheet modelling. The second participant was a senior production line manager (Production Manager) with thirty years' experience. The final contributor was a recent engineering graduate (Management Trainee) who had been with the firm for only a week. The fact that all the interviewees had an engineering background made them more likely to be receptive to a computer based approach to exploring safety decisions than others.

The safety manager had overseen the collection of data and had experimented briefly with the original abstract occupational safety model. He was best able to contribute thoughts on the appropriateness of the model for policy-making and to offer technical observations. The production line manager had a strong vested interest in operational safety as accidents had direct effects upon the running of his department. He would be able to suggest how the model could be used to push the safety message to employees. Finally, the graduate trainee was approaching the subject with 'fresh eyes'. He had studied some occupational safety at university but safety management was largely unfamiliar to him. The fact that he had not been involved in the running of the firm was a definite advantage as he could be very objective with his observations.

(c) <u>Introduction of the Real World Occupational Safety Model to the Interviewees</u>

Using a short presentation, the clients were introduced to the concept of system dynamics. They were taken through the model's conception, construction and operation. The group was pleased to see that the historical match between the simulation and observed safety system had been analysed statistically. This appeared to strengthen their belief in the plausibility of the model. Particular emphasis was placed on facilitating an understanding of the principal feedback loops working in the model through the introduction of the causal loop diagram of occupational safety. Once this was understood, the group were introduced to the RWOSM. Figure 7.1 shows the interface of the RWOSM:

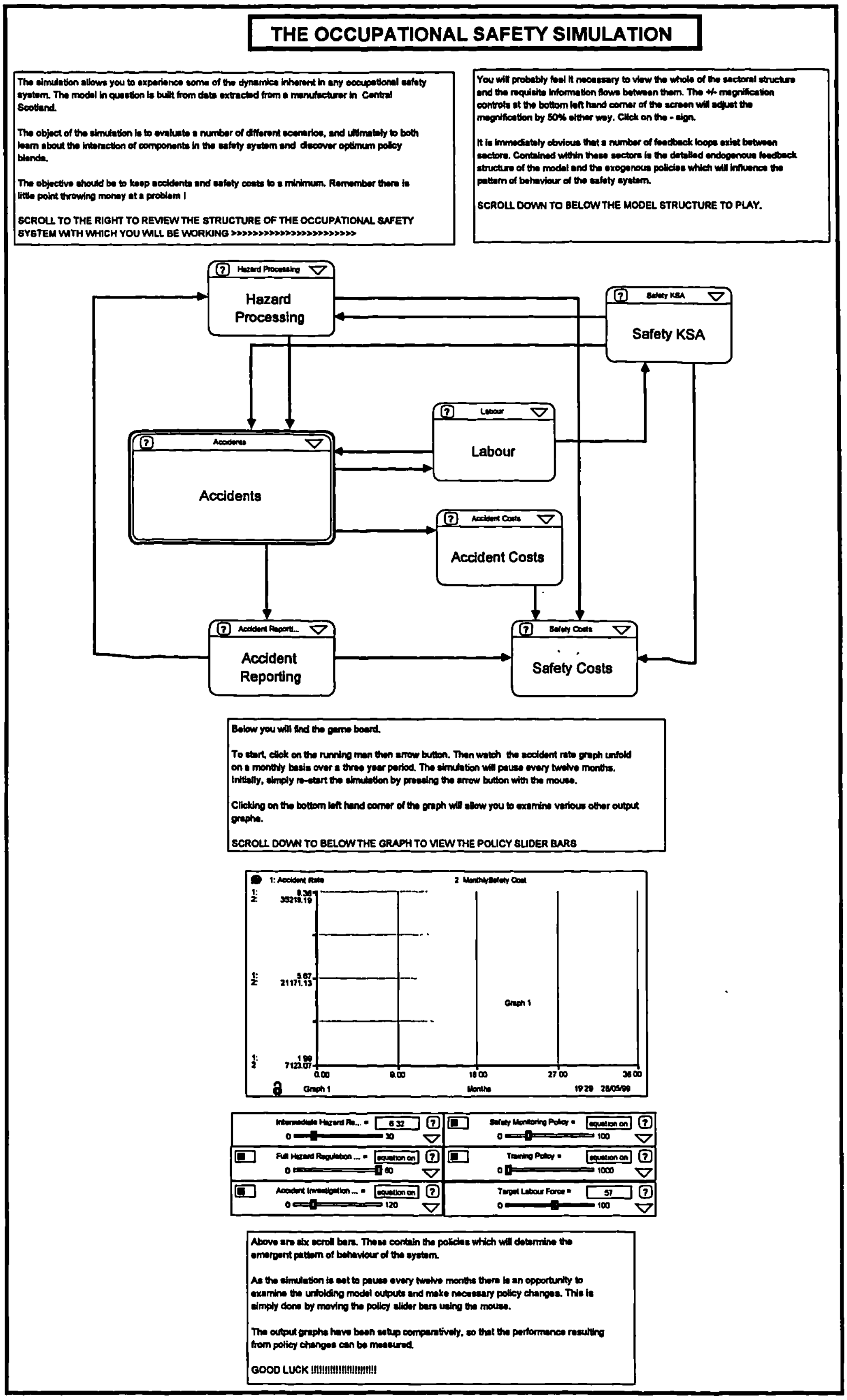

Figure 7.1 The user interface of the real world occupational safety model

The group was asked to scroll down the computer screen and to read the simulation model's operating instructions. The historical simulation was then run. They were able to view a number of simulation outputs representing the behaviour of the safety system within the Finishing Department over the past three-year period. They were most interested, as expected, in examining the change in accident numbers and the cost of running the safety system. The validated model met with the group's approval, as they were satisfied that the model was representative of past safety performance within the department.

The simulation was then set up to analyse policy decisions, and their effects on safety system behaviour for the future three-year period. The group changed from being passive spectators, to becoming participants, taking control of model decisions. They were able to follow through the simulation instructions and quickly involved themselves in model experimentation. Initially they were only introduced to the high-level simulation interface. This contained six slide bars that represented the most important policies contained within the model. The participants were given the opportunity to make policy decisions simply by dragging these bars back and forth to either switch them on or off or through heightening or lessening their effects. Once they had understood the means by which policy decisions could be made they were interested in knowing something about the structure causing the simulation behaviour that was unfolding. They were introduced to selected parts of the model without over-burdening them with detail. The clients experimented with the simulation for a period of nearly one-hour. After that time period they were all satisfied that they had a better understanding of the causes of their safety system's behaviour and the RWOSM's possible uses within the firm.

(d) The Group Interview

Through a semi-structured interview a rich picture of opinion about the model could be captured from the group of managers. The overall boundary of the discussion would be constrained by the question 'Is system dynamics modelling of occupational safety more suitable for **learning** or **policy-making**?' The interviewer wanted the framework to exclude technical debate about the actual operational mechanism of the model so the words 'learning' and 'policy-making' were accentuated. The first stage of the interviewing process involved developing a number of possible themes for discussion. To avoid getting tied up too closely by these themes a 'topic guide' was prepared, which was an essentially loose structure for questions that could be raised at pertinent points in the interview (Easterby-Smith *et al.*, 1991). This is listed in Table 7.1.

There was a temptation for the interviewer to impose his own reference frame on the interviewees both with the questions asked and interpretation of answers. There had to be a play-off between open questions avoiding bias and obtaining the desired information. The interviewer was careful to ensure that probes were not too much of a leading kind.

There appeared to be a high level of trust been the interviewer and interviewees and all agreed to having the interview tape recorded for later transcription. As the interview involved more than one respondent it was able to take the form of a loosely structured steered conversation. The interview was conducted on the 'home ground' of the interviewees, in one of their conference rooms. This seemed the most suitable venue as all the data collection for the model had been conducted on the one site and with the backing of the safety managers there.

Theme	Possible Questions
General perceptions of the model	Is the model more suited as a learning, or policy tool? How might the simulation model assist your firm? What are the strengths and weaknesses of the model?
The Effect of the Interface on the Model's Potential Application	Is the user interface more important on the learning or policy side, and if so why? How did you feel about using a flight simulator type interface? How important are the slide bars in facilitating experimentation?
Model Policies and System Behaviour	Which policies had the most dominant influence over the safety system? How close was experiential versus experimental outcomes? Are the fundamental safety system policies in the model, and, if not, which should be added? Did the simulation model reveal any new insights, if so, what were they? Did the model fit with your intuitions, if so how? Are there too many or too few policies in the model? Would you introduce additional policies?
Model Users	Would you use the model to enlighten or sell ideas to people, if so why? Could the model sell safety to senior managers, if so how? How might the model help towards winning extra resources for safety? Would the model help with resource allocation, if so how? Would specialists use the model for planning and non-specialists for learning?
Model Optimisation	What are the benefits of optimisation? What are the drawbacks of optimisation? Who would wish to optimise the model?
Abstract versus Real World Model	Which model would be more beneficial, an abstract or real world one? Which format would be more appropriate for learning? Would an abstract model allow you to explore policies you would not normally explore, if so how?

Table 7.1 Topic guide for interview questions

The interview was not conducted as a full 'focus group' as it was too strongly guided to be one although the interviewer acted as much as possible as moderator or facilitator. The substantial time in presenting the background to the modelling approach and having the participants explore different scenarios using the simulation model paid real dividends as it made the respondents feel that they were able to comment on the model through having an informed view.

The interview method allowed a reasonably unbiased picture of the group's opinion of the model to emerge. The entire discussion lasted for just over one hour and some interesting insights into the application of the simulation model and occupational safety in the wider sense emerged. The interview did uncover relevant information not anticipated before the discussion. This only served to affirm the choice of interviewing approach.

7.3 Analysing the Results of the Interview

The whole taped interview was transcribed verbatim so as not to lose any detail. See Appendix K for full transcribed interview. The structure used to analyse the discussion had to be derived from the data. This required teasing out themes, patterns and categories from the discussion. The themes set out in the interview framework were evident in the first examination of the fully transcribed interview.

The process of analysing the results of the interview was iterative in nature. The mass of data collected was split into meaningful themes or categories. These categories acted as labels which were used to rearrange the data. Sets of interview data relating to the pre-determined themes of the interview started to emerge. Saunders *et al.* (1997) suggested that the next stage of data analysis involve 'unitising' the data. This consisted of attaching relevant chunks of textual data to the appropriate categories. This was achieved through labelling the units of data with an appropriate category code in the margin of the transcript. Some categories were disaggregated when it was apparent that the large volume of textual data associated with them would be too broad for further analysis whilst others were aggregated to allow sufficient key themes or patterns to emerge.

A combination of deductive and inductive analysis of the interview results was used. The deductive position stemmed from the need to determine whether the simulation model would be successful for educating people about safety and/or helping to guide decision-making in the field. The inductive analysis arose from the fact that new insights into the simulation and application of the model had emerged within the interview. Therefore, the categorisation and analysis of the discussion resulted from a blend of the two. For example a theme emerged in the interview surrounding the use of the model to sell safety to senior managers. This had not been fully anticipated prior to the interview. Thus these responses were analysed inductively.

A number of concepts emerged from the transcribed interview script. Some of these concepts crossed the boundaries of these themes but with the nature of the findings this could be expected. Quotations from the discussion have been extracted from the transcript and analysed to obtain some meaningful interpretations of the interviewees' opinions on the real world occupational model (RWOSM).

(a) Initial Client Responses to the Simulation Model

The discussion opened up with the general question:

> "Is the occupational safety model a learning or policy tool?" (Interviewer)

This was followed up by the more direct question:

> "How might the simulation model assist your company?" (Interviewer)

The initial responses were lengthy and encouraging:

> "Well I think it could be used by managers or anyone involved in the field of safety to learn about causes and effects and what can happen if we change anything in particular, how that might affect the overall picture . . .
> It would be used to try and explore what the most effective measures would be . . .
> We would follow the path that the model suggested was the best path and monitor the effect to see if the two were in agreement . . .
> If successful, then we could use it [the model] to look at the future so that we could set policies so we weren't stabbing in the dark but initially very much a learning tool and probably less of a policy-making tool." (Safety Professional)

> "I think this can certainly be as in this company . . . a way they can see what it [safety] is going to cost . . .

It would certainly highlight that it [following the model's policies] would save a lot of injuries but, at the same time, can save money and that makes good management sense." (Production Manager)

"I've got a degree of scepticism, especially when looking or basing future policies on those sort of results. I wonder how it would differ from department to department, where we consider accidents do occur frequently that are basically unavoidable . . . it looked good, but that would be my one worry." (Management Trainee)

Here three different views of the model unfold. The safety professional appeared to have a good educated layman's understanding of how the model worked and of what its potential and limitations were. He saw the model as suitable for teaching people about the effects on safety of making different policy-decisions in the first instance, and the potential to use it to assist with strategic decision-making in the second. He also erred on the side of caution where he suggested following the policies indicated by the simulation model whilst monitoring how closely the model outputs fitted the future results. This was his approach to determining whether the model was plausible or not.

The line manager immediately saw the model in a demonstrational capacity, describing how you could show people the effects safety decisions have upon accidents and their requisite costs. This appeared to be a double-edged response, acknowledging the use of the model to stress accident reduction and cost minimisation.

Lastly, the trainee, being new to the firm and the field of occupational safety could obviously make lesser of a contribution to the debate. His comments may suggest that he took a less holistic view of the model, querying specific results. He may have been less concerned with the underlying model behaviour and more interested in the model's ability to predict exact outcomes.

The purpose of the model was then reiterated to the group as a prompt in order to guide a better understanding of the model. It was made clear that capturing an understanding of the emergent behaviour of the system, rather than examining the numerical outputs on a point-by-point basis was of importance.

(b) Discussion of the Principal Model Policies

The group had discovered from experimenting with the model policies that training appeared to exert the most leverage over both accidents and safety costs. This resulted in this policy being afforded more attention than others did.

The model had stimulated the group to debate about the role of training and its effectiveness and they were able to discuss this issue at length. A discussion about various training approaches ensued. This allowed the group to query the validity of the model. Questions were raised as to why all the training mediums had been aggregated into one policy:

> "You could decide to spend double the amount of time on training . . . the model doesn't know how effective that training is. Inappropriate training you would expect it to have a minor effect, whereas, better targeted training would obviously be more effective. Now it's probably too much for a model to be able to pick up." (Safety Professional)

"If we've got a lot of duff [poor] training courses, then really we're only ourselves to blame." (Production Manager)

The group was reminded that the model was not working at the operational level. Rather it was strategic, examining wide policy areas:

"You could have broad bands of training, you've got training where you go away on a course off site or if it's on site you're isolated from your work environment . . .
That would be external training . . .
Off-the-job training is a defined course that covers topics and you go back to your job and it might not change the way you work. On-the-job training should, because you're doing it on-the-job, change the way you work, and in many cases the effects could be significantly different." (Safety Professional)

A debate had opened up about the validity of the model. This concerned the aggregation of internal and external training. An understanding developed of the impact of different training approaches upon safety behaviour. The group made it clear that to disaggregate the types of training could reflect real policy more accurately.

This debate could be regarded as an important measure of the group's understanding of the model because the discussion had gone beyond discussing the emergent system behaviour and moved on to querying how the actual structure of the model would improve the simulation's behaviour. The group was trying to find a way to evaluate their training policy most effectively using the model of their work environment. The need for the model to replicate accurately the disaggregated training evident in the firm was very important to the group. Building an accurate representation of safety training in their firm seemed to take precedence here over learning about the general effects of training. In addition to this, the model had been used as a catalyst for a discussion on the firm's approach to safety training.

(c) The Effect of the Interface on the Model's Application

The group were again asked for their opinions on the model's effectiveness in enhancing learning and policy-making. The actual interface was brought into the discussion and its user-friendliness was brought to their attention. They were then queried about the interface's importance within learning or policy-making situations:

> "The problems you would face there are the scepticism. If they're [users] not familiar with computers or they don't understand modelling . . .
>
> They have to be comfortable with the process and understand what it is setting out to achieve . . . the model has been developed to the stage that you can use sliders and check graphs. Depending on the audience you're trying to reach that will only reach a certain proportion of them . . .
>
> Ideally you want something which will work in an interactive way which that [the model] does . . .
>
> With someone at a lower level of management or supervisory level you could play with that and it might be instead of a chart it would show a pile of dead bodies. So that they could visually, not just on a graph, get an appreciation . . . so taking that [the model] a stage further . . . follow the same as a flight simulator and keep developing that, if the aim is to develop a package that can be used for training." (Safety Professional)

The group was asked about the interface for the model acting as a policy tool to assist with resource allocation;

"It doesn't need to be pretty to do that, just understandable." (Safety Professional)

The group was able to differentiate between the needs of the user interface for learning, where it was made clear that the outputs needed to be more visual than graphical, and the low priority given to aesthetics by the planner. Useful suggestions were made as to how to improve the learning experience, for example, the dead bodies piling up instead of a graph unfolding. The slide bars and output graphs close at hand were appreciated. This suggests that the group was satisfied with the current user interface for ease of policy experimentation, but as an aid to learning it needed to be more visual.

(d) The Behaviour of the Model

The interviewees were asked whether they were surprised about any of the behaviour of the simulation output:

"It's interesting to see which ones [policies] affect [the behaviour of the model] and I suppose we could concentrate on basically the ones which we could influence the most, quickly and cheaply . . . get as many people involved." (Production Manager)

"Getting over the credibility gap, let's say you've got a group, say we looked at Finishing Ends One and Two, and you have that group of managers and supervisors, they think the model's credible, we've reached that point, it would allow them to understand safety." (Safety Professional)

The safety professional described how he argued often with the production management group about safety issues and how they complained that they could not fit enough guards on machines:

"Sure, if it should be guarded it should be guarded but to expect that to make a tremendous inroad into accident rates is false. It's what people do that cause accidents. A blend of on-the-job and off-the-job training is required . . . it is generally accepted that training has that benefit and you have a factory where the guarding is not adequate and hardly any accidents and then you can have the converse, where you can have everything guarded and lots of accidents. The difference there is the people." (Safety Professional)

Comments were made about the interesting nature of the model's output and the ease with which policy experimentation could be conducted. The safety professional agreed that he was aware from experience that training would have a major impact upon safety and that the model confirmed his opinion. Again, the model had stimulated debate between managers on how best to run the safety system.

(e) Convincing Senior Management of the Usefulness of the Model

Whether strategies identified in the model could ultimately be pursued would depend on the safety budget. The senior accountants and board members would set this. Safety would have to be sold as a cost centre to these people. The group was queried as to their perceived judgement of senior management's response towards the usefulness of the model:

"if you've got a group of directors . . . they are not at the technology end. So for a start it's a computer and they're not entirely familiar with that and then you've got the scepticism about modelling which would be a concept with which they would, maybe, not be familiar. I think there would be a point where they would say 'Well very interesting but I'm too busy, go talk to someone else'. So before you've got over those two hurdles to get the benefits of the model they might have gone and lost interest . . . they've got to the bullet points [model summary], they want to be there, if the bullet points don't confirm their pre-digested thinking, their own prejudices and beliefs, then you're obviously wrong and they move onto something else." (Safety Professional)

"But saying that, if the bait's taken with a few bullet points then all of a sudden you find that they're running very fast to the beat . . .

The best place to target is the accounts, accountants." (Production Manager)

"That might be the best place to start . . . general mistrust about computers, no knowledge about modelling. I think that's where we are, and most companies might be like that." (Safety Professional)

The group offered a range of opinions on the perception of senior managers. To use the model in a demonstration capacity seemed to be the opinion of the group. Selling the concept and the power of the model for safety evaluation would have to be done carefully, as there appeared to be some doubt about the open-mindedness of the Directors to computer modelling. This appears to confirm the concern over static thinking by many companies' Directors. The model has stimulated comments on the management culture in the firm.

(f) Exploring Alternative Strategies Not Covered by the Model

The group was questioned as to whether they believed that the model's policies covered the fundamental influences on safety:

"What about incentive schemes? You could have that as an additional policy. If you had a slider bar, pounds (£'s) per month per employee invested in the safety scheme. Then you've got a cost . . .

It could have a similar effect to training." (Safety Professional)

This statement from the safety professional strongly suggests that he had a good grasp of the structure of the model despite having minimal contact with it. He was able to identify a key input as units per unit per time. He saw the potential of evaluating strategy by the addition of a viable policy, and identified its dimensions. This was an observation about how the model might be re-engineered in order to improve policy evaluation:

> "Management competence . . . their competence in safety could be measured and some term found which you could vary to influence the model . . .
>
> If you've got ignorance on the part of the senior people and an unwillingness to act that would have massive effects on how your company performs well in any sphere." (Safety Professional)

It was explained that management competence was indirectly included in the model as the policy decisions would be those taken by managers. This fits with the idea of the man in the model described in Section 5.4(f) of Chapter Five.

(g) <u>The Model as an 'Edutainment' Game</u>

The role of the model as an 'Edutainment' game was raised and responses were short but encouraging:

> "somebody who is enlightened in safety using it [the model] as a policy tool, whereas, a person from a more general background using it as an educational or Edutainment tool ?
>
> I think as an Edutainment tool people would be more inclined to play with it [the model] and it's playing with it you actually learn." (Safety Professional)

The observation that the longer people played or experimented with the model, the more they would learn was very astute. This shows that the manager believed in the ability of the model to help people to learn about safety through teaching themselves.

(h) Optimisation of the Model

Optimisation was an area brought up directly by the group. They were probing to discover if the model could be optimised, and if so, how?

> "Could it be programmed to work out itself what the most effective variables are in the model?" (Management Trainee)

> "An optimising program, would you set the target of minimising all costs?" (Safety Professional)

It was explained that the model could be optimised manually using the hill-climbing approach (Coyle, 1996) to identify a policy mix which would minimise costs. It was also pointed out that optimisation programmes were available with certain system dynamics packages such as DYSMAP, Vensim and COSMIC.

The question of removal of human interaction by using an optimisation program was raised by the interviewer. It was suggested that people might not get the opportunity to explore policies if they were to let the computer make the decisions for them:

> "If there was a function you could just switch on and off then you could just use it for both . . .

Like for somebody who was familiar with the model and believed what it told them . . . he'll want to run the optimisation won't he ? He won't want to spend hours in front of the keyboard . . .

But you want the learning course because it might be that the optimisation will have to take account of the amount of money you have available or the amount of time, so you want to optimise given that these inputs must be maintained below this level. So what can we do with the resources we've got ? . . .

"That's an interesting philosophical debate. Do you want to optimise on accidents, which is zero accidents, or do you optimise on cost and you might not choose zero accidents ?" (Safety Professional)

Optimisation was seen as useful for policy-making, in fact an interesting discussion ensued as to whether the objective function of the model should be accident rates or safety costs. Certainly the group were thinking here purely in policy-making terms.

(i) The Users and Uses of the Simulation Model

One question posed to the group was:

"Would they use the model to enlighten other people?" (Interviewer)

"From top to bottom really" (Production Manager)

"I think there's still work to do on enlightening, because we can still slip back into 'Well I can't get enough fitters to fit the guards . . . I can't do anything about safety. . . .

It would be for anybody to come and use it; it would be for learning; once you've achieved that aim, you could then use it by adding features to mould it into a policy tool, but first of all it must be a good learning tool" (Safety Professional)

When queried as to who would use the model and how, the responses were very broad. The consensus seemed to be that anyone who had an interest in occupational safety could use the model to develop a better understanding, and then to aid policy-making.

(j) Abstract or 'Real World' Model

The group was asked their opinion on using an abstract model or one validated with their firm's data:

> "It [an abstract model] would still help us to learn and we might discover policies that we would not normally discover." (Safety Professional)

> "If you took it off a really successful firm, like a Japanese leader, something not necessarily in this industry." (Management Trainee)

> "You could switch on the generic model, which is designed to show how safety works for any company . . . introducing policies and switching them on. If people played with that the next thing they would want is something they could use for their own situation." (Safety Professional)

The safety professional had made a very good point about the uses of exploratory models to discover policies that might not be discovered using an operational model. Also he suggested the desire of model users to experiment with a model built to reflect their firm's circumstances. Both these points have been raised by Shubik (1983) where he compares the merits of real world and abstract gaming models.

(k) Summary of Discussion Findings

A wide range of views were put forward by the three interviewees, all possessing varying degrees and types of knowledge of occupational safety and simulation modelling. The common thread that can be teased out of the discussion is that the model in its present form was found to be helpful by the clients for understanding how to control the behaviour of their firm's occupational safety system.

Many of the explicit observations made by the group pointed to the model being more suitable as a tool for either demonstrating the effects of safety policy, or for helping people to learn more about their firm's safety systems. There was acknowledgement that the simulation would still be of value in learning or even policy-making when set in an abstract context, although there was a greater appreciation of the model in its present real world form. Much of the underlying discussion pointed towards using the model to assist with policy evaluation. Suggestions were made concerning the introduction of other policy parameters into the model.

The results of the policy experiments that the group conducted were certainly pertinent to the discussion. Training was identified as the model policy able to exert either a virtuous or vicious effect over the whole system's performance. The model had allowed the interviewees to appreciate this and much debate had followed as to how training might best be used.

The group had considered carefully the initial query put forward as to whether to use the model as a learning or as a policy tool. This allowed the interview to reveal quite a rich picture of opinion on the uses of the model to assist the firm with safety, and uses beyond the firm. A limitation of the model highlighted in the discussion appeared to be the perception that training in the firm would be better reflected in the RWOSM if its structure was dissagregated to show the effect of different types of training. The lack of criticism levelled by the interviewees may show that their exposure to the RWOSM was too limited, not allowing them to comment adequately on the plausibility of the model's structure and equations.

7.4 Policy Analysis

Policy analysis helps the model user to understand why a system behaves in a certain way (Coyle, 1996). Policy experiments with system dynamics models are used to help design the best possible robust behaviour into the system under study. There are very many possibilities open to the model user and there is no way of knowing in advance which will give the best overall performance in the system. The only way to progress is to experiment with different policies with the intention of designing a scenario which suggests the best outcome, that is the control of any undesirable behaviour within a system. Richardson and Pugh (1981) indicated the need to introduce a limitation to experimentation. They suggested only pursuing feasible real world policy alternatives which could be implemented as policy options in the real system.

Policy analysis can be conducted through changes to the structure of a model or changes to the parameters. The structure of the safety model has remained fixed throughout the study. Therefore the only changes that can be made are to parameter values. These changes should help to find better model results. The real world occupational safety model (RWOSM) contains many parameters making a coherent analysis quite difficult. To deepen the understanding of why the model behaves as it does requires experimentation with at least some of the parameters. The results of the detailed parameter sensitivity analysis conducted on the generic occupational safety model (GOSM) limits the testing of the model to a smaller range of more sensitive parameters. In Chapter Five, the parameter sensitivity tests were described. These were performed in a controlled environment. The tests only involved single parameter changes and were very formal. In reality, a variety of policy changes may achieve the desired results better. Therefore, policy experimentation differs only from the parameter sensitivity analysis in that it involves multiple policy parameter changes.

It is not enough to know that certain policies improve model behaviour. The user needs to know why that behaviour happens. Otherwise, they will not think about implementing the policy decisions in the real system. For this to be achieved the model user must at least understand the principal feedback structure of the model. Also the user must always be aware of the limitations of policy experimentation. A mix of policies in a simulation may show a very desirable outcome, but it may be impossible to translate these changes into the real system. Therefore, the policy parameters must be kept within clearly achievable bounds.

(a) The Five Policy Analysis Scenarios

The policy analysis is designed to identify safety policies which result in an improvement both in accident rates and in safety costs. Some of the more sensitive policies identified from prior sensitivity tests on the GOSM will be numerically modified in order to explore, and then to design a better safety management system. Five scenarios are examined in total. A number of important output metrics are chosen to allow behavioural and numerical analysis of simulation performance. Also cumulative totals and final values are noted for accidents and safety costs.

The first four scenarios reflect some of the policy experiments carried out by the firm's managers when they were introduced to the RWOSM. The last scenario shows the end result of extensive manual optimisation of the model. The first four scenarios are more concerned with policy experimentation, with capturing insights into the range of behaviours that the system is capable of, and the last seeks to design policies through optimisation to give the best performance to the system.

(b) Scenario One: Business as Usual

The first scenario to be explored is 'business as usual'. This consists of keeping the policies fixed at the level at which they were in the final month of the historical simulation with Training Policy being the exception. This policy had fluctuated over the past three years with no underlying trend and, as a consequence, it was fixed in month 37 at 56 man-hours per month to reflect the average training which had occurred over the previous three-year period. This scenario is set as the base run for these policy tests, and alternative scenarios will seek to reduce any undesirable behaviour which the safety system may exhibit through this simulation. Figure 7.2 shows that if no alternative action is taken to improve the safety situation over the next three-year period, the accident situation considerably worsens. Also the knowledge, skill and attitude (KSA) of the employee's declines further and the length of time over which staff stay with the firm continues to diminish.

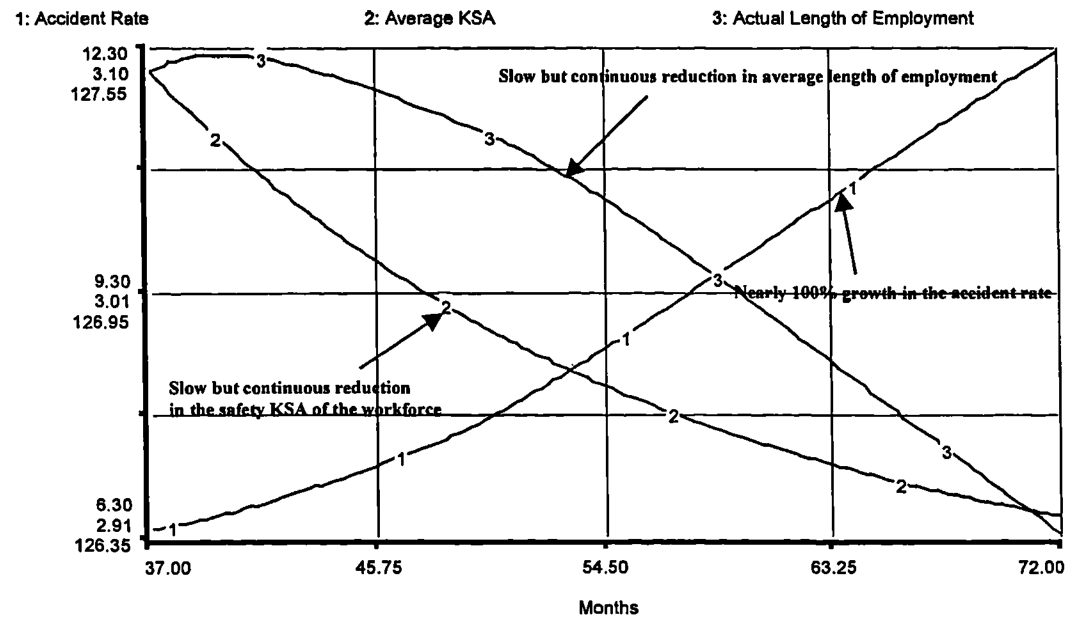

Figure 7.2 Changes in scenario one to the accident rate, average knowledge, skills and attitude and actual length of employment over the three-year period

Figure 7.3 shows the projected transience of the workplace hazards over the next three-year period. The graph reveals a slow but consistent decline in the numbers of Regulated Hazards. The reduction in Regulated Hazards causes a considerable accumulation to arise in Hazards under Full Regulation. Under this scenario, insufficient resources are being allocated to regulate hazards fully. This growing backlog waiting to be processed is largely responsible for fuelling the increasing accident rate.

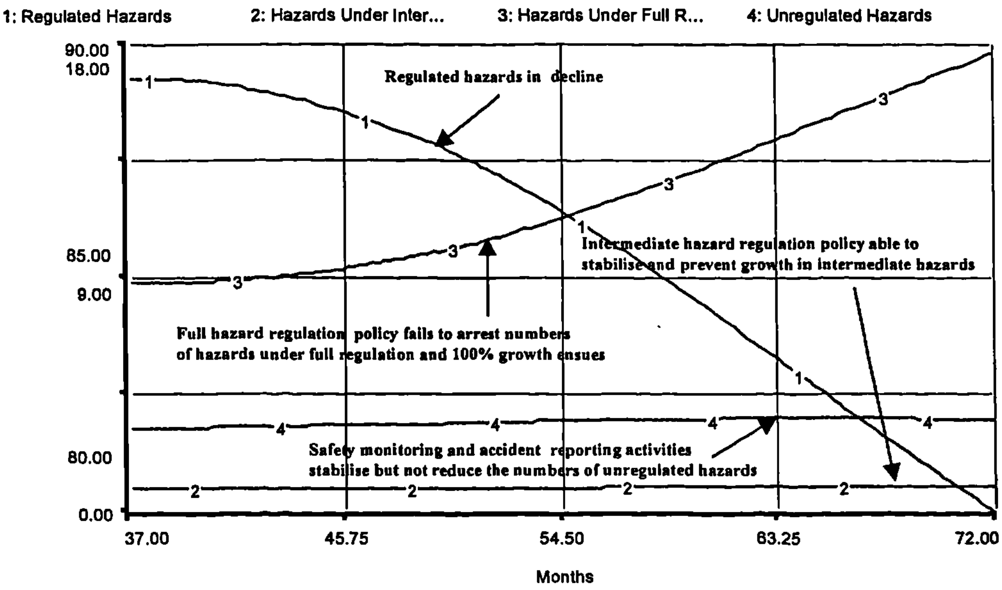

Figure 7.3 Changes in scenario one to the distribution of hazards over the three-year period

Figure 7.4 shows that there is a considerable growth in the costs of both accidents and the running of the safety management system:

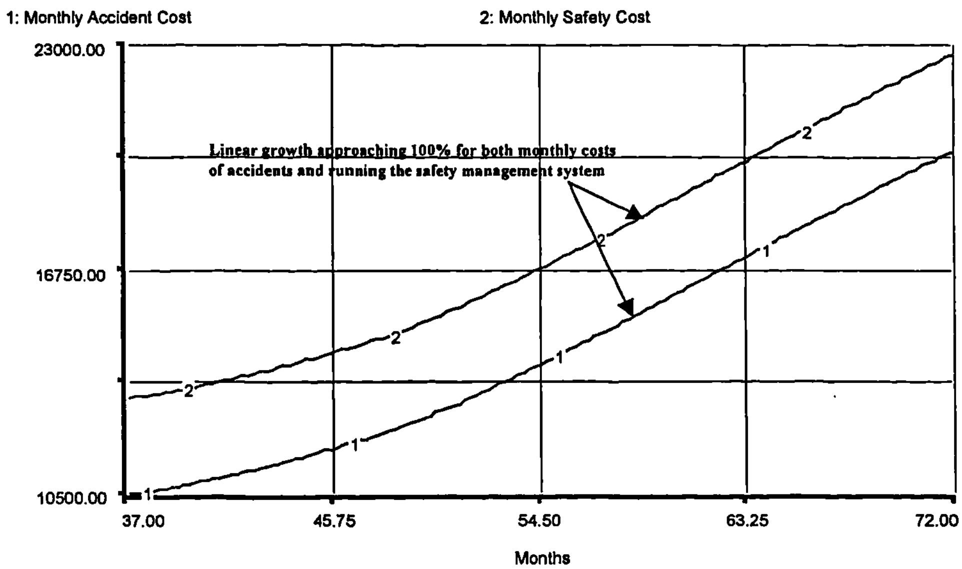

Figure 7.4 Changes in scenario one to the costs of accidents and running the safety management system over the three-year period

The firm could surely not sustain this growth in costs. The 'business as usual' scenario uses a set of policies that fail to arrest and reverse the increases in accident rate or the monthly safety costs. The increased backlog of Hazards Under Full Regulation appears to exacerbate this situation.

(c) Scenario Two: Hazard Regulation

In the 'business as usual' scenario where no policy changes are implemented the performance of the simulated safety system deteriorates with nearly all outputs exhibiting undesirable behaviour. The policy makers may see fit to improve the overall safety system through preventing the accumulations of Hazards Under Intermediate and Full Regulation. The 'hazard regulation' scenario shows the effect of increasing the resources committed to the Intermediate and Full Hazard Regulation Policies by 100% over the base run and keeping all other policies invariant. Figure 7.5 shows numerical but not behavioural improvements in the simulation outputs compared to the base run:

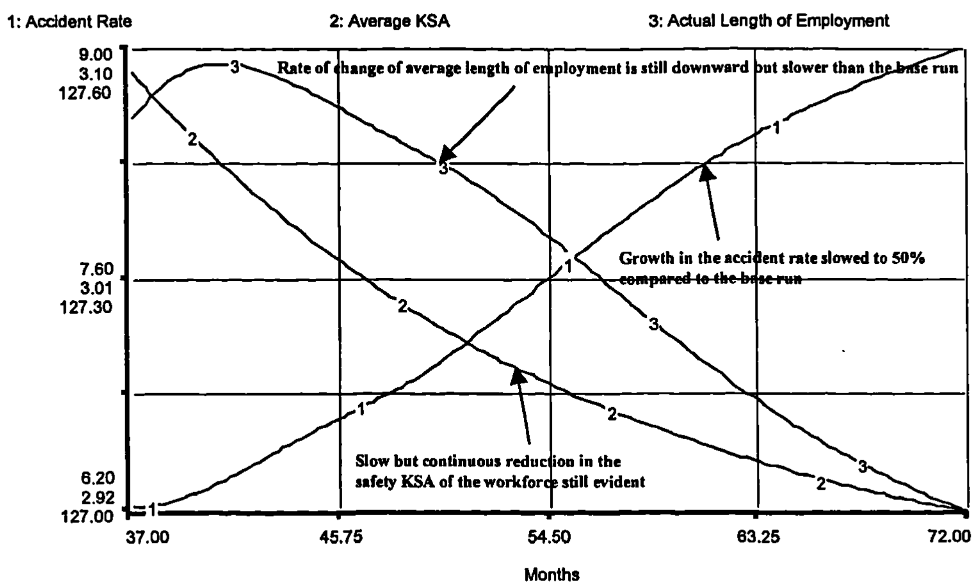

Figure 7.5 Changes in scenario two to the accident rate, average knowledge, skills and attitude and actual length of employment over the three-year period

The increase in the accident rate is less marked, the loss of KSA by the employees slows and the decline in average length of employment is slower.

Figure 7.6 shows that there are numerical but not behavioural improvements to the distribution of hazards in comparison with the base run. The rate of decrease in Regulated Hazards is slowed. The extra resources committed to hazard regulation have ensured that the growth in Hazards Under Full Regulation is largely arrested and that the accumulation in Hazards Under Intermediate Regulation remains under control.

