A RELIABILITY APPROACH TO THE QUANTIFICATION OF OCCUPATIONAL ACCIDENTS IN THE OFFSHORE OIL AND GAS INDUSTRY

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A reliability approach to the quantification of occupational accidents in the offshore oil and gas industry

by

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Abstract

Occupational accidents continue to occur at a frequency unacceptable to the offshore oil and gas industry. Current information and approaches related to the topic have been studied. Using reliability techniques, a holistic quantitative model has been developed and validated which can predict accident frequency. Model inputs include factors directly affecting accident frequency as well as corporate and external elements.

Literature related to occupational accidents has been reviewed, concentrating on (i) modelling approaches taken by researchers over the past half century, (ii) statistical information currently available and (iii) influencing factors suggested by researchers for inclusion in accident models. A gap in the knowledge was confirmed, specifically the absence of a holistic, quantitative approach to oil and gas occupational accidents.

An analysis of current global offshore oil and gas occupational accident statistics was performed, which revealed significant inter-regional and inter-company differences in accident frequency. This result helped to confirm that the group of factors affecting occupational accidents extended beyond the traditionally included direct and corporate elements to include external societal factors.

Based partially on the literature review and database analysis, a model was developed which can predict occupational accident frequency in the offshore oil and gas industry. The model's holistic approach combines accident theories often preferred by representatives from the management, safety, engineering, and psychology disciplines. The approach is based on a chain of influence originating with external factors, which act through corporate elements to affect factors directly influencing the accident process. Expert opinion was used extensively to quantify (i) the relative strengths of the model elements directly affecting accident frequency and (ii) the relationships between the external, corporate, and direct layers.

Using further expert opinion to provide input values, the model was validated by comparing its predictions with known results on Canadian production installations and in the Gulf of Mexico drilling sector.

Acknowledgements

Valuable achievements are seldom possible without the help of others. I have received enormous support from many individuals and groups in the course of completing this work, for which I am grateful.

Whilst my wife, Connie, and children, Julia and Ethan, have always provided moral support to me, their patience and understanding during my pursuit of this degree was essential to its completion. The children went without many weekend outings and evenings of backyard soccer during the past few years whilst I frequently sat before my computer. However, the first complaint has yet to be uttered, and perhaps the missed events made us more appreciative of the ones actually attended.

I would like to acknowledge the help of my supervisory committee, consisting of Dr Faisal Khan, Dr Brian Veitch, and Dr Tahir Husain, for their continuous help throughout the entire process. In some cases, this meant phone calls literally around the world in the middle of the night. From the first cup of coffee to the final detail of the thesis, whether it was dealing with a complicated calculation, providing a virtual bridge to a university administration thousands of miles away, preparing for the comprehensive exam and final defence, or completing the exhausting job of clearly explaining in written form some rather abstract thoughts, I never once felt alone.

My employer, Lloyd's Register EMEA, provided financial support, and the consistent patience and encouragement received from my colleagues and direct supervisor, Mr

Richard Rowe, contributed greatly to a timely completion of the project. Substantial expertise in the occupational accident field is held within Lloyd's Register's safety technology staff, and this was always unselfishly made available to me, even when it meant that a co-worker's day would extend past the time when the usual train had departed.

Many researchers have studied this and closely related topics before I began to ponder the issue. I wish to acknowledge their excellent efforts, which helped to form the basis of my ideas.

I have found this work to be sometimes exhausting, occasionally frustrating, but mostly satisfying. The rewards afforded far outweighed any momentary inconveniences and struggles. On balance, the endeavour has been a pleasure, and this has been largely due to the support I have felt from those around me.

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Introduction

1) Introduction

Occupational accidents constitute a significant and continuing problem for the oil and gas industry. The data show that workers face a similar level of risk from occupational accidents as they do from more catastrophic events (sometimes referred to as organisational accidents) such as explosions, fires, and helicopter crashes (see Figure 1.1). While major events have the potential to cause multiple serious injuries and fatalities, occupational accidents, with their relatively higher frequency but lower number of individuals affected per instance, pose similar dangers overall.

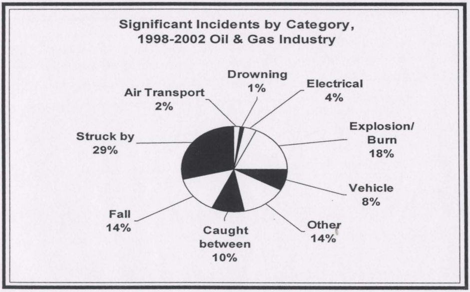

Figure 1.1 – Significant incidents by category
(International Association of Oil & Gas Producers, 2004)

The situation is repeated in the general workplace. It has been documented (UK HSE, 1996) that over a third of all reported major injuries result from a slip or trip, this being the single most common cause of injuries at work. Whilst occupational safety is regulated under various national legislative schemes, analysis is not nearly so rigorous in this area as for the treatment of major accident hazards. The level of overall risk presented by occupational accidents suggests that the situation would benefit from an increase in the degree of quantification applied to their study.