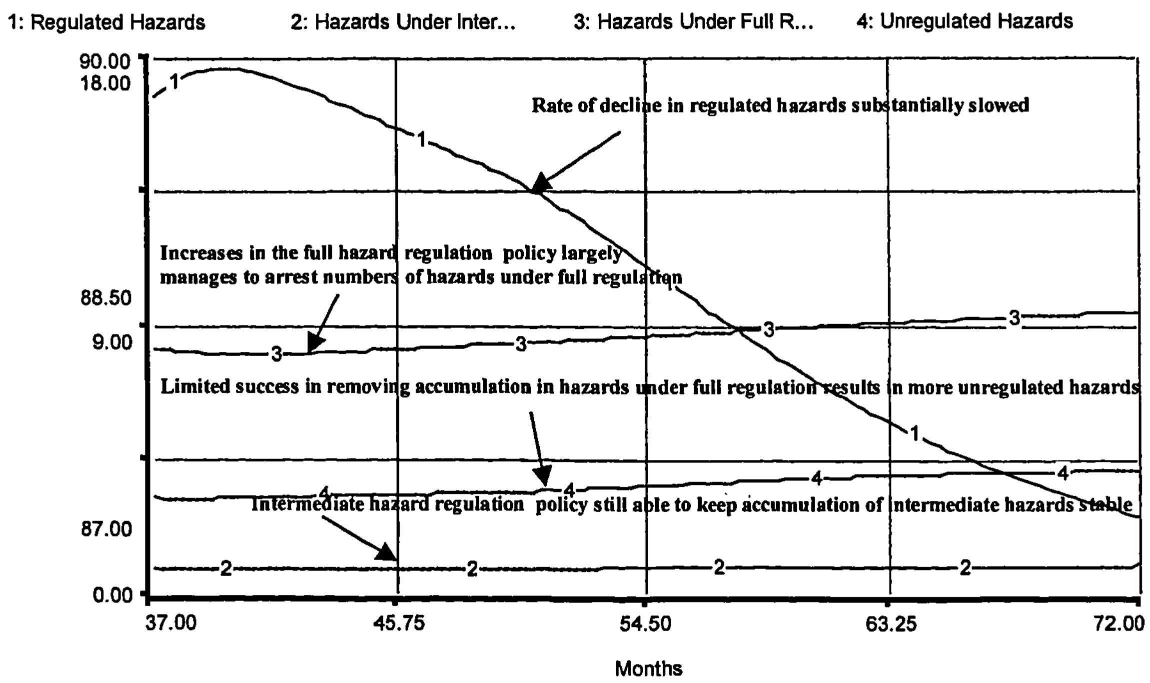

Figure 7.6 Changes in scenario two to the distribution of hazards over the three-year period

Figure 7.7 shows the rate of increase in accident and safety management system costs is much slower than the base run although there is no improvement in the behaviour of these outputs.

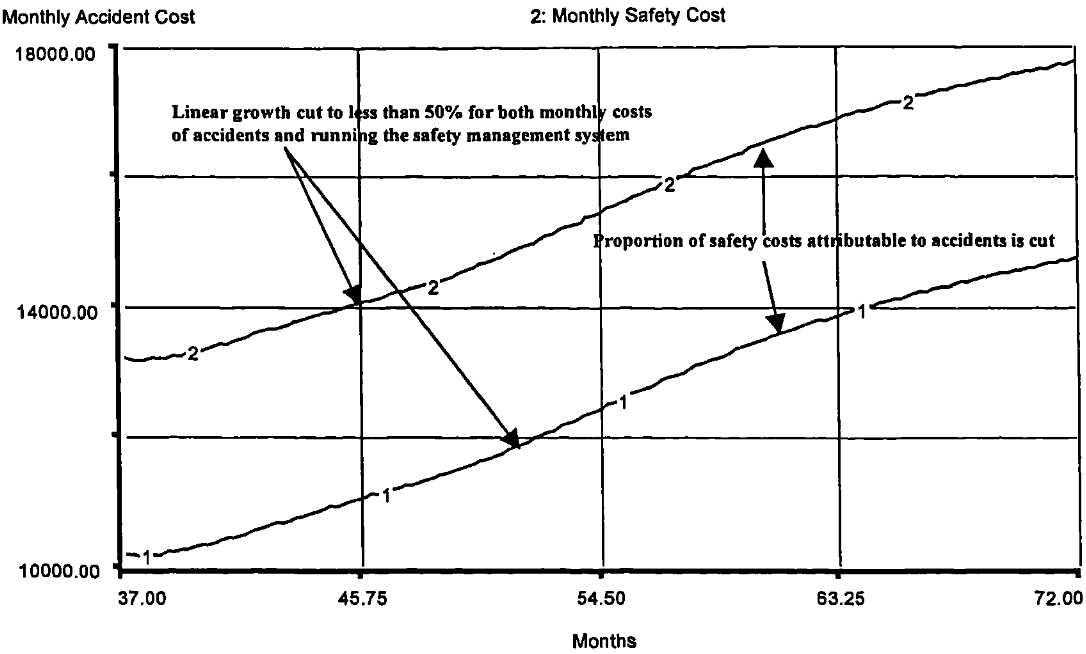

Figure 7.7 Changes in scenario two to the costs of accidents and running the safety management system over the three-year period

The 'hazard regulation' scenario arrests the rates of increase in accidents and safety costs, but fails to reverse these upwards trends. The accrued benefits stem from the increases in hazard regulation resources slowing the accumulations of Hazards under Full Regulation.

(d) Scenario Three: Integrated Hazard Control

In the 'hazard regulation' scenario the performance of the safety management system improved, with lower accidents and safety costs, although the performance metrics in the system were still deteriorating throughout the simulation. An alternative scenario may consist not only of allocating more resources to hazard regulation policies but also increasing the ability to identify more Unregulated Hazards through increases in the Safety Monitoring and Accident Reporting Policies. The 'integrated hazard control' scenario shows the effect of increasing resources committed to the Intermediate and Full Hazard Regulation Policies, and the Safety Monitoring and Accident Reporting

Policies by 100%, keeping all other policies fixed. Figure 7.8 shows that there were minimal numerical improvements to the accident rate, KSA of the employees and average length of employment, but no behavioural improvements compared to the 'hazard control scenario'.

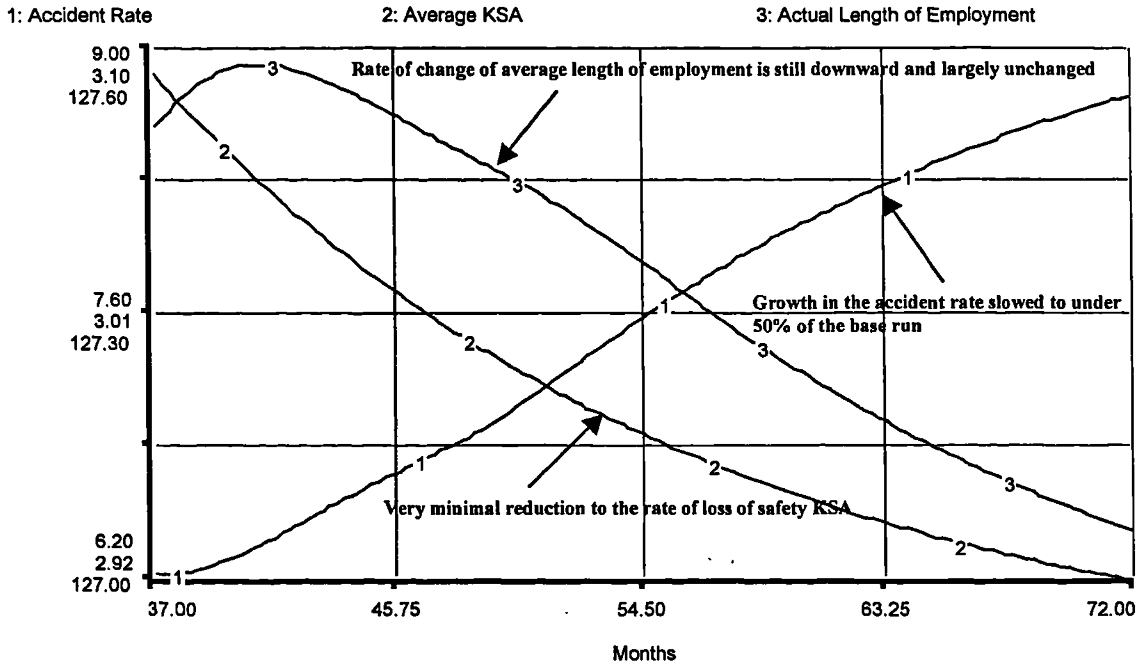

Figure 7.8 Changes in scenario three to the accident rate, average knowledge, skills and attitude and actual length of employment over the three-year period

Figure 7.9 shows that there were minimal numerical improvements but no behavioural improvements to the transience of hazards in comparison with the 'hazard regulation scenario'. The growth in accumulations of active hazards has failed to be arrested.

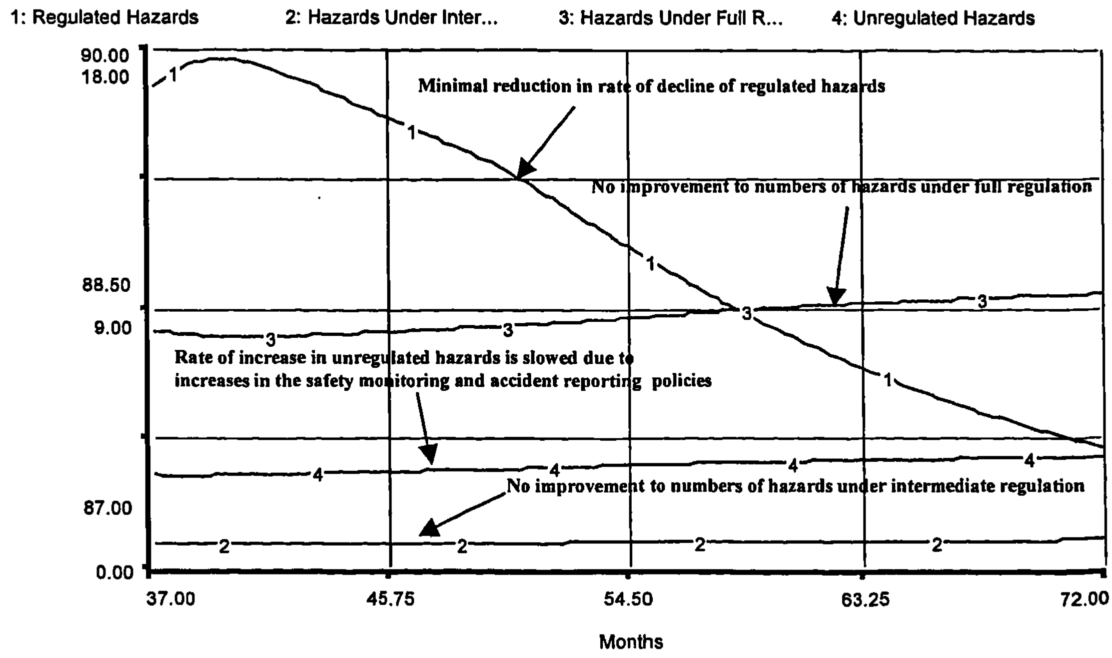

Figure 7.9 Changes in scenario three to distribution of hazards over the three-year period

Figure 7.10 shows the cost of running the safety system under this scenario is higher but the accident costs are similar to the previous one. The gap between safety and accident costs increases in comparison to the 'hazard control scenario' suggesting that the cost-benefit of this scenario is poorer.

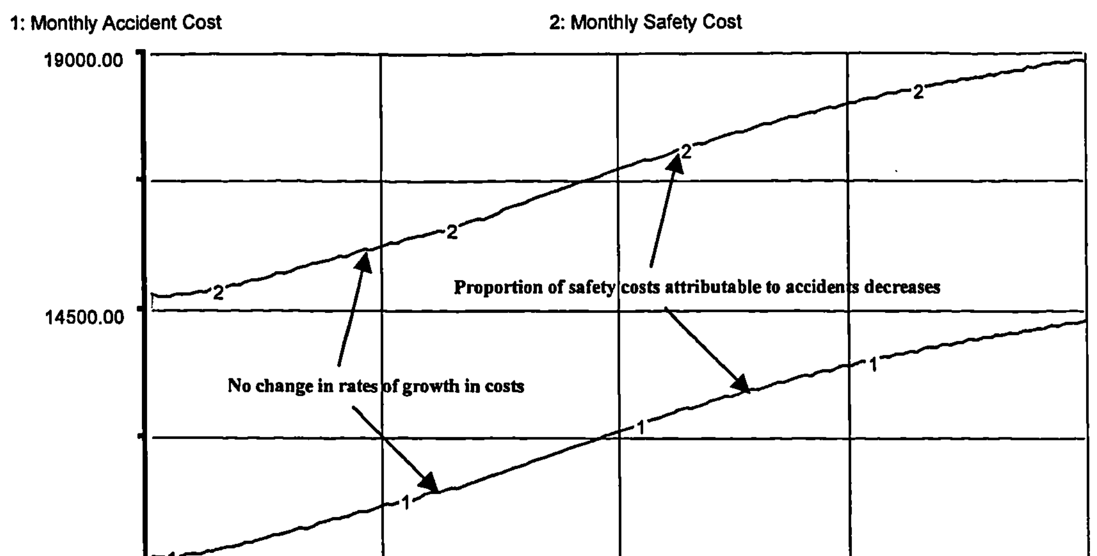

Figure 7.10 Changes in scenario three to the costs of accidents and running the safety management system over the three-year period

There is little improvement in the accident rate and noticeable increases in the costs of running safety for the 'integrated hazard control' scenario. It appears to be less viable than the previous scenario but still better than 'business as usual'.

(e) <u>Scenario Four: Intensive Safety Training</u>

The previous three scenarios have varying success at stemming the increases in accident rates and safety costs. None succeed in improving the behaviour of these important performance outputs. The Training Policy had been identified in sensitivity tests with the GOSM as a policy with the potential to improve the safety system's behaviour. In the 'intensive safety training' scenario, safety training is increased by 100%. All other policies remain fixed at their original values. Figure 7.11 shows that there are considerable numerical and behavioural improvements to the output metrics compared to the previous scenarios.

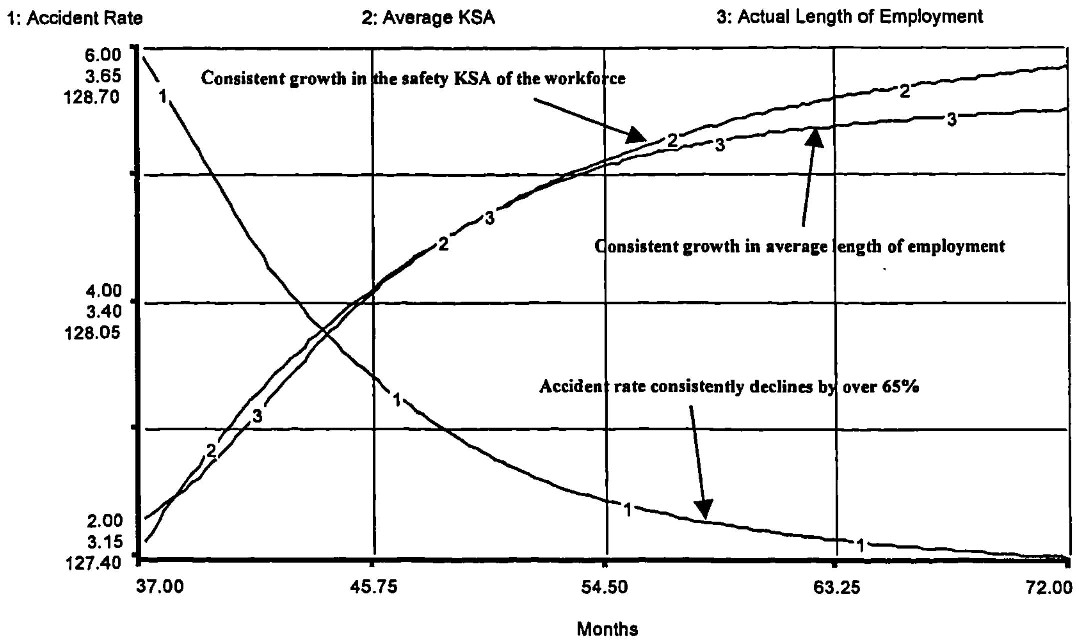

Figure 7.11 Changes in scenario four to the accident rate, average knowledge skills and attitude and actual length of employment over the three-year period

There is a large reduction in the accident rate, and increases in the average length of employment and average KSA. These outputs are logarithmic in shape, with the improvements lessening throughout the simulation. The increased training appears to have improved the performance of these output metrics, particularly in the first half of the simulation.

Figure 7.12 shows that the accumulation of Regulated Hazards increases over time and the active hazards decline in numbers. The additional safety training increases KSA, thus improving the way in which employees work with hazards. The result is that more hazards are able to stay contained in a safe state.

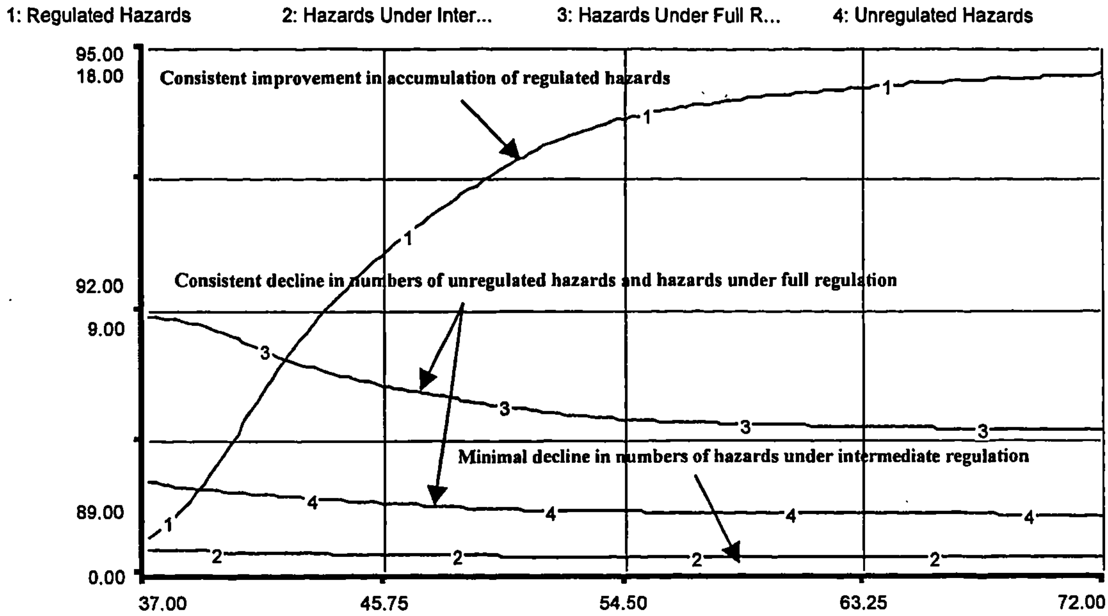

Figure 7.12 Changes in scenario four to the distribution of hazards over the three-year period

Figure 7.13 shows a continuous decline in both the costs of accidents and in the running of the safety management system, with the monthly costs halving by the end of the simulated period. The gap between accident and safety cost increases gradually throughout the period possibly for two reasons. The first as the employee KSA improves the amount of learning per unit of training is lower. The second may result from falling accident rates reducing costs whilst the cost of training remains a fixed cost of safety.

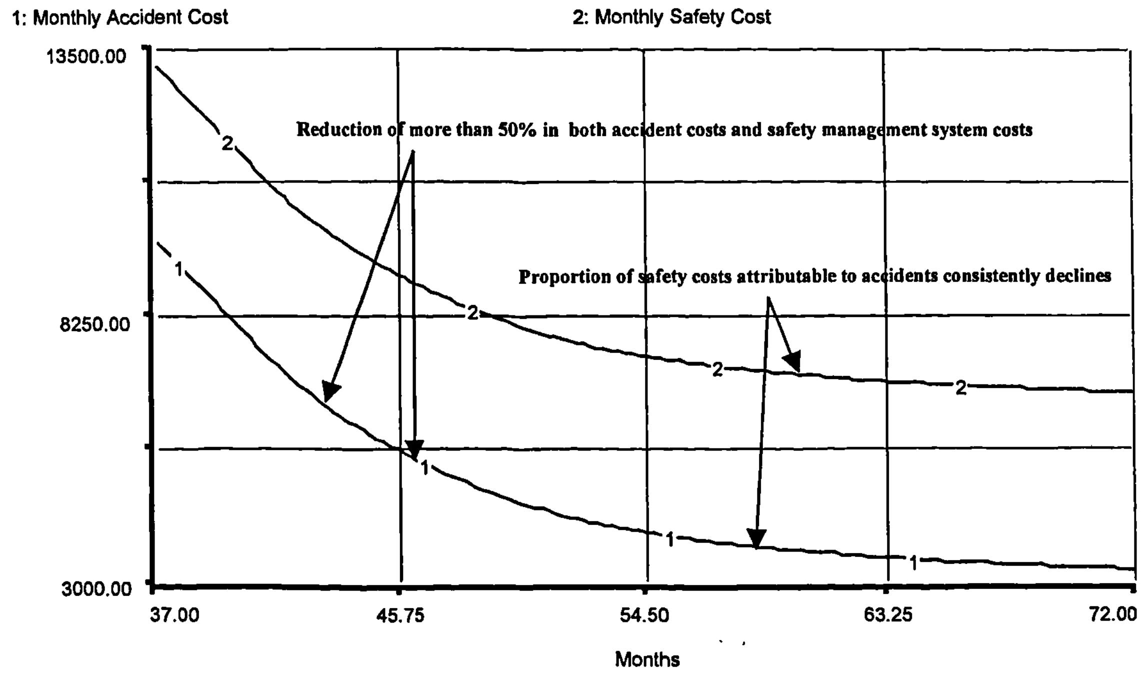

Figure 7.13 Changes in scenario three to the costs of accidents and running the safety management system over the three-year period

The 'intensive safety training' scenario suggests that increases to the volumes of training delivered improves both the numerical and behavioural outputs of the safety system. Waring (1996) warns that people can have a naïve expectation that training will produce miraculous changes in employee's behaviour and accident rates will dramatically fall. In this scenario the increase in the training policy brings about large improvements in the safety system's performance. This is not to say that the benefits have been achieved by training alone. Other policies used to control hazards, along with training, encourage these improvements.

(f) Scenario Five: Fully Integrated Safety Policies

Optimisation through repeated experimentation can be used with system dynamics models for policy design (Coyle, 1996). The 'fully integrated safety policies' scenario seeks to show how, after repeated simulation, a set of dynamic policies can be set which attempt to use resources more efficiently to bring about reductions in accidents and in safety costs. An objective function needs to be chosen for model optimisation. This is a measure of system performance and it is used to guide the optimisation search. It was decided ultimately to use Monthly Safety Cost as the objective function. The Accident Rate was not chosen for two reasons. Firstly, employers have a statutory duty under the HASAWA, 1974 to take 'reasonably practicable' measures to avoid risk and are allowed to balance costs and benefits. The second is the known association between spending money on suitable safety policies and on achieving low accident rates. The optimisation is based on what Coyle called hill-climbing. Through changing the values of important policies and repeating the simulation runs, there is a possibility that lower and lower safety costs can be achieved over time. Policy experiments would be constrained according to the feasibility of implementing these policies in the real safety system. Without the help of optimisation software a close to optimal result could not be achieved but a set of policies could be designed which indicate improved system performance. Training remained high throughout the simulation although it was reduced as accident rates improved. Also, as the accidents lessened, the intensity with which the other policies were pursued was lessened, as there was not the same need to use them. Figure 7.14 shows improved numerical performance against all the previous four scenarios. In comparison with the 'intensive safety training' scenario, the accident rate is considerably reduced as a result of the integrated policy changes. The rate of increase in the average length of employment and employee KSA is also higher.

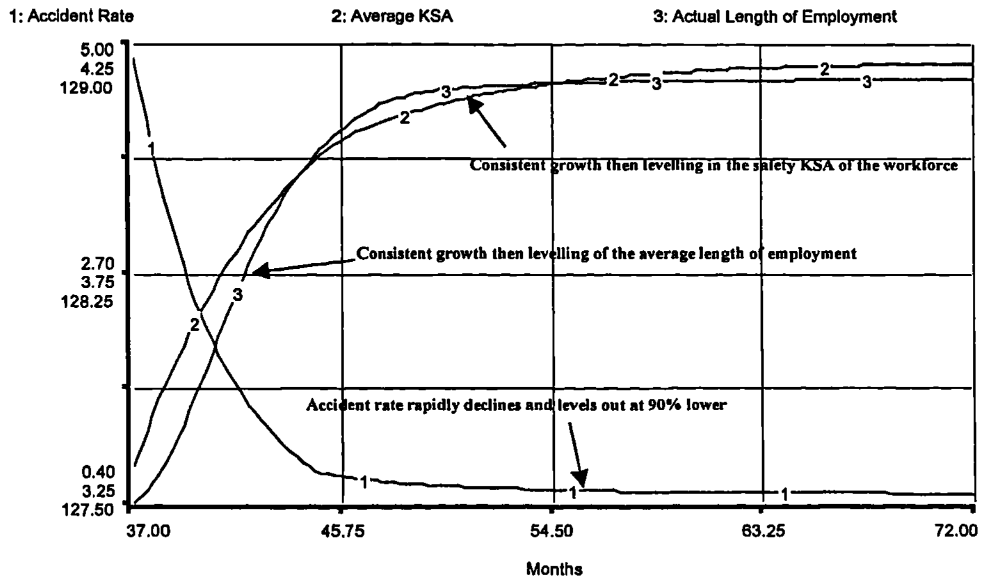

Figure 7.14 Changes in scenario five to the accident rate, average knowledge, skills and attitude and actual length of employment over the three-year period

Figure 7.15 shows improved numerical change to the distribution of hazards. More hazards than previous scenarios are in a regulated state.

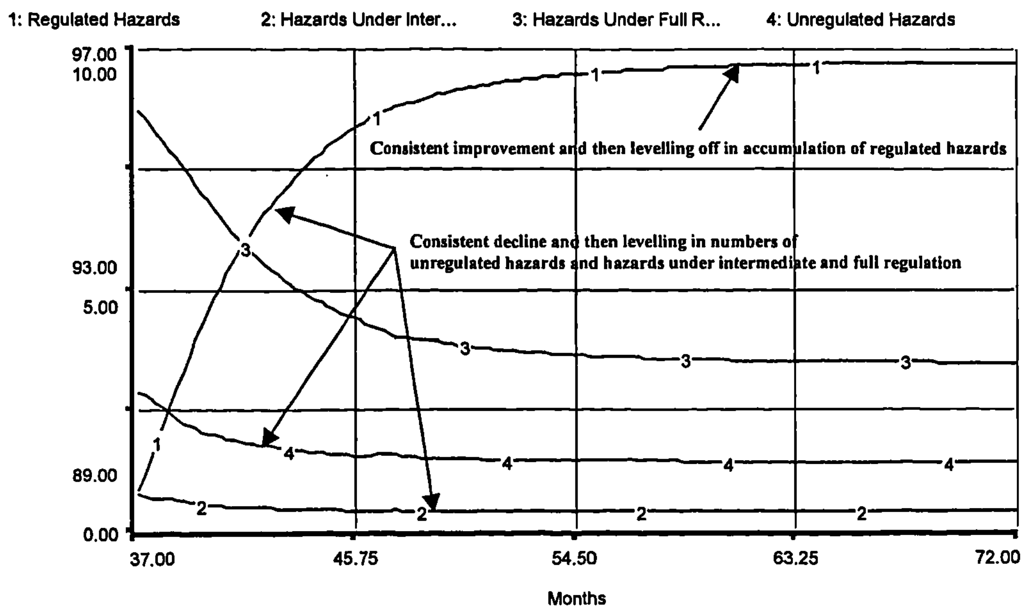

Figure 7.15 Changes in scenario five to the distribution of hazards over the three-year period

Figure 7.16 shows a substantial decline in the monthly accident and safety costs. The behaviour of the outputs is similar to the previous scenario but with improved numerical results.

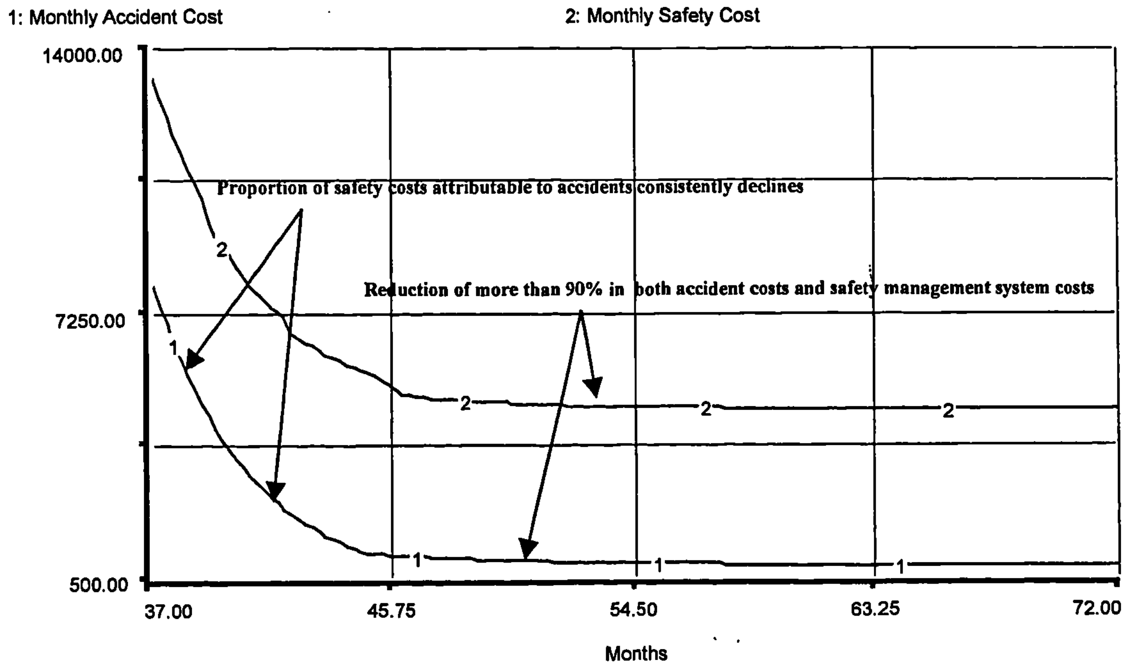

Figure 7.16 Changes in scenario three to the costs of accidents and running the safety management system over the three-year period

The results of the optimisation scenario have shown that the greatest system improvements can be brought about by integrated policy changes. The scenario showed that low accident rates and safety costs could be achieved given prudent policy design. With reference to the basic causal loop diagram of safety in Figure 5.3 the logic can be explained. The domination of the safety KSA loop strengthened throughout this scenario, and as people work more and more safely with hazards, this further reduces the importance of the policies contained around the proactive and reactive safety loops.

(g) Summary of Policy Scenario Tests

The five scenarios appear to suggest that alternative policy mixes have varying degrees of success in controlling the undesirable behaviour of outputs of the RWOSM. The analysis and discussion of these scenarios centred on the dynamic behaviour of many model outputs. It was important not only to know which policy caused changes in system behaviour but also why these changes came about. Adequate explanations of model behaviour have been given. It can also be important when assessing the performance of system dynamics models to measure the final values of simulations. Table 7.2 shows the cumulative accidents, cumulative safety costs, and final values for the accident rate and monthly safety costs for the five scenarios. Table 7.3 analyses the performance of these important metrics for each scenario in comparison to the first scenario or base run.

Output Metric	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Cumulative Accidents	316	272	268	108	36
Cumulative Safety Costs (£)	613,789	565,533	614,747	302,123	213,320
Final Accident Rate	12.12	8.98	8.72	2.00	0.49
Final Monthly Safety Cost (£)	22,515	17,716	18,841	6,730	807

Table 7.2 Comparison of important output metrics in alternative scenarios

Output Metric	Scenario 1 % Change Over Base Run	Scenario 2 % Change Over Base Run	Scenario 3 % Change Over Base Run	Scenario 4 % Change Over Base Run	Scenario 5 % Change Over Base Run
Cumulative Accidents	0	-14	-15	-66	-89
Cumulative Safety Costs (£)	0	-8	0	-51	-65
Final Accident Rate	0	-26	-28	-83	-96
Final Monthly Safety Cost (£)	0	-21	-16	-70	-96

Table 7.3 Comparison of percentage changes in important output metrics between alternative scenarios and the base run scenario

The results in Table 7.3 are encouraging to the policy analyst. All the scenarios where policy changes are made suggest improved system performance. It is evident that in scenarios two and three, hazard control alone would not be sufficient to improve the performance of the safety system substantially. Increased training is shown in scenarios four and five to be a policy which, if increased greatly, can offer even better accident and financial performance in the safety system. The results are so encouraging that they may even lead to the validity of the model being queried. There is a possibility that the parameters and equations concerned with training, learning and KSA were set up in the simulation to have too great an influence upon the simulation model's performance compared to reality. The structural assumptions of the model do allow the benefit of training to lessen as the employees get nearer to a perfect KSA, but there are no means of reflecting the employee complacency which may be brought about by over-training. Despite this criticism of the policy analysis, the changes in system behaviour brought about by the policy changes and the rank successes of the alternative scenarios certainly appear to be plausible. The validity of these findings is increased when the outcomes of the interview are noted. The managers had suggested that training was the policy which could offer the greatest improvements in the performance of their safety system.

7.5 Summary of the Interview Findings and Scenario Testing

The interview with the firm's managers was certainly constructive. Many opinions about the uses of the model were offered. Most comments appeared to consist of valid observations and suggestions. According to the firm's managers, the safety model could be just as easily used as an aid to understanding the structure and behaviour of occupational safety systems as in assisting strategic decision-making. The interviewees also introduced the idea of using the model in a demonstrative capacity. The model had acted as a catalyst for debate between the managers on the running of their safety system. However the lack of criticisms of the model by the interviewees is of concern. Understandably, in such a short period they had been unable to assimilate many of the principles of system dynamics modelling, and as a result they were limited in terms of what they could discuss. Despite this the validity of the interview findings appear to be acceptable, and one could conclude from the discussion that the group of managers found the simulation useful for dealing with safety management.

Policy analysis can be very intuitive and exploratory if the intention of the model user is to experiment with the safety model in order to understand the effects of various policy decisions. This approach was evident in the first four policy scenarios which were simulated. On the other hand, system dynamics simulation can be a detailed and rigorous process if the aim is to design improved policies for implementation in a real safety environment. This was the case with the final policy scenario. The process of continuous improvement in the safety system's behaviour was an emergent one, as learning occurred through simulating each scenario policy improvements could be made. It is evident from the range of plausible scenarios tested that the firm's managers can take policy-decisions based on the model outputs which should lead to improvement in the accident rate and costs of running safety.

In conclusion, the evaluation of the model by the host firm's managers and the range of policy scenarios presented have highlighted some deficiencies and limitations in the safety model's structure and uses. On balance, the evidence suggests that the target of delivering a useful and robust model for occupational safety learning and decision-making has been achieved.

CHAPTER EIGHT

Conclusions and Further Research Implications

8.1 Overview of the Study

This study provided a way of modelling occupational safety and accidents using system dynamics. Literature in the fields of occupational safety, systems thinking and other harder modelling approaches was investigated. The work has been exploratory as no other operational safety models appear to have been published. Using academic and practitioner literature, opinions of experts in the field of safety and personal assumptions, a generic system dynamics model of an occupational safety system has been built. It was subsequently tested with data derived from an industrial setting. A number of alternative empirically-based safety scenarios have been explored and appropriate policy decisions illustrated. The opinions of users of the model have been elicited in order to capture an understanding of the potential uses of the simulation as a pedagogic and decision-making aid.

The material presented in this thesis was divided into eight chapters. Chapter One introduced the broad parameters of the study. The importance of good occupational safety practice, the advantages of experimenting with models, and the aims and objectives of the work were asserted and presented. In Chapter Two the legislation surrounding occupational safety management was described, along with recent evidence on national rates of workplace accidents, and on the legal and financial costs of accidents. The components of a successful safety management system were outlined in Chapter Three. In Chapter Four the nature of systems thinking was spelt out and discussed along with the principles of system dynamics and its applications. Chapter Five showed how the generic system dynamics model of safety was developed and validated to represent a fully operational and dynamic safety system. The method of data collection within the host firm and the subsequent calibration of the model to represent the past behaviour of its safety system was described in Chapter Six. Chapter Seven presented the findings of a discussion with some of the host firm's managers on the use of the model, followed by detailed experimentation with a number of alternative policy scenarios. This final chapter presents a summary of the completed study and describes the future research implications.

8.2 Summary of the Development of the Model

The process of building, testing and evaluating the model was based loosely on a stepwise model building process recommended by Roberts *et al.* (1981, p.8). The development of the operational model fell into two parts. The first was the development of the generic occupational safety model and the second was the validation of the real world occupational safety model.

(a) Validating the Generic Occupational Safety Model

The published work on safety management was reviewed. It was found to be very narrow in scope, prescriptive and systematic in its approach. Systematic approaches to safety, as for example recommended by the HSE (1991a) in its publication *Successful Health and Safety Management* are valuable sources of information but are conceived and written in rather compartmentalised and mechanistic ways (Waring, 1996). Most of the researchers concerned with safety modelling discussed the application of probabilistic models. These were diagnostic rather than interpretative, and were neither dynamic nor strategic in nature. Fortunately, a few authors appeared to have taken a systemic view of occupational safety (Waring, 1990a, 1990b, 1996; Andersen *et al.*, 1986). The lack of published literature on the application of systems thinking, or more specifically system dynamics modelling to the evaluation of occupational safety strategy was turned into an advantage as it offered the opportunity to develop and test a completely new approach to decision-making in safety management.

The problem of accidents at work was clearly a dynamic one. The accident trend across a range of industries was shown in Figure 2.1 of Chapter Two. In most cases there was a clear downward movement in accident rates. A causal loop diagram was developed to explain the important causal linkages in occupational safety systems. This loop diagram, shown in Figure 5.3 of Chapter Five, proved to be an excellent vehicle for two reasons. First, it captured the underlying system structure driving the accident problem, and second it was used at a later point in the modelling process as an excellent medium to explain the reasons for the simulated behaviour. The causal loop diagram consisted of three feedback loops, one reinforcing and two balancing. The overall reinforcing nature of the diagram suggested that the problem of accidents was one that could be managed through implementation of alternative policies.

Using the causal loop diagram and information drawn from more detailed and specific literature, the full quantitative system dynamics model of an occupational safety system was constructed. As this was a new application for system dynamics, the model was subjected to a detailed methodological examination. Great emphasis was placed on continuous validation in an effort to ensure that the model was internally coherent. A number of structural validation tests were performed on the model, including structural verification and dimensional consistency checks for every parameter and equation. A number of behavioural tests were performed to evaluate the robustness of the model's structure to the introduction of parameter changes. These consisted of extreme behaviour tests and a rigorous set of sensitivity tests. It was evident from these experiments that the model parameters to which the simulation was most sensitive were associated with employees. This raised the question as to how dominant the reinforcing Safety Knowledge, Skills and Attitude loop was over system behaviour.

The structure of the generic model offered the ability for plausible safety behaviour representative of a real occupational safety system to be generated. In particular, the range of validation tests showed that one could have a measure of faith in the essential assumptions behind the model. If an operational system dynamics model were to be accepted as a good representation of reality then it would need to be tested empirically.

(b) Validating the Real World Occupational Safety Model

The latter half of the modelling effort concentrated on testing the model with real world data. A detailed case study of accidents at work was undertaken in a medium-sized manufacturer in Central Scotland. The host firm was unlike many other manufacturers in that its accident trend had not shown significant improvement in recent years.

However its safety record was still much better than most in its industrial sector. This different trend affirmed the importance of the ability of the model to replicate a range of accident behaviour, and served to justify the rigorous and methodical approaches to sensitivity testing in the generic model. The purpose of validating the generic model with empirical data was to test whether the model could be simulated to match the historically observed outputs of the firm's safety system, then to use the simulation to identify future improved safety scenarios.

The generic model was translated into a real world model through the parameterisation of the model with a large volume of hard and descriptive data gathered from the host firm. Most of the harder data was obtained through the firm's archives, whilst the more subjective data was elicited from discussions with managers and the survey responses of line employees. This data was collected below the level of aggregation in the model and summarised into a suitable form for numerical parameter verification. The real world model was calibrated to fit the firm through modifications to the less accurately measured constants and the hypothetical table functions.

The behaviour reproduction test showed that the simulation model produced an adequate replication of past accidents and distributions of hazards in the firm. This added greatly to the confidence that the firm's managers placed in the model outputs. As far as they were concerned this was the most important test of model validation.

8.3 Uses of the Real World Occupational Safety Model

The real world model was not only built to demonstrate that a system dynamics model could replicate the behaviour of a historical safety system but as a means of improving understanding of how policy decisions made in a complex system affect the performance of workplace safety.

(a) Using the Occupational Safety Model as a Heuristic Teaching Tool or for Policy-Making

The discussion with the managers of the host firm led to insights into the potential of the model as a pedagogic tool in either a generic or real world form. It was suggested that people who were unfamiliar with safety management could experiment with the model to learn about the effects that potential safety decisions would have on accidents. Setting up the model as a gaming tool was seen as important to helping people learn about safety. Comments were made about people being more inclined to play with the model in an edutainment form, and through playing they would actually learn.

It was evident from the discussion that the managers were particularly interested in using the model at a lower level for learning, and at a higher level for policy analysis. They did not offer blind faith in the model but suggested that they were prepared to follow the policies that the simulation showed to be desirable, while monitoring how accurately the predictions of behaviour were. They also mentioned that they could put more resources into the policies which the model suggested exerted the most leverage over the system's performance. The findings suggested that they had placed enough confidence in the recommendations of the model.

The managers raised the idea of using the model in a demonstrative capacity. They saw the opportunity to interest Company Directors in the importance of safety management. The model had also served as a catalyst for debate about safety issues within the firm. Had the model not focused the attention of the managers on the more strategic aspects of safety management then some of the debate about safety practice in the firm may not have evolved as far as it did.

(b) Policy Analysis Using the Real World Occupational Safety Model

A range of feasible policy scenarios aimed at improving the future accident situation and costs of safety in the host firm were explored. The simulation outputs appeared to be plausible for each scenario tested. The policy tests showed how improvements in system performance could be brought about by running simulations and then examining a range of output metrics to understand the changes if any, brought about by alternative decisions. Clearly the decisions which concerned improvements to employee knowledge, skills and attitude were shown to improve the accident and financial performance of the firm's safety system.

8.4 The Main Limitations of the Study

Due to the complexities involved in the operation of a safety management system, there was the danger of introducing error at every stage of the model building process. The introduction of error, especially at the earlier stages of any simulation model may set serious limitations on the credibility and usefulness of a model. This worry gave rise to the prominence of model validation as a theme throughout the work. Inevitably as with any study there are limitations which cannot be fully resolved. This section lists the five principal limitations to this modelling study.

There may be errors built into the structural assumptions of the model. Important equations and parameters may have been excluded. A model is a simplification of reality, and it has to be accepted that not every factor that affects safety can be included in its structure. Through careful examination of the safety literature the attributes of safety considered to contribute most strongly to accident behaviour were included in the generic model. Their inclusion was supported by both structural and parameter verification tests. The rigorous sensitivity tests sought to further verify the internal consistency of the model to help identify and remove any structure causing erroneous model behaviour.

Further errors may have been introduced in the validation and calibration of the real world model. The ability of the model to replicate past safety behaviour in the host firm would be partly influenced by the accuracy with which model parameters were validated numerically. The comprehensive methods of data collection below the level of model aggregation sought to minimise this error. Despite this, comparing the observed hazard distribution against the simulated one showed that there was a systematic error associated with bias. This was attributed to the underestimation of the transience of the hazard states. This was considered to be acceptable for the purpose of the study because it did not affect any underlying policy decisions.

There was also the possibility that the process of calibrating the real world model may have resulted in the Safety Training Policy having more influence over safety performance than it has in reality. There is no doubt that it could exert great influence over the performance of the system. It may have been prudent to introduce an attribute to the model to represent 'training fatigue', to show the results of over-training.

Another limitation of the work involves the managers of the host firm. They were not involved in the model building process other than helping with some data collection. A number of authors such as Richardson and Pugh (1981) and Vennix *et al.* (1996, 1997) rightly suggested that insights are more likely to come out of the process of modelling rather than products of the modelling study. When a client cannot be involved in the modelling process, the tasks of the modeller is harder, and the likelihood of the results being implemented is diminished. This possibility has to be accepted as a limitation of this work.

A final limitation of the model may lie in the fact that the simulation can only suggest which policies will help, not how those policies should be introduced into a system. The process of implementing policy recommendations is likely to generate a whole set of problems.

8.5 Suggestions for Further Research

There is a great deal of scope for further work using the occupational safety model. The managers of the host firm suggested that the model outputs had confirmed their suspicions that training was the policy which had the capacity to exert the most influence over the accident trend. They indicated that they were likely to increase the level of training within their firm. If the firm did this, it could be revisited to see which policies were adopted, and if they were successfully implemented did the model's behaviour prediction hold true?

The real world model was tested in only one firm. This does not confirm that the model can be applied in all workplaces. All it indicates is that it was successfully tested in one. Further confidence in the model could be built if it was tested for a number of different workplaces and a range of plausible but different modes of safety behaviour could be exhibited. It may become evident as the model is calibrated to replicate occupational safety in different workplaces that some of the structure may need to be overhauled or even further structure introduced.

As it is the feedback structure of a system dynamics model that tends to be a strong determinant of its behaviour over time, policy improvement often involves the addition of new feedback links that represent improved ways of manipulating available information in the system. This can be achieved through the addition of model structure to represent policy alternatives rather than simply changing the numerical values of policy parameters. The occupational safety model's structure was fixed throughout its testing with the host firm. Given the intention of applying the model to a range of different types of firm a problem may arise if the present model structure fails to replicate the behaviour of safety in a particular firm. The limitation may lie in the fact that the model's structure remains fixed throughout the simulation. Coyle (1996) may have a clear answer to this. He suggests that in order to experiment more conveniently with structural options in a system dynamics model the introduction of structural parameters may be appropriate. A 'binary structural parameter' having a value of zero or one can allow model behaviour to be tested by switching feedback loop structure on and off. Alternatively, using a 'continuous structural parameter' which can have a value from zero to one can be used to look at the behaviour of the model given experimentation with different weightings attached to parts of the feedback structure. Using this approach, 'several occupational safety models' can be stored within one grand occupational safety model, and the opportunity is at hand to use certain feedback structure when appropriate for different firms.

The development of optimisation software to support policy analysis and design has been one of the more substantial developments in the field of system dynamics since its inception. In Section 7.3f of Chapter Seven, a scenario was examined using manual optimisation, known as hill climbing. Unfortunately, the Ithink software does not support optimisation software. There is the potential to translate the occupational safety simulation model into system dynamics software which has an optimisation facility (DYSMAP, COSMIC or Vensim) and search for better policies with the aid of optimisation. It would be interesting to determine whether there would be a significant difference between the chosen objective functions, i.e. accidents or safety costs using manual or software facilitated optimisation. These results may add to the debate amongst system dynamics modellers as to the appropriateness of simulation through optimisation.

8.6 Summary of the Occupational Safety Modelling Study

With regard to the purpose of the study, the aim and objectives of the study appear to have been met in full. Knowledge of system dynamics modelling and its applications has been demonstrated. A model of accidents at work has been produced, calibrated carefully and tested with data from a real firm. The model has been able to simulate a range of alternative future scenarios, which if implemented could reduce accidents at work and the costs of running a safety management system. The work is exploratory, and contributes to the body of knowledge surrounding strategic decision-making in occupational safety management and also to the literature on systems modelling.

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APPENDIX A

Note on the Use of MIN Statements in Model Equations

In system dynamics modelling there are invariably several ways of solving any given problem. MIN statements should only be used when the logic of the model requires them and never to cover up strange behaviour (Coyle, 1996). MIN can be used as a limiting function in an equation. For example the expression MIN(A,B) takes the value of A or B, whichever is the lesser (Richardson and Pugh, 1981).

The MIN function appears in one equation in Appendix A (Accident Reports Completed) and three equations in Appendix C (Hazard Identification Rate, Hazards Arrive for Full Regulation and Hazards Become Regulated). The underlying structure of these four equations is the same and takes the form:

Outflow.KL = MIN(Level.K/Time to Clear Backlog,Indicated Outflow)

The inclusion of the MIN function in the above rate equation prevents the *Level* becoming negative under the circumstances where the *Indicated Outflow* is greater than the *Level/Time to Clear Backlog*. *Indicated Outflow* is a constraint used to impose a maximum capacity or ceiling on the *Outflow* or process rate. Using the MIN statement returns the smaller value among *Level/Time to Clear Backlog* and *Indicated Outflow*.

The *Time to Clear Backlog* is a time constant. Richardson and Pugh (1981, p.142) suggest that a time constant represents the average lifetime or average dwell time of an item in a level. In this formulation the dwell time for an item in the *Level* is represented by a management's intention to turn around the contents of a level in a given time.

Accident Reporting Sector

Accident Reporting Equations

Accident_Reports_Being_Processed(t) = Accident_Reports_Being_Processed(t - dt) + (Accident_Reports_In - Accident_Reports_Completed) * dt
INIT Accident_Reports_Being_Processed = 2.06

Accident_Reports_In = Accident_Rate*Proportion_of_Accidents_Reported
Accident_Reports_Completed =
MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog, Accident_Reporting_Policy/Accident_Reporting_Time)
Cumulative_Accident_Reporting_Cost(t) = Cumulative_Accident_Reporting_Cost(t - dt) + (Monthly_Accident_Reporting_Cost) * dt
INIT Cumulative_Accident_Reporting_Cost = 0

Monthly_Accident_Reporting_Cost =
Accident_Reporting_Policy*Accident_Reporting_Cost
Cumulative_Accident_Reports(t) = Cumulative_Accident_Reports(t - dt) + (Accident_Reports_Completed) * dt
INIT Cumulative_Accident_Reports = 0

Accident_Reports_Completed =
MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog, Accident_Reporting_Policy/Accident_Reporting_Time)
Accident_Reporting_Cost = 100
Accident_Reporting_Policy = 25
Accident_Reporting_Time = 10
Proportion_of_Accidents_Reported = 1
Time_to_Clear_Accident_Report_Backlog = 1

Accident Reports Being Processed

Accident Reports Being Processed is a level. It represents the accidents reports which are awaiting attention.

Accident Reports Being Processed.K = Accident Reports Being Processed.J (Accident Reports) + {Accident Reports In.JK (Accident Reports/Month) - Accident Reports Completed.JK (Accident Reports/Month)} * DT (Month)

Units: Accident Reports

$$\text{Accident Reports Being Processed} = [AR] + \left(\frac{[AR]}{[T]} - \frac{[AR]}{[T]}\right) \times [T]$$
$$= [AR]$$

Accident Reports In

Accident Reports In is a rate equation. It is the new additions in the given month to the accident reports stock. The rate is dependent upon accidents being generated in the given month. Every time an accident occurs, no matter how minor it should be reported, as there is a need at least to document it in an accident records log book. In many cases a full accident report and investigation are needed (Stranks, 1994a).

Accident Reports In.KL = Accident Rate.KL (Accidents/Month) * Proportion of Accidents Reported (Accident Reports/Accident)

Units: Accident Reports per Month

$$\text{Accident Reports In} = \frac{[A]}{[T]} \times \frac{[AR]}{[A]}$$
$$= [AR] \times [T]^{-1}$$

Accident Reports Completed

Accident Reports Completed is a rate equation. It represents the accident reports processed in a given month. The rate is dependent upon the minimum of Accident Reports Being Processed; and time dedicated to accident reporting divided by the time it takes to process one accident report.

Accident Reports Completed.KL = MIN{Accident Reports Being Processed.K (Accident Reports)/Time to Clear Accident Report Backlog (Months), Accident Reporting Policy (Hours/Month)/Accident Reporting Time (Hours/Accident Report)}

Units: Accident Reports per Month

$$\text{Accident Reports Completed} = \frac{[AR]}{[T]}, \frac{[T]}{[T]} \Big/ \frac{[T]}{[AR]}$$
$$= [AR] \times [T]^{-1}$$

Cumulative Accident Reporting Cost

Cumulative Accident Reporting Cost is a level. It represents the cost to date of the Accident Reporting Policy.

Cumulative Accident Reporting Cost.K = Cumulative Accident Reporting Cost.J (£'s) + Monthly Accident Reporting Cost.JK (£'s/Month) * DT (Month)

Units: £'s

$$\text{Cumulative Accident Reporting Cost} = [C] + \frac{[C]}{[T]} \times [T]$$
$$= [C]$$

Monthly Accident Reporting Cost

Monthly Accident Reporting Cost is a rate. It represents the cost in a given month of the Accident Reporting Policy. The rate is dependent upon the time dedicated to accident reporting multiplied by the cost per hour of accident reporting.

Monthly Accident Reporting Cost.KL = Accident Reporting Policy (Hours/Month) * Accident Reporting Cost (£'s/Hour)

Units: £'s per Month

$$\text{Monthly Acident Reporting Cost} = \frac{[T]}{[T]} \times \frac{[C]}{[T]}$$
$$= [C] \times [T]^{-1}$$

Cumulative Accident Reports

Cumulative Accident Reports is a level. It represents the completed accident reports to date.

Cumulative Accident Reports.K = Cumulative Accident Reports.J (Accident Reports) + Accident Reports Completed.JK (Accident Reports/Month) * DT (Month)

Units: Accident Reports

$$\text{Cumulative Accident Reports} = [AR] + \frac{[AR]}{[T]} \times [T]$$
$$= [AR]$$

Accident Reporting Cost

Accident Reporting Cost is a constant. It represents the hourly cost incurred when processing accident reports.

Accident Reporting Cost (£'s/Hour)

Units: £'s per Hour

$$\text{Accident Reporting Cost} = \frac{[C]}{[T]} = [C] \times [T]^{-1}$$

Accident Reporting Policy

Accident Reporting Policy is a constant. It represents the man-hours in a given month dedicated to accident report writing and accident investigation.

Accident Reporting Policy (Hours/Month)

Units: Hours per Month

$$\text{Accident Reporting Policy} = \frac{[T]}{[T]} \text{ i.e. [Dimensionless]}$$

Accident Reporting Time

Accident Reporting Time is a constant. It represents the time required to process an accident report.

Accident Reporting Time (Hours/Accident Report)

Units: Hours per Accident Report

$$\text{Accident Reporting Time} = \frac{[T]}{[AR]} = [T] \times [AR]^{-1}$$

Proportion of Accidents Reported

Proportion of Accidents Reported is a constant. It represents the proportion of accidents which are reported to the safety function, as an accident report can only be produced if the accident is reported.

Proportion of Accidents Reported (Accidents Reports/Accidents)

Units: Accident Reports per Accident

$$\text{Proportion of Accidents Reported} = \frac{[AR]}{[A]} = [AR] \times [A]^{-1}$$

Time to Clear Accident Report Backlog

Time to Clear Accident Report Backlog is a time constant. It represents the management policy or intention to turn around an accident report in a given time.

Time to Clear Accident Report Backlog (Months)

Units: Months

Time to Clear Accident Report Backlog = [T]

APPENDIX B

Accidents Sector

Accidents Equations

Cumulative_Accidents(t) = Cumulative_Accidents(t - dt) + (Accident_Rate) * dt
INIT Cumulative_Accidents = 0

Accident_Rate = Accident_Incidence*Labour
Cumulative_Accident_Cost(t) = Cumulative_Accident_Cost(t - dt) + (Monthly_Accident_Cost) * dt
INIT Cumulative_Accident_Cost = 0

Monthly_Accident_Cost = Accident_Rate*Cost_per_Accident
Accident_Incidence = ((Unregulated_Hazards/Unregulated_Hazard_Regulation_Weighting)+(Hazards_Under_Intermediate_Regulation/Intermediate_Hazard_Regulation_Weighting)+(Hazards_Under_Full_Regulation/Full_Hazard_Regulation_Weighting))*Risk
Cost_per_Accident = 100
Full_Hazard_Regulation_Weighting = 2
Intermediate_Hazard_Regulation_Weighting = 1.5
Unregulated_Hazard_Regulation_Weighting = 1
Risk = GRAPH(Average_KSA)
(0.00, 0.05), (0.5, 0.049), (1.00, 0.0473), (1.50, 0.0383), (2.00, 0.021), (2.50, 0.017), (3.00, 0.0138), (3.50, 0.0105), (4.00, 0.007), (4.50, 0.003), (5.00, 0.00)

Cumulative Accidents

Cumulative Accidents is a level. It represents the total accidents occurring to date.

Cumulative Accidents.K = Cumulative Accidents.J (Accidents) + Accident Rate.JK (Accidents/Month) * DT (Month)

Units: Accidents

$$\text{Cumulative Accidents} = [A] + \frac{[A]}{[T]} \times [T]$$
$$= [A]$$

Accident Rate

Accident Rate is a rate. It represents the monthly accident rate. The rate is dependent upon the Accident Incidence per employee and the size of the Labour force.

Accident Rate.KL = Accident Incidence.K (Accidents/Employee/Month) * Labour.K (Employees)

Units: Accidents per Month

$$\text{Accident Rate} = \left(\frac{[A]}{[E]} \Big/ [T] \right) \times [E]$$
$$= [A] \times [T]^{-1}$$

Cumulative Accident Cost

Cumulative Accident Cost is a level. It represents the cost of accidents to date.

Cumulative Accident Cost.K = Cumulative Accident Cost.J (£'s) + Monthly Accident Cost.JK (£'s/Month) * DT (Month)

Units: £'s

$$\text{Cumulative Accident Cost} = [C] + \frac{[C]}{[T]} \times [T]$$
$$= [C]$$

Monthly Accident Cost

Monthly Accident Cost is a rate. It represents the cost of accidents in a given month.

Monthly Accident Cost.KL = Accident Rate.KL (Accidents/Month) * Cost per Accident (£'s/Accident)

Units: £'s per Month

$$\text{Monthly Accident Cost} = \frac{[A]}{[T]} \times \frac{[C]}{[A]}$$
$$= [C] \times [T]^{-1}$$

Accident Incidence

Accident Incidence is an auxiliary rate. It represents the monthly accidents per employee.

For an accident to occur a hazard has to be present, and that hazard must have a risk attached to it. In order to cause an injury accident an employee must be present. A rather complicated calculation is required to show how hazards and the associated risks interact in order to generate an accident.

The hazard moves through a self-renewing life cycle. If the hazard is fully regulated it is inactive and poses no danger, therefore it can not contribute towards an accident. In its other three hazard states it is active and has the potential to cause harm. The probability that it will cause harm lessens as it moves through the unregulated, intermediately regulated and fully regulated states. In the equation for deriving accident incidence, weightings are attached to each active hazard state with the effect that the weighting diminishing as the hazard moves through its life cycle.

There is always a risk associated with an active hazard as the workforce will never achieve perfect KSA's. Summating the hazards divided by their associated weightings, then multiplying the sum by the risk will produce a synthetic value which represents the Accident Incidence per employee.

Accident Incidence Rate.KL = {Hazards Under Full Regulation.K (Hazards) /Full Hazard Regulation Weighting (Hazard/Hazards/Month)} + {Hazards Under Intermediate Regulation.K (Hazards)/Intermediate Hazard Regulation Weighting (Hazard/Hazards/Month)} + {Unregulated Hazards.K (Hazards)/Unregulated Hazard Regulation Weighting (Hazard/Hazards/Month)} * Risk (Accidents/Hazard/Employee)

Units: Accidents per Employee per Month

$$\text{Accident Incidence Rate} = \left(\frac{[H]}{[H]}\times\frac{[H]}{[T]}+\frac{[H]}{[H]}\times\frac{[H]}{[T]}+\frac{[H]}{[H]}\times\frac{[H]}{[T]}\right)\times\frac{[A]}{[H]}\times\frac{1}{[E]}$$
$$= [A]\times[E]^{-1}\times[T]^{-1}$$

Cost per Accident

Cost per Accident is a constant. It represents the cost incurred for every accident. Costs include:
indemnity insurance;
first-aid treatment;
absence from work; and
property damage.

Cost per Accident (£'s/Accident)

Units: £'s per Accident

$$\text{Cost per Accident} = \frac{[C]}{[A]}$$
$$= [C]\times[A]^{-1}$$

Full Hazard Regulation Weighting

Full Hazard Regulation Weighting is a constant. It represents the contribution that a hazard presently receiving full regulation will make towards an accident per month. Full Hazard Regulation Weighting (Hazard/Hazards/Month)

Units: Hazards per Hazard per Month

$$\text{Full Hazard Regulation Weighting} = \frac{[H]}{[H]} \Big/ [T] = [T]^{-1}$$

Intermediate Hazard Regulation Weighting

Intermediate Hazard Regulation Weighting is a constant. It represents the contribution that a hazard presently receiving intermediate regulation will make towards an accident per month.

Intermediate Hazard Regulation Weighting (Hazard/Hazards/Month)

Units: Hazards per Hazard per Month

$$\text{Intermediate Hazard Regulation Weighting} = \frac{[H]}{[H]} \Big/ [T] = [T]^{-1}$$

Unregulated Hazard Regulation Weighting

Unregulated Hazard Weighting is a constant. It represents the contribution that an unregulated hazard will make towards an accident per month.

Unregulated Hazard Weighting (Hazard/Hazards/Month)

Units: Hazards per Hazard per Month

$$\text{Unregulated Hazard Regulation Weighting} = \frac{[H]}{[H]} \Big/ [T] = [T]^{-1}$$

Risk

Risk is a table function. It represents the likelihood that a hazard will result in an accident to an employee. It converts active hazards into accidents per employee. It is dependent upon the Average KSA that employees possess. The structural assumption is that the relationship is negative and logistical. The x-axis consists of a range between zero, representing an Average Safety KSA of zero, and five representing a perfect Average Safety KSA. Risk, on the y-axis is set between zero and 0.1. Preliminary sensitivity tests showed that if Risk was set beyond the 0.1 maximum then rather erroneous and exaggerated outputs were experienced in the model's behaviour.

Risk = Table{Average KSA.K}

Units: Accidents per Hazard per Employee

$$\text{Risk} = \frac{[A]}{[H]} \Big/ [E]$$
$$= [A] \times [H]^{-1} \times [E]^{-1}$$

APPENDIX C

Hazard Processing Sector

Hazard Processing Equations

Cumulative_Full_Hazard_Regulation_Cost(t) =
Cumulative_Full_Hazard_Regulation_Cost(t - dt) +
(Monthly_Full_Hazard_Regulation_Cost) * dt
INIT Cumulative_Full_Hazard_Regulation_Cost = 0

Monthly_Full_Hazard_Regulation_Cost =
Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost
Cumulative_Intermediate_Hazard_Regulation_Cost(t) =
Cumulative_Intermediate_Hazard_Regulation_Cost(t - dt) +
(Monthly_Intermediate_Hazard_Regulation_Cost) * dt
INIT Cumulative_Intermediate_Hazard_Regulation_Cost = 0

Monthly_Intermediate_Hazard_Regulation_Cost =
Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost
Cumulative_Safety_Monitoring_Cost(t) = Cumulative_Safety_Monitoring_Cost(t - dt)
+ (Monthly_Safety_Monitoring_Cost) * dt
INIT Cumulative_Safety_Monitoring_Cost = 0

Monthly_Safety_Monitoring_Cost =
Safety_Monitoring_Policy*Safety_Monitoring_Cost
Hazards_Under_Full_Regulation(t) = Hazards_Under_Full_Regulation(t - dt) +
(Hazards_Arrive_for_Full_Regulation - Hazards_Become_Regulated) * dt
INIT Hazards_Under_Full_Regulation = 1.36

Hazards_Arrive_for_Full_Regulation =
MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Interm
ediate_Regulation_Backlog,Intermediate_Hazard_Regulation_Policy/Intermediate_Haz
ard_Regulation_Time)
Hazards_Become_Regulated =
MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulatio
n_Backlog,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)

Hazards_Under_Intermediate_Regulation(t) =
Hazards_Under_Intermediate_Regulation(t - dt) + (Identification_Rate - Hazards_Arrive_for_Full_Regulation) * dt
INIT Hazards_Under_Intermediate_Regulation = 1.36

Identification_Rate = MIN(Unregulated_Hazards/Time_to_Identify_Unregulated Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Hazards_Arrive_for_Full_Regulation =
MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Regulated_Hazards(t) = Regulated_Hazards(t - dt) + (Hazards_Become_Regulated - Hazard_Generation_Rate) * dt
INIT Regulated_Hazards = 85

Hazards_Become_Regulated =
MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation_Backlog,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Unregulated_Hazards(t) = Unregulated_Hazards(t - dt) + (Hazard_Generation_Rate - Identification_Rate) * dt
INIT Unregulated_Hazards = 1.36

Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Identification_Rate =
MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Full_Hazard_Regulation_Cost = 10
Full_Hazard_Regulation_Policy = 15
Full_Hazard_Regulation_Time = 10
Intermediate_Hazard_Regulation_Cost = 10
Intermediate_Hazard_Regulation_Policy = 5
Intermediate_Hazard_Regulation_Time = 2
RBAAIH =
(Unregulated_Hazards+Hazards_Under_Intermediate_Regulation+Hazards_Under_Full_Regulation)/Regulated_Hazards
Safety_Monitoring_Cost = 10
Safety_Monitoring_Policy = 20
Time_to_Clear_Hazards_Under_Full_Regulation_Backlog = 1
Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog = 1
Time_to_Identify_Unregulated_Hazards = 1
Accident_Repeater = GRAPH(Accident_Reports_Completed)
(1.00, 0.00), (2.00, 0.01), (3.00, 0.02), (4.00, 0.03), (5.00, 0.04), (6.00, 0.055), (7.00, 0.07), (8.00, 0.085), (9.00, 0.1), (10.0, 0.125), (11.0, 0.165), (12.0, 0.215), (13.0, 0.265), (14.0, 0.32), (15.0, 0.365), (16.0, 0.425), (17.0, 0.49), (18.0, 0.545), (19.0, 0.6), (20.0, 0.68)
Hazards_Identified_from_Safety_Monitoring = GRAPH(Safety_Monitoring_Policy)
(0.00, 0.00), (10.0, 0.125), (20.0, 0.325), (30.0, 0.575), (40.0, 0.925), (50.0, 1.53), (60.0, 3.15), (70.0, 4.35), (80.0, 4.73), (90.0, 4.93), (100, 5.00)

Unsafe_Acts = GRAPH(Average_KSA)
(0.00, 0.1), (0.5, 0.099), (1.00, 0.098), (1.50, 0.096), (2.00, 0.089), (2.50, 0.074), (3.00, 0.038), (3.50, 0.022), (4.00, 0.016), (4.50, 0.012), (5.00, 0.009)

Cumulative Full Hazard Regulation Cost

Cumulative Full Hazard Regulation Cost is a level. It represents the cost to date of the Full Hazard Regulation Policy.
Cumulative Full Regulation Cost.K = Cumulative Full Regulation Cost.J (£'s) + Monthly Full Regulation Cost.JK (£'s/Month) * DT (Month)

Units: £'s

$$\text{Cumulative Full Hazard Regulation Cost} = [C] + \frac{[C]}{[T]} \times [T] \\ = [C]$$

Monthly Full Hazard Regulation Cost

Monthly Full Hazard Regulation Cost is a rate. It represents the cost of the Full Hazard Regulation Policy in a given month. The rate is dependent upon the time per month dedicated to full hazard regulation and the hourly cost of that activity.

Monthly Full Hazard Regulation Cost.KL = Full Hazard Regulation Policy (Hours/Month) * Full Hazard Regulation Cost (£'s/Hour)

Units: £'s per Month

$$\text{Monthly Full Hazard Regulation Cost} = \frac{[T]}{[T]} \times \frac{[C]}{[T]} \\ = [C] \times [T]^{-1}$$

Cumulative Intermediate Hazard Regulation Cost

Cumulative Intermediate Hazard Regulation Cost is a level. It represents the cost to date of the Intermediate Hazard Regulation Policy.

Cumulative Intermediate Hazard Regulation Cost.K = Cumulative Intermediate Hazard Regulation Cost.J (£'s) + Monthly Intermediate Hazard Regulation Cost.JK (£'s/Month) * DT [Month]

Units: £'s

$$\text{Cumulative Intermediate Regulation Cost} = [C] + \frac{[C]}{[T]} \times [T] \\ = [C]$$

Monthly Intermediate Hazard Regulation Cost

Monthly Intermediate Hazard Regulation Cost is a rate. It represents the cost of the Intermediate Hazard Regulation Policy in a given month. The rate is dependent upon the time per month dedicated to intermediate hazard regulation and the hourly cost of that activity.

Monthly Intermediate Hazard Regulation Cost.KL = Intermediate Hazard Regulation Policy (Hours/Month) * Intermediate Hazard Regulation Cost (£'s/Hour)

Units: £'s per Month

$$\text{Monthly Intermediate Hazard Regulation Cost} = \frac{[T]}{[T]} \times \frac{[C]}{[T]} \\ = [C] \times [T]^{-1}$$

Cumulative Safety Monitoring Cost

The Cumulative Safety Monitoring Cost is a level. It represents the total cost to date of the Safety Monitoring Policy.

Cumulative Safety Monitoring Cost.K = Cumulative Safety Monitoring Cost.J (£'s) + {Safety Monitoring Policy (Hours/Month) * Safety Monitoring Cost (£'s/Hour)} * DT (Month)

Units: £'s

$$\text{Cumulative Safety Monitoring Cost} = [C] + \frac{[T]}{[T]} \times \frac{[C]}{[T]} \times [T] \\ = [C]$$

Monthly Safety Monitoring Cost

Monthly Safety Monitoring Cost is a rate. It represents the cost of the Safety Monitoring Policy in a given month. The rate is dependent upon the time per month dedicated to safety monitoring and the hourly cost of that activity.

Monthly Safety Monitoring Cost.KL = Safety Monitoring Policy (Hours/Month) * Safety Monitoring Cost (£'s/Hour)

Units: £'s per Month

$$\text{Monthly Safety Monitoring Cost} = \frac{[T]}{[T]} \times \frac{[C]}{[T]} \\ = [C] \times [T]^{-1}$$

Hazards Under Full Regulation

Hazards Under Full Regulation is a level. It represents active hazards which are receiving full remedial attention.

Hazards Under Full Regulation.K = Hazards Under Full Regulation.J (Hazards) + {Hazards Arrive For Full Regulation.JK (Hazards/Month) - Hazards Become Regulated.JK (Hazards/Month)} * DT (Month)

Units: Hazards

$$\text{Hazards Under Full Regulation} = [H] + \left(\frac{[H]}{[T]} - \frac{[H]}{[T]}\right) \times [T]$$
$$= [H]$$

Hazards Arrive for Full Regulation

Hazards Arrive for Full Regulation is a rate. It represents the hazards in a given month which move from receiving intermediate regulation to full regulation. The rate is dependent upon the minimum of two calculations. The rate will take on the lowest value of either the hazards being intermediately regulated; or the time per month dedicated to intermediate hazard regulation divided by the hours it takes to intermediately regulate a hazard. In effect the rate is governed by the ceiling which decision-makers may place on intermediate regulation activity. Too high a ceiling will result in wasted resource allocation. Too low a ceiling will afford an inadequate allocation of resources leading to a backlog of unprocessed intermediate hazards, contributing to more workplace accidents.

Hazards Arrive for Full Regulation.KL = MIN{Hazards Under Intermediate Regulation.K (Hazards)/Time to Clear Hazards Under Intermediate Regulation Backlog (Months), Intermediate Hazard Regulation Policy (Hours/Month)/Intermediate Regulation Time (Hours/Hazard)}

Units: Hazards

$$\text{Hazards Arrive for Full Regulation} = \frac{[H]}{[T]}, \frac{[T]}{[T]} \Big/ \frac{[T]}{[H]}$$
$$= [H] \times [T]^{-1}$$

Hazards Become Regulated

Hazards Become Regulated is a rate. It represents the number of active hazards in a given month that are rendered fully safe. The rate is dependent upon the minimum of two calculations. The rate will take on the lowest value of either the hazards being fully regulated; or the hours per month dedicated to full hazard regulation divided by the hours it takes to fully regulate a hazard. In effect the rate is governed by the ceiling which decision-makers may place on full regulation activity. Too high a ceiling will result in wasted resource allocation. Too low a ceiling will afford an inadequate allocation of resources leading to a backlog of unprocessed intermediate hazards contributing to more workplace accidents.

Hazards Become Regulated.KL = MIN{Hazards Under Full Regulation.K (Hazards)/Time to Clear Hazards Under Full Regulation Backlog (Month), Full Hazard Regulation Policy (Hours/Month)/Full Regulation Time (Hours/Hazard)}

Units: Hazards per Month

$$\text{Hazards Become Regulated} = \frac{[H]}{[T]}, \frac{[T]}{[T]} \Big/ \frac{[T]}{[H]}$$
$$= [H] \times [T]^{-1}$$

Hazards Under Intermediate Regulation

Hazards Under Intermediate Regulation is a level. It represents the active hazards which are receiving intermediate remedial attention.
Hazards Under Intermediate Regulation.K = Hazards Under Intermediate Regulation.J (Hazards) + {Hazard Identification Rate.JK (Hazards/Month) - Hazards Arrive for Full Regulation.JK (Hazards/Month)} * DT (Month)

Units: Hazards

$$\text{Hazards Under Intermediate Regulation} = [H] + \left(\frac{[H]}{[T]} - \frac{[H]}{[T]}\right) \times [T]$$
$$= [H]$$

Hazard Identification Rate

Hazard Identification Rate is a rate. It represents the unregulated hazards which become identified as active in a given month. The rate is dependent on the minimum of two calculations. The rate will take on the lowest value of either the Unregulated Hazards; or the combination of Accident Reports Completed and Hazards Identified from Safety Monitoring. In theory, for every accident report completed then an unregulated hazard becomes identified. In practice there are a finite number of hazards in a workplace. As more hazards become unregulated and result in accidents, then the likelihood of a particular unregulated hazard causing multiple accidents increases. This is reflected in the calculation of the effect of accident report completion on the hazard identification rate, with the ability of accident reports to identify hazards declining as the stock of unregulated hazards increases. It is more desirable to identify unregulated hazards before the accident occurs rather than afterwards. This is reflected in the hazards which can be identified through safety monitoring. The greater the number of hazards which can be identified through safety monitoring, the greater the rate of unregulated hazard identification.

It is unlikely that unregulated hazards can be efficiently identified through either accident reporting or safety monitoring alone. A synergy can be achieved through both proactively identifying hazards before the accident happens and clearing up rogue hazards through accident reporting.

The rate is governed by the ceiling which decision-makers may place on both accident reporting and safety monitoring activities. Too high a ceiling on both will result in wasted resource allocation. Too low a ceiling will afford an inadequate allocation of resources leading to a backlog of unprocessed unregulated hazards contributing to more workplace accidents.

Hazard Identification Rate.KL = MIN{Unregulated Hazards.K (Hazards)/Time to Identify Unregulated Hazards (Months), Accident Reports Completed.KL (Accident Reports/Month) * {1 - Accident Repeater.K (Hazards/Accident Report)} + Hazards Identified from Safety Monitoring (Hazards/Hour)}

Units: Hazards per Month

$$\text{Hazard Identification Rate} = \frac{[H]}{[T]}, \frac{[AR]}{[T]} \times \frac{[H]}{[AR]} + \frac{[H]}{[T]}$$
$$= [H] \times [T]^{-1}$$

Regulated Hazards

Regulated Hazards is a level. It represents the hazards which are safely contained in an inactive state.

Regulated Hazards.K = Regulated Hazards.J (Hazards) + {Become Regulated.JK (Hazards/Month) - Hazard Generation Rate.JK (Hazards/Month)} * DT (Month)

Units: Hazards

$$\text{Regulated Hazards} = [H] + \left(\frac{[H]}{[T]} - \frac{[H]}{[T]}\right) \times [T]$$
$$= [H]$$

Hazard Generation Rate

Hazard Generation Rate is a rate. It represents the number of hazards which move from a regulated to an unregulated state in a given month. The rate is dependent upon Unsafe Acts. As the number of unsafe acts increases then more regulated hazards will move into an active state. This is represented by multiplying regulated hazards by unsafe acts.

Hazard Generation Rate.KL = Regulated Hazards.K (Hazards) * Unsafe Acts (Hazards/Hazards/Month)

Units: Hazards per Month

$$\text{Hazard Generation Rate} = \frac{[H]}{[T]}$$
$$= [H] \times [T]^{-1}$$

Unregulated Hazards

Unregulated Hazards is a level. It represents hazards which are in an active state, and are not receiving remedial attention.
Unregulated Hazards.K = Unregulated Hazards.J (Hazards) + {Hazard Generation Rate.JK (Hazards/Month) - Hazard Identification Rate.JK (Hazards/Month)} * DT (Month)

Units: Hazards

$$\text{Unregulated Hazards} = [H] + \left(\frac{[H]}{[T]} - \frac{[H]}{[T]}\right) \times [T]$$
$$= [H]$$

Full Hazard Regulation Cost

Full Hazard Regulation Cost is a constant. It represents the average cost per hour of the Full Hazard Regulation Policy which can consist of one or more of the following activities:

premises modification;
process re-design;
re-design of system of work;
safety engineering; and
work environment modification.

Full Hazard Regulation Cost (£'s/Hour)

Units: £'s per Hour

$$\text{Full Hazard Regulaion Cost} = [C] \times [T]^{-1}$$

Full Hazard Regulation Policy

Full Hazard Regulation Policy is a constant. It represents the man-hours spent per month on regulating hazards. It may involve one or more of the following activities:

premises modification;
process re-design;
re-design of system of work;
safety engineering; and
work environment modification (HSE, 1991a; Stranks, 1994a; Waring 1996).

Full Hazard Regulation Policy (Hours/Month)

Units: Hours per Month

$$\text{Full Hazard Regulation Policy} = \frac{[T]}{[T]} \text{ i.e. [Dimensionless]}$$

Full Hazard Regulation Time

Full Hazard Regulation Time is a constant. It represents the time required to be spent on full regulation activity in order to fully regulate the average hazard.

Full Hazard Regulation Time (Hours/Hazard)

Units: Hours per Hazard

$$\text{Full Hazard Regulation Time} = \frac{[T]}{[H]}$$
$$= [T] \times [H]^{-1}$$

Intermediate Hazard Regulation Cost

Intermediate Hazard Regulation Cost is a constant. It represents the average cost per hour of the Intermediate Hazard Regulation Policy which can involve one or more of the following activities:

premises modification;
process re-design;
re-design of system of work; and
safety engineering; and
work environment modification (HSE, 1991a; Stranks, 1994a; Waring 1996).

Intermediate Hazard Regulation Cost (£'s/Hour)

Units: £'s per Hour

$$\text{Intermediate Hazard Regulaion Cost} = [C] \times [T]^{-1}$$

Intermediate Hazard Regulation Policy

Intermediate Hazard Regulation Policy is a constant. It represents the man-hours spent in a given month intermediately regulating hazards. It may consist of one or more of the following activities:

premises modification;
safety engineering;
process re-design;
re-design of system of work; and
work environment modification (HSE, 1991a; Stranks, 1994a; Waring 1996)..

Intermediate Hazard Regulation Policy (Hours/Month)

Units: Hours per Month

$$\text{Intermediate Hazard Regulaion Policy} = \frac{[T]}{[T]} \text{ i.e. [Dimensionless]}$$

Intermediate Hazard Regulation Time

Intermediate Regulation Time is a constant. It represents the average time required to regulate an intermediate hazard.

Intermediate Hazard Regulation Time (Hours/Hazard)

Units: Hours per Hazard

$$\text{Intermediate Hazard Regulation Time} = \frac{[T]}{[H]} = [T] \times [H]^{-1}$$

Ratio Between Active and Inactive Hazards

Ratio Between Active and Inactive Hazards is an auxiliary rate. It represents a measure of the number of Regulated Hazards in the workplace relative to the sum of the Unregulated Hazards, Hazards Under Intermediate Regulation and Hazards Under Full Regulation.