A contributing factor to the ongoing occupational accident issue may be the presence of a line of thinking which adopts a certain inevitability to the events, i.e. "accidents ***will*** happen". An unfortunate reaction to this position would be to accept the inevitable and relax efforts to reduce accident frequency. Fortunately, this reaction is not widespread in the oil and gas community or industry in general. Following a review (International Labour Organisation (ILO), 2003) of global industrial accidents, the ILO makes the following comment: "Fatalities are not fated; accidents don't just happen; illness is not random; they are caused." Most oil and gas operators' views and policies mirror these comments. Particularly for projects based in mature markets, safety culture, systems, and equipment are well developed and effective, resulting in a relatively low likelihood of accident (International Association of Oil & Gas Producers (OGP), 2005). However, as reserves are depleted in traditional locations (for example the North Sea and the Gulf of Mexico) and companies turn to frontier regions (for example Africa, China, Latin and South America), the implementation of an effective safety culture becomes more difficult. Accident statistics in these regions show less favourable results (OGP, 2005).

Attempts to address the problem have been ongoing for more than a quarter of a century. For example, Sweden's Royal Institute of Technology in Stockholm set up a special occupational accident research unit in 1978, with a mandate to use a USD $3M budget to conduct accident research and establish occupational injuries as an important discipline for teaching and applied research within the technical faculty.

Despite all the excellent efforts, however, the problem remains. Current research on occupational accidents is mostly qualitative in nature, compared to the more quantitative methods often employed to understand and mitigate the effects of explosions and the like. The relative lack of quantitative model development represents a specific gap in the oil and gas occupational accident research. Also, while most models specifically consider factors directly affecting accidents, and some include corporate elements, few address the effect of factors outside the organisation, and none do the latter with an extensively numerical approach.

The present work applies reliability theory to the occupational accident problem. A model has been developed which, given a series of inputs, can

- predict the likelihood of occupational accidents on a specific offshore platform
- estimate accident rate within an industry sector (for example Gulf of Mexico drilling or North Sea production)
- provide a means to effectively direct resource deployment to produce optimal safety results

In taking a holistic approach to accident causation, the model combines accident theories usually favoured (and sometimes applied in isolation) by specialists representing the management, engineering, safety, and psychology disciplines. Three groups of factors, or layers, are considered to affect accident frequency:

1. **direct factors**, including individual staff behaviours and capabilities, weather, safety design, and personal protective equipment
2. **corporate factors** provided by the supporting organisation, including the level and quality of safety procedures, training, and culture
3. **external factors**, such as societal value placed on life and financial pressures such as shareholder pressure, price of oil, and royalty regime

The model recognises the relationships between the layers and the relative importance of the factors affecting accidents. Expert opinion has been used extensively in the quantification of the relationships and element importance and also in the application of the model to specific cases.

The remainder of this thesis has been structured in line with the general progression of the work from literature review to model development and testing, as follows:

- Chapter two summarises the literature reviewed. The goals of the review were to understand the approaches taken by other researchers, and to provide a basis for the choice of the most appropriate set of influencing factors possible for inclusion in the subsequently developed model.
- Chapter three describes a series of statistical analyses conducted with a view to demonstrating that both inter regional and inter company safety performance differed significantly. The successful demonstration supported the contentions that both external societal issues and corporate programmes affected safety performance. The results of a survey of safety professionals, which invited

quantitative opinion with respect to relative factor importance and inter layer influence, are discussed.

- Chapter four describes the development of the occupational accident predictive model. The choice of a reliability model is defended, and the model structure is detailed. The mathematical methods by which relative factor importance and inter layer influence are accounted for are described. The effects of changes in individual factor performance on overall safety results are demonstrated, and a series of hypothetical realistic scenarios are presented.
- Testing of the model is described in chapter five. Three hindcasting exercises were performed, in which the model's ability to "predict" known accident results in the Newfoundland and Nova Scotia offshore industries and the Gulf of Mexico drilling sector were evaluated. An expert panel provided the necessary input respecting the actual safety situations existing in the areas. Results were satisfactory in the Nova Scotia and Gulf of Mexico cases, and some explanations are provided for the less encouraging results achieved in the Newfoundland example.
- Chapter six summarises the conclusions of the work together with some suggestions for further research.

2

Literature review

2) Literature review

There is no shortage of public information describing industrial accidents. Analyses of incidents occurring in many fields are available, describing approaches to the problem from many different angles – by cause, by type, by region, and other variations. The literature review* has been conducted in a systematic way, designed to support the primary research goal of developing a quantitative, holistic model to analyse offshore occupational accidents and predict their frequency. This chapter has been structured as follows, in line with the natural progression from a general review of accident analyses to the specific work of formulating the accident model.

Existing models – A review of existing accident models is presented. The first models were proposed more than half a century ago, and there is much to be learned from the philosophies developed by previous researchers. It was also important to confirm that no model currently exists to cover the specific problem under consideration.

Statistics associated with occupational accidents – A review of literature which analyzes existing accident data and the associated source databases is presented. The databases offer subdivisions of the data along many different lines – for example by region, by (anonymous) company, by age, according to activity undertaken, by type of installation, and others. An analysis of the data has been conducted and is described in Chapter 3.

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* Attwood, D, Khan, F, and Veitch, B, 2005a. Occupational accident models – where have we been and where are we going? Accepted for publication in the *Journal of Loss Prevention in the Process Industries*.

<u>Factors affecting occupational accidents</u> – An important activity in the development of the model proposed by this research was the choice and organisation of factors affecting occupational accident frequency. Literature offering insight into the factors important to the problem has been reviewed.