RBAAIH.K = {Unregulated Hazards.K (Hazards) + Hazards Under Intermediate Regulation.K (Hazards) + Hazards Under Full Regulation.K (Hazards)}/Regulated Hazards.K (Hazards)

Units: None

$$\text{Ratio Between Active and Inactive Hazards} = \frac{[H]}{[H]} \text{ i.e. [Dimensionless]}$$

Safety Monitoring Cost

Safety Monitoring Cost is a constant. It represents the cost per hour of one or more of the following safety monitoring activities:

fire inspections;
guard inspections;
risk assessments;
safety committee work; and
safety tours.

Safety Monitoring Cost (£'s/Hour)

Units: £'s per Hour

$$\text{Safety Monitoring Cost} = \frac{[C]}{[T]} = [C] \times [T]^{-1}$$

Safety Monitoring Policy

The Safety Monitoring Policy is a constant. It represents the man-hours spent per month in measuring and evaluating safety performance. It may involve one or more of the following activities:

fire inspections;
guard inspections;
risk assessments;
safety committees; and

safety tours (HSE, 1991a; Stranks, 1994a; Waring 1996).

Safety Monitoring Policy (Hours/Month)

Units: Hours per Month

Safety Monitoring Policy = $\frac{[T]}{[T]}$ i.e. [Dimensionless]

Time to Clear Hazards Under Full Regulation Backlog

Time to Clear Hazards Under Full Regulation Backlog is a time constant. It represents the management policy or intention to turn around or fully regulate a hazard in a given time.

Time to Clear Hazards Under Full Regulation Backlog (Months)

Units: Months

Time to Clear Hazards Under Full Regulation Backlog = [T]

Time to Clear Hazards Under Intermediate Regulation Backlog

Time to Clear Hazards Under Intermediate Regulation Backlog is a time constant. It represents the management policy or intention to turn around or intermediately regulate a hazard in a given time.

Time to Clear Hazards Under Intermediate Regulation Backlog (Months)

Units: Months

Time to Clear Hazards Under Intermediate Regulation Backlog = [T]

Time to Identify Unregulated Hazards

Time to Identify Unregulated Hazards is a time constant. It represents the management policy or intention to locate an unregulated hazard in a given time.

Time to Identify Unregulated Hazards (Months)

Units: Months
Time to Identify Unregulated Hazards = [T]

Accident Repeater

Accident Repeater is a table function. It represents the likelihood that a repeated accident will be identified as emanating from the same hazard. It is dependent upon the number of accident reports completed. The structural assumptions are that the relationship between accident reports completed and accident repeaters is positive and exponential. The more accident reports completed, the greater the chance that an accident emanates from the same hazard. This is reflected in the shape of the relationship between the two variables. The relationship is mildly exponential as at the top end of the range a good number of multiple accidents would result from the same hazard. The range goes beyond the normal operating region of the model. If one accident report is completed, then by definition the accident repeater is set at zero to suggest that the likelihood of one unregulated hazard causing multiple accidents is nil. The probability of an accident repeater rises in a logistical fashion to a maximum of 20 accident reports where this figure can be regarded as well beyond the normal operating region of the model.

Accident Repeater = Table{Accident Reports Completed}

Units: Hazards per Accident Report

$$\text{Accident Repeater} = \frac{[H]}{[AR]} = [H] \times [AR]^{-1}$$

Hazards Identified from Safety Monitoring

Hazards Identified from Safety Monitoring is a table function. It represents the hazards which can be identified per hour of safety monitoring activity. Hazards identified from safety monitoring depend upon the time dedicated to safety monitoring activity in a given month. The structural assumptions are that the relationship between the variables is logistical and positive. The shape reflects the fact that low safety monitoring activity will render lower productivity than a moderate level. This is due to economies of scale. The time it takes for example to arrange a team to conduct a safety tour or attend a safety committee will be fixed, whatever actions are carried out under each broader activity. At the maximum end of the scale a law of diminishing returns sets in where the productivity of the activity declines.

Hazards Identified from Safety Monitoring = Table{Safety Monitoring Policy}

Units: Hazards per Hour

$$\text{Hazards Identified from Safety Monitoring} = \frac{[H]}{[T]} = [H] \times [T]^{-1}$$

Unsafe Acts

Unsafe Acts is a table function. It represents the likelihood in a given month that employees will not work safely with hazards and cause a regulated hazard to move into an unregulated state. It is dependent upon the average KSA of the employees. Examples of unsafe acts may be non-compliance with safe systems of work, ignorance of permit-to-work systems or horseplay (Stranks, 1994a). The structural assumptions are that the relationship between unsafe acts and average KSA is negative and exponential, as one would expect unsafe acts to diminish as KSA improves. The x-axis ranges between zero and five, representing a safety KSA of zero through to five being a perfect KSA. The y-axis ranges from 0.1 to 0.009. A zero value is not achieved as a small allowance is made for 'Acts of God' or technical failure beyond the employee contributing to unsafe acts. These figures represent the probability that an unsafe act will occur. The highest value for an unsafe act is 0.1.

Unsafe Acts = Table{Average KSA.K}

Units: Hazards per Hazards per Month

$$\text{Unsafe Acts} = \frac{[H]}{[H]} \Big/ [T]$$
$$= [T]^{-1}$$

APPENDIX D

Labour Sector

Labour Sector Equations

Cumulative_Labour_Quits(t) = Cumulative_Labour_Quits(t - dt) + (Quits) * dt
INIT Cumulative_Labour_Quits = 0

Quits = Labour/Actual_Length_of_Employment
Labour(t) = Labour(t - dt) + (Hires - Quits) * dt
INIT Labour = Target_Labour_Force

Hires = ((Target_Labour_Force-Labour)/Staff_Adjustment_Time)+Replacing_Attrition
Quits = Labour/Actual_Length_of_Employment
Actual_Length_of_Employment = Base_Length_of_Employment*(1-Quit_Likelihood)
Base_Length_of_Employment = 120
Perceived_Accident_Incidence = SMTH3(Accident_Incidence,3)
Replacing_Attrition = Quits
Staff_Adjustment_Time = 4
Target_Labour_Force = 100
Quit_Likelihood = GRAPH(Perceived_Accident_Incidence)
(0.00, 0.00), (0.1, 0.001), (0.2, 0.003), (0.3, 0.006), (0.4, 0.014), (0.5, 0.028), (0.6, 0.08), (0.7, 0.0915), (0.8, 0.096), (0.9, 0.098), (1, 0.1)

Cumulative Labour Quits

Cumulative Labour Quits is a level. It represents the number of employees that have left the workforce to date.

Cumulative Labour Quits.K = Cumulative Labour Quits.J (Employees) + Quits.JK (Employees/Month) * DT (Month)

Units: Employees

$$\text{Cumulative Labour Quits} = [E] + \frac{[E]}{[T]} \times [T]$$
$$= [E]$$

Quits

Quits is a rate. It represents the employees leaving the workforce in a given month. The rate is dependent upon the size of the workforce divided by the number of months that the average employee remains with the firm.

Quits.KL = Labour.K (Employees)/Actual Length of Employment.K (Months)

Units: Employees per Month

$$\text{Quits} = \frac{[E]}{[T]}$$
$$= [E]\times[T]^{-1}$$

Labour

Labour is a level. It is the current size of the workforce.

Labour.K = Labour.J (Employees) + {Hires.JK (Employees/Month) - Quits.JK (Employees/Month)} * DT (Month)

Units: Employees

$$\text{Labour} = [E] + \left(\frac{[E]}{[T]} - \frac{[E]}{[T]}\right)\times[T]$$
$$= [E]$$

Hires

Hires is a rate. It represents the new recruits joining the workforce in a month. The rate is dependent upon the difference between the target or desired labour force size and the actual labour force size. This is divided by the staff adjustment time, i.e. the time it takes for the recruitment of new hires. Added to this is the replacement of attrition or employees who have quit the firm.

Hires.KL = {{Target Labour Force (Employees) - Labour.K (Employees)}/Staff Adjustment Time (Months)} + Replacing Attrition.KL (Employees/Month)

Units: Employees per Month

$$\text{Hires} = \frac{[E]-[E]}{[T]} + \frac{[E]}{[T]}$$
$$= [E]\times[T]^{-1}$$

Actual Length of Employment

Actual Length of Employment is an auxiliary rate. It represents the duration of employment for the average employee. The auxiliary is dependent upon a multiplication of the Base Length of Employment and the Quit Likelihood. This will represent the actual time in months an employee stays with the firm. Accidents to employees reduce with age and experience (Petersen, 1988).

Actual Length of Employment.K = Base Length of Employment (Months/Employee) * {1 - Quit Likelihood (Dimensionless)}

Units: Months

$$\text{Actual Length of Employment} = [T]$$

Base Length of Employment

Base Length of Employment is a constant. It represents the duration of employment in months that would be expected for the average employee, assuming that their safety morale is running at 100%.

Base Length of Employment (Months)

Units: Months

$$\text{Base Length of Employment} = [T]$$

Perceived Accident Incidence

Perceived Accident Incidence is an auxiliary rate. It represents how the workforce perceive the accidents happening per employee. It is a measure of their safety morale. The auxiliary is dependent upon the underlying accident incidence smoothed over time using a third-order smooth. A third-order smoothing is used to remove fluctuations in the accident incidence. The accident incidence is exponentially weighted over a three month time period. This may allow employees to build up a representative picture of the underlying accident incidence. Dissent and morale changes as a result of accidents may take time to occur. There may be talk in the canteen or it may take time for the union safety representative to broadcast the accident picture to the workforce. Concurrently, specific accidents, unless they are of a very serious nature are forgotten over time and employees will make a mental calculation of the accident incidence over a relatively recent period.

Perceived Accident Incidence.K = Accident Incidence.K (Accidents/Employee/Month)/Time over which Accident Incidence is Averaged (Months)

Units: Accidents per Employee

$$\begin{aligned}\text{Perceived Accident Incidence} &= \left(\frac{[A]}{[E]}\Big/[T]\right)\times[T]^{-1}\\ &= \frac{[A]}{[E]}\end{aligned}$$

Replacing Attrition

Replacing Attrition is an auxiliary rate. It represents the replacement of the quitters with new hires. The auxiliary is dependent upon how many employees quit the firm in a given month.

Replace Attrition.K = Quits.JK (Employees/Month)

Units: Employees per Month

$$\text{Replace Attrition} = \frac{[E]}{[T]}$$
$$= [E] \times [T]^{-1}$$

Staff Adjustment Time

Staff Adjustment Time is a constant. It represents the delay in months required to replace employee attrition. The adjustment time is set to four months to include activities such as advertising posts, interviewing candidates and any induction training carried out.

Staff Adjustment Time (Months)

Units: Months

$$\text{Staff Adjustment Time} = [T]$$

Target Labour Force

Target Labour Force is a constant. It represents the desired size of the workforce.

Target Labour Force (Employees)

Units: Employees

$$\text{Target Labour Force} = [E]$$

Quit Likelihood

Quit Likelihood is a table function. It represents the probability that an employee will exit the workforce as a result of the Perceived Accident Incidence. The relationship between the variables is positive and logistic. A logistical curve would be representative of the position where a low Perceived Accident Incidence would have little impact upon the desire of employees to quit the firm, whereas a moderate to high Perceived Accident Incidence would accelerate the desire to quit. As the Perceived Accident Incidence reaches a very high level the rate of acceleration of quits would slow as only a few die-hard employees would remain in the firm for any sort of duration. The x-axis ranges on a scale from zero to one. The y-axis ranges from zero to 0.1. This represents a scenario beyond the normal operating region of the model. If the Perceived Accident Incidence is zero then the safety morale is running at 100%. The result is that employees will not quit the firm as a result of any accident trend. At the maximum end of the scale, a Perceived Accident Incidence of one accident per employee per month would be evident in a safety system that was out of control and failing at every opportunity. The Quit Likelihood under these circumstances would be 10% of the workforce per month.

Quit Likelihood = Table{Perceived Accident Incidence.K}

Units: Employees per Employees

Quit Likelihood = Dimensionless

APPENDIX E

Safety Costs Sector

Safety Costs Equations

Cumulative_Safety_Cost(t) = Cumulative_Safety_Cost(t - dt) + (Monthly_Safety_Cost) * dt
INIT Cumulative_Safety_Cost = 0

Monthly_Safety_Cost =
Monthly_Accident_Cost+(Safety_Monitoring_Policy*Safety_Monitoring_Cost)+(Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost)+(Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost)+(Accident_Reporting_Policy*Accident_Reporting_Cost)+(Training_Policy*Safety_Training_Cost)

Cumulative Safety Cost

Cumulative Safety Cost is a level. It represents the overall cost of safety activity and accidents to date.

Cumulative Safety Cost.K = Cumulative Safety Cost.J (£'s) + Monthly Safety Cost.JK (£'s/Month) * DT (Months)

Units: £'s

$$\text{Cumulative Safety Cost} = [C] + \frac{[C]}{[T]} \times [T]$$
$$= [C]$$

Monthly Safety Cost

Monthly Safety Cost is a rate. It represents the overall monthly cost of safety activities and accidents. The rate is dependent upon the sum of the costs associated with the following activities:

accident reporting and investigation;
safety monitoring;
intermediate hazard regulation;

full hazard regulation;
safety training; and in addition
accidents.

Monthly Safety Cost.KL = Monthly Accident Cost.KL (£'s/Month) + {Safety Monitoring Policy (Hours/Month) * Safety Monitoring Cost (£'s/Hour)} + {Full Hazard Regulation Policy (Hours/Month) * Full Hazard Regulation Cost (£'s/Hour)} + {Intermediate Hazard Regulation Policy (Hours/Month) * Intermediate Hazard Regulation Cost (£'s/Hour)} + {Accident Reporting Policy (Hours/Month) * Accident Reporting Cost (£'s/Hour)} + {Training Policy (Hours/Month) * Safety Training Cost (£'s/Hour)}

Units: £'s per Month

$$\text{Monthly Safety Cost} = \frac{[C]}{[T]} + \left(\frac{[T]}{[T]} \times \frac{[C]}{[T]} + \frac{[T]}{[T]} \times \frac{[C]}{[T]} + \frac{[T]}{[T]} \times \frac{[C]}{[T]} + \frac{[T]}{[T]} \times \frac{[C]}{[T]} + \frac{[T]}{[T]} \times \frac{[C]}{[T]}\right)$$
$$= \frac{[C]}{[T]}$$

APPENDIX F

Safety Knowledge, Skills and Attitude Sector

Safety KSA Equations

Cumulative_Safety_Training_Cost(t) = Cumulative_Safety_Training_Cost(t - dt) + (Monthly_Safety_Training_Cost) * dt
INIT Cumulative_Safety_Training_Cost = 0

Monthly_Safety_Training_Cost = Training_Policy*Safety_Training_Cost
Safety_KSA(t) = Safety_KSA(t - dt) + (Learning + Gain_in_KSA - Loss_of_KSA - Dissipation_of__KSA) * dt
INIT Safety_KSA = 400

Learning = DELAY(Multiplier*Discrepancy,3)
Gain_in_KSA = Hires*KSA_per_New_Employee
Loss_of_KSA = Quits*Loss_per_Exit
Dissipation_of__KSA = Safety_KSA*Fixed_Proportion_of_KSA_Lost
Average_KSA = Safety_KSA/Labour
Discrepancy = 1-(Safety_KSA/Target_Safety_KSA)
Fixed_Proportion_of_KSA_Lost = 0.01
KSA_per_New_Employee = Average_KSA*Ratio_Between_Hires_and_Average_KSA
Loss_per_Exit = Average_KSA*Ratio_Between_Quitters_and_Average_KSA
Maximum_KSA_per_Employee = 5
Ratio_Between_Hires_and_Average_KSA = 0.7
Ratio_Between_Quitters_and_Average_KSA = 1.3
Safety_Training_Cost = 10
Target_Safety_KSA = Labour*Maximum_KSA_per_Employee
Training_Effectiveness = 0.75
Training_Policy = 200
Multiplier = GRAPH((Training_Effectiveness*Training_Policy)*(IF(Safety_KSA<Target_Safety_KSA)THEN(1)ELSE(0)))
(0.00, 0.00), (50.0, 10.0), (100, 20.0), (150, 30.0), (200, 40.0), (250, 50.0), (300, 60.0), (350, 70.0), (400, 80.0), (450, 90.0), (500, 100)

Cumulative Safety Training Cost

Cumulative Safety Training Cost is a level. It represents the cost to date of the Safety Training Policy.

Cumulative Safety Training Cost.K = Cumulative Safety Training Cost.J (£'s) + Monthly Safety Training Cost.JK (£'s/Month) * DT [Month]

Units: £'s

$$\text{Cumulative Safety Training Cost} = [C] + \frac{[C]}{[T]} \times [T]$$
$$= [C]$$

Monthly Safety Training Cost

Monthly Safety Training Cost is a rate. It represents the monthly cost of the Safety Training Policy. The rate is dependent upon the time spent on safety training in a given month.

Monthly Safety Training Cost.KL = Training Policy (Hours/Month) * Safety Training Cost (£'s/Hour)

Units: £'s per Month

$$\text{Monthly Safety Training Cost} = \frac{[T]}{[T]} \times \frac{[C]}{[T]}$$
$$= [C] \times [T]^{-1}$$

Safety KSA

Safety KSA is a level. It represents the current safety KSA possessed by the workforce.

Safety KSA.K = Safety KSA.J (KSA) + {Learning.JK (KSA/Month) + Gain in Safety KSA.JK (KSA/Month) - Loss in KSA.JK (KSA/Month) - Dissipation of KSA.JK (KSA/Month} * DT (Months)

Units: KSA

$$\text{Safety KSA} = K + \left(\frac{[K]}{[T]} + \frac{[K]}{[T]} - \frac{[K]}{[T]} - \frac{[K]}{[T]} \right) \times [T]$$
$$= K$$

Learning

Learning is a rate. It represents the Safety KSA gained by the workforce through training in a given month. The rate is dependent upon the multiplier multiplied by the discrepancy between the Target Safety KSA and actual Safety KSA. A delay of 3 months is built into the rate to reflect the delay between learning and application of the learning. This allows the training to be converted into Safety KSA. The greater the multiplier and/or the KSA discrepancy, the greater the learning of KSA by the trainees.

Learning.KL = (Multiplier.K (KSA/Month) * Discrepancy.K (Dimensionless)

Units: KSA per Month

$$\text{Learning} = \frac{[K]}{[T]} = [K]\times[T]^{-1}$$

Gain in KSA

Gain in KSA is a rate. It represents the Safety KSA brought to the workforce by the new monthly recruits. The rate is dependent upon the number of new hires in a month multiplied by the safety KSA that the average hires bring with them to the workplace. It is appropriate in this case to use a rate on rate calculation as new hires instantaneously bring some safety KSA to the workplace.

Gain in KSA.KL = Hires.JK (Employees/Month) * KSA per New Employee (KSA/Employee)

Units: KSA per Month

$$\text{Gain in KSA} = \frac{[E]}{[T]}\times\frac{[K]}{[E]} = [K]\times[T]^{-1}$$

Loss of KSA

Loss of KSA is a rate. It represents the Safety KSA that in a given month quitters take from the workforce when they leave the firm's employment. The rate is dependent upon the number of quitters in a month multiplied by the safety KSA that they possess. In this case it is appropriate to use a rate on rate calculation as quitters will instantaneously take safety KSA away from the workplace.

Loss in KSA.KL = Quits.JK (Employees/Month) * Loss per Exit (KSA/Employee)

Units: KSA per Month

$$\text{Loss in KSA} = \frac{[E]}{[T]}\times\frac{[K]}{[E]} = [K]\times[T]^{-1}$$

Dissipation of KSA

Dissipation of KSA is a rate. It represents the Safety KSA lost by the workforce in a given month. The rate is dependent upon the current level of Safety KSA possessed by the workforce multiplied by the Safety KSA that is lost over a given month.

Dissipation of KSA.KL = Safety KSA.K (KSA) * Fixed Proportion of KSA Lost (KSA/KSA/Month)

Units: KSA per Month

$$\text{Dissipation of KSA} = [K] \times \frac{[K]}{[K]} \Big/ [T]$$
$$= [K] \times [T]^{-1}$$

Average KSA

Average KSA is an auxiliary rate. It represents the safety KSA possessed by the average employee. The auxiliary is dependent upon the current level of Safety KSA divided by the number of employees.

Average KSA.K = Safety KSA.K (KSA)/Labour.K (Employees)

Units: KSA per Employee

$$\text{Average KSA} = \frac{[K]}{[E]}$$
$$= [K] \times [E]^{-1}$$

Discrepancy

Discrepancy is an auxiliary rate. It represents the gap between the optimum workforce safety KSA and the actual Safety KSA of the workforce. It is dependent upon the ratio between Safety KSA and Target Safety KSA.

Discrepancy.K = 1 – {Safety KSA.K (KSA)/Target Safety KSA (KSA)}

$$\text{Discrepancy} = \frac{[K]}{[K]} \text{ i.e. [Dimensionless]}$$

Fixed Proportion of KSA Lost

Fixed Proportion of KSA Lost is a constant. It represents the proportion of the workforce Safety KSA lost per month. Safety KSA is lost over time by employees (Stranks, 1994a). The constant represents a form of half-life for Safety KSA. This loss is a good justification for refresher training.

Fixed Proportion of KSA Lost (KSA/KSA/Month)

Units: KSA per KSA per Month

$$\text{Fixed Proportion of KSA Lost} = \frac{[K]}{[K]} \Big/ [T]$$
$$= [T]^{-1}$$

KSA per New Employee

KSA per New Employee is an auxiliary rate. It represents the safety KSA that a recruit brings to the workplace. Any functional person will bring with them to a workplace some safety KSA. One would assume that they would have picked up a level of safety KSA through previous employment, education and life experience.

KSA per New Employee.K = Average KSA.K (KSA/Employee) * Ratio Between Hires and Average KSA (Dimensionless)

Units: KSA per Employee

$$\text{KSA per New Employee} = \frac{[K]}{[E]}$$
$$= [K] \times [E]^{-1}$$

Loss per Exit

Loss per Exit is an auxiliary rate. It represents the Safety KSA that the quitter takes from the workplace. It is dependent upon the safety KSA possessed by the average employee multiplied by the ratio between the quitters safety KSA and the Average Safety KSA.

Loss per Exit.K = Average KSA.K (KSA/Employee) * Ratio Between Quitters and Average KSA.K (Dimensionless)

Units: KSA per Employee

$$\text{Loss per Exit} = \frac{[K]}{[E]}$$
$$= [K] \times [E]^{-1}$$

Maximum KSA per Employee

Maximum KSA per Employee is a constant. It represents the point at which an employee has perfect safety KSA.

Maximum KSA (KSA/Employee)

Units: KSA per Employee

$$\text{Maximum KSA} = \frac{[K]}{[E]}$$
$$= [K] \times [E]^{-1}$$

Ratio Between Hires and Average KSA

Ratio Between Hires and Average KSA is an auxiliary rate. It represents the difference between the Safety KSA possessed by the average employee and that of the new employee. One would expect the Safety KSA of the new employee to be lower than that possessed by the average employee.

Ratio Between Hires and Average KSA (KSA/Employee/KSA/Employee)

Units: None

$$\text{Ratio Between Hires and Average KSA} = \frac{[K]}{[E]} \Big/ \frac{[K]}{[E]} \text{ i.e. [Dimensionless]}$$

Ratio Between Quitters and Average KSA

Ratio Between Quitters and Average KSA is an auxiliary rate. It represents the difference between the safety KSA possessed by the quitter and that of the average employee. As employees increase their length of employment, then their safety KSA increases. One would therefore expect the safety KSA of the quitter to exceed that of the average employee.

Ratio Between Quitters and Average KSA (KSA/Employee/KSA/Employee)

$$\text{Ratio Betwen Quitters and Average KSA} = \frac{[K]}{[E]} \Big/ \frac{[K]}{[E]} \text{ i.e. [Dimensionless]}$$

Safety Training Cost

The Safety Training Cost is a constant. It represents the cost per hour of an aggregation of on-the-job, in-house, and external training.

Safety Training Cost (£'s/Hour)

Units: (£'s/Hour)

$$\text{Safety Training Cost} = \frac{[C]}{[T]} = [C] \times [T]^{-1}$$

Target Safety KSA

Target Safety KSA is an auxiliary rate. It represents the maximum safety KSA that the workforce can attain. The auxiliary is dependent upon the size of the labour force multiplied by the maximum safety KSA attainable by each employee.

Target KSA.K (Employee) = Labour.K * Maximum KSA per Employee (KSA/Employee)

Units: KSA

$$\text{Target KSA} = [E] \times \frac{[K]}{[E]}$$
$$= [K]$$

Training Effectiveness

Training Effectiveness is a constant. It represents a measure of how close safety training is to the maximum achievable. Training Effectiveness is a proportion of maximum training effectiveness.

Training Effectiveness (Training/Training)

Units: None

$$\text{Training Effectiveness} = \frac{[T]^{-1}}{[T]^{-1}} \text{ i.e. [Dimensionless]}$$

Training Policy

Training Policy is a constant. It represents all the direct and indirect man-hours spent by managers and workers in a given month using on-the-job, in-house, and external training.

Training Policy (Hours/Month)

Units: Hours per Month

$$\text{Training Policy} = \frac{[T]}{[T]} \text{ i.e. [Dimensionless]}$$

Multiplier

Multiplier is an auxiliary rate. It converts the training time given in a month into the learning of Safety KSA. It is constrained by the gap between the Target Safety KSA and the actual Safety KSA possessed by the workforce, then multiplied by how effective the training is.

Multiplier.K = Table{Training Effectiveness (Dimensionless) * Training Policy (Hours/Month) * {IF{Safety KSA.K (KSA) < Target KSA.K (KSA) THEN{1} ELSE{0}}}}

Units: KSA per Hour

$$\text{Multiplier} = \frac{[K]}{[T]}$$
$$= [K] \times [T]^{-1}$$

APPENDIX G

Constant Modification Parameter Tests

Metric	Base Run
Cumulative Accidents	103
Average KSA	4.00
Actual Length of Employment	120
Cumulative Accident Reports	103
RBAAIH	0.05
Cumulative Safety Costs	255314

Table G1 Fixed constant base run output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	787	374	103	103	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	119	119	120	120	120	120	120	120
Cumulative Accident Reports	0	31	63	94	103	103	103	103
RBAAIH	0.77	0.25	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	198746	188665	192814	224064	286564	317814	349064	380314

Table G2 Accident reporting policy output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	103	103	103	103	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	103	103	103	103	100	83	71	63
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	255314	255314	255314	255314	255314	255314	255314	255314

Table G3 Accident reporting time output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	4999	246	151	119	94	87	83	79
Average KSA	3.97	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	108	120	120	120	120	120	120	120
Cumulative Accident Reports	125	125	125	119	94	88	83	80
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	744866	269597	260075	256901	254362	253727	253274	252934

Table G4 Unregulated hazard regulation weighting output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	3350	198	135	114	97	93	90	87
Average KSA	3.97	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	109	120	120	120	120	120	120	120
Cumulative Accident Reports	125	125	125	114	97	93	90	88
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	580038	264836	258488	256372	254679	254256	253954	253727

Table G5 Intermediate hazard regulation weighting output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	2466	159	111	95	83	79	77	75
Average KSA	3.99	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	117	120	120	120	120	120	120	120
Cumulative Accident Reports	125	125	111	95	83	80	78	76
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	491609	260868	256108	254521	253251	252934	252707	252537

Table G6 Full hazard regulation weighting output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	103	103	103	103	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	103	103	103	103	103	103	103	103
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	245314	247814	250314	252814	257814	260314	262814	265314

Table G7 Safety monitoring policy output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	701	426	152	103	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	124	124	122	103	103	103	103	103
RBAAIH	1.30	0.48	0.10	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	312640	285765	258903	254689	255939	256564	257189	257814

Table G8 Intermediate hazard regulation policy output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	103	103	103	103	103	103	103	152
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	103	103	103	103	103	103	103	122
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10
Cumulative Safety Costs	255314	255314	255314	255314	255314	255314	255314	260153

Table G9 Intermediate hazard regulation time output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	556	431	306	181	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	124	124	124	123	103	103	103	103
RBAAIH	1.34	0.74	0.39	0.16	0.05	0.05	0.05	0.05
Cumulative Safety Costs	293114	282495	271880	261266	257189	259064	260939	262814

Table G10 Full hazard regulation policy output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	103	103	103	103	156	223	271	306
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	103	103	103	103	123	124	124	124
RBAAIH	0.05	0.05	0.05	0.05	0.12	0.23	0.32	0.39
Cumulative Safety Costs	255314	255314	255314	255314	260643	267304	272062	275630

Table G11 Full hazard regulation time output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	10569	392	153	115	97	92	89	87
Average KSA	0.48	3.34	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	97	92	89	87
RBAAIH	4.69	0.32	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1301918	284194	260289	256494	254655	254219	253911	253681

Table G12 Base length of employment output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	103	103	103	103	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	103	103	103	103	103	103	103	103
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	255314	255314	255314	255314	255314	255314	255314	255314

Table G13 Staff adjustment time output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1771	636	270	145	82	67	56	48
Average KSA	1.87	2.82	3.40	3.76	4.17	4.28	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	83	68	57	49
RBAAIH	2.67	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	322109	233585	222007	234459	278229	301740	325637	349795

Table G14 Training policy output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1771	636	270	145	82	67	56	48
Average KSA	1.87	2.82	3.40	3.76	4.17	4.28	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	83	68	57	49
RBAAIH	2.67	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	422109	308585	272007	259459	253229	251740	250637	249795

Table G15 Training effectiveness output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	167	143	124	113	94	84	75	66
Average KSA	3.71	3.78	3.85	3.92	4.08	4.16	4.24	4.33
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	123	122	121	113	94	85	76	67
RBAAIH	0.10	0.07	0.05	0.05	0.05	0.04	0.04	0.04
Cumulative Safety Costs	261710	259283	257399	256345	254355	253414	252494	251599

Table G16 Ratio between hires and average knowledge, skills and attitude output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	43	53	69	85	122	160	209	209
Average KSA	4.65	4.47	4.30	4.15	3.86	3.73	3.61	3.61
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	44	54	69	86	121	123	123	123
RBAAIH	0.04	0.04	0.04	0.04	0.05	0.09	0.13	0.13
Cumulative Safety Costs	249257	250252	251852	253547	257247	260990	265912	265912

Table G17 Ratio between quits and average knowledge, skills and attitude output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	45	56	71	87	121	153	197	245
Average KSA	4.60	4.43	4.28	4.14	3.87	3.75	3.64	3.53
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	46	57	72	87	120	123	123	124
RBAAIH	0.04	0.04	0.04	0.04	0.05	0.08	0.12	0.16
Cumulative Safety Costs	249502	250612	252108	253681	257095	260286	264729	269547

Table G18 Fixed proportion of knowledge, skills and attitude lost output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	103	103	103	103	103	103	103	103
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	103	103	103	103	103	103	103	103
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	255314	255314	255314	255314	255314	255314	255314	255314

Table G19 Learning delay output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	105	103	103	103	103	103	103	103
Average KSA	3.99	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Actual Length of Employment	108	120	120	120	120	120	120	120
Cumulative Accident Reports	105	103	103	103	103	103	103	103
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cumulative Safety Costs	255508	255314	255314	255314	255314	255314	255314	255314

Table G20 Perceived accident incidence smooth output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	6.64	3.51	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	1.00	0.93	0.78	0.35	0.00	0.00	0.00	0.00
RBAAIH	14.40	5.33	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.22	0.35	0.49	0.49	0.49	0.49	0.49	0.49

Table G21 Accident reporting policy gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.12	0.39	0.41	0.39
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G22 Accident reporting time gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	47.53	1.85	0.93	0.62	0.36	0.31	0.26	0.23
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.21	0.28	0.42	0.61	0.36	0.30	0.26	0.23
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	1.92	0.07	0.04	0.02	0.01	0.01	0.01	0.01

Table G23 Unregulated hazard regulation weighting gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	31.53	1.23	0.62	0.42	0.24	0.20	0.17	0.15
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.21	0.28	0.42	0.41	0.24	0.20	0.17	0.15
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	1.27	0.05	0.02	0.02	0.01	0.01	0.01	0.01

Table G24 Intermediate hazard regulation weighting gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	22.94	0.72	0.16	0.30	0.80	0.46	0.34	0.27
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.21	0.28	0.15	0.30	0.78	0.45	0.33	0.26
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.93	0.03	0.01	0.01	0.03	0.02	0.01	0.01

Table G25 Full hazard regulation weighting gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table G26 Safety monitoring policy gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	5.81	4.19	0.94	0.01	0.01	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.21	0.27	0.37	0.01	0.01	0.00	0.00	0.00
RBAAIH	25.00	11.47	2.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.22	0.16	0.03	0.01	0.01	0.01	0.01	0.01

Table G27 Intermediate hazard regulation policy gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.47
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.19
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02

Table G28 Intermediate hazard regulation time gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	4.40	4.25	3.95	3.05	0.01	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.21	0.28	0.41	0.79	0.01	0.00	0.00	0.00
RBAAIH	25.80	18.40	13.60	8.80	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.15	0.14	0.13	0.09	0.03	0.03	0.03	0.03

Table G29 Full hazard regulation policy gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.01	2.07	2.33	2.17	1.97
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.01	0.77	0.40	0.27	0.21
RBAAIH	0.00	0.00	0.00	0.00	5.60	7.20	7.20	6.80
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.08	0.09	0.09	0.08

Table G30 Full hazard regulation time gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	101.61	3.74	0.97	0.46	0.25	0.21	0.18	0.16
Average KSA	0.88	0.22	0.13	0.09	0.05	0.04	0.04	0.03
Actual Length of Employment	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cumulative Accident Reports	0.21	0.27	0.38	0.45	0.24	0.20	0.18	0.15
RBAAIH	92.80	7.20	1.20	0.00	0.00	0.00	0.00	0.20
Cumulative Safety Costs	4.10	0.15	0.04	0.02	0.01	0.01	0.01	0.01

Table G31 Base length of employment gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G32 Staff adjustment time gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	16.20	6.90	3.24	1.62	0.80	0.69	0.60	0.53
Average KSA	0.53	0.39	0.30	0.24	0.17	0.14	0.12	0.11
Actual Length of Employment	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.20	0.27	0.40	0.75	0.78	0.67	0.59	0.52
RBAAIH	52.40	19.47	6.40	2.40	0.80	0.40	0.27	0.20
Cumulative Safety Costs	0.26	0.11	0.26	0.33	0.36	0.36	0.37	0.37

Table G33 Training policy gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	16.20	6.90	3.24	1.62	0.80	0.69	0.60	0.53
Average KSA	0.53	0.39	0.30	0.24	0.17	0.14	0.12	0.11
Actual Length of Employment	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.20	0.27	0.40	0.75	0.78	0.67	0.59	0.52
RBAAIH	52.40	19.47	6.40	2.40	0.80	0.40	0.27	0.20
Cumulative Safety Costs	0.65	0.28	0.13	0.06	0.03	0.03	0.02	0.02

Table G34 Training effectiveness gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.62	0.52	0.41	0.41	0.37	0.37	0.36	0.36
Average KSA	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.19	0.25	0.35	0.39	0.36	0.36	0.35	0.35
RBAAIH	1.00	0.53	0.00	0.00	0.00	0.40	0.27	0.20
Cumulative Safety Costs	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01

Table G35 Ratio between hires and average knowledge, skills and attitude gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.59	0.65	0.67	0.68	0.76	1.10	1.37	1.03
Average KSA	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.10
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.57	0.64	0.65	0.66	0.69	0.39	0.26	0.20
RBAAIH	0.20	0.27	0.40	0.80	0.00	1.60	2.13	1.60
Cumulative Safety Costs	0.02	0.03	0.03	0.03	0.03	0.04	0.06	0.04

Table G36 Ratio between quits and average KSA gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.56	0.61	0.62	0.63	0.70	0.97	1.22	1.38
Average KSA	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.55	0.59	0.60	0.61	0.66	0.38	0.26	0.20
RBAAIH	0.20	0.27	0.40	0.80	0.00	1.20	1.87	2.20
Cumulative Safety Costs	0.02	0.02	0.03	0.03	0.03	0.04	0.05	0.06

Table G37 Fixed proportion of KSA lost gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G38 Learning delay gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G39 Perceived accident incidence smooth gearing

Metric	Base Run
Accident Incidence	0.02
Accident Reports Being Processed	2.06
Actual Length of Employment	119.98
Average KSA	4.00
Monthly Safety Cost	5,106.29
RBAAIH	0.05

Table G40 Step constant base run output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	35	12	0	0	0	0	0	0
Accident Reports Being Processed	281	85	22	7	0	0	0	0
Actual Length of Employment	47	24	0	0	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	50	27	0	0	0	0	0	0
RBAAIH	40	17	0	0	0	0	0	0

Table G41 Accident reporting policy settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	0	0	0	0	5	12	18	22
Actual Length of Employment	0	0	0	0	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	0	0	0	0	0	0	0	0
RBAAIH	0	0	0	0	0	0	0	0

Table G42 Accident reporting time settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	2189	59	15	4	2	3	3	3
Actual Length of Employment	18	7	6	5	0	0	0	0
Average KSA	16	0	0	0	0	0	0	0
Monthly Safety Cost	72	10	0	2	15	17	19	20
RBAAIH	0	0	0	0	0	0	0	0

Table G43 Unregulated hazard regulation weighting settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	1438	37	8	3	2	2	3	3
Actual Length of Employment	14	7	6	4	0	0	0	0
Average KSA	12	0	4	0	0	0	0	0
Monthly Safety Cost	68	1	1	4	14	16	17	17
RBAAIH	0	0	0	0	0	0	0	0

Table G44 Intermediate hazard regulation weighting settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	1073	26	5	3	2	2	2	2
Actual Length of Employment	11	7	5	4	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	0	1	1	6	13	15	16	16
RBAAIH	0	0	0	0	0	0	0	0

Table G45 Full hazard regulation weighting settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	0	0	0	0	0	0	0	0
Actual Length of Employment	0	0	0	0	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	11	11	11	11	11	11	11	11
RBAAIH	0	0	0	0	0	0	0	0

Table G46 Safety monitoring policy settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	45	26	0	0	0	0	0	0
Accident Reports Being Processed	283	113	9	0	0	0	0	0
Actual Length of Employment	57	38	10	0	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	60	41	14	11	11	11	11	11
RBAAIH	50	30	1	0	0	0	0	0

Table G47 Intermediate hazard regulation policy settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	0	0	0	0	0	0	0	9
Actual Length of Employment	0	0	0	0	0	0	0	9
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	0	0	0	0	0	0	0	14
RBAAIH	0	0	0	0	0	0	0	2

Table G48 Intermediate hazard regulation time settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	47	36	42	5	0	0	0	0
Accident Reports Being Processed	279	172	81	17	0	0	0	0
Actual Length of Employment	59	48	34	17	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	61	50	37	20	11	11	11	11
RBAAIH	51	40	27	9	0	0	0	0

Table G49 Full hazard regulation policy settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	1	11	18	22
Accident Reports Being Processed	0	0	0	0	12	34	59	81
Actual Length of Employment	0	0	0	0	13	23	30	34
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	0	0	0	0	17	26	33	37
RBAAIH	0	0	0	0	5	16	22	27

Table G50 Full hazard regulation time settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	137	29	4	0	0	0	0	0
Accident Reports Being Processed	6212	112	60	49	29	34	37	39
Actual Length of Employment	149	49	38	27	0	0	0	0
Average KSA	69	47	36	25	20	25	27	29
Monthly Safety Cost	151	103	82	81	97	103	105	107
RBAAIH	141	33	0	0	0	0	0	0

Table G51 Base length of employment settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	0	0	0	0	0	0	0	0
Actual Length of Employment	0	0	0	0	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	0	0	0	0	0	0	0	0
RBAAIH	0	0	0	0	0	0	0	0

Table G52 Staff adjustment time settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	39	29	17	0	0	6	10	12
Accident Reports Being Processed	165	91	68	61	45	52	56	58
Actual Length of Employment	55	51	47	39	0	0	8	11
Average KSA	53	49	44	37	36	42	46	49
Monthly Safety Cost	109	105	101	93	114	120	124	127
RBAAIH	43	32	18	0	0	11	15	17

Table G53 Training policy settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	39	29	17	0	0	6	10	12
Accident Reports Being Processed	185	91	68	61	45	52	56	58
Actual Length of Employment	55	51	47	39	0	0	8	11
Average KSA	53	49	44	37	36	42	46	49
Monthly Safety Cost	109	105	101	83	114	120	124	127
RBAAIH	43	32	18	0	0	11	15	17

Table G54 Training effectiveness settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	6	2	0	0	0	0	0	1
Accident Reports Being Processed	61	58	54	47	33	40	45	48
Actual Length of Employment	40	37	33	26	0	0	0	0
Average KSA	38	35	31	24	23	31	35	38
Monthly Safety Cost	84	91	87	80	101	109	113	116
RBAAIH	0	0	0	0	0	0	3	7

Table G55 Ratio between hires and average knowledge, skills and attitude settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	8	5	0	0	0	5	13	19
Accident Reports Being Processed	54	51	47	39	54	61	65	68
Actual Length of Employment	7	0	0	0	32	39	43	46
Average KSA	45	42	37	30	30	37	41	44
Monthly Safety Cost	123	120	115	108	86	83	97	100
RBAAIH	13	10	6	0	0	0	14	22

Table G56 Ratio between quits and average knowledge, skills and attitude settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	7	4	0	0	0	4	11	17
Accident Reports Being Processed	53	50	46	39	53	60	64	67
Actual Length of Employment	6	0	0	0	31	38	43	45
Average KSA	44	41	36	29	29	36	40	43
Monthly Safety Cost	122	119	114	107	85	82	97	99
RBAAIH	13	9	5	0	0	0	11	19

Table G57 Fixed proportion of knowledge, skills and attitude lost settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	0	0	0	0	0	0	0	0
Actual Length of Employment	0	0	0	0	0	0	0	0
Average KSA	0	0	0	0	0	0	0	0
Monthly Safety Cost	0	0	0	0	0	0	0	0
RBAAIH	0	0	0	0	0	0	0	0

Table G58 Learning delay settling time

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0	0	0	0	0	0	0	0
Accident Reports Being Processed	73	0	0	0	0	0	0	0
Actual Length of Employment	107	0	0	0	0	0	0	0
Average KSA	50	0	0	0	0	0	0	0
Monthly Safety Cost	135	0	0	0	0	0	0	0
RBAAIH	0	0	0	0	0	0	0	0

Table G59 Perceived accident incidence smooth settling time

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.08	0.04	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	106.10	34.63	10.19	3.94	2.06	2.06	2.06	2.06
Actual Length of Employment	119.91	119.95	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	2500	1875	1250	625	625	1250	1875	2500
RBAAIH	0.17	0.09	0.05	0.05	0.05	0.05	0.05	0.05

Table G60 Accident reporting policy point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2.06	2.06	2.06	2.06	0.63	3.96	6.35	8.13
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5106	5106	5106	5106	5106	5106	5106	5106
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G61 Accident reporting time point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.96	0.05	0.03	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	947.86	26.36	7.38	2.38	1.87	1.75	1.65	1.59
Actual Length of Employment	108.06	119.94	119.96	119.97	119.98	119.98	119.98	119.98
Average KSA	3.98	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	9636	5392	5202	5106	5087	5075	5065	5059
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G62 Unregulated hazard regulation weighting point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.66	0.04	0.03	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	628.84	16.84	2.22	2.27	1.94	1.85	1.79	1.75
Actual Length of Employment	109.65	119.95	119.97	119.97	119.98	119.98	119.98	119.98
Average KSA	4.01	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	11483	5297	5170	5127	5097	5085	5079	5075
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G63 Intermediate hazard regulation weighting point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.49	0.03	0.03	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	469.63	12.10	2.80	2.22	1.97	1.90	1.86	1.82
Actual Length of Employment	116.76	119.96	119.97	119.97	119.97	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	9838	5249	5154	5122	5097	5090	5086	5082
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G64 Full hazard regulation weighting point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	4096	4956	5006	5056	5156	5206	5256	5306
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G65 Safety monitoring policy point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.08	0.05	0.03	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	106.69	36.80	2.47	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	119.91	119.94	119.97	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5658	5403	5150	5094	5119	5131	5144	5156
RBAAIH	0.22	0.13	0.06	0.05	0.05	0.05	0.05	0.05

Table G66 Intermediate hazard regulation policy point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.45
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.97
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5106	5106	5106	5106	5106	5106	5106	5148
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06

Table G67 Intermediate hazard regulation time point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02
Accident Reports Being Processed	100.34	58.16	24.35	3.97	2.06	2.06	2.06	2.06
Actual Length of Employment	119.93	119.94	119.95	119.97	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5539	5419	5300	5181	5144	5181	5129	5256
RBAAIH	0.18	0.17	0.12	0.08	0.05	0.05	0.05	0.05

Table G68 Full hazard regulation policy point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.04
Accident Reports Being Processed	2.06	2.06	2.06	2.06	2.58	8.72	16.81	24.35
Actual Length of Employment	119.98	119.98	119.98	119.98	119.97	119.96	119.96	119.95
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5106	5106	5106	5106	5157	5221	5266	5300
RBAAIH	0.05	0.05	0.05	0.05	0.07	0.09	0.11	0.12

Table G69 Full hazard regulation time point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.60	0.04	0.03	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2652.47	34.15	2.95	2.24	1.96	1.90	1.85	1.82
Actual Length of Employment	1.08	29.99	59.99	89.98	149.97	179.97	209.96	239.95
Average KSA	3.54	3.55	3.84	3.95	4.03	4.05	4.07	4.08
Monthly Safety Cost	15986	5313	5162	5124	5106	5089	5084	5081
RBAAIH	2.21	0.08	0.05	0.05	0.05	0.05	0.05	0.05

Table G70 Base length of employment point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5106	5106	5106	5106	5106	5106	5106	5106
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G71 Staff adjustment time point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01
Accident Reports Being Processed	53.38	25.28	8.39	2.49	1.71	1.41	1.16	0.93
Actual Length of Employment	119.94	119.95	119.96	119.97	119.98	119.98	119.98	119.99
Average KSA	3.44	3.60	3.74	3.88	4.12	4.22	4.32	4.41
Monthly Safety Cost	3106	3606	4106	4606	5606	6106	6606	7106
RBAAIH	0.10	0.08	0.06	0.05	0.05	0.04	0.04	0.04

Table G72 Training policy point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01
Accident Reports Being Processed	53.38	25.28	8.39	2.49	1.71	1.41	1.16	0.93
Actual Length of Employment	119.94	119.95	119.96	119.97	119.98	119.98	119.99	119.98
Average KSA	3.44	3.60	3.74	3.88	4.12	4.22	4.32	4.41
Monthly Safety Cost	5383	5280	5204	5150	5070	5039	5013	4991
RBAAIH	0.10	0.08	0.06	0.05	0.05	0.04	0.04	0.04

Table G73 Training effectiveness point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01
Accident Reports Being Processed	3.75	2.60	2.37	2.22	1.92	1.78	1.64	1.50
Actual Length of Employment	119.97	119.97	119.97	119.97	119.98	119.98	119.98	119.98
Average KSA	3.82	3.86	3.91	3.95	4.05	4.09	4.14	4.19
Monthly Safety Cost	5172	5155	5138	5122	5091	5077	5062	5048
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04

Table G74 Ratio between hires and average knowledge, skills and attitude point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03
Accident Reports Being Processed	1.05	1.29	1.54	1.80	2.35	3.30	7.72	14.90
Actual Length of Employment	119.99	119.98	119.98	119.98	119.97	119.97	119.96	119.96
Average KSA	4.37	4.27	4.18	4.09	3.91	3.83	3.75	3.67
Monthly Safety Cost	5002	5026	5052	5079	5136	5167	5199	5234
RBAAIH	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.07

Table G75 Ratio between quits and average knowledge, skills and attitude point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03
Accident Reports Being Processed	1.12	1.35	1.58	1.82	2.33	2.95	6.42	9.67
Actual Length of Employment	119.99	119.98	119.98	119.98	119.97	119.97	119.97	119.96
Average KSA	4.34	4.25	4.16	4.08	3.92	3.84	3.77	3.69
Monthly Safety Cost	5009	5032	5056	5081	5134	5162	5191	5230
RBAAIH	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.07

Table G76 Fixed proportion of knowledge, skills and attitude lost point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5106	5106	5106	5106	5106	5106	5106	5106
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G77 Learning delay point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	2.13	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	108.00	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	3.98	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5113	5106	5106	5106	5106	5106	5106	5106
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table G78 Perceived accident incidence smooth point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	3.00	1.33	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	50.50	21.08	7.89	3.65	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.51	0.84	1.51	3.51	3.51	1.51	0.84	0.51
RBAAIH	2.40	1.07	0.00	0.00	0.00	0.00	0.00	0.00

Table G79 Accident reporting policy point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	0.00	0.00	0.00	0.00	2.78	1.84	2.78	2.95
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G80 Accident reporting time point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	47.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	459.13	15.73	5.17	0.62	0.37	0.30	0.27	0.23
Actual Length of Employment	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.89	0.07	0.04	0.00	0.01	0.01	0.01	0.01
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G81 Unregulated hazard regulation weighting point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	32.00	1.33	1.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	304.26	9.57	0.16	0.41	0.23	0.20	0.17	0.15
Actual Length of Employment	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	1.25	0.05	0.02	0.02	0.01	0.01	0.01	0.01
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G82 Intermediate hazard regulation weighting point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	23.50	0.67	1.00	4.00	4.00	2.00	1.33	1.00
Accident Reports Being Processed	226.98	6.50	0.72	0.31	0.17	0.16	0.13	0.12
Actual Length of Employment	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.93	0.04	0.02	0.01	0.01	0.01	0.01	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G83 Full hazard regulation weighting point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.20	0.04	0.04	0.04	0.04	0.04	0.04	0.04
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G84 Safety monitoring policy point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	3.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	50.79	22.49	0.40	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.11	0.08	0.02	0.01	0.01	0.01	0.01	0.01
RBAAIH	8.50	5.33	1.00	0.00	0.00	0.00	0.00	0.00

Table G85 Intermediate hazard regulation policy point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50

Table G86 Intermediate hazard regulation time point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	2.00	2.00	2.00	2.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	47.71	36.31	21.64	3.71	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.08	0.08	0.08	0.06	0.03	0.03	0.01	0.03
RBAAIH	6.50	8.00	7.00	6.00	0.00	0.00	0.00	0.00

Table G87 Full hazard regulation policy point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	2.00	1.00	1.33	1.00
Accident Reports Being Processed	0.00	0.00	0.00	0.00	1.01	6.47	9.55	10.82
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04
RBAAIH	0.00	0.00	0.00	0.00	4.00	4.00	4.00	3.50

Table G88 Full hazard regulation time point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	79.00	1.33	1.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	1286.61	20.77	0.86	0.35	0.19	0.16	0.14	0.12
Actual Length of Employment	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Average KSA	0.12	0.15	0.08	0.05	0.03	0.02	0.02	0.02
Monthly Safety Cost	2.13	0.05	0.02	0.01	0.00	0.01	0.01	0.00
RBAAIH	108.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G89 Base length of employment point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G90 Staff adjustment time point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.50	1.33	1.00	0.00	0.00	1.00	0.67	0.50
Accident Reports Being Processed	24.91	15.03	6.15	0.83	0.68	0.63	0.58	0.55
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.14	0.13	0.13	0.12	0.12	0.11	0.11	0.10
Monthly Safety Cost	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
RBAAIH	2.50	2.00	1.00	0.00	0.00	1.00	0.67	0.50

Table G91 Training policy point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.50	1.33	1.00	0.00	0.00	1.00	0.67	0.50
Accident Reports Being Processed	24.91	15.03	6.15	0.83	0.68	0.63	0.58	0.55
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.14	0.13	0.13	0.12	0.12	0.11	0.11	0.10
Monthly Safety Cost	0.05	0.05	0.04	0.03	0.03	0.03	0.02	0.02
RBAAIH	2.50	2.00	1.00	0.00	0.00	1.00	0.67	0.50

Table G92 Training effectiveness point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.50	0.67	0.00	0.00	0.00	0.00	0.00	0.50
Accident Reports Being Processed	0.82	0.35	0.30	0.31	0.27	0.27	0.27	0.27
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.05	0.05	0.04	0.05	0.05	0.04	0.05	0.05
Monthly Safety Cost	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.50

Table G93 Ratio between hires and average knowledge, skills and attitude point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.50	0.67	0.00	0.00	0.00	1.00	0.67	0.50
Accident Reports Being Processed	0.49	0.50	0.50	0.50	0.56	1.20	3.66	6.23
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08
Monthly Safety Cost	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
RBAAIH	0.50	0.67	1.00	0.00	0.00	0.00	0.67	1.00

Table G94 Ratio between quits and average knowledge, skills and attitude point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.50	0.67	0.00	0.00	0.00	1.00	0.67	0.50
Accident Reports Being Processed	0.46	0.46	0.47	0.47	0.52	0.86	2.82	3.69
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Monthly Safety Cost	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RBAAIH	0.50	0.67	1.00	0.00	0.00	0.00	0.67	1.00

Table G95 Fixed proportion of knowledge, skills and attitude lost point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G96 Learning delay point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table G97 Perceived accident incidence smooth point value gearing

G.1 Spearman's Rank Correlation Coefficient Calculations

A simple test was required in order to see whether there was a fit or not between the constant parameters for the fixed constant, settling time and point value sensitivity rankings. The Spearman's coefficient of rank correlation was chosen, as it measures whether there is a statistical difference between two sets of ordinal data (Curwin and Slater, 1991).

The equation for Spearman's Rank Correlation Coefficient is:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

Where,

d = the difference in the ranks between each pair of variables

n = the number of pairs

6 = a constant

$\sum$ = the sum of all the pairs of data

The significance of the correlation results were then measured to determine whether there was a level of association between the three measures of sensitivity at 99% significance. As Spearman's Rank measurement can only be used to compare association between two sets of data, the results of each test were compared against the other two. If there was a statistically significant relationship between all, then it could be concluded that the tests suggested similar patterns of sensitivity. The calculations based on Tables G98 to G100 indicate the degree of association between ranks, and if they are statistically significant.

Parameter	Mean Fixed Constant	Mean Settling Time	Mean Fixed Constant Rank	Mean Settling Time Rank	d	d^2
Accident Reporting Policy	0.76	13.48	9	12	-3.00	9.00
Accident Reporting Time	0.03	1.19	15	16	-1.00	1.00
Base Length of Employment	4.69	172.63	1	1	0.00	0.00
Fixed Proportion of Knowledge Lost	0.39	37.88	12	6	6.00	36.00
Full Hazard Regulation Policy	1.76	24.50	4	10	-6.00	36.00
Full Hazard Regulation Time	0.78	10.85	8	13	-5.00	25.00
Full Hazard Regulation Weighting	0.62	25.21	10	9	1.00	1.00
Intermediate Hazard Regulation Policy	1.06	17.33	6	11	-5.00	25.00
Intermediate Hazard Regulation Time	0.04	0.71	14	17	-3.00	9.00
Intermediate Hazard Regulation Weighting	0.79	35.02	7	7	0.00	0.00
Learning Delay	0.00	0.00	18	18.5	-0.50	0.25
Perceived Accident Incidence Smooth	0.00	7.60	18	14	4.00	16.00
Ratio Between Hires and Average KSA	0.19	32.85	13	8	5.00	25.00
Ratio Between Quits and Average KSA	0.40	38.73	11	5	6.00	36.00
Safety Monitoring Policy	0.01	1.83	16	15	1.00	1.00
Staff Adjustment Time	0.00	0.00	18	18.5	-0.50	0.25
Training Effectiveness	2.51	48.23	3	3	0.00	0.00
Training Policy	2.53	48.02	2	4	-2.00	4.00
Unregulated Hazard Regulation Weighting	1.19	51.77	5	2	3.00	9.00
Sum of d^2						233.50

Table G98 Spearman's rank correlation coefficient test for mean fixed constant sensitivity versus mean settling time sensitivity

$$\text{Spearman's Rank Correlation Coefficient}(r_s) = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

$$= 1 - \frac{6\sum 233.50}{19(19^2-1)}$$

$$= 0.7952$$

The correlation coefficient can be compared to a significance level $r_0 = 0.01$. The test will indicate whether the result is significant on 99% of occasions. The correlation coefficient needs to equal or exceed the published tabulated value for the result to be statistically significant (Murdoch and Barnes, 1986).

$$H_0 : |r| \neq r_0$$
$$H_1 : |r| \neq r_1$$

To decide whether the null hypothesis is correct v must be found.

$$v = n - 2$$
$$= 19 - 2$$
$$= 17$$

The correlation coefficient table shows v at a 99% significance level to be 0.5751.

$$|r| > r_0$$
$$0.7952 > 0.5751$$

As the calculated figure is greater than 0.5751, then the null hypothesis may be rejected. The rank correlation between the mean fixed constant sensitivity and mean settling time sensitivity has been shown to be statistically significant on 99 out of 100 occasions.

Parameter	Mean Fixed Constant	Mean Point Value Gearing	Mean Fixed Constant Rank	Mean Point Value Gearing Rank	d	d^2
Accident Reporting Policy	0.76	13.48	9	2	7.00	49.00
Accident Reporting Time	0.03	0.22	15	13	2.00	4.00
Base Length of Employment	4.69	31.48	1	1	0.00	0.00
Fixed Proportion of Knowledge Lost	0.39	0.37	12	12	0.00	0.00
Full Hazard Regulation Policy	1.76	3.03	4	6	-2.00	4.00
Full Hazard Regulation Time	0.78	1.02	8	10	-2.00	4.00
Full Hazard Regulation Weighting	0.62	5.70	10	5	5.00	25.00
Intermediate Hazard Regulation Policy	1.06	1.97	6	7	-1.00	1.00
Intermediate Hazard Regulation Time	0.04	0.01	14	15.5	-1.50	2.25
Intermediate Hazard Regulation Weighting	0.79	7.31	7	4	3.00	9.00
Learning Delay	0.00	0.00	18	18	0.00	0.00
Perceived Accident Incidence Smooth	0.00	0.00	18	18	0.00	0.00
Ratio Between Hires and Average KSA	0.19	0.13	13	14	-1.00	1.00
Ratio Between Quits and Average KSA	0.40	0.45	11	11	0.00	0.00
Safety Monitoring Policy	0.01	0.01	16	15.5	0.50	0.25
Staff Adjustment Time	0.00	0.00	18	18	0.00	0.00
Training Effectiveness	2.51	1.34	3	9	-6.00	36.00
Training Policy	2.53	1.40	2	8	-6.00	36.00
Unregulated Hazard Regulation Weighting	1.19	11.10	5	3	2.00	4.00
Sum of d^2						175.50

Table G99 Spearman's rank correlation coefficient test for mean fixed constant sensitivity versus mean point value sensitivity

$$\text{Spearman's Rank Correlation Coefficient}(r_s) = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

$$= 1 - \frac{6\sum 175.50}{19(19^2-1)}$$

$$= 0.8461$$

The correlation coefficient can be compared to a significance level $r_0 = 0.01$. The test will indicate whether the result is significant on 99% of occasions. The correlation coefficient needs to equal or exceed the published tabulated value for the result to be statistically significant (Murdoch and Barnes, 1986).

$$H_0 : |r| \neq r_0$$
$$H_1 : |r| \neq r_1$$

To decide whether the null hypothesis is correct v must be found.

$$
\begin{aligned}
v &= n - 2 \\
&= 19 - 2 \\
&= 17
\end{aligned}
$$

The correlation coefficient table shows v at a 99% significance level to be 0.5751.

$$
\begin{aligned}
&|r| > r_0 \\
&0.8461 > 0.5751
\end{aligned}
$$

As the calculated figure is greater than 0.5751, then the null hypothesis may be rejected. The rank correlation between the mean fixed constant sensitivity and mean point value sensitivity has been shown to be statistically significant on 99 out of 100 occasions.

Parameter	Mean Settling Time	Mean Point Value Gearing	Mean Settling Time Rank	Mean Point Value Gearing Rank	d	d^2
Accident Reporting Policy	13.48	13.48	12	2	10.00	100.00
Accident Reporting Time	1.19	0.22	16	13	3.00	9.00
Base Length of Employment	172.63	31.48	1	1	0.00	0.00
Fixed Proportion of Knowledge Lost	37.88	0.37	6	12	-6.00	36.00
Full Hazard Regulation Policy	24.50	3.03	10	6	4.00	16.00
Full Hazard Regulation Time	10.85	1.02	13	10	3.00	9.00
Full Hazard Regulation Weighting	25.21	5.70	9	5	4.00	16.00
Intermediate Hazard Regulation Policy	17.33	1.97	11	7	4.00	16.00
Intermediate Hazard Regulation Time	0.71	0.01	17	15.5	1.50	2.25
Intermediate Hazard Regulation Weighting	35.02	7.31	7	4	3.00	9.00
Learning Delay	0.00	0.00	18.5	18	0.50	0.25
Perceived Accident Incidence Smooth	7.60	0.00	14	18	-4.00	16.00
Ratio Between Hires and Average KSA	32.85	0.13	8	14	-6.00	36.00
Ratio Between Quits and Average KSA	38.73	0.45	5	11	-6.00	36.00
Safety Monitoring Policy	1.83	0.01	15	15.5	-0.50	0.25
Staff Adjustment Time	0.00	0.00	18.5	18	0.50	0.25
Training Effectiveness	48.23	1.34	3	9	-6.00	36.00
Training Policy	48.02	1.40	4	8	-4.00	16.00
Unregulated Hazard Regulation Weighting	51.77	11.10	2	3	-1.00	1.00
Sum of d^2						355.00

Table G100 Spearman's rank correlation coefficient test for mean settling time sensitivity versus mean point value sensitivity

$$\text{Spearman's Rank Correlation Coefficient}(r_s) = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

$$= 1 - \frac{6\sum 355.00}{19(19^2-1)}$$

$$= 0.6886$$

The correlation coefficient can be compared to a significance level $r_0 = 0.01$. The test will indicate whether the result is significant on 99% of occasions. The correlation coefficient needs to equal or exceed the published tabulated value for the result to be statistically significant (Murdoch and Barnes, 1986).

$$H_0 : |r| \neq r_0$$
$$H_1 : |r| \neq r_1$$

To decide whether the null hypothesis is correct v must be found.

$$v = n - 2$$
$$= 19 - 2$$
$$= 17$$

The correlation coefficient table shows v at a 99% significance level to be 0.5751.

$$|r| > r_0$$
$$0.6886 > 0.5751$$

As the calculated figure is greater than 0.5751, then the null hypothesis may be rejected. The rank correlation between the mean fixed constant sensitivity and mean point value sensitivity has been shown to be statistically significant on 99 out of 100 occasions.

APPENDIX H

Initial Value Parameter Tests

Metric	Base Run
Accident Incidence	0.02
Accident Reports Being Processed	2.06
Actual Length of Employment	119.98
Average KSA	4.00
Monthly Safety Cost	5,106.29
RBAAIH	0.05

Table H1 Initial values base run output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.09	0.07	0.04	0.02	0.02	0.02	0.02	0.03
Average KSA	1700.50	1112.45	496.75	48.72	2.03	1.96	1.79	3.88
Actual Length of Employment	119.89	119.91	119.95	119.97	119.98	119.98	119.98	119.97
Cumulative Accident Reports	3.96	3.97	3.98	3.99	4.01	4.03	4.07	4.17
RBAAIH	5803	5591	5283	5110	5103	5096	5080	5155
Cumulative Safety Costs	0.35	0.24	0.11	0.05	0.05	0.05	0.05	0.09

Table H2 Safety knowledge, skills and attitude output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.02	0.01	0.04	0.09	0.19	0.30
Average KSA	0.00	0.00	0.93	1.05	142.30	762.96	2342.22	4269.30
Actual Length of Employment	120.00	120.00	119.97	119.98	119.95	119.89	119.65	119.13
Cumulative Accident Reports	188.68	7.55	4.45	4.21	3.80	3.60	3.40	3.22
RBAAIH	4900	4900	4991	5005	5378	6276	8268	10991
Cumulative Safety Costs	0.28	0.28	0.09	0.04	0.09	0.23	0.58	0.98

Table H3 Labour output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.01	0.01	0.02	0.04	0.07	0.10	0.14
Average KSA	0.11	0.59	1.08	1.57	30.76	100.10	169.80	264.77
Actual Length of Employment	120.00	119.99	119.99	119.98	119.95	119.92	119.88	119.80
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	4911	4959	5008	5057	5304	5614	5925	6271
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.09	0.16	0.21	0.27

Table H4 Regulated hazards output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.03	2.04	2.05	2.05	2.07	2.08	2.09	2.09
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.97	119.97
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5103	5104	5105	5106	5107	5108	5109	5109
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H5 Unregulated hazards output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.03	2.04	2.05	2.05	2.07	2.08	2.09	2.09
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.97	119.97
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5103	5104	5105	5106	5107	5108	5109	5109
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H6 Hazards under intermediate regulation output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.03	2.04	2.05	2.05	2.07	2.08	2.09	2.09
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.97	119.97
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5103	5104	5105	5106	5107	5108	5109	5109
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H7 Hazards under full regulation output

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5106	5106	5106	5106	5106	5106	5106	5106
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H8 Accident reports being processed output

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	3.54	3.33	2.00	0.00	0.00	0.00	0.00	0.50
Average KSA	832.81	718.70	480.28	90.60	0.06	0.10	0.17	0.88
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04
RBAAIH	0.14	0.13	0.07	0.00	0.00	0.00	0.01	0.01
Cumulative Safety Costs	6.06	5.07	2.40	0.00	0.00	0.00	0.00	0.80

Table H9 Safety knowledge, skills and attitude output gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.02	0.01	0.04	0.09	0.19	0.30
Average KSA	0.00	0.00	0.93	1.05	142.30	762.96	2342.22	4269.30
Actual Length of Employment	120.00	120.00	119.97	119.98	119.95	119.89	119.65	119.13
Cumulative Accident Reports	188.68	7.55	4.45	4.21	3.80	3.60	3.40	3.22
RBAAIH	4900	4900	4991	5005	5378	6276	8268	10991
Cumulative Safety Costs	0.28	0.28	0.09	0.04	0.09	0.23	0.58	0.98

Table H10 Labour output gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1.01	0.67	1.00	0.00	4.00	5.00	5.33	6.00
Average KSA	0.96	0.95	0.95	0.95	55.73	95.18	108.57	127.53
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.04	0.04	0.04	0.04	0.15	0.20	0.21	0.23
Cumulative Safety Costs	0.00	0.00	0.00	0.00	3.20	4.40	4.27	4.40

Table H11 Regulated hazards output gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.03	2.04	2.05	2.05	2.07	2.08	2.09	2.09
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.97	119.97
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5103	5104	5105	5106	5107	5108	5109	5109
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H12 Unregulated hazards output gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.03	2.04	2.05	2.05	2.07	2.08	2.09	2.09
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.97	119.97
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5103	5104	5105	5106	5107	5108	5109	5109
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H13 Hazards under intermediate regulation output gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table H14 Hazards under full regulation output gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Average KSA	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
Actual Length of Employment	119.98	119.98	119.98	119.98	119.98	119.98	119.98	119.98
Cumulative Accident Reports	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RBAAIH	5106	5106	5106	5106	5106	5106	5106	5106
Cumulative Safety Costs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H15 Accident reports being processed output gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.10	0.63	0.34	0.08	0.00	0.00	0.00	0.00
Accident Reports Being Processed	1705.50	1112.45	496.75	56.08	0.26	0.00	0.00	0.00
Actual Length of Employment	108.01	112.94	119.01	119.91	120.00	120.00	120.00	120.00
Average KSA	0.00	1.00	2.00	3.00	5.00	6.00	7.00	8.00
Monthly Safety Cost	15929	11160	8301	5656	4900	4900	4900	4900
RBAAIH	1.08	0.90	0.53	0.15	0.03	0.09	0.15	0.19

Table H16 Safety knowledge, skills and attitude point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.07	0.21	0.43	0.58
Accident Reports Being Processed	0.00	0.00	0.00	0.01	142.30	762.96	2342.22	4269.30
Actual Length of Employment	120.00	120.00	120.00	120.00	119.92	119.61	118.09	113.58
Average KSA	400.00	16.00	8.00	5.33	3.20	2.67	2.29	2.00
Monthly Safety Cost	4900	4900	4900	4900	5738	8069	12470	16464
RBAAIH	0.28	0.28	0.20	0.03	0.13	0.35	0.66	1.01

Table H17 Labour point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.01	0.02	0.04	0.07	0.10	0.14
Accident Reports Being Processed	0.11	0.59	1.08	1.57	30.76	100.10	169.80	264.77
Actual Length of Employment	120.00	119.99	119.99	119.98	119.95	119.92	119.88	119.80
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	4911	4959	5008	5057	5306	5621	5936	6286
RBAAIH	4.80	0.19	0.10	0.06	0.09	0.16	0.21	0.27

Table H18 Regulated hazards point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.01	1.33	1.00	0.00	4.00	5.00	5.33	6.00
Accident Reports Being Processed	0.96	0.95	0.95	0.95	55.73	95.18	108.57	127.53
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.04	0.04	0.04	0.04	0.16	0.20	0.22	0.23
RBAAIH	95.96	3.73	2.00	0.80	3.20	4.40	4.27	4.40

Table H19 Unregulated hazards point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Accident Reports Being Processed	1.69	1.78	1.87	1.97	2.16	2.26	2.38	2.49
Actual Length of Employment	119.98	119.98	119.98	119.98	119.97	119.97	119.97	119.97
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5043	5059	5074	5090	5122	5138	5154	5170
RBAAIH	0.03	0.04	0.04	0.04	0.05	0.06	0.06	0.06

Table H20 Hazards under intermediate regulation point value

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Accident Reports Being Processed	1.86	1.91	1.96	2.01	2.13	2.23	2.33	2.44
Actual Length of Employment	119.98	119.98	119.98	119.98	119.97	119.97	119.97	119.97
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5059	5071	5082	5094	5118	5130	5142	5154
RBAAIH	0.03	0.04	0.04	0.04	0.05	0.06	0.06	0.06

Table H21 Hazards under full regulation point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Accident Reports Being Processed	0.00	0.52	1.03	1.54	2.58	3.09	3.60	4.12
Actual Length of Employment	119.97	119.97	119.98	119.98	119.98	119.98	119.98	119.98
Average KSA	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monthly Safety Cost	5119	5111	5106	5106	5106	5106	5106	5106
RBAAIH	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table H22 Accident reports being processed point value

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	54.55	40.67	32.00	12.00	4.00	2.00	1.33	1.00
Accident Reports Being Processed	835.27	718.70	480.28	104.89	3.50	2.00	1.33	1.00
Actual Length of Employment	0.10	0.08	0.02	0.00	0.00	0.00	0.00	0.00
Average KSA	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Monthly Safety Cost	2.14	1.58	1.25	0.43	0.16	0.08	0.05	0.04
RBAAIH	20.81	22.67	19.20	8.00	1.60	1.60	2.67	2.80

Table H23 Safety knowledge, skills and attitude point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.00	1.33	2.00	4.00	10.00	19.00	27.33	28.00
Accident Reports Being Processed	1.00	1.33	2.00	3.98	272.31	738.74	1514.67	2071.48
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05
Average KSA	99.00	4.00	2.00	1.33	0.80	0.67	0.57	0.50
Monthly Safety Cost	0.04	0.05	0.08	0.16	0.49	1.16	1.92	2.22
RBAAIH	4.60	6.13	6.00	1.60	6.40	12.00	16.27	19.20

Table H24 Labour point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	1.01	1.33	1.00	0.00	4.00	5.00	5.33	6.00
Accident Reports Being Processed	0.96	0.95	0.95	0.95	55.73	95.18	108.57	127.53
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.04	0.04	0.04	0.04	0.16	0.20	0.22	0.23
RBAAIH	95.96	3.73	2.00	0.80	3.20	4.40	4.27	4.40

Table H25 Regulated hazards point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.51	0.67	0.00	0.00	0.00	1.00	0.67	0.50
Accident Reports Being Processed	0.28	0.28	0.28	0.29	0.29	0.29	0.29	0.38
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RBAAIH	0.40	0.27	0.40	0.80	0.00	0.40	0.27	0.20

Table H26 Unregulated hazards point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.51	0.00	0.00	0.00	0.00	0.00	0.67	0.50
Accident Reports Being Processed	0.18	0.18	0.18	0.17	0.19	0.19	0.21	0.21
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
RBAAIH	0.40	0.27	0.40	0.80	0.00	0.40	0.27	0.20

Table H27 Hazards under intermediate regulation point value gearing

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Accident Reports Being Processed	0.10	0.10	0.10	0.10	0.14	0.17	0.17	0.18
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
RBAAIH	0.40	0.27	0.40	0.80	0.00	0.40	0.27	0.20

Table H28 Hazards under full regulation point value gearing

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Accident Incidence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accident Reports Being Processed	1.00	1.00	1.00	1.01	1.01	1.00	1.00	1.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly Safety Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table H29 Accident reports being processed point value gearing

H.1 Spearman's Rank Correlation Coefficient Calculations

Spearman's coefficient of rank correlation was used in order to see whether there was a statistically significant association between the initial value parameters for the fixed initial value and point value sensitivity rankings. Table H30, and the calculations which follow indicate the level of association between ranks, and whether these are statistically significant.

Parameter	Mean Initial Value Output Gearing	Mean Initial Value Point Value Gearing	Mean Initial Value Output Gearing Rank	Mean Initial Value Point Value Gearing Rank	d	d^2
Accident Reports Being Processed	0.00	0.17	5.5	6	-0.50	0.25
Hazards under Full Regulation	0.00	0.09	5.5	7	-1.50	2.25
Hazards under Intermediate Regulation	0.00	0.13	5.5	6	-0.50	0.25
Labour	98.98	101.78	1	1	0.00	0.00
Regulated Hazards	8.98	11.13	3	3	0.00	0.00
Safety KSA	44.75	49.75	2	2	0.00	0.00
Unregulated Hazards	0.00	0.18	5.5	4	1.50	2.25
Sum of d^2						5.00

Table H30 Spearman's rank correlation coefficient test for mean fixed constant sensitivity versus mean settling time sensitivity

$$\text{Spearman's Rank Correlation Coefficient}(r_s) = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

$$= 1 - \frac{6\sum 5}{7(7^2-1)}$$

$$= 0.9107$$

The correlation coefficient can be compared to a significance level $r_0 = 0.01$. The test will indicate whether the result is significant on 99% of occasions. The correlation coefficient needs to equal or exceed the published tabulated value for the result to be statistically significant (Murdoch and Barnes, 1986).

$$H_0 : |r| \neq r_0$$
$$H_1 : |r| \neq r_1$$

To decide whether the null hypothesis is correct v must be found.

$$\begin{aligned} v &= n - 2 \\ &= 7 - 2 \\ &= 5 \end{aligned}$$

The correlation coefficient table shows v at a 99% significance level to be 0.8745.

$$|r| > r_0$$
$$0.9107 > 0.8745$$

As the calculated figure is greater than 0.8745, then the null hypothesis may be rejected. The rank correlation between the mean fixed constant sensitivity and mean settling time sensitivity has been shown to be statistically significant on 99 out of 100 occasions.

APPENDIX I

Table Function Parameter Tests

Accident Repeater Table Parameters

Accident Reports Completed	Accident Repeater Original	Accident Repeater Slope	Accident Repeater Shape
1	0.000	0.000	0.000
2	0.010	0.005	0.036
3	0.020	0.010	0.072
4	0.030	0.015	0.107
5	0.040	0.020	0.143
6	0.055	0.028	0.179
7	0.070	0.035	0.215
8	0.085	0.043	0.251
9	0.100	0.050	0.286
10	0.125	0.063	0.322
11	0.165	0.083	0.358
12	0.215	0.108	0.394
13	0.265	0.133	0.429
14	0.320	0.160	0.465
15	0.365	0.183	0.501
16	0.425	0.213	0.537
17	0.490	0.245	0.573
18	0.545	0.273	0.608
19	0.600	0.300	0.644
20	0.680	0.340	0.680

Table I1 Alternative accident repeater table function parameters

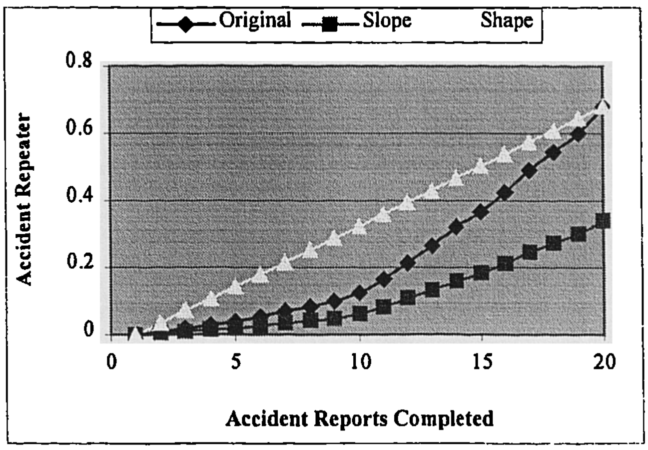

Figure I1 Alternative accident repeater table function parameters

The original Accident Repeater table is both positive and exponential in shape (see Appendix C for full details). This appears to be the most plausible set of table parameters. Halving the rate of change of Accident Repeater is an alternative assumption that should not necessarily be discounted. The original slope may have overestimated the rate at which accident report numbers leading to accident repeaters. The only other plausible relationship is a linear one, although the justification given for the original table largely discounts this possibility.

Hazards Identified from Safety Monitoring Table Parameters

Safety Monitoring Policy	Original	Slope	Shape
0	0.000	0.000	0.000
10	0.125	0.063	1.750
20	0.325	0.163	2.750
30	0.575	0.288	3.500
40	0.925	0.463	4.000
50	1.530	0.770	4.250
60	3.150	1.575	4.450
70	4.350	2.175	4.650
80	4.730	2.365	4.800
90	4.930	2.465	4.930
100	5.000	2.500	5.000

Table I2 Alternative hazards identified from safety monitoring table function parameters

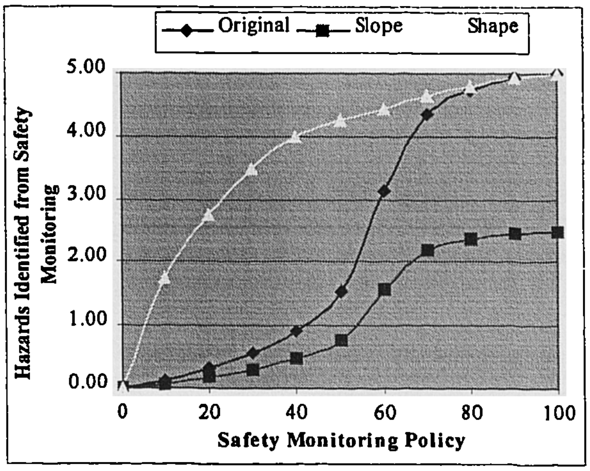

Figure I2 Alternative hazards identified from safety monitoring table function parameters

The original Hazards Identified from Safety Monitoring table is both positive and logistical in shape (see Appendix C for full details). This appears to be the most plausible set of table parameters. Halving the rate of change of Hazards Identified from Safety Monitoring is an alternative assumption that should not necessarily be discounted. The original slope may suggest that the Safety Monitoring Policy is better at identifying active hazards than it is in reality. An alternative assumption about the shape of the table function is a logarithmic relationship. The hazards which can be identified from safety monitoring may in reality show a fast rate of change at the lower range of activity, and this rate gradually slowing off as more safety monitoring is carried out.