<u>Other literature on occupational accidents</u> – Some literature has been reviewed which did not fit well into the above categories, for example papers offering detailed evaluations of the importance of safety culture, human factors studies, and discussions analysing costs associated with offshore accidents. Reviews of this literature are presented at the end of the chapter.

The literature deals with both occupational and large scale (organisational) events. However, since the basic philosophy of accident causation is considered to be similar for both cases, and the model development discussed later in this thesis adopts a first principles approach which is independent of accident size, the review has not been subdivided according to accident size.

2.1) Existing models

Although model development and refinement is just one of a number of ways of attempting to understand and positively affect a problem, it is considered to be the most suitable way of studying the occupational accident issue. The effectiveness of models in the study of accidents has been noted by several authors (Lees, 1996a,b). Wolfram (1993) went so far as to say that the practice of engineering revolves around the use of models. He described how they have been used for centuries for many different purposes and with great success. This section presents a review of some of the models which have been used in the study of accidents. The section concludes with a summary and description of the novelty of the present approach to the problem.

2.1.1) Early accident models

Early accident models studied the fundamental process of accident occurrence and provided the foundation for later models employing more current analysis techniques.

In the late 1940's, Gordon's (1949) "Epidemiological Model" recognised the parallel between the general accident process and the popular theory of how a disease overwhelmed a susceptible patient. Essentially, an accident situation was considered to require the same elements as a person falling ill - a host, an agent, and an environment. The "agent" in the accident analogy was considered to be some form of damage-inflicting energy. For example, in a shock accident, the agent would be electromotive force. In a fall from height, the agent would be gravity.

The philosophy proposed by Houston (1971) in his "Driving Force" model was similar to Gordon's, with the elements replaced by a driving force (agent), a target (host) and a trigger, which caused the driving force to injure the target. The usual driving forces were energy and toxins. Threshold values were considered for the targets and triggers, below which the accident could not occur. Both probabilistic and deterministic parameters of the model were considered, including:

- the probability that all required factors (driving force, target, and trigger) were present simultaneously
- the fraction of the driving force which reached the target
- the ratio of damage done under actual conditions to that seen under standard conditions
- the total time for process execution

Various actions were proposed to reduce accident likelihood, including removal of input factors, reduction (via preventive action) of the probability of the simultaneous presence of all factors, and/or reduction of the driving force fraction and damage ratios.

Haddon (1973) subsequently contributed to the model with a consideration of how accident likelihood or effect could be reduced by limiting the "energy" driving force's effectiveness. Examples of the proposed methods for achieving this were:

- reduction of the initial amount of energy
- prevention of energy release
- separation (in space or time) of the released energy from the target
- erection of a barrier between the released energy and the target

- strengthening of the target's ability to withstand deleterious effects of the energy
- rapid detection, evaluation, and reaction to the encroaching energy

2.1.2) Models based on holistic approaches

The recognition of causal elements distinct from the obvious direct factors has become a common feature in many recent accident models. Approaches which took a holistic view of accident causation are discussed in this section.

2.1.2.1) Le Bot's analysis of Three Mile Island

The benefits of considering, and dangers of ignoring, all elements of corporate safety programmes have been accepted for some time (see for example Owen and Raeburn, 1991). Le Bot (2004) reviewed ongoing attempts to integrate human reliability data in accident models, and retrospectively analysed the Three Mile Island nuclear disaster. Le Bot concluded that either of the two commonly cited causes of the accident, (i) a commissioning error, specifically the inappropriate shutdown of safety injection, or (ii) operator error resulting from a situational misdiagnosis, should be discounted in favour of a fundamental holistic system breakdown, including the following elements:

- insufficient operator training
- incomplete or incorrect procedures
- ineffective system and human interfaces
- organisational inefficiencies, specifically in failing to take proper note of previous incidents
- poor design of the control room

The present work's inclusion of corporate factors in the analysis is philosophically similar to Le Bot's conclusions about accident causation, although related to a very different type of accident.

2.1.2.2) Wang's comments on offshore structure design

In some disciplines, holistic, multi-level approaches have historically been taken only if traditional deterministic methods have failed. Recently, however, holistic approaches have been applied to areas previously solidly in the realm of deterministic strategies, such as basic design. For example, Wang (2001), in a paper describing novel approaches to the design of offshore structures, made the following points:

- It is difficult to accurately apply probabilistic risk assessment in circumstances where human error contributes to accident likelihood.
- Approximate reasoning techniques may be appropriate in the analysis of the risks associated with offshore systems.
- Experts' knowledge should be used in the design process.

Wang has noted the importance of the inclusion of human factors, the recognition of uncertainty, and the need for expert knowledge in basic offshore structure design. The inclusion of these elements in a field generally considered to be primarily deterministic confirms the absolute necessity to include them in the less deterministic business of predicting occupational accident frequency.

2.1.2.3) Geyer and Bellamy's approach

Geyer and Bellamy (1991) have proposed a model to study pipework failure which included the broader, socio-technical background to accidents, including elements at the direct, corporate, and external levels, as shown in Table 2.1.

Table 2.1 – Factors proposed by Geyer and Bellamy

Top Level	Lower Levels	
Direct	Impact	Mitigation
	Accidental release	
Corporate	Operator reliability	Communication
	Organisation	Management
	Information	Feedback control
	Engineering reliability	
External	System climate	

Although the application under consideration was comparatively narrower in scope than that studied by this research, the model offered insight into the multi-causal nature of accidents and further supported the validity of the holistic approach adopted for the present model.