Multiplier Table Parameters

Multiplier	Original	Slope	Shape
0	0.0	0.0	0.0
50	10.0	5.0	4.0
100	20.0	10.0	8.5
150	30.0	15.0	15.5
200	40.0	20.0	24.5
250	50.0	25.0	39.5
300	60.0	30.0	78.5
350	70.0	35.0	89.5
400	80.0	40.0	94.0
450	90.0	45.0	98.5
500	100.0	50.0	100.0

Table I3 Alternative multiplier table function parameters

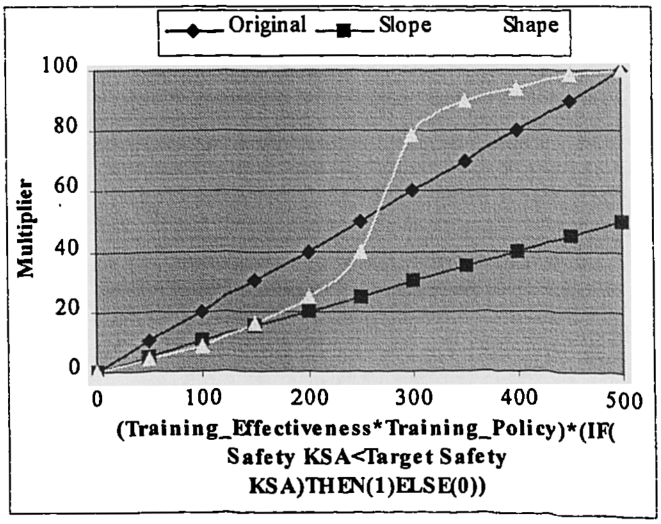

Figure I3 Alternative multiplier table function parameters

The original Multiplier table is both positive and linear in shape (see Appendix F for full details). This appears to be the most plausible set of table parameters as the Multiplier simply acts to convert the dimensions from Safety Training into Learning. Halving the rate of change of Hazards Identified from Safety Monitoring is an alternative assumption that should not necessarily be discounted. The original slope may suggest that Safety Training Policy is better at identifying active hazards than it is in reality. An alternative assumption about the shape of the table function is a logistical relationship. Although, given the role of the table function in the model, this is unlikely to be appropriate.

Quit Likelihood Table Parameters

Quit Likelihood	Original	Slope	Shape
0.0	0.000	0.000	0.000
0.1	0.001	0.001	0.027
0.2	0.003	0.002	0.050
0.3	0.006	0.003	0.066
0.4	0.014	0.007	0.078
0.5	0.028	0.014	0.085
0.6	0.080	0.040	0.090
0.7	0.092	0.046	0.094
0.8	0.096	0.048	0.097
0.9	0.098	0.049	0.099
1.0	0.100	0.050	0.100

Table I4 Alternative quit likelihood table function parameters

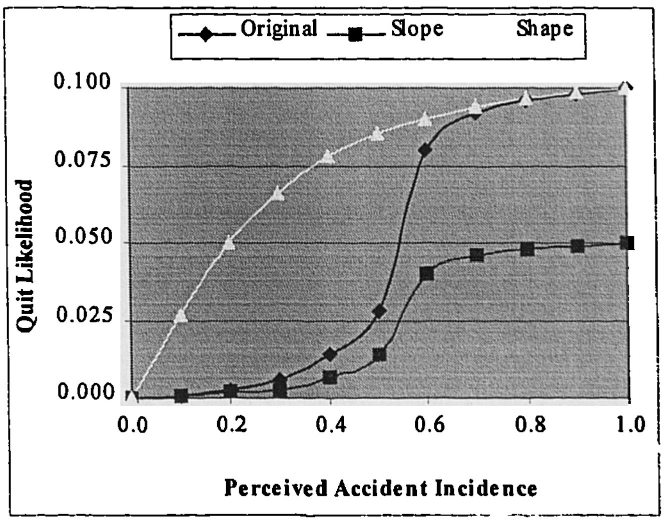

Figure I4 Alternative quit likelihood table function parameters

The original Quit Likelihood table is both positive and logistical in shape (see Appendix D for full details). This appears to be the most plausible set of table parameters. Halving the rate of change for Quit Likelihood is an alternative assumption that should not necessarily be discounted. The original slope may suggest that in reality, staff turn over too quickly given changes in the Perceived Accident Incidence. An alternative assumption about the shape of the table function is a logarithmic relationship. This may be plausible in certain occupations, but it is unlikely that at the lower ranges of the Perceived Accident Incidence that staff would quit employment so readily.

Risk Table Parameters

Risk	Original	Slope	Shape
0.0	0.050	0.025	0.050
0.5	0.049	0.025	0.049
1.0	0.047	0.024	0.048
1.5	0.044	0.022	0.047
2.0	0.036	0.018	0.046
2.5	0.015	0.008	0.044
3.0	0.008	0.004	0.042
3.5	0.004	0.002	0.039
4.0	0.002	0.001	0.030
4.5	0.001	0.000	0.015
5.0	0.000	0.000	0.000

Table I5 Alternative risk table function parameters

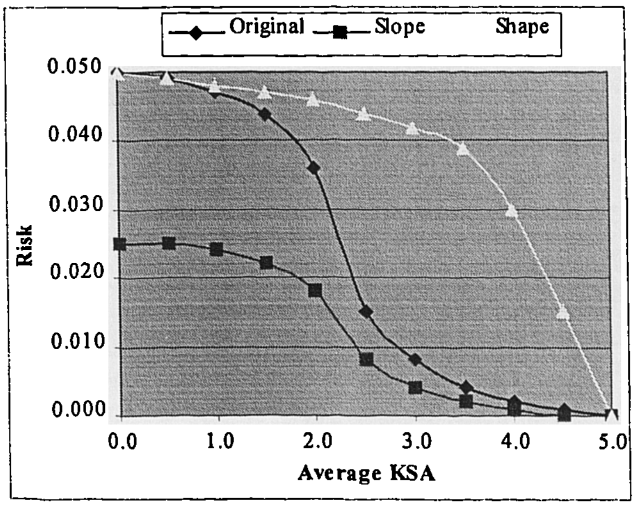

Figure I5 Alternative risk table function parameters

The original Risk table is both negative and logistical in shape (see Appendix B for full details). This appears to be the most plausible set of table parameters. Halving the rate of change for Risk is an alternative assumption that may be appropriate. The original slope may facilitate an over-representation of Risk. An alternative assumption about the shape of the table function is a logarithmic relationship. This is not so plausible, as the shape indicates little change in Risk across most of the range of Average KSA until the right of the scale is reached.

Unsafe Acts Table Parameters

Unsafe Act	Original	Slope	Shape
0.0	0.100	0.050	0.100
0.5	0.099	0.050	0.070
1.0	0.098	0.049	0.055
1.5	0.096	0.048	0.040
2.0	0.089	0.045	0.030
2.5	0.074	0.037	0.022
3.0	0.038	0.019	0.018
3.5	0.022	0.011	0.015
4.0	0.016	0.008	0.012
4.5	0.012	0.006	0.010
5.0	0.009	0.005	0.009

Table I6 Alternative unsafe acts table function parameters

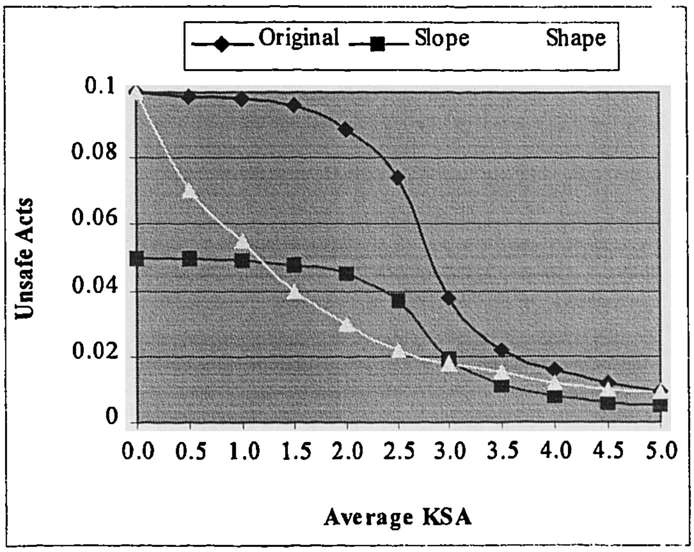

Figure I6 Alternative unsafe acts table function parameters

The original Unsafe Acts table is both negative and logistical in shape (see Appendix C for full details). These appears to be the most plausible set of table parameters. Halving the rate of change for Unsafe Acts is an alternative assumption that may be appropriate as the original table may have overestimated the likelihood of Unsafe Acts, given a level of KSA. An alternative assumption about the shape of the table function is an exponential relationship. This is not so plausible, as the shape suggests that Unsafe Acts drop off quickly at the lower end of the KSA range.

Metric	Base Run
Cumulative Accidents	103
Average KSA	4.00
Actual Length of Employment	120
Cumulative Accident Reports	103
RBAAIH	0.05
Cumulative Safety Costs	255314

Table I7 Original table function output

Original Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	10569	392	153	115	97	92	89	87
Average KSA	0.48	3.34	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	97	92	89	87
RBAAIH	4.69	0.32	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1301918	284194	260289	256494	254655	254219	253911	253681

Table I8 Base length of employment output for original table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1771	636	270	145	82	67	56	48
Average KSA	1.87	2.82	3.40	3.76	4.17	4.28	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	83	68	57	49
RBAAIH	2.67	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	322109	233585	222007	234459	278229	301740	325637	349795

Table I9 Training policy output for original table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1771	636	270	145	82	67	56	48
Average KSA	1.87	2.82	3.40	3.76	4.17	4.28	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	83	68	57	49
RBAAIH	2.67	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	422109	308585	272007	259459	253229	251740	250637	249795

Table I10 Training effectiveness output for original table function

Accident Repeater Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11299	365	154	115	96	92	89	86
Average KSA	0.48	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	96	92	89	87
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1374949	281487	260385	256541	254629	254176	253856	253616

Table I11 Base length of employment output for slope changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1799	613	262	147	81	66	55	46
Average KSA	1.87	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	324922	231271	221212	234672	278147	301604	325464	349596

Table I12 Training policy output for slope changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1724	613	262	147	81	66	55	46
Average KSA	1.92	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.50	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	417352	306271	271212	259672	253147	251604	250464	249596

Table I13 Training effectiveness output for slope changed accident repeater table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11843	365	154	115	96	92	89	86
Average KSA	0.48	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	96	92	89	87
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1429336	281487	260385	256541	254629	254176	253856	253616

Table I14 Base length of employment output for shape changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1902	623	262	147	81	66	55	46
Average KSA	1.87	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	335220	232344	221212	234672	278147	301604	325464	349596

Table I15 Training policy output for shape changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1902	623	262	147	81	66	55	46
Average KSA	1.87	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	435220	307344	271212	259672	253147	251604	250464	249596

Table I16 Training effectiveness output for shape changed accident repeater table function

Hazards Identified from Safety Monitoring Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11215	365	154	110	96	92	89	86
Average KSA	0.48	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	96	92	89	87
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1366512	281487	260385	256541	254629	254176	253856	253616

Table I17 Base length of employment output for slope changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1784	613	262	147	81	66	55	46
Average KSA	1.87	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	323447	231271	221212	234672	278147	301604	325464	349596

Table I18 Training policy output for slope changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1784	613	262	147	81	66	55	46
Average KSA	1.87	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	423447	306271	271212	259672	253147	251604	250464	249596

Table I19 Training effectiveness output for slope changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	8858	365	154	115	96	92	89	86
Average KSA	0.48	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	96	92	89	87
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1130815	281487	260385	256541	254629	254176	253856	253616

Table I20 Base length of employment output for shape changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1559	613	262	147	81	66	55	46
Average KSA	1.88	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	300880	231271	221212	234672	278147	301604	325464	349596

Table I21 Training policy output for shape changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1559	613	262	147	81	66	55	46
Average KSA	1.88	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	400880	306271	271212	259672	253147	251604	250464	249596

Table I22 Training effectiveness output for shape changed hazards identified from safety monitoring table function

Multiplier Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11982	1534	495	333	229	211	200	191
Average KSA	0.25	2.51	3.06	3.27	3.46	3.51	3.55	3.57
Actual Length of Employment	1	27	60	90	150	180	210	240
Cumulative Accident Reports	125	124	124	124	123	123	123	123
RBAAIH	4.56	1.88	0.51	0.31	0.17	0.15	0.13	0.13
Cumulative Safety Costs	1443184	398428	294517	278308	267861	266141	264994	264143

Table I23 Base length of employment output for slope changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1902	1155	623	401	192	147	118	103
Average KSA	1.87	2.4	2.81	3.13	3.59	3.76	3.89	4
Actual Length of Employment	108	110	119	120	120	120	120	120
Cumulative Accident Reports	124	124	124	124	123	122	118	103
RBAAIH	2.6	1.7	0.8	0.4	0.1	0.1	0.1	0.1
Cumulative Safety Costs	335220	285546	257344	260106	289249	309672	331825	355314

Table I24 Training policy output for slope changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1902	1155	623	401	192	147	117	103
Average KSA	1.87	2.4	2.81	3.13	3.59	3.76	3.9	4
Actual Length of Employment	108	109.98	119.22	119.71	119.93	119.96	119.97	119.98
Cumulative Accident Reports	123.95	123.87	123.76	123.62	123.07	122.34	116.76	103.14
RBAAIH	2.57	1.66	0.78	0.41	0.13	0.08	0.05	0.05
Cumulative Safety Costs	435220	360546	307344	285106	264249	259672	256714	255314

Table I25 Training effectiveness output for slope changed multiplier table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11977	1455	473	315	219	203	192	184
Average KSA	0.26	2.55	3.09	3.3	3.49	3.54	3.57	3.6
Actual Length of Employment	1	27	60	90	150	180	210	240
Cumulative Accident Reports	125	124	124	124	123	123	123	123
RBAAIH	4.56	1.75	0.48	0.28	0.15	0.14	0.13	0.12
Cumulative Safety Costs	1442702	390460	292349	276525	266931	265338	264218	263388

Table I26 Base length of employment output for shape changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1902	1290	769	448	149	97	59	37
Average KSA	1.87	2.3	2.68	3.05	3.75	4.05	4.34	4.56
Actual Length of Employment	108	109	118	120	120	120	120	120
Cumulative Accident Reports	124	124	124	124	122	97	60	39
RBAAIH	2.57	1.85	1.02	0.47	0.08	0.05	0.04	0.04
Cumulative Safety Costs	335220	298959	271925	264767	284940	304658	325918	348720

Table I27 Training policy output for shape changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1902	1290	769	448	149	97	59	37
Average KSA	1.87	2.3	2.68	3.05	3.75	4.05	4.34	4.56
Actual Length of Employment	108	109	118	120	120	120	120	120
Cumulative Accident Reports	124	124	124	124	122	97	60	39
RBAAIH	2.57	1.85	1.02	0.47	0.08	0.05	0.04	0.04
Cumulative Safety Costs	435220	373959	321925	289767	259940	254658	250918	248720

Table I28 Training effectiveness output for shape changed multiplier table function

Quit Likelihood Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11829	366	154	115	96	92	89	86
Average KSA	0.50	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	124	123	115	96	92	89	87
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1427935	281556	260394	256543	254630	254177	253856	253617

Table I29 Base length of employment output for slope changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1898	624	262	147	81	66	55	46
Average KSA	1.88	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	114	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	334818	232412	221226	234677	278148	301604	325464	349597

Table I29 Training policy output for slope changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1898	624	262	147	81	66	55	46
Average KSA	1.88	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	114	119	120	120	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.57	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	434818	307412	271226	259677	253148	251604	250464	249597

Table I30 Training effectiveness output for slope changed quit likelihood table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11846	374	155	116	96	92	89	86
Average KSA	0.48	3.31	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	29	59	89	149	179	209	239
Cumulative Accident Reports	125	124	123	115	97	92	89	87
RBAAIH	4.53	0.32	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1429593	282422	260495	256571	254643	254187	253865	253624

Table I31 Base length of employment output for shape changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1925	633	264	147	82	66	55	46
Average KSA	1.86	2.79	3.38	3.75	4.17	4.28	4.37	4.44
Actual Length of Employment	108	112	117	119	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	47
RBAAIH	2.59	0.8	0.22	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	337478	233309	221408	234734	278160	301612	325470	349601

Table I32 Training policy output for shape changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1925	633	264	147	82	66	55	55
Average KSA	1.86	2.79	3.38	3.75	4.17	4.28	4.37	4.37
Actual Length of Employment	108	112	117	119	120	120	120	120
Cumulative Accident Reports	124	124	123	122	82	67	56	56
RBAAIH	2.59	0.8	0.22	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	437478	308309	271408	259734	253160	251612	250470	250470

Table I33 Training effectiveness output for shape changed quit likelihood table function

Risk Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	23687	758	315	233	193	184	177	172
Average KSA	0.48	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	125	125	125	125	125	125	125
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	2613705	320797	276529	268297	264258	263353	262712	262234

Table I34 Base length of employment output for slope changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	3835	1273	545	300	163	132	109	92
Average KSA	1.86	2.8	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	110	120	120	120	120	120	120
Cumulative Accident Reports	125	125	125	125	125	125	109	92
RBAAIH	2.58	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	528476	297251	249518	250007	286296	308208	330928	354193

Table I35 Training policy output for slope changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	3835	1273	545	300	163	132	109	92
Average KSA	1.86	2.8	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	110	120	120	120	120	120	120
Cumulative Accident Reports	125	125	125	125	125	125	109	92
RBAAIH	2.58	0.78	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	628476	372251	299518	275007	261296	258208	255928	254193

Table I36 Training effectiveness output for slope changed risk table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	11869	1294	615	482	415	398	385	376
Average KSA	0.48	3.33	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	29	60	90	150	180	210	240
Cumulative Accident Reports	125	125	125	125	125	125	125	125
RBAAIH	4.53	0.31	0.08	0.05	0.05	0.05	0.05	0.04
Cumulative Safety Costs	1431922	374390	306492	293197	286533	284763	283507	282570

Table I37 Base length of employment output for shape changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	4546	1939	969	590	357	297	252	217
Average KSA	1.86	2.79	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	108	119	120	120	120	120	120
Cumulative Accident Reports	125	125	125	125	125	125	125	125
RBAAIH	2.59	0.79	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	599620	363943	291916	278958	305734	324666	345169	366733

Table I38 Training policy output for shape changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	4546	1939	969	590	357	297	252	217
Average KSA	1.86	2.79	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	108	119	120	120	120	120	120
Cumulative Accident Reports	125	125	125	125	125	125	125	125
RBAAIH	2.59	0.79	0.21	0.08	0.04	0.04	0.04	0.04
Cumulative Safety Costs	699620	438943	341916	303958	280734	274666	270169	266733

Table I39 Training effectiveness output for shape changed risk table function

Unsafe Acts Table Function Tests

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	15575	1339	600	414	305	286	273	264
Average KSA	0.48	3.32	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	29	60	90	150	180	210	240
Cumulative Accident Reports	125	125	125	125	125	125	125	125
RBAAIH	10.74	1.49	0.73	0.57	0.46	0.44	0.42	0.41
Cumulative Safety Costs	1802549	378914	305044	286394	275492	273572	272293	271391

Table I40 Base length of employment output for slope changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	3439	1866	980	566	247	192	153	127
Average KSA	1.86	2.79	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	109	119	120	120	120	120	120
Cumulative Accident Reports	125	125	125	125	125	125	125	116
RBAAIH	8.67	3.17	1.15	0.71	0.4	0.34	0.29	0.26
Cumulative Safety Costs	488912	356580	293022	276615	294717	314187	335279	357685

Table I41 Training policy output for slope changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	3439	1866	980	566	247	192	153	127
Average KSA	1.86	2.79	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	108	109	119	120	120	120	120	120
Cumulative Accident Reports	125	125	125	125	125	125	125	116
RBAAIH	8.67	3.17	1.15	0.71	0.4	0.34	0.29	0.26
Cumulative Safety Costs	588912	431580	343022	301615	269717	264187	260279	257685

Table I42 Training effectiveness output for slope changed unsafe acts table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	8986	153	103	87	74	71	69	67
Average KSA	0.48	3.34	3.75	3.91	4.05	4.09	4.12	4.14
Actual Length of Employment	1	30	60	90	150	180	210	240
Cumulative Accident Reports	125	122	103	87	75	72	70	68
RBAAIH	2.66	0.05	0.04	0.04	0.04	0.03	0.03	0.03
Cumulative Safety Costs	1143578	260256	255347	253713	252436	252121	251897	251729

Table I43 Base length of employment output for shape changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	396	188	134	101	64	53	45	38
Average KSA	1.89	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	122	121	118	101	65	54	46	39
RBAAIH	0.25	0.07	0.05	0.04	0.03	0.03	0.03	0.03
Cumulative Safety Costs	184565	188833	208404	230100	276398	300293	324458	348808

Table I44 Training policy output for shape changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	396	188	134	101	64	53	45	38
Average KSA	1.89	2.81	3.39	3.76	4.17	4.29	4.37	4.44
Actual Length of Employment	120	120	120	120	120	120	120	120
Cumulative Accident Reports	122	121	118	101	65	54	46	39
RBAAIH	0.25	0.07	0.05	0.04	0.03	0.03	0.03	0.03
Cumulative Safety Costs	384565	263833	258404	255100	251398	250293	249458	248808

Table I45 Training effectiveness output for shape changed unsafe acts table function

Accident Repeater Table Function Tests Percentage Changes

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.07	0.01	0.00	0.01	0.00	0.00	0.01
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I46 Base length of employment percentage change for slope changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.02	0.04	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I47 Training policy percentage change for slope changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.03	0.04	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I48 Training effectiveness percentage change for slope changed accident repeater table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.12	0.07	0.01	0.00	0.01	0.00	0.00	0.01
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I49 Base length of employment percentage change for shape changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.02	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I50 Training policy percentage change for shape changed accident repeater table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.02	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table I51 Training effectiveness percentage change for shape changed accident repeater table function

Hazards Identified from Safety Monitoring Table Function Tests Percentage Changes

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.06	0.07	0.01	0.04	0.01	0.00	0.00	0.01
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I52 Base length of employment percentage change for slope changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.01	0.04	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I53 Training policy percentage change for slope changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.01	0.04	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I54 Training effectiveness percentage change for slope changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.16	0.07	0.01	0.00	0.01	0.00	0.00	0.01
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I55 Base length of employment percentage change for shape changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.12	0.04	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I56 Training policy percentage change for shape changed hazards identified from safety monitoring table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.12	0.04	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I57 Training effectiveness percentage change for shape changed hazards identified from safety monitoring table function

Multiplier Table Function Tests Percentage Changes

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.13	2.91	2.24	1.90	1.36	1.30	1.25	1.20
Average KSA	0.48	0.25	0.18	0.16	0.15	0.14	0.14	0.14
Actual Length of Employment	0.08	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.07	0.27	0.34	0.38	0.41
RBAAIH	0.03	4.88	5.38	5.20	2.40	2.00	1.60	2.25
Cumulative Safety Costs	0.11	0.40	0.13	0.09	0.05	0.05	0.04	0.04

Table I58 Base length of employment percentage change for slope changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.82	1.31	1.77	1.35	1.19	1.11	1.15
Average KSA	0.00	0.15	0.17	0.17	0.14	0.12	0.11	0.10
Actual Length of Employment	0.00	0.08	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.01	0.48	0.80	1.07	1.10
RBAAIH	0.04	1.13	2.71	4.13	2.25	1.00	0.25	0.25
Cumulative Safety Costs	0.04	0.22	0.16	0.11	0.04	0.03	0.02	0.02

Table I59 Training policy percentage change for slope changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.82	1.31	1.77	1.35	1.19	1.09	1.15
Average KSA	0.00	0.15	0.17	0.17	0.14	0.12	0.11	0.10
Actual Length of Employment	0.00	0.08	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.01	0.48	0.80	1.05	1.10
RBAAIH	0.04	1.13	2.71	4.13	2.25	1.00	0.25	0.25
Cumulative Safety Costs	0.03	0.17	0.13	0.10	0.04	0.03	0.02	0.02

Table I60 Training effectiveness percentage change for slope changed multiplier table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.13	2.71	2.09	1.74	1.26	1.21	1.16	1.11
Average KSA	0.46	0.24	0.18	0.16	0.14	0.13	0.13	0.13
Actual Length of Employment	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.07	0.27	0.34	0.38	0.41
RBAAIH	0.03	4.47	5.00	4.60	2.00	1.80	1.60	2.00
Cumulative Safety Costs	0.11	0.37	0.12	0.08	0.05	0.04	0.04	0.04

Table I61 Base length of employment percentage change for shape changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	1.03	1.85	2.09	0.82	0.44	0.06	0.23
Average KSA	0.00	0.18	0.21	0.19	0.10	0.05	0.01	0.03
Actual Length of Employment	0.00	0.08	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.01	0.47	0.42	0.06	0.21
RBAAIH	0.04	1.37	3.86	4.88	1.00	0.25	0.00	0.00
Cumulative Safety Costs	0.04	0.28	0.22	0.13	0.02	0.01	0.00	0.00

Table I62 Training policy percentage change for shape changed multiplier table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	1.03	1.85	2.09	0.82	0.44	0.06	0.23
Average KSA	0.00	0.18	0.21	0.19	0.10	0.05	0.01	0.03
Actual Length of Employment	0.00	0.08	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.01	0.47	0.42	0.06	0.21
RBAAIH	0.04	1.37	3.86	4.88	1.00	0.25	0.00	0.00
Cumulative Safety Costs	0.03	0.21	0.18	0.12	0.03	0.01	0.00	0.00

Table I63 Training effectiveness percentage change for shape changed multiplier table function

Quit Likelihood Table Function Tests Percentage Changes

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.12	0.07	0.01	0.00	0.01	0.00	0.00	0.01
Average KSA	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I64 Base length of employment percentage change for slope changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.02	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I65 Training policy percentage change for slope changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.07	0.02	0.03	0.01	0.01	0.01	0.02	0.04
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04
RBAAIH	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table I66 Training effectiveness percentage change for slope changed quit likelihood table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.12	0.05	0.01	0.01	0.01	0.00	0.00	0.01
Average KSA	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.04	0.01	0.01	0.01	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RBAAIH	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table I67 Base length of employment percentage change for shape changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.09	0.00	0.02	0.02	0.00	0.01	0.02	0.04
Average KSA	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.06	0.03	0.01	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04
RBAAIH	0.03	0.03	0.05	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table I68 Training policy percentage change for shape changed quit likelihood table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.09	0.00	0.02	0.02	0.00	0.01	0.02	0.14
Average KSA	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.02
Actual Length of Employment	0.00	0.06	0.03	0.01	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.14
RBAAIH	0.03	0.03	0.05	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table I69 Training effectiveness percentage change for shape changed quit likelihood table function

Risk Table Function Tests Percentage Changes

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1.24	0.93	1.06	1.03	0.99	0.99	0.99	0.98
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.01	0.02	0.09	0.29	0.36	0.40	0.44
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	1.01	0.13	0.06	0.05	0.04	0.04	0.03	0.03

Table I70 Base length of employment percentage change for slope changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1.17	1.00	1.02	1.07	0.99	0.97	0.95	0.92
Average KSA	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.01	0.01	0.02	0.02	0.50	0.84	0.92	0.89
RBAAIH	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.64	0.27	0.12	0.07	0.03	0.02	0.02	0.01

Table I71 Training policy percentage change for slope changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1.17	1.00	1.02	1.07	0.99	0.97	0.95	0.92
Average KSA	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.01	0.01	0.02	0.02	0.50	0.84	0.92	0.89
RBAAIH	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.49	0.21	0.10	0.06	0.03	0.03	0.02	0.02

Table I72 Training effectiveness percentage change for slope changed risk table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.12	2.30	3.02	3.19	3.28	3.32	3.33	3.32
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.01	0.02	0.09	0.29	0.36	0.40	0.44
RBAAIH	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.10	0.32	0.18	0.14	0.13	0.12	0.12	0.11

Table I73 Base length of employment percentage change for shape changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1.57	2.05	2.59	3.07	3.36	3.43	3.49	3.53
Average KSA	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.01	0.01	0.02	0.02	0.50	0.84	1.19	1.55
RBAAIH	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.86	0.56	0.31	0.19	0.10	0.08	0.06	0.05

Table I74 Training policy percentage change for shape changed risk table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	1.57	2.05	2.59	3.07	3.36	3.43	3.49	3.53
Average KSA	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.01	0.01	0.02	0.02	0.50	0.84	1.19	1.55
RBAAIH	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Safety Costs	0.66	0.42	0.26	0.17	0.11	0.09	0.08	0.07

Table I75 Training effectiveness percentage change for shape changed risk table function

Unsafe Acts Table Function Tests Percentage Changes

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.47	2.42	2.92	2.60	2.14	2.11	2.07	2.03
Average KSA	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.08	0.28	0.35	0.40	0.43
RBAAIH	1.29	3.66	8.13	10.40	8.20	7.80	7.40	9.25
Cumulative Safety Costs	0.38	0.33	0.17	0.12	0.08	0.08	0.07	0.07

Table I76 Base length of employment percentage change for slope changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.94	1.93	2.63	2.90	2.01	1.86	1.73	1.64
Average KSA	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.02	0.50	0.83	1.18	1.36
RBAAIH	2.25	3.06	4.48	7.88	9.00	7.50	6.25	5.50
Cumulative Safety Costs	0.52	0.53	0.32	0.18	0.06	0.04	0.03	0.02

Table I77 Training policy percentage change for slope changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.94	1.93	2.63	2.90	2.01	1.86	1.73	1.64
Average KSA	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.00	0.01	0.02	0.50	0.83	1.18	1.36
RBAAIH	2.25	3.06	4.48	7.88	9.00	7.50	6.25	5.50
Cumulative Safety Costs	0.40	0.40	0.26	0.16	0.07	0.05	0.04	0.03

Table I78 Training effectiveness percentage change for slope changed unsafe acts table function

Metric	Adjustment Fraction							
	-99%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.15	0.61	0.32	0.24	0.23	0.23	0.23	0.23
Average KSA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.00	0.02	0.16	0.24	0.23	0.22	0.22	0.22
RBAAIH	0.43	0.84	0.50	0.20	0.20	0.40	0.40	0.25
Cumulative Safety Costs	0.12	0.08	0.02	0.01	0.01	0.01	0.01	0.01

Table I79 Base length of employment percentage change for shape changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.78	0.70	0.50	0.30	0.22	0.21	0.20	0.21
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.02	0.03	0.04	0.17	0.22	0.21	0.20	0.19
RBAAIH	0.91	0.91	0.76	0.50	0.25	0.25	0.25	0.25
Cumulative Safety Costs	0.43	0.19	0.06	0.02	0.01	0.00	0.00	0.00

Table I80 Training policy percentage change for shape changed unsafe acts table function

Metric	Adjustment Fraction							
	-100%	-75%	-50%	-25%	+25%	+50%	+75%	+100%
Cumulative Accidents	0.78	0.70	0.50	0.30	0.22	0.21	0.20	0.21
Average KSA	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Actual Length of Employment	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Accident Reports	0.02	0.03	0.04	0.17	0.22	0.21	0.20	0.19
RBAAIH	0.91	0.91	0.76	0.50	0.25	0.25	0.25	0.25
Cumulative Safety Costs	0.09	0.15	0.05	0.02	0.01	0.01	0.00	0.00

Table I81 Training effectiveness percentage change for shape changed unsafe acts table function

APPENDIX J

Data Collated for Parameterisation of the Real World Occupational Safety Model

Month	Over 3 Day Injuries	Lost Time (days)	3 Days or Less Injuries	Lost Time (days)	Total Lost Time (days)	Minor Injuries	Total Accident Injuries
Apr.	1	7			7		1
May	4	25	2	3	28		6
Jun.						2	2
Jul.	3	28	2	4	32	1	6
Aug.	3	52			52	3	6
Sep.	3	36			36	3	6
Oct.	2	9	1	2	11	1	4
Nov.	3	44			44	1	4
Dec.			2	6	6	1	3
Jan.						3	3
Feb.	3	16	1	1	17	2	6
Mar.	3	21	1	1	22		4
Totals	25	238	9	17	255	17	51

Table J1 Accident and lost time statistics 1993-94

Month	Over 3 Day Injuries	Lost Time (days)	3 Days or Less Injuries	Lost Time (days)	Total Lost Time (days)	Minor Injuries	Total Accident Injuries
Apr.	0	0	0	0	0	2	2
May	1	5	1	0.5	5.5	8	10
Jun.	3	18.5	0	0	18.5	6	9
Jul.	1	5	0	0	5	2	3
Aug.	2	9	0	0	9	3	5
Sep.	7	161	0	0	161	1	8
Oct.	1	6	0	0	6	8	9
Nov.	0	0	2	5	5	3	5
Dec.	3	24	1	2	26	4	8
Jan.	0	0	0	0	0	2	2
Feb.	1	15	0	0	15	2	3
Mar.	1	64	1	0	65	2	4
Totals	20	307.5	5	7.5	316	43	68

Table J2 Accident and lost time statistics 1994-95

Month	Over 3 Day Injuries	Lost Time (days)	3 Days or Less Injuries	Lost Time (days)	Total Lost Time (days)	Minor Injuries	Total Accident Injuries
Apr.	3	21			21	6	9
May	2	11	1	2	13	3	6
Jun.	5	208			208	2	7
Jul.	1	5			5	3	4
Aug.	2	33			33	2	4
Sep.	5	79	1	3	82	2	8
Oct.	1	4			4	1	2
Nov.	6	105	1	2	107	5	12
Dec.	2	8			8	4	6
Jan.			1	2	2	3	4
Feb.	1	19			19	5	6
Mar.	1					3	4
Totals	29	493	4	9	502	39	72

Table J3 Accident and lost time statistics 1995-96

Employee Type	Employee	Description of Duties/Use of Time	Hours involved in accident reporting
Line Management	Finishing End Manager	Investigation and Paperwork	5
	Shift Supervisors	Investigation	2
Safety Management	Safety Manager	Investigation and Paperwork	3
Operative	Safety Representative	Investigation	3
Any	Injured Party	Investigation/Recipient of Medical Attention	2
Any	Witness	Investigation	1
Any	First Aider	Dispensing First Aid Treatment	0.5
Total			16.5

Table J4 Average accident reporting and investigation for an over-3-day injury

Employee Type	Employee	Description of Duties/Use of Time	Hours involved in accident reporting
Line Management	Finishing End Manager	Investigation and Paperwork	3
	Shift Supervisors	Investigation	2
Safety Management	Safety Manager	Investigation and Paperwork	1.5
Operative	Safety Representative	Investigation	2
Any	Injured Party	Investigation/Recipient of Medical Attention	1
Any	Witness	Investigation	0.5
Any	First Aider	Dispensing First Aid Treatment	0.5
Total			10.5

Table J5 Average accident reporting and investigation for an under-3-day injury

Employee Type	Employee	Description of Duties/Use of Time	Hours involved in accident reporting
Line Management	Finishing End Manager	Paperwork	0.5
	Shift Supervisors	Paperwork	0.25
Safety Management	Safety Manager	Paperwork	0.25
Operative	Safety Representative	N/A	0
Any	Injured Party	Recipient of Medical Attention	0.25
Any	Witness	N/A	0
Any	First Aider	Dispensing First Aid Treatment	0.25
Total			1.5

Table J6 Average accident reporting and investigation for a minor injury

Injury Types	April 1993 – March 1994	April 1994 – March 1995	April 1995 – March 1996	April 1993 – March 1996
Minor	17	43	39	99
Under 3 day	9	5	4	18
Over 3 day	25	20	29	74
Total Injuries	51	68	72	191

Table J7 Injury statistics over the three-year period

Month	Regulated Hazards	Unregulated Hazards	Hazards Under Intermediate Regulation	Hazards Under Full regulation
19	96		4	2
20	99		3	
21	99		3	
22	93	1	7	1
23	92		5	5
24	91	4	6	1
25	93		7	2
26	93	2	7	
27	92		9	1
28	93		6	3
29	97		5	
30	97		1	4
31	101		1	
32	100		2	
33	100		2	
34	99		3	
35	97		4	1
36	95	2	4	1
Totals	1727	9	79	21

Table J8 Distribution of hazards over the eighteen-month period

Hazard Number	Intermediate Hazard Regulation – Duration (man-hours)				Full Hazard Regulation – Duration (man-hours)			
	Line Mgmt.	Line Employees	Safety Managers	Total Duration (hours)	Line Mgmt.	Line Employees	Safety Managers	Total Duration (hours)
1	0.25	1		1.25	1			1
2	0.25	1		1.25				0
3	0.25	1		1.25	1	4		5
4	1	3		4				0
5	3			3	3			3
6				0				0
7				0				0
8	0.5			0.5				0
9				0				0
10	1			1	1	45	2	48
11	1		1	2	1			1
12	1			1	1	8		9
13	2			2				0
14	1			1				0
15	1	2		3	1	2		3
16	2			2	2	30	1	33
17	2	2		4	1	30	1	32
18	1	1		2				0
19	2			2	2	60	2	64
20	1	1		2	1	4		5
21				0				0
22	1	1		2				0
23				0				0
24	1	1		2				0
25				0				0
26				0				0
27				0				0
28	2	2		4	2	40	2	44
29				0				0
30	2	2		4	1	20	1	22
31	1	1		2	2	16		18
32	0.5			0.5				0
33				0	4			4
34				0				0
35	1	1		2	0.5	5		5.5
36	2	2		4	1	30	1	32
37				0				0
38	1	1		2	0.5	16	1	17.5
39				0				0
40				0	2	80	2	84
41	0.25	1		1.25				0
Total	32	24	1	57	28	391	13	432

Table J9 Time taken to intermediately and fully regulate workplace hazards over the eighteen-month period

Title	No. of Persons	Guard Inspection (man-hrs)	Fire Inspections (man-hrs)	Risk Assessment (man-hrs)	Safety Tours (man-hrs)	Safety Committees (man-hrs)	Safety Time (man-hrs)
Line Management	5	-	1	-	-	2	3
Line Employees	3	-	1	-	-	2	3
Safety Managers	2	-	2	-	-	2	4
Fire Officer	1	-	8	-	-	-	8
Total Safety Time (man-hrs)	-	-	12	-	-	6	18

Table J10 Time dedicated to the safety monitoring policy (April 1993-June 1994)

Title	No. of Persons	Guard Inspection (man-hrs)	Fire Inspections (man-hrs)	Risk Assessments (man-hrs)	Safety Tours (man-hrs)	Safety Committees (man-hrs)	Safety Time (man-hrs)
Line Management	5	-	1	10	-	2	13
Line Employees	3	-	1	8	-	2	11
Safety Managers	2	-	2	2	-	5	9
Fire Officer	1	-	8	-	-	-	8
Total Safety Time (man-hrs)	-	-	12	20	-	9	41

Table J11 Time dedicated to the safety monitoring policy (July 1994-July 1995)

Title	No. of Persons	Guard Inspection (man-hrs)	Fire Inspections (man-hrs)	Risk Assessments (man-hrs)	Safety Tours (man-hrs)	Safety Committees (man-hrs)	Safety Time (man-hrs)
Line Management	5	1	1	10	-	2	14
Line Employees	3	1	1	8	-	2	12
Safety Managers	2	-	2	2	-	5	9
Fire Officer	1	-	8	-	-	-	8
Total Safety Time (man-hrs)	-	2	12	20	-	9	43

Table J12 Time dedicated to the Safety Monitoring Policy (August 1995-February 1996)

Title	No. of Persons	Guard Inspection (man-hrs)	Fire Inspections (man-hrs)	Risk Assessments (man-hrs)	Safety Tours (man-hrs)	Safety Committees (man-hrs)	Safety Time (man-hrs)
Line Management	5	1	1	10	2	2	16
Line Employees	3	1	1	8	2	2	14
Safety Managers	2	-	2	2	2	6	12
Fire Officer	1	-	8	-	-	-	8
Total Safety Time (man-hrs)	-	2	12	20	6	10	50

Table J13 Time dedicated to the safety monitoring policy (March 1996-Present)

Finishing End 1		Finishing End 2	
Employment Starting Date	Months in the Job	Employment Starting Date	Months in the Job
Feb. 1978	217	May 1979	202
Mar. 1978	216	Jul. 1979	200
Mar. 1978	216	Mar. 1980	192
Mar. 1978	216	Jul. 1986	117
Mar. 1978	216	Oct. 1987	102
Mar. 1978	216	Sep. 1988	90
Mar. 1978	216	Apr. 1989	83
Mar. 1978	216	Jun. 1989	81
Aug. 1978	211	Oct. 1989	78
Nov. 1978	208	Apr. 1990	71
Jul. 1980	189	Jun. 1990	69
Mar. 1981	180	Nov. 1990	64
Jun. 1981	177	May 1991	58
Jun. 1981	177	May 1991	58
Oct. 1981	174	Sep. 1993	30
Jun. 1981	171		
Aug. 1982	163		
Nov. 1982	160		
Nov. 1982	160		
Nov. 1982	160		
Oct. 1983	151		
Aug. 1984	139		
Apr. 1985	131		
May. 1986	118		
Jun. 1986	117		
Jun. 1986	117		
Mar. 1988	96		
Apr. 1988	95		
May 1988	94		
Jul. 1988	92		
Jul. 1988	91		
Sep. 1988	90		
Jun. 1989	81		
Jun. 1989	81		
Oct. 1989	77		
May 1990	70		
May 1990	70		
Jun. 1990	69		
Jul. 1990	68		
Oct. 1991	55		
Feb. 1994	25		
May 1994	22		
Total Months	5808		1495

Table J14 Employment durations for all Finishing Department staff

Month	In-House and External Training (man-hours)	On-the-Job Training (man-hours)	Monthly Training (man-hours)
1	0	7.5	7.5
2	0	52.5	52.5
3	0	22.5	22.5
4	0	30	30
5	0	0	0
6	0	7.5	7.5
7	195	0	195
8	0	15	15
9	45	0	45
10	0	15	15
11	0	15	15
12	0	90	90
13	0	60	60
14	120	30	150
15	30	60	90
16	37.5	15	52.5
17	82.5	22.5	105
18	67.5	37.5	105
19	112.5	30	142.5
20	15	0	15
21	30	0	30
22	0	7.5	7.5
23	0	15	15
24	0	0	0
25	0	0	0
26	90	22.5	112.5
27	52.5	60	112.5
28	0	37.5	37.5
29	60	0	60
30	15	22.5	37.5
31	60	0	60
32	15	7.5	22.5
33	0	22.5	22.5
34	0	240	240
35	0	22.5	22.5
36	0	7.5	7.5
Total Training (man-hours)	1065	975	2040

Table J15 Safety training time over the three-year period

Month	Hours of Training (man-hrs)	Cost of Training (£'s)
1	7.5	87
2	52.5	609
3	22.5	261
4	30	348
5	0	0
6	7.5	87
7	0	0
8	15	174
9	0	0
10	15	174
11	15	174
12	90	1044
13	60	696
14	30	348
15	60	696
16	15	174
17	22.5	261
18	37.5	435
19	30	348
20	0	0
21	0	0
22	7.5	87
23	15	174
24	0	0
25	0	0
26	22.5	261
27	60	696
28	37.5	435
29	0	0
30	22.5	261
31	0	0
32	7.5	87
33	22.5	261
34	240	2784
35	22.5	261
36	7.5	87
Totals	975	11310

Table J16 Monthly costs of on-the-job training

Month	Training Form	Training Provider	Man Hours of Training	Cost of Training Delivery (£'s)	Wage Costs (£'s)	Cost of Training (£'s)
7	First aid refresher course	RoSPA	22.5	146	187	333
	Safety in the use of chainsaws	Safety consultant	37.5	353	311	664
	Safety awareness of woodworking machines	Local Education Institution	135	890	1119	2009
9	First aid refresher course	RoSPA	15	98	124	222
	Fire team training	Central Region Fire Brigade	30	122	249	371
14	Lift truck training	In-house	22.5	93	187	280
	Safety awareness of woodworking machines	Local Education Institution	75	494	622	1116
	Fire team training	Central Region Fire Brigade	22.5	92	187	279
15	Safety in the use of chainsaws	Safety consultant	15	141	124	265
	Fire team training	Central Region Fire Brigade	15	61	124	185
16	Lift truck training	In-house	15	62	124	186
	Safety Management Development Certificate	RoSPA	15	147	124	271
	Fire team training	Central Region Fire Brigade	7.5	31	62	93
17	Lift truck training	In-house	7.5	31	62	93
	Safety awareness of woodworking machines	Local Education Institution	22.5	148	187	335
	Risk Assessment Training	RoSPA	22.5	264	187	451
	Safety Management Development Certificate	RoSPA	30	294	248	542
18	Lift truck training	In-house	7.5	31	62	93
	Safety awareness of woodworking machines	Local Education Institution	22.5	148	187	335
	Safety in the use of chainsaws	Safety consultant	37.5	353	311	664
19	Lift truck training	In-house	15	62	124	186
	Safety awareness of woodworking machines	Local Education Institution	37.5	247	311	558
	Risk Assessment Training	RoSPA	30	352	248	600
	Fire team training	Central Region Fire Brigade	30	122	248	370
20	Risk Assessment Training	RoSPA	30	352	248	600
21	Risk Assessment Training	RoSPA	30	352	248	600
25	Safety awareness of woodworking machines	Local Education Institution	37.5	247	311	558
26	Lift truck training	In-house	7.5	31	62	93
	Safety in the use of chainsaws	Safety consultant	30	282	248	530
	Risk Assessment Training	RoSPA	30	352	248	600
	Fire team training	Central Region Fire Brigade	22.5	92	187	279
27	Safety in the use of chainsaws	Safety consultant	45	423	373	796
	Fire team training	Central Region Fire Brigade	7.5	31	62	93
29	Lift truck training	In-house	15	62	124	186
	Safety in the use of chainsaws	Safety consultant	45	423	373	796
30	Lift truck training	In-house	7.5	31	62	93
	Fire team training	Central Region Fire Brigade	7.5	31	62	93
31	First aid refresher course	RoSPA	30	122	248	370
	Safety Management Development Certificate	RoSPA	30	294	248	542
32	Safety Management Development Certificate	RoSPA	7.5	73	62	135
	Fire team training	Central Region Fire Brigade	7.5	31	62	93
Totals			1080			16958

Table J17 Monthly costs of in-house and external training

J1 Draft Workforce Safety Knowledge, Skills and Attitude Survey

(a) Aims:

1. To measure a number of facets of safety knowledge, skills and attitude, both knowledge and skills possessed by the workforce and knowledge and skills actually used by employees using a survey based upon a structured questionnaire.
2. To sample as many respondents as possible from the 57 employed in the Finishing Department.
3. To test the statistical significance of the survey data so as to determine whether there is a close enough fit between the data to allow it to represent the level of safety KSA for the department under observation.
4. To calculate an overall average safety KSA using values derived from the use of scaled questions in the questionnaire.
5. To use this data to initialise the Safety KSA level in the system dynamics safety model.

(b) Danger Points to Watch Out For

It is necessary to:-

1. reveal the purpose of the research to the respondents in a way that will promote their co-operation without biasing their responses;
2. be clear and concise;
3. be devoid of jargon, esoteric language or ambiguity;
4. allow the respondents to answer questions from their own knowledge;
5. be non-leading and devoid of bias; and
6. ensure that respondents do not find the wording of questions offensive or embarrassing.

(c) Relevance

1. Is the survey relevant and accurate enough to measure the safety KSA of shopfloor employees ?
2. Will it be answered honestly ?
3. Will the questions be understood ?

(d) The Questionnaire Structure

For clarity in the construction of the questionnaire it has been broken down into a number of sections. Each section has a role to play in supplying information to the safety knowledge picture. The information which is sought from the respondents is described briefly at the onset of each section under the 'Aim'.

The questionnaire is fully structured. A Likert scale using a range of 1-5 is used to log the responses for every survey question. The greater the number the greater the contribution of the answer to the overall safety knowledge level.

(e) The Survey of Shopfloor Safety Knowledge, Skills and Attitude

There are 23 questions below, in 8 sections.

(i) Reporting Procedures

Aim: To discover how aware employees are of their legal duty to report and benefit from reporting accidents and dangerous hazards.

Q1 *If it arises, how often do you or a work colleague report a workplace danger, no matter how insignificant it appears to be, to a manager or supervisor?*

1	2	3	4	5
Never or almost never		Sometimes		Always or nearly always

Q2 *When would you or a work colleague report potentially dangerous working conditions to a manager or supervisor, no matter how unimportant they might appear to be at the time?*

1	2	3	4	5
Never or almost never		After it worsens		Immediately

Q3 *In the event of an accident occurring how clear are your instructions on the accident reporting procedure that you are expected to follow?*

1	2	3	4	5
Very unclear		Quite clear in some ways, not in others		Very clear

(ii) Use of Safe Systems of Work

Aim: To discover whether employees actually use safe systems of work (if they are in place), including formalised work procedures and use of personal protective equipment.

Q4 *How often do you use personal protective equipment (protective gloves, overalls, goggles, etc.) which are made available to you when technically they should be used?*

1	2	3	4	5
Never or almost never		As often as not		Always or nearly always

Q5 *How often do you see other staff using the personal protective equipment (protective gloves, overalls, goggles, etc.) which are made available to them when they are meant to be used?*

1	2	3	4	5
Never or almost never		As often as not		Always or nearly always

Q6 *How clear are your procedures for safe working?*

1	2	3	4	5
Not at all		Fairly clear		Very clear

Q7 *How often do you follow the procedures for safe working?*

1	2	3	4	5
Never or almost never		As often as not		Always or nearly always

Q8 *How often do you see other employees following safe work procedures?*

1	2	3	4	5
Never or almost never		As often as not		Always or nearly always

Q9 *How often do you or your colleagues take short cuts with your work at the expense of safety (e.g. to speed up production or because it is normal to work in such a way)?*

1	2	3	4	5
Very often		As often as not		Never or almost never

(iii) Use of Safety Training

Aim: To explore how useful safety training is for shopfloor employees.

Q10 *How often do you have safety training?*

1	2	3	4	5
Never		Sometimes		Very Often

If you have never had any please go to Question 12 after circling 1 for this question.

Q11 *How much has the safety training that you have received increased your understanding of safety, dangers, and safety procedures?*

1	2	3	4	5
Not at all		Quite Useful		Very Useful

(iv) Safety Awareness

Aim: To determine how aware employees believe they are about workplace safety.

Q12 *How aware of your workplace hazards and risks of injury are you?*

1	2	3	4	5
Unaware		Partly aware		Very aware

Q13 *How aware of workplace hazards and their risk to injury do you think other staff are?*

1	2	3	4	5
Unaware		Partly Aware		Very Aware

(v) Opinions of Managers' and Supervisors' Safety Knowledge

Aim: To get a measure of how aware employees think that their managers and supervisors are about safety matters.

Q14 *How knowledgeable about workplace safety matters do you think your managers and supervisors are?*

1	2	3	4	5
Not at all		Fairly		Very

(vi) Safe Behaviour

Aim: To discover the regularity with which unsafe acts are committed.

Q15 *How often do you take risks in order to complete a task?*

1	2	3	4	5
Very often		As often as not		Never

Q16 *How often have you noticed other staff take risks with their work?*

1	2	3	4	5
Very often		As often as not		Never

Q17 *How often have you noticed unsafe behaviour at work, where it is possible it could lead to injury at the time, or later?*

1	2	3	4	5
Very often		As often as not		Never

(vii) Decision Making

Aim: To discover how involved staff are in decision-making about workplace safety.

Q18 *How often are you or your immediate work colleagues involved in discussions or decision-making about safety at work?*

1	2	3	4	5
Never		As often as not		Frequently

Q19 *How well do you consider your safety interests to be represented within your company's structure (e.g. is there an elected safety representative or a union safety representative) ?*

1	2	3	4	5
Not at all		Moderately		Strongly

(viii) Recruitment

Aim: To estimate the level of safety knowledge the typical recruit brings to the organisation.

Q20 *How knowledgeable are you of safety in your workplace now compared to when you joined the company?*

1	2	3	4	5
The Same		Slightly More		Much more

Q21 *How knowledgeable do you think new recruits are on safety compared to yourself?*

1	2	3	4	5
Less		The Same		More

Q22 *How do you think your knowledge of safety has developed since joining the company?*

1	2	3	4	5
Not at all		Moderately		Extensively

(ix) Natural Staff Wastage

Aim: To estimate the amount of safety knowledge the typical leaver takes away from the organisation.

Q23 *How knowledgeable do you think colleagues leaving the company were about safety compared to you at the time they left?*

1	2	3	4	5
Less		The Same		More

J2 Matrix Showing Level of Significance and Correlation Between Responses

Question	Q1	Q2	Q3	Q4	Q5	Q6
Q1	1 P= .	0.2919 P= .166	0.1215 P= .572	0.2109 P= .323	0.3455 P= .098	0.1538 P= .473
Q2	0.2919 P= .166	1 P= .	0.3057 P= .146	0.0209 P= .923	0.0777 P= .718	0.2536 P= .232
Q3	0.1215 P= .572	0.3057 P= .146	1 P= .	-0.051 P= .813	-0.1436 P= .503	0.1611 P= .452
Q4	0.2109 P= .323	0.0209 P= .923	-0.051 P= .813	1 P= .	0.1127 P= .600	0.1996 P= .350
Q5	0.3455 P= .098	0.0777 P= .718	-0.1436 P= .503	0.1127 P= .600	1 P= .	0.3066 P= .145
Q6	0.1538 P= .473	0.2536 P= .232	0.1611 P= .452	0.1996 P= .350	0.3066 P= .145	1 P= .
Q7	0.4148 P= .044	0.1069 P= .619	0.0067 P= .975	0.3185 P= .129	0.1373 P= .522	0.3485 P= .095
Q8	-0.0492 P= .819	0.1178 P= .583	-0.14 P= .514	0.1859 P= .385	0.1978 P= .354	0.7728 P= .000
Q9	0.4636 P= .023	0.0098 P= .964	0.008 P= .971	0.3793 P= .068	-0.2087 P= .328	0.0869 P= .686
Q10	0.3641 P= .080	-0.176 P= .411	-0.286 P= .175	0.4009 P= .052	0.1205 P= .575	0.1867 P= .382
Q11	0.4786 P= .018	0.0868 P= .687	0.026 P= .904	0.3226 P= .124	0.1771 P= .408	0.3573 P= .086
Q12	0.0224 P= .917	0.2022 P= .343	-0.1174 P= .585	-0.0658 P= .760	-0.0222 P= .918	-0.2467 P= .245
Q13	0.0836 P= .698	-0.049 P= .820	0.1831 P= .392	-0.1116 P= .604	0.3294 P= .116	0.0508 P= .813
Q14	0.3342 P= .111	0.0538 P= .803	0.175 P= .413	0 P=1.000	0.1935 P= .365	0.5229 P= .009
Q15	0.3593 P= .085	0.1117 P= .603	-0.1168 P= .587	0.4001 P= .053	0.0615 P= .775	0.1364 P= .525
Q16	0.3326 P= .112	0.0265 P= .902	-0.1677 P= .433	0.2049 P= .337	-0.2704 P= .201	-0.0948 P= .659
Q17	0.2885 P= .172	0.1891 P= .376	0.1325 P= .537	-0.104 P= .629	-0.0519 P= .810	0.1715 P= .423

Q18	0.1622 P=.449	-0.0836 P=.698	0.000 P=1.000	0.2857 P=.176	0.2254 P=.290	0.84 P=.696
Q19	0.2913 P=.167	0.2599 P=.220	0.1643 P=.443	0.1974 P=.355	0.0667 P=.757	0.4209 P=.041
Q20	0.4037 P=.050	0.1649 P=.441	0.2578 P=.224	0.2601 P=.220	0.1466 P=.494	0.1211 P=.573
Q21	0.0057 P=.979	-0.0222 P=.918	0.006 P=.978	0.0169 P=.938	-0.4084 P=.048	0.0359 P=.868
Q22	0.5947 P=.002	0.2823 P=.181	0.413 P=.045	0.1286 P=.549	0.1802 P=.399	0.3932 P=.057
Q23	0.1195 P=.578	0.2773 P=.190	0.0751 P=.727	-0.0702 P=.745	0.087 P=.686	0.4077 P=.048
	Q7	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**
Q1	0.4148 P=.044	-0.0492 P=.819	0.4636 P=.023	0.3641 P=.080	0.4786 P=.018	0.0224 P=.917
Q2	0.1069 P=.619	0.1178 P=.583	0.0098 P=.964	-0.176 P=.411	0.0868 P=.687	0.2022 P=.343
Q3	0.0067 P=.975	-0.14 P=.514	0.008 P=.971	-0.286 P=.175	0.026 P=.904	-0.1174 P=.585
Q4	0.3185 P=.129	0.1859 P=.385	0.3793 P=.068	0.4009 P=.052	0.3226 P=.124	-0.0658 P=.760
Q5	0.1373 P=.522	0.1978 P=.354	-0.2087 P=.328	0.1205 P=.575	0.1771 P=.408	-0.0222 P=.918
Q6	0.3485 P=.095	0.7728 P=.000	0.0869 P=.686	0.1867 P=.382	0.3573 P=.086	-0.2467 P=.245
Q7	1 P=.	0.2789 P=.187	0.512 P=.011	0.3505 P=.093	0.4272 P=.037	-0.2847 P=.177
Q8	0.2789 P=.187	1 P=.	0.1903 P=.373	0.1642 P=.443	0.188 P=.379	-0.2283 P=.283
Q9	0.512 P=.011	0.1903 P=.373	1 P=.	0.3339 P=.111	0.2617 P=.217	-0.185 P=.387
Q10	0.3505 P=.093	0.1642 P=.443	0.3339 P=.111	1 P=.	0.7983 P=.000	0.1385 P=.519
Q11	0.4272 P=.037	0.188 P=.379	0.2617 P=.217	0.7983 P=.000	1 P=.	0.3307 P=.114
Q12	-0.2847 P=.177	-0.2283 P=.283	-0.185 P=.387	0.1385 P=.519	0.3307 P=.114	1 P=.

Q13	0.0849 P= .693	0.1 P= .642	-0.0801 P= .710	-0.24 P= .259	0.0699 P= .746	0.0617 P= .775
Q14	0.5146 P= .010	0.4166 P= .043	0.1915 P= .370	0.4445 P= .030	0.5985 P= .002	-0.1271 P= .554
Q15	0.6153 P= .001	0.1577 P= .462	0.4771 P= .018	0.4848 P= .016	0.4213 P= .040	-0.0503 P= .816
Q16	0.1122 P= .602	0.1168 P= .587	0.578 P= .003	0.2932 P= .164	0.1906 P= .372	0.0167 P= .938
Q17	0.0916 P= .670	0.2212 P= .299	0.1555 P= .468	0.1112 P= .605	0.131 P= .542	-0.1848 P= .387
Q18	0.2623 P= .216	0.0826 P= .701	0.0892 P= .678	0.2673 P= .207	0.229 P= .282	0.1974 P= .355
Q19	0.5436 P= .006	0.4565 P= .025	0.3699 P= .075	0.4154 P= .044	0.5896 P= .002	0.1818 P= .395
Q20	0.2843 P= .178	0.1128 P= .600	0.149 P= .487	0.4056 P= .049	0.5748 P= .003	-0.1198 P= .577
Q21	0.0155 P= .943	-0.0609 P= .777	-0.0342 P= .874	0.3468 P= .097	0.345 P= .099	0.0699 P= .746
Q22	0.5423 P= .006	0.0877 P= .684	0.3014 P= .152	0.2579 P= .224	0.6306 P= .001	-0.0762 P= .724
Q23	0.2669 P= .207	0.4971 P= .013	0.2083 P= .329	0.0328 P= .879	0.1585 P= .459	0.097 P= .652
	Q13	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**
Q1	0.0836 P= .698	0.3342 P= .111	0.3593 P= .085	0.3326 P= .112	0.2885 P= .172	0.1622 P= .449
Q2	-0.049 P= .820	0.0538 P= .803	0.1117 P= .603	0.0265 P= .902	0.1891 P= .376	-0.0836 P= .698
Q3	0.1831 P= .392	0.175 P= .413	-0.1168 P= .587	-0.1677 P= .433	0.1325 P= .537	0 P=1.000
Q4	-0.1116 P= .604	0 P=1.000	0.4001 P= .053	0.2049 P= .337	-0.104 P= .629	0.2857 P= .176
Q5	0.3294 P= .116	0.1935 P= .365	0.0615 P= .775	-0.2704 P= .201	-0.0519 P= .810	0.2254 P= .290
Q6	0.0508 P= .813	0.5229 P= .009	0.1364 P= .525	-0.0948 P= .659	0.1715 P= .423	0.084 P= .696
Q7	0.0849 P= .693	0.5146 P= .010	0.6153 P= .001	0.1122 P= .602	0.0916 P= .670	0.2623 P= .216

Q8	0.1 P= .642	0.4166 P= .043	0.1577 P= .462	0.1168 P= .587	0.2212 P= .299	0.0826 P= .701
Q9	-0.0801 P= .710	0.1915 P= .370	0.4771 P= .018	0.578 P= .003	0.1555 P= .468	0.0892 P= .678
Q10	-0.24 P= .259	0.4445 P= .030	0.4848 P= .016	0.2932 P= .164	0.1112 P= .605	0.2673 P= .207
Q11	0.0699 P= .746	0.5985 P= .002	0.4213 P= .040	0.1906 P= .372	0.131 P= .542	0.229 P= .282
Q12	0.0617 P= .775	-0.1271 P= .554	-0.0503 P= .816	0.0167 P= .938	-0.1848 P= .387	0.1974 P= .355
Q13	1 P= .	0.2968 P= .159	0.2897 P= .170	0.0772 P= .720	0.2622 P= .216	0.2008 P= .347
Q14	0.2968 P= .159	1 P= .	0.4917 P= .015	0.207 P= .332	0.4464 P= .029	0.2146 P= .314
Q15	0.2897 P= .170	0.4917 P= .015	1 P= .	0.4696 P= .021	0.261 P= .218	0.4001 P= .053
Q16	0.0772 P= .720	0.207 P= .332	0.4696 P= .021	1 P= .	0.6307 P= .001	0.3858 P= .063
Q17	0.2622 P= .216	0.4464 P= .029	0.261 P= .218	0.6307 P= .001	1 P= .	0.3269 P= .119
Q18	0.2008 P= .347	0.2146 P= .314	0.4001 P= .053	0.3858 P= .063	0.3269 P= .119	1 P= .
Q19	0.2774 P= .189	0.6354 P= .001	0.5025 P= .012	0.4497 P= .027	0.4722 P= .020	0.6251 P= .001
Q20	0.1219 P= .570	0.4466 P= .029	0.2428 P= .253	0.2122 P= .320	0.478 P= .018	0.0578 P= .788
Q21	-0.2816 P= .182	0.0145 P= .947	-0.0129 P= .952	0.2147 P= .314	0.0543 P= .801	0 P=1.000
Q22	0.353 P= .091	0.5679 P= .004	0.379 P= .068	0.2001 P= .349	0.2466 P= .245	0.147 P= .493
Q23	0.1863 P= .383	0.5724 P= .003	0.2144 P= .314	0.3494 P= .094	0.4745 P= .019	0.386 P= .062
	Q19	**Q20**	**Q21**	**Q22**	**Q23**	
Q1	0.2913 P= .167	0.4037 P= .050	0.0057 P= .979	0.5947 P= .002	0.1195 P= .578	
Q2	0.2599 P= .220	0.1649 P= .441	-0.0222 P= .918	0.2823 P= .181	0.2773 P= .190	

Q3	0.1643 P= .443	0.2578 P= .224	0.006 P= .978	0.413 P= .045	0.0751 P= .727	
Q4	0.1974 P= .355	0.2601 P= .220	0.0169 P= .938	0.1286 P= .549	-0.0702 P= .745	
Q5	0.0667 P= .757	0.1466 P= .494	-0.4084 P= .048	0.1802 P= .399	0.087 P= .686	
Q6	0.4209 P= .041	0.1211 P= .573	0.0359 P= .868	0.3932 P= .057	0.4077 P= .048	
Q7	0.5436 P= .006	0.2843 P= .178	0.0155 P= .943	0.5423 P= .006	0.2669 P= .207	
Q8	0.4565 P= .025	0.1128 P= .600	-0.0609 P= .777	0.0877 P= .684	0.4971 P= .013	
Q9	0.3699 P= .075	0.149 P= .487	-0.0342 P= .874	0.3014 P= .152	0.2083 P= .329	
Q10	0.4154 P= .044	0.4056 P= .049	0.3468 P= .097	0.2579 P= .224	0.0328 P= .879	
Q11	0.5896 P= .002	0.5748 P= .003	0.345 P= .099	0.6306 P= .001	0.1585 P= .459	
Q12	0.1818 P= .395	-0.1198 P= .577	0.0699 P= .746	-0.0762 P= .724	0.097 P= .652	
Q13	0.2774 P= .189	0.1219 P= .570	-0.2816 P= .182	0.353 P= .091	0.1863 P= .383	
Q14	0.6354 P= .001	0.4466 P= .029	0.0145 P= .947	0.5679 P= .004	0.5724 P= .003	
Q15	0.5025 P= .012	0.2428 P= .253	-0.0129 P= .952	0.379 P= .068	0.2144 P= .314	
Q16	0.4497 P= .027	0.2122 P= .320	0.2147 P= .314	0.2001 P= .349	0.3494 P= .094	
Q17	0.4722 P= .020	0.478 P= .018	0.0543 P= .801	0.2466 P= .245	0.4745 P= .019	
Q18	0.6251 P= .001	0.0578 P= .788	0 P=1.000	0.147 P= .493	0.386 P= .062	
Q19	1 P= .	0.3195 P= .128	0.163 P= .447	0.5332 P= .007	0.7273 P= .000	
Q20	0.3195 P= .128	1 P= .	0.0921 P= .669	0.4796 P= .018	0.0852 P= .692	
Q21	0.163 P= .447	0.0921 P= .669	1 P= .	0.2276 P= .285	-0.2401 P= .258	

Q22	0.5332 P= .007	0.4796 P= .018	0.2276 P= .285	1 P= .	0.1896 P= .375	
Q23	0.7273 P= .000	0.0852 P= .692	-0.2401 P= .258	0.1896 P= .375	1 P= .	

APPENDIX K

The Occupational Safety Model: More Suitable for Learning or for Policy-Making? A Group Discussion

Interviewer: **The occupational safety model, learning or policy tool?** The first question if I can open up the focus group is **how might the simulation model assist your company?**

Respondent 1: Well I think it could be used by managers or anyone involved in the field of safety to learn what cause and effects, and what can happen if we change our approach to anything in particular, how that might affect the overall picture, and I suppose that it would be used then to try and explore what the most effective measures would be, and then obviously we would if we were to continue with that approach we would follow the path that the model said was the best path and monitor the effect to see if the two were in agreement, yes? That would build up to the point where if successful then we could use it to take, look at the future so that we could set policies so we weren't stabbing in the dark, but initially very much a learning tool and probably less of a policy making tool.

Respondent 2: I think, you know, for this company or any new company, you know, we would have difficulties getting the culture changed as we had. I think you were here long enough to know that we were along time in getting to grips with what we wanted to do, and I think this can certainly be as in this company or any other company that is really going into health and safety fresh in a big way they can see initially how much, you know, what its going to cost, but the costs will probably not be overtaken immediately by results; but eventually it will be and, thereafter, you would be on a downward, you know, flight path with, you know, obviously continuing courses in health and safety training and equipment, whatever, but it would be a lot less than in the initial period, but it would also let any new company, not new company, anybody really starting out it would certainly highlight that it would save a lot of injuries, but at the same time can save money and makes good management sense.

Respondent 3: Well HM, I've seen a few model packages like that and I must admit I've got a degree of scepticism, especially when looking or basing future policies on them, those sort of results. I would wonder how it would differ from department to department, hm, where we consider areas where accidents do occur frequently that are basically unavoidable, you know, whether that's because of its outdoors and wet weather, and people are liable to slip no matter what, hm, but again yes, it looked good, and that, yes, that would be my one worry.

Interviewer: Yes, that's a very good point about the shortcoming of this type of model, it can't be everything to all. You can capture an understanding of the behaviour of the system, rather than examining the size of the numbers. We are more interested in letting you examine the shapes of the graphical outputs rather than looking on a point-by-point basis at the numbers.

Respondent 1: Yes, I think the thing that maybe the model, I not sure how it would help or work. For instance, you could decide to spend double the amount of time on training, but their is training, effective training and more effective training and yet the model doesn't know how effective that is the training is, inappropriate training you would expect it to have a minor effect, whereas, better targeted training would obviously be more effective. Now it's probably too much for a model to be able to pick that up.

Respondent 2: Would that not be down to the model?

Respondent 1: Yes.

Respondent 2: The assumption of what you take, or what people say they take from a training course

Respondent 1: but it would be

Respondent 2: If we've got a lot of duff training courses and then really were only ourselves to blame.

Respondent 1: Yes, but if you've got the case where you actually said that the supervisors are given the job of training the men for a certain length of time each month, yes, and that's better controlled in one area than the other, you know, better targeted, or you find that in one area although you planned to do it wasn't actually being achieved and a lot of time was being wasted

Interviewer: OK

Respondent 1: Sort of real world things.

Interviewer: So we can see that as a problem with the model, but to evaluate the effectiveness of every single piece of training and trying to build that into the model adds a whole lot more complexities, and the fact that if you're concentrating very much at the operational level, this model being a high level planning tool you'd be missing the point of the model to demonstrate

Respondent 1: the effect, yes

Interviewer: the overall effect of policies. How training as a whole has an effect, how accident reporting as whole has an effect, and so on. It would detract from the learning experience if we were bogged down with keeping drilling down to the construction level of the model, changing every single type of training each time you wanted to simulate?

Respondent 1: No, but you could maybe have broad bands of training, you've got training where you go away on a course off site, or if it's on site you're isolated from your work environment.

Interviewer: Fine.

Respondent 1: A bit of theory, a few videos, whatever, might come out with a qualification. That would be, hm, external training.

Interviewer: Yes, I've got the three levels of training in the model, the external, the in-house and the on-the-job, I just aggregated them together.

Respondent 1: Well I think that each one of them is markedly different.

Interviewer: Right OK.

Respondent 1: Certainly.

Respondent 2: The results?

Respondent 1: Hm, no I think its approach, not each one of them, in-house and external are basically off-the-job and on-the-job training.

Respondent 2: Yes.

Respondent 1: Off-the-job training is a defined course that covers topics, and you go back to your job and it might not change the way you work. On-the-job training should actually, hm, because you're doing it on-the-job it should change the way you work, and in many cases the effects I think could be significantly different.

Interviewer: So this is a validation issue you are raising?

Respondent 1: Yes.

Interviewer: To validate this model to represent what happens or could happen in your workplace. So can we move back to how the actual model itself, given that it has been verified in a reasonable way, **how might it be able to assist your company, you think initially as a learning tool and later to build policies or would you use it to train people?**

Respondent 1: I think we could do yes. The problems you would face there are the scepticism. If they're are not familiar with computers or they don't understand modelling, hm, you've got to sit them down, but they have to be comfortable with the process and understand what it is setting out to achieve, and in that respect I suppose that the model has been developed to the stage that you can use sliders and check graphs. Depending on the audience you're trying to reach that will only reach a certain proportion of them. I don't know if there are different ways of doing it.

Interviewer: **So as far as computer modelling goes the user interface is very important on the learning side, not so much on the policy side?**

Respondent 1: On the learning side, yes?

Interviewer: Yes, **for learning without those slide bars would it be quite difficult for people to get bitten by the modelling bug?**

Respondent 1: Yes, I mean ideally you would want something which would work in an interactive way which that does, but it would be further down playing the game, where someone at a lower level of management, supervisory level, you could sit them down and say play with that and it might be instead of a chart it would show you a pile of dead bodies. So that they could visually, not just on a graph but get an appreciation, something that if I wind that up an operator died, whatever, so taking that a stage further.

Interviewer: **Flight simulator type of interface?**

Respondent 1: Yes, hm. all our training packages, I'm trying to think of one as an example, follow the same as a flight simulator and keep developing that I think. If the aim is to develop a package that can be used for training, yes.

Interviewer: I see, but as a policy tool to assist you in deciding where to allocate your resources.

Respondent 1: Yes it doesn't need to be pretty to do that, it just needs to be understandable you know.

Interviewer: **So were you surprised about any of the behaviour of the simulation output?**

Respondent 2: Its interesting to see which one's affect, and I suppose we could concentrate on basically the ones in which we could influence most, you know, quickly, cheaply and involve, get as many people as possible involved which would offer as quicker end result.

Respondent 1: With something like that and getting over the credibility gap right, and let's say you've got a group, say we looked at departments one and two and you have that management group, supervisors, managers, departmental managers, hm, they think the models credible, we've reached that point, then it would allow them to understand. I mean we've had debates about, hm, we don't improve on safety as quickly as we would like because we can't fit enough guards on the platforms and stuff like that, and I'm coming from the point of view that you don't need to spend all this money on guards and platforms, sure if it should be guarded then it should be guarded, but to expect that to make a tremendous inroad into accident rates is false. It's what people do that cause accidents. How do you influence that, and obviously training them on-the-job as opposed to sending them away on courses, although a blend is probably what's required, and then making sure that that is supervised, so they don't go back to what they were doing before.

Interviewer: **So this was an intuition you had? You suspected that training would be able to exert a lot of leverage over accident rates and the associated costs?**

Respondent 1: Yes, there is no substitute for knowing what you're doing.

Interviewer: **So experientially you've come to that conclusion?**

Respondent 1: Yes.

Interviewer: **Does the model back up your hypothesis?**

Respondent 1: Yes, it was probably based, my hypothesis on a proportion of the reading that you've done to build the model in the first place. Which is there's a lot of work that has been done on looking at its effects, so yes, it seems to be one of those things which is generally accepted that training has that benefit, and you can have a factory where the guarding is not adequate and hardly any accidents, and then you can have the converse where you can have everything guarded and lots of accidents. The difference there is the people.

Respondent 3: I was looking with Ally at the accident reports and I mean probably about ninety percent are for such minor things. You know its nothing really to do with what's guarding it, it's basically the attitude of the worker is "I can do this job better out the door". I mean, I know elders in the past who never wore a helmet simply because the job they can do it better without, you know.

Respondent 2: Do you?

Respondent 3: Oh yes, there's a lot of attitude you know.

Respondent 2: I think we've lost a lot of those attitudes nowadays. One, we keep pushing them on. OK, the first time it may take longer because you have to do it in a safe manner, but if you work at it long enough I'm sure you'll end up coming up with a method that's quicker and probably safer than what your initial changes were. Although they are accepting that now, and I think this has all come from training. I think the initial problem with the training aspect was to get them to accept responsibility. It was always someone else's responsibility, the health and safety officer, his job to sort this out. I mean it all, it took a long while and it's dead and buried, and people now know who is responsible and who they are responsible, you know, how many people are responsible for.

Interviewer: So you sort of enlightened

Respondent 2: I certainly would have, I think in the early days could have helped that process.

Interviewer: **Would you use the model to enlighten people, or bring training to their attention?**

Respondent 2: From top to bottom really.

Respondent 1: Yes, I think there's still work to do on enlightening, because we can still slip back into "Well I can't get enough fitters to fit the guards or manufacture the guards I need, therefore, I can't do anything about safety". There's still some of that left, yes.

Respondent 2 Not as much as before, I think a lot have changed their policies in terms of risk assessment (line managers and supervisors) even though they do them and can't finish them because they have no hardware. They're now more interested in the ones that cause most accidents where they have lost days, and which are reasonable policy statements to implement.

Interviewer: **Did the model help you appreciate an understanding of the propensity of the costs arising from the safety system as a whole?**

Respondent 2: People have always discussed it, but didn't always agree with it, you know, "Do you have to spend money on health and safety in terms of payback", never mind in terms of injury, although just financial payback is that there are large rewards.

Respondent 1: I think part of the problem would be, hm, getting the people at the top to sit down for long enough to appreciate the model and overcome the scepticism, and then look at the cost. That is a major problem, and I don't know whether we would achieve that.

Interviewer: **So to demonstrate a point you could possibly use that model and maybe the senior management would be interested in the financial**

Respondent 1: Yes, sure they would

Interviewer: **Outputs of that model?**

Respondent 1: They would but I don't know if you would, hm,

Respondent 2: Capture them for long enough?

Respondent 1: Yes, I don't know given that, and I can't say that this is universal, because I don't know what our senior boots are like, but, hm, if you've got a group of directors, they'll tend to be, forty would be young, you know. They are not at the technology end. Some of them have not really kept up. So for a start it's a computer and they're not entirely familiar with that. If letters need typed somebody else does that. They may use it for certain things. So technology is not as familiar as for people who are younger, and then you've got the scepticism about modelling which would be a concept which they would maybe not be familiar with, hm, and I think there would be a point where they would tend to cut off and just say "Well very interesting but I'm too busy, go and talk to someone else". So before you've got over those two hurdles to get to the benefits of the model they might have gone and lost interest. To get their attention it needs to be less than fifteen minutes.

Interviewer: **Are we bringing a new angle in, so we've got learning, we've got policy evaluation and demonstration**

Respondent 1: Demonstration, yes.

Interviewer: **Trying to sell a point rather than trying to teach them?**

Respondent 1: They would not have sat through your presentation. They'd have wanted to cut to, you know, what's the point? In theory, I'm not saying in practice all the time, in theory they want to, you need to hit them with what they call the bullet points, where are you headed? Although I've not sat in a lot of meetings, and maybe you can confirm that or correct me here. What I feel is that they've got to the bullet points, they want to be there, if the bullet points don't confirm their pre-digested thinking, their own prejudices and beliefs, then you're obviously wrong and they move onto something else.

Respondent 2: But saying that if the bait's taken

Respondent 1: The bait's taken

Respondent 2: with a few bullet points then all of a sudden you find that their running very fast to the beat and

Respondent 1: So there is a technique there.

Interviewer: **So if you win their confidence with this type of model that could have a real cascade effect in the way that resources are placed, and target safety as a cost centre, and you could maybe obtain more resources?**

Respondent 2: The best place to target is the Accounts, accountants

Respondent 1: Yes, yes

Respondent 2: Because that's where their interest is.