2.1.2.4) McCauley-Bell and Badiru's application of fuzzy set theory

McCauley-Bell and Badiru (1996a, 1996b) have applied fuzzy set theory (FST) to the study of risk factors associated with occupational injuries, albeit specific to cumulative trauma disorders (CTD) of the hand and forearm.

Details of the principles of FST are conveniently available on websites such as en.wikipedia.org and www.doc.ic.ac.uk, or through texts such as Klir et al. (1997). As the name suggests, fuzzy set theory is associated with the logic underlying modes of reasoning which are approximate rather than exact. Fuzzy logic is therefore helpful in quantifying approximate concepts such as common sense and human reasoning.

Similar to the strategy adopted for this research, the first part of the authors' work involved the choice and categorization of factors influencing the likelihood of injury.
A systematic process identifying likely contributory factors in hand/forearm CTD's was executed, which included the following elements:

- preliminary, followed by detailed, text analysis
- expert interviews
- observations of medical exams of individuals thought to have hand/forearm CTDs
- concept mapping

The latter involved a structured and facilitated meeting during which related concepts were manipulated and placed by experts at strategically important locations on an initially blank screen. The relationships between, and relative importance of, the different aspects emerged as factors were physically moved around the map.

The result of these activities was the identification of a series of three groups of factors, which are listed below, together with some examples of individual factors within the groups.

- factors associated with the task itself – awkward joint posture, force applied, task duration, vibration, etc.

- factors related to personal situation – health condition, age, hobbies and habits, previous cumulative trauma disorders, etc.
- factors related to organisational and workplace environment – equipment, peer influence, training, awareness, etc.

The holistic nature of the categories was consistent with results determined by other researchers. These accidents were considered to have been caused partially by task, partially by personal situation, and partially by corporate/environmental aspects.

Analysis of the groups and factors revealed the following relative importance weightings of the groups:

- task related factors: 0.64
- personal situation factors: 0.25
- organisational factors: 0.11

Within the groups, the importance of individual factors was analysed using a process of pair comparison, during which experts were asked to identify which of a pair of factors was more important than the other, and to what degree. Repeating this process for all pairs produced a ranking of the individual factors within each group.

Analysis of the data revealed the following:

- clustering of factors – For example, arthritis and age tended to appear simultaneously, as did diabetes and obesity.
- synergy – It could be shown that, in some cases, the combined effect of two factors was greater than the sum of the effects of the individual factors.

Following the analysis of all inputs, defuzzification (the process of combining all fuzzy outputs into a specific composite result) produced the final, "crisp" output, which quantified the risk of a subject injury for a given person while conducting a specific task in a given environment. The model was tested in an assembly plant environment, and proved quite accurate in predicting injuries, with ninety six of one hundred twenty cases correctly predicted.

This model provided an example of a tool used to bring a degree of quantification to a generally qualitative dataset. Such capability was also needed for the present research, which required the quantification of the relative importance of corporate culture, safety programmes, and other factors, in the occupational accident process. No readily available data usually exist for these types of analyses, but the authors have proposed a way of overcoming this obstacle.

The degree of rigour applied to the initial data gathering process described in Part I of the research was also noteworthy. As was the case for the study of cumulative trauma disorders, there is no shortage of opinion regarding the primary causes of oil and gas occupational accidents. The challenge has been to use a systematic approach in order to arrive at accurate and useful conclusions.

2.1.2.5) Trontin and Bejean

Trontin and Bejean (2004) have studied the role of the relationship between insurance companies and the firms (and their employees) they insure, in accident prevention. They considered the incentives and resulting willingness of the insured companies and employees to take accident preventive measures within their respective insurance environments. The sizes of the companies and other behavioural motivations were also considered. Some results, and theories proposed by the authors, were as follows:

- The frequency of occupational accidents was inversely proportional to the size of the company. This was true for all categories of company considered, but particularly so in the construction industry. The accident frequency showed an increase from firms of 1-9 employees to 10-49, but a steady drop-off with increase in size from there on up to >1000 employees.
- Large firms sometimes lost the motivation to apply measures to prevent occupational accidents following the procurement of an insurance policy, which eliminated most of the potential for financial loss resulting from accidents. If accident rates rose in response to this phenomenon, the insurance company sometimes reacted by instituting a bonus/penalty programme. This usually resulted in the insured company again improving its preventive action programme.
- Relationships between staff and their employers were also considered, including such elements as the tendency to falsely report illnesses as occupational accidents in the face of different compensations available for each, and the reduction in attention paid to safety activities following improvements in safety equipment and machinery.
- The alternative perspective of smaller firms was considered as well. Many of the motivations were similar, but smaller firms likely had proportionally fewer resources to apply to accident prevention, and relationships tended to be more

family-like than those within larger organisations. The authors proposed that these factors may have played a role in the motivations for accident prevention and reporting. For example, employees in smaller, "family" businesses may have been less likely to report injuries or take time off because they may have believed themselves to be more essential to day-to-day company success than large-firm counterparts.

- The differing roles of managers and supervisors in small and large firms were considered in the evaluation as well.