Respondent 1: That might be the place to start. Certainly, then you're into the robustness of the model and not in terms of how well validated it has been, but in the middle of the demonstration is it going to hiccup. For a valid reason, which any reasonable person would allow you to dig yourself out of, but that would be "Look it doesn't even work", you know, general mistrust about computers, no knowledge about modelling, yes and that's the kind of group, as I say I'm sure a lot of companies are vastly different, but I think that's where we are, and most companies might be like that. But we've got Andy here; he's up amongst these guys.

Respondent 2: What?

Respondent 1: So yes, the aim is to sell to that group.

Interviewer: Right, OK. **They could possibly use it as a tool amongst others to assess where they're going put resources?**

Respondent 1: Yes, they're more likely to, if they believed it you could get them running with it, hm, they might hand it to someone else to do the analysis. What about when it comes to senior people, would they be inclined to say that "If the model works in this area (departments one and two) will it work in others?" I don't know. Well there are systems, I don't think there's, its like governments trying to model economies is it?

Interviewer: No this is a micro model.

Respondent 1: Yes, it's a micro model, yes. It would be one of the things that might convince them, might be to point out the distinction. Nobody has yet successfully modelled economies, yes? You know we control interest rates and that's about as much as we can do I think. Although lots of people have tried to do, hm, maybe you could say that this is a discrete system, and there will be external factors which would just smash the model, yes. Like if the, you know, some factors that, what happens if drugs suddenly started being taken up? We'd have to introduce something for that into the model.

Interviewer: Yes, you could do, we could change the shape of the risk function.

Respondent 1: I was thinking of some *force majeure* that would sort of negate a lot of things.

Interviewer: We could build something like that into the model, but I think it would only require initialising the variables differently, rather than introducing new ones. **Do you think there were about the right amount of variables in the model? It wasn't crowded out by introducing too many policies, or were their too many policies?**

Respondent 1: No, I think you could distinguish, an attempt to distinguish between off and on-the-job training. I didn't think anything else was missing, or needed to be added.

Interviewer: **So you're meaning three slider bars for training?**

Respondent 1: Well two, off and on.

Interviewer: Just off and on, yes

Respondent 1: On the slider bars maybe a button that you press to give you a full explanation of what you're actually changing.

Interviewer: Right, that's still got to be done and will be done at the latter stages. It's just a case of putting all the bells and whistles onto the model.

Respondent 1: OK.

Interviewer: That's quite possible. **If we introduced more policies into the model what sort of dangers do you think that would have on understanding the model, the effect of policies on its behaviour?**

Respondent 3: If you understood what was there already if you added more policies I couldn't see that being a big problem.

Yes, I mean they would have to be different though. I mean you've got proactive, reactive.

Respondent 3: I think its geared to three to ten year periods you know, things are going to change, you know, technology wise and methodology as well.

Interviewer: **Would there not be a danger that too many policy options would distract the user away from the principal policy areas, and the user would start to lose an understanding of the effects of the main policies?**

Respondent 1: I see what you mean, hm, well if there were too many slider bars then we wouldn't know what was doing what wouldn't we? I think if the policies were kept mainstream then things don't get too complicated. I mean, most of those policy sliders aggregate a number of decisions don't they? Yes they do.

Interviewer: **Do you think that the policies cover the fundamental influences on safety?**

Respondent 1: Yes, what about incentive schemes?

Interviewer: Right, that could be built into the model and be tied in a cause-effect with morale and accident rates, but that's a good one for the future.

Respondent 1: I mean there's incentive communication which could be part of training, certainly incentive, because you can't buy safety. You actually don't buy safety, what you do is you either force people not to report things.

Respondent 2: You can buy results.

Respondent 1: You can buy results, yes, or you do if the incentive is such that by taking that risk I could lose my extra day off, I'm not going to take that risk. So that people make a choice, there is a direct correlation between what they do and what they get.

Interviewer: **So you think this model would give an output, you would look at the behaviour given implementation of a safety incentive scheme?**

Respondent 1: Yes, you could have that as an additional policy.

Interviewer: **Could you see how that might latch onto the model, these variables, these additional policies?**

Respondent 1: Yes.

Interviewer: **Could they fit fairly easily into the model we've got. ?**

Respondent 1: Yes, if you had a slider bar, pounds (£'s) per month per employee invested in the incentive scheme. Then you've got a cost and depending, there will be, we haven't introduced the incentive scheme so you can't get the data, but they do produce results.

Respondent 2: Are they legal?

Respondent 1: Yes, they're quite legal.

Interviewer: **Do you think the model could be modified, to put in some hypothetical figures, some guestimates and see what the knock on effect on its behaviour, as opposed to looking at the hard**

numbers?

Respondent 1: Yes, yes

Interviewer: **On a point-by-point month-by-month basis?**

Respondent 1: I think it's, hm, to the individual employee it could have depending how it was done of course several effects, one is it could, you take a cynical view they're just paying us not to report things, and so you have to structure it so you don't force that out. I've heard of people like, I think its Shell, they ask for their contractors to report what's happening and they've got strong incentives. What they do is they analyse the reports and there's the well established pyramid, you know where you've fatalities at the top, and it'd be fine but you're, hm, pyramids like missing the base and you'd be lucky enough not to have a fatality. They'd say, "Well they're fiddling the figures", and the incentives and rewards you're expecting to get aren't coming your way. So they can force you to be honest.

Interviewer: **So providing that we have this external knowledge, hm, of others experiences, got hold of from the literature or other practitioners, trainers, we can then build these effects into the model, and so given that, do you think that that model could give a good representation of what could happen if we introduced this completely new policy of incentives?**

Respondent 1: It could have a similar effect to training. You know the real world provisos, providing you do it in an ethical and sensible manner, but I think it could have a significant effect, if you don't do it ethically or sensibly then that would be short-term until you had the serious accident.

Interviewer: **Moving now back round to the model as a policy tool, possibly to the idea of somebody who is very enlightened in safety using it as a policy tool**

Respondent 1: Yes.

Interviewer: **Whereas a person from a more general background using it as an educational or as an edutainment tool?**

Respondent 1: Yes, I think as an edutainment tool people would be more inclined to play with it, and its by playing with it you actually learn.

Respondent 3: Could it be programmed to work out itself what are the most effective variables in the model? Whereas you're keeping the fifty-seven employees, is that realistic say over five years, you know?

Interviewer: No, that's why we can change the levels of labour and measure the effects given those changes.

Respondent 3: Could you give like a range?

Respondent 1: An optimising program, like you would set the target of minimising all costs, you know, total costs?

Respondent 3: You don't need to analyse them, just.

Interviewer: To optimise, yes I've optimised manually; it's not perfect. Now there are three system dynamics packages on the market, one has actually got software able to optimise models, and as you've said, hm, you can reach an optimum blend of policies, it'll just keep calibrating over hundred's of runs until it comes up with the answer.

Respondent 1: It's one of those things to truly optimise it, there are more runs than there are atoms in the universe.

Respondent 3: That's right, but what you can do is get pretty close.

Interviewer: **Do you think that might be of detriment to the human's interaction with the model? Do you think the benefits that you might accrue from optimisation software would be offset by the fact that people aren't learning about policies or are not discovering policy effects for themselves, they're letting the computer make the decisions for them?**

Respondent 1: If there was a function you could just switch on and off then you could just use it for both.

Interviewer: Right.

Respondent 1: Like for somebody who was familiar with the model and believed what it told them, em, well the model's accurate, that guys using it, then yes, he'll want to run the optimisation won't he? He won't want to spend hours in front of a keyboard.

Interviewer: That's exactly how one of the packages on the market can work.

Respondent 1: But you want the learning course, the learning tool, because it might be that the optimisation will have to take account of the amount of money you have available or the amount of time, so you want to optimise given that these inputs must be maintained below this level. So want can we do with the resources we've got?

Interviewer: Yes that's exactly what is reflected in the model, it is showing given the resources that the company have, how best to optimise. What we didn't really see was the exaggerated impact of throwing money at the problem. So what you actually would find is you're trying to over optimise, running all the policies at one-hundred percent. The additional benefits that you accrue in the accident system are absolutely minimal or none at all, so you find that the safety costs are rising, so we've got that costs curve upwardly sloping, that's something you can visually digest.

Respondent 1: Yes, because the optimisation we want to, well we don't want to optimise, that's an interesting philosophical debate. Do you want to optimise on accidents, which is zero accidents, or do you optimise on cost and you might not choose zero accidents? But philosophically you're always aiming to achieve zero accidents. Yes, that'd be interesting. Look at those companies that have zero accidents.

Respondent 2: See how much it costs.

Respondent 1: Yes, see how much it costs. I suppose once you've got there, the cost of staying there might not be that costly.

Interviewer: **Do you think that the model showed that in the short-term safety appears not to be so profitable?**

Respondent 1: Do you mean that by increasing training then there was an immediate cost, but the benefit didn't come through? Yes, I can understand that.

Interviewer: There is a small time lag.

Respondent 1: Yes, I know that's how the model's built.

Respondent 2: What?

Respondent 1: The model's built to put a time lag in, where you spend money and you get the benefits later.

Interviewer: Let's concentrate on the shortfalls of this model, I know a few have been mentioned, but I think we should re-iterate them now for clarity. **What are the fundamental weaknesses of this model as a policy, learning or demonstration tool?**

Respondent 3: Again, you could say that the less employees the less chance of an accident, again that's not really accurate though, but would that be built into the model as well? The model accepts it, say there's only fifty-five people in, there could be a lack of cover somewhere, which may result in an accident, or another example say there's a flu epidemic and eight people are off from a shift.

Interviewer: That's very good. No that hasn't been included in the model, but it's a very relevant point. A flu epidemic could have over a few weeks period a very negative effect on accident rates, as people are trying to cover for others. Although, I'm trying to reduce the level of complexity of the model, that would be an interesting shock to bring into the model in the future.

Respondent 2: So the scenario really would all depend on how experienced the fifty-seven men are, because in the layout we're talking about if we had eight or more people missing then you wouldn't be able to operate as fifty-seven men.

Interviewer: **And the model doesn't show that?**

Respondent 2: You'd only be able to operate part of the plant, and if you have a wide blend of experience it doesn't matter which part's of the plant you operate you'd still have sufficient skills maybe only to work on a, with enough training they should be able still to work in a safe manner. I don't know really how much, hm, effect it would have. Anyway, in department's one and two there's quite a high incidence of accidents. It wasn't a low accident area was it?

Interviewer: No, no it was higher than the company average, yes. **So you're actually saying here that we could maybe see this as a strength that we can still demonstrate about the effect of training upon the model's behaviour, and allowing people to move safely between tasks?**

Respondent 2: What about the length of service that should determine the amount of quality and amount of skill and training received?

Interviewer: The staff turnover is included in the model as well as the average length of employment. It shows that as turnover increases then knowledge is lost.

Respondent 2: Having more flexible people should offset a sudden burst of absenteeism.

Interviewer: So there are two sides to this argument.

Respondent 2: We are a company who do not shut for holidays. There's always cross-training for holiday cover, we run right through so, or we would shut down a machine completely.

Respondent 1: What were the three areas?

Respondent 2: Well the total credibility needs to be sold hard I think, and its possibly one thing if you were giving a presentation, you wouldn't want to spend much time on.

Interviewer: Getting people straight down to playing with the model rather than

Respondent 2: That's right.

Interviewer: Giving the presentation.

Respondent 2: If you had a document to say that this model is ninety-five percent credible, no matter where you operate it then you can get on with the business of telling them exactly, showing them the results so, you know, I think, how you get that across I don't know. I mean the one sample we've got is it reflective totally in this company? I don't know how that works or how that is built into the model. I mean there's other areas with maybe less people where their accidents are almost zero. Arthur's point about putting the model across to people who haven't really got a lot of time to listen to half an hour of justification on its credibility, just get that point across quickly, then move across onto the main issues, the bullet points.

Respondent 1: You can always completely ignore, and say this model allows you to see the effect of different policies on, hm, safety and costs related to safety.

Interviewer: **That's a weakness and a strength as far as senior management are concerned?**

Respondent 1: Yes, you could say that they would question you, and you might get bogged down with questions, whereas, if they don't have it you might introduce it if they do question it. The need for information would be driven by them then, and it would be the quickest route into getting them to use the model. "How do you work that out?", and then that point, it's a point of interest, rather than you trying to tell them before you show them the model that it's going to work, it's going to be the right thing.

Interviewer: OK.

Respondent 2: I have to say that I didn't think about the points that the others brought up in a negative form, and from the beginning just accept that you are here for a purpose, and I accepted the credibility of the whole model from the start.

Interviewer: **Are you trusting of the model builder?**

Respondent 2: It makes things easier, because it's something you want to use immediately without, well later on you might say well it's not quite accurate on this one aspect, we've put in millions of pounds (£'s) worth of training and it hasn't really affected it as much as the model showed, but I mean through time you'd find out the trend anyway wouldn't you?

Interviewer: You'd find out whether training brought accident rates down and if so by how much.

Respondent 2: Yes, you'd see the difference and the effect.

Interviewer: You might not get the exact numerical measures but would be able to measure the patterns that emerge.

Respondent 1: Yes, so we made the point about the interface about that approach being user friendly, what other points were you homing in on?

Interviewer: **The sort of variables selected; do you think that we've mentioned all of the important ones, apart from the safety incentive scheme and the absenteeism?**

Respondent 2: What about any of the auditing, I'm talking about with insurance health and safety?

Respondent 1: External audits? Yes, we have liability insurance, we have to. That's starting to bring in the wider aspects.

Interviewer: That's in the costs, that's been built into the safety costs. The cost is four-hundred and fifty thousand pounds (£'s) for four-hundred and fifty employees; those were the figures for 1996. Stuart has given me those figures. He told me the premium is set on a linear scale, so if you have zero accidents your indemnity fees are very, very small, so it worked out at nearly two-hundred pounds (£'s) an accident just on insurance.

Respondent 1: I mean that's proper that we're spending on that.

Respondent 2: It's all the life stuff isn't it.

Respondent 1: We have to sell a lot of board to make money.

Interviewer: If we can start to wind the discussion down as I think we've covered all the points now and it's been very enriching. I've learnt a lot about the potential for the model, the pitfalls of the model applied within a real company. So the question is, **is it a learning tool, a policy tool, or both, and if it's both which side do thing it leans towards in this particular company?** Just in a few words I think.

Respondent 1: In a few words I think, hm, to succeed as a policy tool it has to first succeed as a learning tool. If it isn't in the first place a learning tool then it will never be a policy tool. It's not either, or it's one then the other.

Interviewer: One then the other?

Respondent 1: Yes.

Interviewer: **People within the group would use the tool for different reasons?**

Respondent 1: Yes, but you know it would be for anybody to come and use it, it would be for learning, once you've achieved that aim, you could then use it by adding features to mould it into a policy tool, but first of all it must be a good learning tool.

Interviewer: Just one more question to tag on the end. We're actually modelling a real company, your company. An abstract model I think can only purely be used to teach people. I think a real model can both be used for learning and policy. **Do you see that as more useful to you, a model of your own environment, or do you think that you would bring in bias, or would it allow you to explore policies that you wouldn't normally explore in your own work environment?**

Respondent 1: You mean if we had an abstract model that brought in all possible policies?

Interviewer: That didn't necessarily reflect what was happening in your company.

Respondent 1: It would still help us to learn and we might discover policies that we would not normally consider.

Interviewer: Right.

Respondent 3: If you took it off a really successful firm, like a Japanese leader, something not necessarily in this industry, like you know.

Respondent 1: Well what about if you wanted to be really sophisticated you could switch on the generic model, which is the one which is designed to show how safety works for any company, and introduces all the possible policies, and switch them on. I think if you had that model which was just like the average company, and people played with that the next thing they would want is something they could use for their own situation. So maybe we'll skip a stage and the question I'd ask back is, you know, never mind what policies we'd like to see on it, what policies should be on it that we don't know about?

Interviewer: Good point, I think all the three facets of safety, i.e. accident reporting, safety monitoring and safety learning are covered in the model. I don't have any new fundamental policies to offer you that you weren't aware of already. Anybody got anything further to add?

Respondent 1: Management competence affects safety performance, which I suppose management competence affects every sphere of business, but their competence in safety could be measured and some, hm, term found which you could vary to influence the model.

Interviewer: Yes, to enhance the model, a fundamental enhancement.

Respondent 3: Disharmonies between management, you know, conflict arises and lends a belief quite a lot within companies, that type of variable could be incorporated as well?

Respondent 1: Yes, well I always say, well we're sort of entering another field because the, one of the things which is normally stressed is the direction from the top of the company. If they are not really interested. In fact if you look at the guidance we get from the HSE. Did you check out HSG65?

Interviewer: 'Successful Health and Safety Management', the booklet?

Respondent 1: Leadership's a key factor in there, which I suppose that the model's aimed at leadership that, it's aimed at people who want to lead health and safety effectively.

Respondent 3: It's for them to use it isn't it?

Respondent 1: I know that wasn't expressed very well but.

Interviewer: We should have built senior management's understanding of safety into the model, and the leverage that they can exert over this system is very, very important, because we measured the workforce's safety understanding and how they work, but it may well have been more difficult to measure senior management. Although how you set the policies, the amount of resources allowed would be directly attributable to the safety budget that management allow. So in effect management's commitment and understanding would be reflected in the allocation of resources to safety. The maximum limits of each safety resource.

Respondent 1: Yes, if you've got ignorance on the part of the senior people and an unwillingness to act that would have massive effects on how your company performs, well in any sphere. Do you want to come in Andy?

Respondent 2: No, I think we said all we can.

Interviewer: Thanks a lot for your time, and I hope the model has been of interest to you and will help you with your decision making in the future.

APPENDIX L

A Full Listing of the Generic Occupational Safety Model Equations (Written in Ithink ©High Performance Systems)

Accident_Reports_Being_Processed(t) = Accident_Reports_Being_Processed(t - dt) + (Accident_Reports_In - Accident_Reports_Completed) * dt
INIT Accident_Reports_Being_Processed = 2.06

Accident_Reports_In = Accident_Rate*Proportion_of_Accidents_Reported
Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Cumulative_Accident_Reporting_Cost(t) = Cumulative_Accident_Reporting_Cost(t - dt) + (Monthly_Accident_Reporting_Cost) * dt
INIT Cumulative_Accident_Reporting_Cost = 0

Monthly_Accident_Reporting_Cost = Accident_Reporting_Policy*Accident_Reporting_Cost
Cumulative_Accident_Reports(t) = Cumulative_Accident_Reports(t - dt) + (Accident_Reports_Completed) * dt
INIT Cumulative_Accident_Reports = 0

Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Accident_Reporting_Cost = 100
Accident_Reporting_Policy = 25
Accident_Reporting_Time = 10
Proportion_of_Accidents_Reported = 1
Cumulative_Accidents(t) = Cumulative_Accidents(t - dt) + (Accident_Rate) * dt
INIT Cumulative_Accidents = 0

Accident_Rate = Accident_Incidence*Labour
Cumulative_Accident_Cost(t) = Cumulative_Accident_Cost(t - dt) + (Monthly_Accident_Cost) * dt
INIT Cumulative_Accident_Cost = 0

Monthly_Accident_Cost = Accident_Rate*Cost_per_Accident
Accident_Incidence = ((Unregulated_Hazards/Unregulated_Hazard_Regulation_Weighting)+(Hazards_Under_Intermediate_Regulation/Intermediate_Hazard_Regulation_Weighting)+(Hazards_Under_Full_Regulation/Full_Hazard_Regulation_Weighting))*Risk
Cost_per_Accident = 100
Full_Hazard_Regulation_Weighting = 2

Intermediate_Hazard_Regulation_Weighting = 1.5
Unregulated_Hazard_Regulation_Weighting = 1
Risk = GRAPH(Average_KSA)
(0.00, 0.05), (0.5, 0.049), (1.00, 0.0473), (1.50, 0.0383), (2.00, 0.021), (2.50, 0.017), (3.00, 0.0138), (3.50, 0.0105), (4.00, 0.007), (4.50, 0.003), (5.00, 0.00)
Cumulative_Full_Hazard_Regulation_Cost(t) = Cumulative_Full_Hazard_Regulation_Cost(t - dt) + (Monthly_Full_Hazard_Regulation_Cost) * dt
INIT Cumulative_Full_Hazard_Regulation_Cost = 0

Monthly_Full_Hazard_Regulation_Cost = Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost
Cumulative_Intermediate_Hazard_Regulation_Cost(t) = Cumulative_Intermediate_Hazard_Regulation_Cost(t - dt) + (Monthly_Intermediate_Hazard_Regulation_Cost) * dt
INIT Cumulative_Intermediate_Hazard_Regulation_Cost = 0

Monthly_Intermediate_Hazard_Regulation_Cost = Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost
Cumulative_Safety_Monitoring_Cost(t) = Cumulative_Safety_Monitoring_Cost(t - dt) + (Monthly_Safety_Monitoring_Cost) * dt
INIT Cumulative_Safety_Monitoring_Cost = 0

Monthly_Safety_Monitoring_Cost = Safety_Monitoring_Policy*Safety_Monitoring_Cost
Hazards_Under_Full_Regulation(t) = Hazards_Under_Full_Regulation(t - dt) + (Hazards_Arrive_for_Full_Regulation - Hazards_Become_Regulated) * dt
INIT Hazards_Under_Full_Regulation = 1.36

Hazards_Arrive_for_Full_Regulation = MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Hazards_Become_Regulated = MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation_Backlog,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazards_Under_Intermediate_Regulation(t) = Hazards_Under_Intermediate_Regulation(t - dt) + (Identification_Rate - Hazards_Arrive_for_Full_Regulation) * dt
INIT Hazards_Under_Intermediate_Regulation = 1.36

Identification_Rate = MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Hazards_Arrive_for_Full_Regulation = MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Regulation_Backlog,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Regulated_Hazards(t) = Regulated_Hazards(t - dt) + (Hazards_Become_Regulated - Hazard_Generation_Rate) * dt
INIT Regulated_Hazards = 85

Hazards_Become_Regulated = MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation_Backlog,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Unregulated_Hazards(t) = Unregulated_Hazards(t - dt) + (Hazard_Generation_Rate - Identification_Rate) * dt
INIT Unregulated_Hazards = 1.36

Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Identification_Rate = MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Full_Hazard_Regulation_Cost = 10

Full_Hazard_Regulation_Policy = 15
Full_Hazard_Regulation_Time = 10
Intermediate_Hazard_Regulation_Cost = 10
Intermediate_Hazard_Regulation_Policy = 5
Intermediate_Hazard_Regulation_Time = 2
RBAAIH =
(Unregulated_Hazards+Hazards_Under_Intermediate_Regulation+Hazards_Under_Full_Regulation)/Regulated_Hazards
Safety_Monitoring_Cost = 10
Safety_Monitoring_Policy = 20
Accident_Repeater = GRAPH(Accident_Reports_Completed)
(1.00, 0.00), (2.00, 0.01), (3.00, 0.02), (4.00, 0.03), (5.00, 0.04), (6.00, 0.055), (7.00, 0.07), (8.00, 0.085), (9.00, 0.1), (10.0, 0.125), (11.0, 0.165), (12.0, 0.215), (13.0, 0.265), (14.0, 0.32), (15.0, 0.365), (16.0, 0.425), (17.0, 0.49), (18.0, 0.545), (19.0, 0.6), (20.0, 0.68)
Hazards_Identified_from_Safety_Monitoring = GRAPH(Safety_Monitoring_Policy)
(0.00, 0.00), (10.0, 0.125), (20.0, 0.325), (30.0, 0.575), (40.0, 0.925), (50.0, 1.53), (60.0, 3.15), (70.0, 4.35), (80.0, 4.73), (90.0, 4.93), (100, 5.00)
Unsafe_Acts = GRAPH(Average_KSA)
(0.00, 0.1), (0.5, 0.099), (1.00, 0.098), (1.50, 0.096), (2.00, 0.089), (2.50, 0.074), (3.00, 0.038), (3.50, 0.022), (4.00, 0.016), (4.50, 0.012), (5.00, 0.009)
Cumulative_Labour_Quits(t) = Cumulative_Labour_Quits(t - dt) + (Quits) * dt
INIT Cumulative_Labour_Quits = 0

Quits = Labour/Actual_Length_of_Employment
Labour(t) = Labour(t - dt) + (Hires - Quits) * dt
INIT Labour = Target_Labour_Force

Hires = ((Target_Labour_Force-Labour)/Staff_Adjustment_Time)+Replacing_Attrition
Quits = Labour/Actual_Length_of_Employment
Actual_Length_of_Employment = Base_Length_of_Employment*(1-Quit_Likelihood)
Base_Length_of_Employment = 120
Perceived_Accident_Incidence = SMTH3(Accident_Incidence,3)
Replacing_Attrition = Quits
Staff_Adjustment_Time = 4
Target_Labour_Force = 100
Quit_Likelihood = GRAPH(Perceived_Accident_Incidence)
(0.00, 0.00), (0.1, 0.001), (0.2, 0.003), (0.3, 0.006), (0.4, 0.014), (0.5, 0.028), (0.6, 0.08), (0.7, 0.0915), (0.8, 0.096), (0.9, 0.098), (1, 0.1)
Cumulative_Safety_Cost(t) = Cumulative_Safety_Cost(t - dt) + (Monthly_Safety_Cost) * dt
INIT Cumulative_Safety_Cost = 0

Monthly_Safety_Cost =
Monthly_Accident_Cost+(Safety_Monitoring_Policy*Safety_Monitoring_Cost)+(Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost)+(Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost)+(Accident_Reporting_Policy*Accident_Reporting_Cost)+(Training_Policy*Safety_Training_Cost)
Cumulative_Safety_Training_Cost(t) = Cumulative_Safety_Training_Cost(t - dt) + (Monthly_Safety_Training_Cost) * dt
INIT Cumulative_Safety_Training_Cost = 0

Monthly_Safety_Training_Cost = Training_Policy*Safety_Training_Cost
Safety_KSA(t) = Safety_KSA(t - dt) + (Learning + Gain_in_KSA - Loss_of_KSA - Dissipation_of__KSA) * dt
INIT Safety_KSA = 400

Learning = DELAY(Multiplier*Discrepancy,3)
Gain_in_KSA = Hires*KSA_per_New_Employee
Loss_of_KSA = Quits*Loss_per_Exit
Dissipation_of__KSA = Safety_KSA*Fixed_Proportion_of_KSA_Lost
Average_KSA = Safety_KSA/Labour

Discrepancy = 1-(Safety_KSA/Target_Safety_KSA)
Fixed_Proportion_of_KSA_Lost = 0.01
KSA_per_New_Employee = Average_KSA*Ratio_Between_Hires_and_Average_KSA
Loss_per_Exit = Average_KSA*Ratio_Between_Quitters_and_Average_KSA
Maximum_KSA_per_Employee = 5
Proportion_of_Accidents_Reported = 1
Ratio_Between_Hires_and_Average_KSA = 0.7
Ratio_Between_Quitters_and_Average_KSA = 1.3
Safety_Training_Cost = 10
Target_Safety_KSA = Labour*Maximum_KSA_per_Employee
Time_to_Clear_Accident_Report_Backlog = 1
Time_to_Clear_Hazards_Under_Full_Regulation_Backlog = 1
Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog = 1
Time_to_Identify_Unregulated-Hazards = 1
Training_Effectiveness = 0.75
Training_Policy = 200
Multiplier =
GRAPH((Training_Effectiveness*Training_Policy)*(IF(Safety_KSA<Target_Safety_KSA)THEN(1)ELSE(0)))
(0.00, 0.00), (50.0, 10.0), (100, 20.0), (150, 30.0), (200, 40.0), (250, 50.0), (300, 60.0), (350, 70.0), (400, 80.0), (450, 90.0), (500, 100)

APPENDIX M

A Full Listing of the Real World Occupational Safety Model Equations (Written in Ithink ©High Performance Systems)

Accident_Reports_Being_Processed(t) = Accident_Reports_Being_Processed(t - dt) + (Accident_Reports_In - Accident_Reports_Completed) * dt
INIT Accident_Reports_Being_Processed = 1
Accident_Reports_In = Accident_Rate*Proportion_of_Accidents_Reported
Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Cumulative_Accident_Reporting_Cost(t) = Cumulative_Accident_Reporting_Cost(t - dt) + (Monthly_Accident_Reporting_Cost) * dt
INIT Cumulative_Accident_Reporting_Cost = 0

Monthly_Accident_Reporting_Cost = Accident_Reporting_Policy*Accident_Reporting_Cost
Cumulative_Accident_Reports(t) = Cumulative_Accident_Reports(t - dt) + (Accident_Reports_Completed) * dt
INIT Cumulative_Accident_Reports = 0

Accident_Reports_Completed = MIN(Accident_Reports_Being_Processed/Time_to_Clear_Accident_Report_Backlog,Accident_Reporting_Policy/Accident_Reporting_Time)
Accident_Reporting_Cost = 13
Accident_Reporting_Policy = 34+STEP(11,13)+STEP(3,25)
Accident_Reporting_Time = 8
Proportion_of_Accidents_Reported = 1
Cumulative_Accidents(t) = Cumulative_Accidents(t - dt) + (Accident_Rate) * dt
INIT Cumulative_Accidents = 0

Accident_Rate = Accident_Incidence*Labour
Cumulative_Accident_Cost(t) = Cumulative_Accident_Cost(t - dt) + (Monthly_Accident_Cost) * dt
INIT Cumulative_Accident_Cost = 0

Monthly_Accident_Cost = Accident_Rate*Cost_per_Accident
Accident_Incidence = ((Unregulated_Hazards/Unregulated_Hazard_Regulation_Weighting)+(Hazards_Under_Intermediate_Regulation/Intermediate_Hazard_Regulation_Weighting)+(Hazards_Under_Full_Regulation/Full_Hazard_Regulation_Weighting))*Risk
Cost_per_Accident = 1636
Full_Hazard_Regulation_Weighting = 2
Intermediate_Hazard_Regulation_Weighting = 1.5

Unregulated_Hazard_Regulation_Weighting = 1
Risk = GRAPH(Average_KSA)
(0.00, 0.05), (0.5, 0.049), (1.00, 0.0473), (1.50, 0.0383), (2.00, 0.021), (2.50, 0.017), (3.00, 0.0138), (3.50, 0.0105), (4.00, 0.007), (4.50, 0.003), (5.00, 0.00)
Cumulative_Full_Hazard_Regulation_Cost(t) = Cumulative_Full_Hazard_Regulation_Cost(t - dt) + (Monthly_Full_Hazard_Regulation_Cost) * dt
INIT Cumulative_Full_Hazard_Regulation_Cost = 0

Monthly_Full_Hazard_Regulation_Cost = Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost
Cumulative_Intermediate_Hazard_Regulation_Cost(t) = Cumulative_Intermediate_Hazard_Regulation_Cost(t - dt) + (Monthly_Intermediate_Hazard_Regulation_Cost) * dt
INIT Cumulative_Intermediate_Hazard_Regulation_Cost = 0

Monthly_Intermediate_Hazard_Regulation_Cost = Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost
Cumulative_Safety_Monitoring_Cost(t) = Cumulative_Safety_Monitoring_Cost(t - dt) + (Monthly_Safety_Monitoring_Cost) * dt
INIT Cumulative_Safety_Monitoring_Cost = 0

Monthly_Safety_Monitoring_Cost = Safety_Monitoring_Policy*Safety_Monitoring_Cost
Hazards_Under_Full_Regulation(t) = Hazards_Under_Full_Regulation(t - dt) + (Hazards_Arrive_for_Full_Regulation - Hazards_Become_Regulated) * dt
INIT Hazards_Under_Full_Regulation = 1

Hazards_Arrive_for_Full_Regulation = MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Hazards_Become_Regulated = MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazards_Under_Intermediate_Regulation(t) = Hazards_Under_Intermediate_Regulation(t - dt) + (Identification_Rate - Hazards_Arrive_for_Full_Regulation) * dt
INIT Hazards_Under_Intermediate_Regulation = 4.5

Identification_Rate = MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Hazards_Arrive_for_Full_Regulation = MIN(Hazards_Under_Intermediate_Regulation/Time_to_Clear_Hazards_Under_Intermediate_Regulation,Intermediate_Hazard_Regulation_Policy/Intermediate_Hazard_Regulation_Time)
Regulated_Hazards(t) = Regulated_Hazards(t - dt) + (Hazards_Become_Regulated - Hazard_Generation_Rate) * dt
INIT Regulated_Hazards = 96

Hazards_Become_Regulated = MIN(Hazards_Under_Full_Regulation/Time_to_Clear_Hazards_Under_Full_Regulation,Full_Hazard_Regulation_Policy/Full_Hazard_Regulation_Time)
Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Unregulated_Hazards(t) = Unregulated_Hazards(t - dt) + (Hazard_Generation_Rate - Identification_Rate) * dt
INIT Unregulated_Hazards = 0.5

Hazard_Generation_Rate = Regulated_Hazards*Unsafe_Acts
Identification_Rate = MIN(Unregulated_Hazards/Time_to_Identify_Unregulated_Hazards,((Accident_Reports_Completed*(1-Accident_Repeater))+Hazards_Identified_from_Safety_Monitoring))
Full_Hazard_Regulation_Cost = 9
Full_Hazard_Regulation_Policy = 22.7

Full_Hazard_Regulation_Time = 16
Intermediate_Hazard_Regulation_Cost = 11
Intermediate_Hazard_Regulation_Policy = 3.2
Intermediate_Hazard_Regulation_Time = 2.1
RBAAIH =
(Unregulated_Hazards+Hazards_Under_Intermediate_Regulation+Hazards_Under_Full_Regulation)/Regulated_Hazards
Safety_Monitoring_Cost = 13
Safety_Monitoring_Policy = 18+STEP(23,15)+STEP(2,28)+STEP(7,35)
Accident_Repeater = GRAPH(Accident_Reports_Completed)
(1.00, 0.00), (2.00, 0.01), (3.00, 0.02), (4.00, 0.03), (5.00, 0.04), (6.00, 0.055), (7.00, 0.07), (8.00, 0.085), (9.00, 0.1), (10.0, 0.125), (11.0, 0.165), (12.0, 0.215), (13.0, 0.265), (14.0, 0.32), (15.0, 0.365), (16.0, 0.425), (17.0, 0.49), (18.0, 0.545), (19.0, 0.6), (20.0, 0.68)
Hazards_Identified_from_Safety_Monitoring = GRAPH(Safety_Monitoring_Policy)
(0.00, 0.00), (10.0, 0.125), (20.0, 0.325), (30.0, 0.575), (40.0, 0.925), (50.0, 1.53), (60.0, 3.15), (70.0, 4.35), (80.0, 4.73), (90.0, 4.93), (100, 5.00)
Unsafe_Acts = GRAPH(Average_KSA)
(0.00, 0.1), (0.5, 0.099), (1.00, 0.098), (1.50, 0.096), (2.00, 0.089), (2.50, 0.074), (3.00, 0.038), (3.50, 0.022), (4.00, 0.016), (4.50, 0.012), (5.00, 0.009)
Cumulative_Labour_Quits(t) = Cumulative_Labour_Quits(t - dt) + (Quits) * dt
INIT Cumulative_Labour_Quits = 0

Quits = Labour/Actual_Length_of_Employment
Labour(t) = Labour(t - dt) + (Hires - Quits) * dt
INIT Labour = Target_Labour_Force

Hires = ((Target_Labour_Force-Labour)/Staff_Adjustment_Time)+Replacing_Attrition
Quits = Labour/Actual_Length_of_Employment
Actual_Length_of_Employment = Base_Length_of_Employment*(1-Quit_Likelihood)
Base_Length_of_Employment = 129
Perceived_Accident_Incidence = SMTH3(Accident_Incidence,3)
Replacing_Attrition = Quits
Staff_Adjustment_Time = 4
Target_Labour_Force = 57
Quit_Likelihood = GRAPH(Perceived_Accident_Incidence)
(0.00, 0.00), (0.1, 0.001), (0.2, 0.003), (0.3, 0.006), (0.4, 0.014), (0.5, 0.028), (0.6, 0.08), (0.7, 0.0915), (0.8, 0.096), (0.9, 0.098), (1, 0.1)
Cumulative_Safety_Cost(t) = Cumulative_Safety_Cost(t - dt) + (Monthly_Safety_Cost) * dt
INIT Cumulative_Safety_Cost = 0

Monthly_Safety_Cost =
Monthly_Accident_Cost+(Safety_Monitoring_Policy*Safety_Monitoring_Cost)+(Full_Hazard_Regulation_Policy*Full_Hazard_Regulation_Cost)+(Intermediate_Hazard_Regulation_Policy*Intermediate_Hazard_Regulation_Cost)+(Accident_Reporting_Policy*Accident_Reporting_Cost)+(Training_Policy*Safety_Training_Cost)
Cumulative_Safety_Training_Cost(t) = Cumulative_Safety_Training_Cost(t - dt) + (Monthly_Safety_Training_Cost) * dt
INIT Cumulative_Safety_Training_Cost = 0

Monthly_Safety_Training_Cost = Training_Policy*Safety_Training_Cost
Safety_KSA(t) = Safety_KSA(t - dt) + (Learning + Gain_in_KSA - Loss_of_KSA - Dissipation_of_KSA) * dt
INIT Safety_KSA = 213.75

Learning = DELAY(Multiplier*Discrepancy,3)
Gain_in_KSA = Hires*KSA_per_New_Employee
Loss_of_KSA = Quits*Loss_per_Exit
Dissipation_of_KSA = Safety_KSA*Fixed_Proportion_of_KSA_Lost
Average_KSA = Safety_KSA/Labour
Discrepancy = 1-(Safety_KSA/Target_Safety_KSA)

Fixed_Proportion_of_KSA_Lost = 0.02

KSA_per_New_Employee = Average_KSA*Ratio_Between_Hires_and_Average_KSA

Loss_per_Exit = Average_KSA*Ratio_Between_Quitters_and_Average_KSA

Maximum_KSA_per_Employee = 5

Proportion_of_Accidents_Reported = 1

Ratio_Between_Hires_and_Average_KSA = 0.85

Ratio_Between_Quitters_and_Average_KSA = 1.01

Safety_Training_Cost = 14

Target_Safety_KSA = Labour*Maximum_KSA_per_Employee

Time_to_Clear_Accident_Report_Backlog = 1

Time_to_Clear_Hazards_Under_Full_Regulation_Backlog = 1

Time_to_Clear_Hazards_Under_Intermediate_Regulation_Backlog = 1

Time_to_Identify_Unregulated_Hazards = 1

Training_Effectiveness = 0.75

Training_Policy = GRAPH(TIME) (0.00, 7.50), (1.00, 52.5), (2.00, 22.5), (3.00, 30.0), (4.00, 0.00), (5.00, 7.50), (6.00, 195), (7.00, 15.0), (8.00, 45.0), (9.00, 15.0), (10.0, 15.0), (11.0, 90.0), (12.0, 60.0), (13.0, 150), (14.0, 90.0), (15.0, 52.5), (16.0, 105), (17.0, 105), (18.0, 143), (19.0, 15.0), (20.0, 30.0), (21.0, 7.50), (22.0, 15.0), (23.0, 0.00), (24.0, 0.00), (25.0, 113), (26.0, 113), (27.0, 37.5), (28.0, 60.0), (29.0, 37.5), (30.0, 60.0), (31.0, 22.5), (32.0, 22.5), (33.0, 240), (34.0, 22.5), (35.0, 7.5)

Multiplier =
GRAPH((Training_Effectiveness*Training_Policy)*(IF(Safety_KSA<Target_Safety_KSA)THEN(1)ELSE(0)))
(0.00, 0.00), (50.0, 10.0), (100, 20.0), (150, 30.0), (200, 40.0), (250, 50.0), (300, 60.0), (350, 70.0), (400, 80.0), (450, 90.0), (500, 100)