Trontin and Bejean's work provided insight into the motivational factors which affect the likelihood of occupational accidents and staff willingness to report them. Individual and group psychology, and their effect on day-to-day behaviour, are important considerations in this research. The present model adopts a holistic view of the process, which includes elements of staff behaviour and motivation.

2.1.2.6) Embrey's MACHINE

Embrey (1992) has proposed a model, named "Model of Accident Causation using Hierarchical Influence Network", or "MACHINE", which considered accident causation to be a three-level process, as below.

- direct causes, for example, failure to carry out specified equipment checks or to follow prescribed maintenance procedures
- level one causal influences, for example incomplete definition of responsibilities, insufficient or ineffective training, or unclear procedures

- level two causal influences, for example design errors, poor human resource management, or risk management errors

Embrey recognised three categories of accident causation – human errors, hardware failures, and external events. The first two were investigated from the perspective of the three process levels mentioned above. The third category (external events), examples of which are seismic and geological events, was considered to be outside the scope of work.

Embrey's model recognised the probabilistic nature of links in the causative network, stating that:

> "the existence of a good human resource management policy will *increase the probability* that there will be an adequate match between demands and resources and effective training. However, the existence of the good human resource policy does not *guarantee* that resources will be matched or training optimised."

In order to describe the calculation methodology, Embrey presented an example application, in which the model attempted to predict operator error based on three inputs: quality of training, availability of operating instructions, and time pressure. These, in turn, were considered to be affected by a series of lower level causations, including project management, assignment of job roles, staffing levels, and task complexity. An assessment team of suitably qualified experts was used to assign numerical values to the linkages between factors, considering concepts such as the degree to which operational experience had been fed back to the training department, the effect of task complexity on time pressure, and the ability of the instruction generating policy to positively affect instruction availability. These values were combined to determine outputs, both intermediate, including measures of quality of training and time pressure, and final, the probability of human operator error.

Embrey's model recognised the complexity of the accident process. He referred to the use of a three-level model as a convenient first approximation and later cautioned that it did not attempt to cover every interrelationship involved, instead concentrating on only those deemed critical. To keep the work to a manageable level, he chose an example, operator error, which constituted only a subset of the total accident process. Despite this, the figures included in the paper were complex (see for example the *partial* re-creation in Figure 2.1), and he described the pattern of influences between levels as being "many on many".

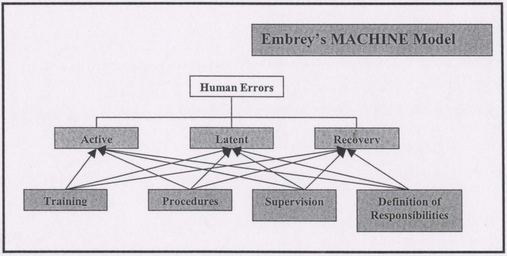


Figure 2.1 – Embrey's "MACHINE" model

Embrey's approach was not dissimilar to that proposed by this research. He saw the accident process as complicated and influenced by factors at several levels, including management and organisational. The quantitative combination of the various factors produced an overall estimate of accident likelihood. The current proposal applies many of Embrey's concepts to the offshore occupational accident problem.

2.1.3) Primarily quantitative and statistical models

One of the objectives of the current research was to apply a quantitative approach to the prediction of accident frequency. The intention has been to offer a tool to assist in management decisions associated with safety programme implementation. In this section several previous models are discussed which have included quantitative elements in their approach.

2.1.3.1 Kjellen's comparison analysis

In an attempt to include occupational accident risk in the overall design process of Norwegian offshore projects and thereby satisfy existing legislative requirements, Kjellen and Sklet (1995) evaluated the existing risk analyses methods specific to occupational accidents. They concluded that there were no combinations of types of accident criteria and risk analysis methods that covered the full range of occupational accidents.

In light of this conclusion, Kjellen (1995) went on to propose his own "Comparison Analysis" method for calculating the likelihood of occupational accidents on offshore installations. The method relied on a comparison of conditions on a case system with those observed and documented on an existing, or reference, system. A panel of experts was asked to judge whether, and to what degree, the case system's safety programme was different from that of the reference system. Next, a comparison was made between the frequencies of the various activities being executed on the two systems.

As an example, injuries occurring during a particular drilling activity can be considered. Suppose that it had been documented that the rate of a specific type of injury during this activity on a specific drilling rig (i.e. the reference case) was one per man year worked. Suppose also that a superior (compared to the reference rig) safety system on a proposed new (i.e. case) system was expected to produce a 20% reduction in the specific type of accident under consideration. Furthermore, improvements in drilling technology might mean that the specific activity need only be undertaken half as frequently on the case rig as previously. Comparison analysis could then lead to the conclusion that the likelihood of occurrence of this type of injury would be 1 × 0.80 (covering the 20% safety improvement) × 0.5 (covering the reduced frequency of the activity) = 0.4 per man year worked. The total type of accidents foreseen for each activity and the total type of activities would then be summed to provide a total accident rate for the case installation.

Kjellen has proposed an interesting method for predicting accident rates on offshore platforms based on historical results from existing platforms. However, several areas for improvement in the model have been noted by the author, including stricter definitions of decision rules, improvements in assumptions, and recognition of ongoing databases.

The current work expands on the concepts employed in the "Comparison Analysis" approach. Kjellen's method accounted for safety improvements in specific areas and changes in activity frequency, but the current work includes factors at the direct, corporate and societal levels, proposes relationships between them, and recognises their relative importance and specific contribution to the overall safety programme.

2.1.3.2) Quantitative risk assessment

Quantitative Risk Assessment (QRA, defined as a risk assessment procedure that determines both probability of occurrence and consequences) is an increasingly popular way of assessing risks in the offshore industry. Pietersen and Engelhard (1991) have described the process, which makes use of, among other tools, traditional fault and event trees. Some general comments on the current use of QRA follow:

- QRA is used primarily to model large catastrophic accidents, for example
  - unintended release of hydrocarbons from process equipment and pipelines
  - primary structural failure
  - helicopter crashes
  - ship collisions
- QRA has gained sufficient popularity to be the subject of regulatory requirements.
- The process involves quantitatively evaluating the likelihood of occurrence of accident-inducing, preventive, and mitigative events, and combining these with the respective consequences to provide a measure of risk (both individual and group), which is then evaluated against a required value. The sequence of steps is as follows:

- determine inventory of basic data
- identification of initial events
- inventory of protective measures
- determination of accident scenarios (utilises an event tree process)
- determination of effects and damage (event tree)
- determination of failure frequencies (event trees and fault trees)
- risk determination
- risk evaluation
- escape route evaluation
- recommendations for risk reduction (if necessary)

Quantitative risk assessment is gaining increasing respect in the offshore industry. Whilst limited evidence exists of the inclusion of corporate or societal factors when using QRA, and its application to date has primarily been to larger accidents, it does offer possibilities for the occupational accident problem, particularly by offering a degree of quantification to the problem. The biggest challenge to an effective application of QRA to the study of occupational accidents would likely be the assignment of accurate input values to factors usually understood on a qualitative basis only.

2.1.3.3) Fault tree models

Wells et al. (1992) have proposed a traditional and relatively simple fault tree approach to the accident problem. The authors proposed that accidents are initiated by an event having the potential of escalating into a more serious situation, but doing so only if a series of enabling events occurs or a series of preventive actions fails to occur, including for example:

- operator protection
- equipment protection
- operator recovery
- mitigative measures

Johnson (1980) has developed a fault tree based model referred to as "The Management Oversight and Risk Tree" (MORT) model. MORT is more complicated than Wells et al.'s approach, incorporating more elements of the safety system.

Fault tree models offer the same benefits and challenges to the study of occupational accidents as the QRA methods discussed in the previous section.

2.1.3.4) Event tree models

Munteanu and Aldemir (2003) have applied a dynamic event tree approach to accident modelling, considering the specific example of pressure retaining equipment in nuclear facilities. The key benefit of their model, whose elements are listed below, was its ability to use probabilistic arguments to provide advice to operators on a real time basis.

- The model uses state/parameter estimation capability within a module referred to as a "dynamic system doctor (DSD)". The system states and parameters are user-defined, and the algorithm models system evolution in terms of the probability of transitions in time between the respective states (referred to as "cell-to-cell mapping technique"). A Markov chain analysis is used to determine the probability of finding the system in a given state at a particular time. The principles and limitations of Markov analyses are described in Billinton and Allan (1983). The basic concept involves considering the components of a system to be in one or another of a number of states (for example working or failed), determining the probabilities of the system moving from one state to another, and then using probability theory to calculate the likelihood of the system being in particular states following a number of time intervals.

- Dynamic event tree capability resides in a module called "integrated safety assessment (ISA)". This module is comprised of a plant simulator, a scheduler, and a probability module. The analysis commences with the occurrence of an initiating event, and the resulting evolution is followed by the plant simulator. The scheduler initiates and controls events along the respective event branches, and terminates the simulation when no further "branching" is expected. The probability module calculates the probability of each scenario, and also contains stopping or "branch pruning" rules which prevent the creation of numerically unmanageably sized trees.

The authors proposed the following advantages of the approach.

- an appropriate choice of cells to effectively manage uncertainties in the monitored system states and inputs
- a probabilistic measure to rank the likelihood of system faults

- capability to use any of a series of methods to generate the cell-to-cell transition probabilities
- provision of the upper and lower bounds of state variables and parameters during model execution, which is important in the determination of safety margins
- production of fewer branches, thereby reducing problem size and computational effort

Munteanu and Aldemir's work provided an example of a mathematical approach to accident modelling, as applied to pressure retaining hardware in the nuclear industry. Weaknesses in the approach, when considered in the context of occupational accident modelling, were the inherent complexity in the event tree approach, and the failure to include non-traditional (i.e. corporate, human, societal) factors in the calculation.

2.1.3.5 Thompson's confirmatory model

Thompson et al. (1998) have statistically analysed the relationships between safety climate (defined by Mearns et al. (1997) as *a 'snapshot' of the current perceived state of safety on a plant or installation*), management support for safety, and perceived safety conditions at a US federal aviation administration logistics centre. Witt, Hellman, and Hilton (1994) had previously modelled the relationships, as shown in Figure 2.2, with the elements defined as below.

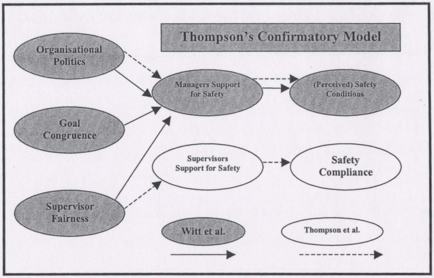


Figure 2.2 – Thompson's confirmatory model

- "Organisational Politics" is the process of influencing others' decision making through means outside those prescribed by organisational policy. Examples include such actions as social ingratiating, hiding agendas, or not elevating unpleasant or controversial matters.
- "Goal (in)congruence" is the degree to which the goals of management are matched by those of the workforce. It is heavily affected by the workforce's perception of management attitudes. An example from the safety field is the degree to which management is perceived to be willing to set aside safe practices in order to meet operational targets.
- "Supervisor fairness" is essentially a measure of how strongly employees believe their concerns, once passed to their supervisors, will receive a fair hearing by management.

- "Management Support for Safety" is delivered at two management levels. Senior managers establish priorities, set production schedules that may accommodate safe operations, and control incentives and penalties associated with safety (and other) compliance. Supervisors are the "conduit" linking management safety concerns to the shop floor. They are more influential in indicating safety priorities to the workforce than senior managers.
- "Safety Perception", as measured by surveying workforce opinion, is the authors' preferred method of measuring overall workplace safety. They view accident rates, accident costs, and safety audits as less reliable alternatives.

Thompson et al. have refined the original model, which considered the three climate factors (politics, congruence, and supervisor fairness) to be mediated by a single management element to influence workplace safety environment. They hypothesized that the political element was mediated by the more senior managers to affect safety *conditions*, whereas supervisor fairness was considered to act through supervisory support to be the primary driver for safety *compliance*.

The hypotheses were tested by reviewing survey results from two years (1992, 1995) at the facility. Results of the exercise are summarised as follows:

- In general both hypotheses were shown to be supported by the survey results. Safety compliance was heavily affected by the supervisory management level, whilst safety conditions, probably as would be intuitively expected, drew more heavy influence from the more senior levels of management. Moreover, senior management was more directly influenced by the organisational politics than the other top level factors.

- Management influence was shown to be pervasive, not only influencing workplace climate and safety, but also affecting the influence of supervisors on safety perceptions.

Although originating from a very different industry, Thompson et al.'s research and conclusions were consistent with the philosophy proposed by the present work. Thompson et al. proposed that corporate climate and processes influence the workplace safety situation through the intermediate levels of senior management and supervisory personnel. The present work applies similar concepts to a different industry and on an even more extended basis, to include elements outside the organisation, for example, societal and regulatory aspects.

2.1.3.6 Tomas' structural equation model

Tomas et al. (1999) have evaluated the suitability of a structural equation modelling (SEM) approach to describe occupational accidents (Figure 2.3). The authors defended their approach by suggesting that accidents should be treated as if they had resulted from a complex sequence of events, and that SEM best handles such complexity. The data for the work were obtained by questionnaire from three Spanish companies, chosen because of their categorisation as high risk on insurance company and regional government lists.

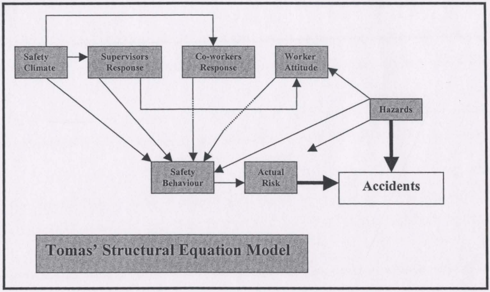


Figure 2.3 – Tomas' structural equation model

The authors have suggested that the overwhelming majority of accidents are blamed on human factors. However, they have taken the analysis to a higher level, attempting to understand the relative importance of factors such as lack of attention, lack of training, co-workers' attitudes toward safety, workers' own attitudes, and organisational processes in determining why workers behave in an unsafe way.

The authors have measured each element in Figure 2.3 by asking a series of related questions. For example, safety behaviour was evaluated by asking about correct use of machines, observance of safety rules, speed at work, alcohol ingestion, etc. Three hypotheses were evaluated, as follows.

- Attitude toward safety influences workers' behaviour.
- Safety behaviour has a direct effect on the occurrence of accidents.

- Hazards predict the real probability of accidents occurring (i.e. the hazard, rather than the workers' ability to deal with it, presents the primary indicator for accident occurrence).

The paths between the elements were evaluated statistically, and some conclusions (based on one of the three datasets) were as follows.

- There was a significant explanatory chain that flowed from safety climate through supervisors, co-workers and worker attitudes and behaviours, to accidents.
- Unexpectedly, safety climate did not have a significant direct effect on either safety behaviour or co-workers response.
- Supervisor response significantly affected co-workers' response, attitude and safety behaviour.
- ***Attitudes affected behaviour, while behaviour influenced the actual probability of accidents occurring.***
- ***Hazards did not have a direct impact on accidents*** (i.e. most hazards are dealt with effectively by a capable and motivated workforce).

The results from the other two datasets were similar, with an exception being an increased level of significance associated with the hazard/accident relationship.

The work supported the concept that using number of accidents as a measure of safety can be problematic. This is because, in general, most corporate participants have few or no accidents, resulting in a highly skewed, low variability distribution. Following some statistical investigation, the authors concluded that the most consistent method of measuring safety included a combination of raw accident number and the relative severity of the previous three accidents.

The results were interesting in the context of the present research in a number of ways. For example, the concept of attitudes affecting behaviour and behaviour in turn causing accidents is a cornerstone of the layered approach of the proposed accident model. Also, Tomas et al.'s work showed a relatively low explanatory connection between hazards and accidents, as indicated by the final conclusion above. This result contradicted the notion that accidents are caused by hazards impinging on helpless workers. Rather, the conclusion to be drawn is that accidents generally occur when staff are ill prepared to deal with hazards which, in general, can be reasonably expected. The present work makes use of several of the authors' conclusions, but transposes them to a specific industry on a much broader geographic scale, and also expands the philosophy outside the company to include societal, regulatory, and global fiscal issues.

2.1.3.7) Guastello's cusp model

Guastello (1989) has proposed a quantitative model to study occupational accidents in the sheet metal business in the mid 1980's. The research concluded that accident rate in the industry usually took one of two approximate values. Either a near-zero result was achieved, or a rate of approximately eleven accidents per 100 person years of exposure was observed. The model implied a sharp transition in safety performance between the two levels. Once a particular threshold (cusp) in the characteristics of influencing criteria had been surpassed, performance moved to the other level. However, Guastello noted that the return to the original level did not necessarily occur at exactly the same point, similar in principle to the re-seating of a safety relief valve, which does not occur at the exact popping pressure.

Accident rate data were collected from the same eight companies in two different years (1984, 1985), thereby ensuring relative similarity between the two populations. Following the initial data gathering, a series of safety recommendations were made, and one goal of the work was to see if, and how quickly, implementation of the recommendations would actually improve measurable safety results. Some of the hypotheses investigated were as follows.

- Accident rates will decrease in proportion to the time available for the organisations to work on their recommendations.
- Accident rates will decrease in proportion to any shrinkage in workgroup size.
- Improvements will occur to a greater extent where safety management is good, anxiety and stress are high, and staff believe that accidents are controllable.

Some of the primary conclusions of Guastello's work were as follows:

- Larger group size was associated with higher accident rates.
- Accident rates decreased more for groups having greater time to implement safety recommendations.
- Groups with initially high accident rates combined with high safety management ratings, a significant belief that accidents can be controlled, and longer amounts of time with recommendations showed the strongest improvement as a result of the intervention.

- Surprisingly, groups with high anxiety and high physical and social stress were also better disposed to improvement than other groups.
- No relationship was confirmed between the physical hazards and danger level criteria.

Guastello noted that his model was unlikely to be valid in other industries. A traffic environment was specifically mentioned as being an unsuitable application, since, unlike the factory setting studied, environmental factors (e.g. sleet, rain, snow) impose a constantly changing set of external factors on the situation on an ongoing basis. This indicates that the cusp model would also be unsuitable for offshore occupational accident research, where external factors, including both the weather effects mentioned in the automobile example, and other factors such as politics, fiscal regime, etc., are considered to provide significant influence.

Despite this, many of the concepts discussed in Guastello's paper were similar in philosophy to those proposed by this research. Examples of this are:

- the notion that appropriate employee attitudes and beliefs will positively affect safety results
- the concept that accident occurrence need not necessarily be directly correlated with the existence of hazards, instead depending more strongly on corporate and personal factors

2.1.3.8) Brown's sociotechnical / safe behaviour model

Brown et al. (2000) have studied safety in the steel industry. They considered the accident process from the three perspectives mentioned below.

- person as cause – This view contends that employee attitudes and behaviours are the most important factors in the accident process.
- system as cause – Proponents almost always point to system design as the dominating factor. The example of an accident resulting from the location of brake pedals on opposite sides of crawler crane floors in similar vehicles used at the same yard is offered to demonstrate how operator error is often blamed for accidents having a significant design flaw element in the root cause.
- system-person sequence as cause – Central to this view, which is also embedded in the present research, is the notion that *system factors influence safety outcomes through people.* Proponents recognise the existence of social factors, personal predispositions, and the role systems play in affecting personal behaviour.

Brown et al. tested the validity of the three views through a survey of more than five hundred employees in a southeastern US steel mill. A series of eighty items was developed to investigate the proposed factors, and the workers were asked to quantitatively indicate the level at which the items were applicable to their specific work situation. The workers were also asked to rate the seriousness of the factors in the accident process.

Brown et al.'s model is shown schematically in Figure 2.4. Some comments with respect to the specific factors follow the figure.

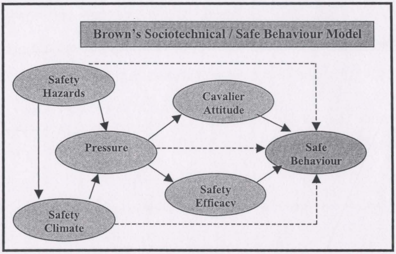


Figure 2.4 - Brown's sociotechnical/safe behaviour model

- Safety hazards – these affect safety results on two levels. Firstly, their presence can cause accidents. Secondly, the existence of *preventable and unnecessary* safety hazards can negatively affect staff confidence in management commitment to safety. The resulting poor attitude can negatively affect safety results.
- Safety climate – the authors supported the view that a positive safety climate, as manifested by such things as an open door policy for hazard and accident reporting, a sincere concern for employee well-being, and fairness in accident investigations, would provide tangible safety result improvements.
- Pressure – The authors reported a spike in accident rates during periods of peak production at virtually every plant investigated. They reported a significant relaxation of safety concerns with an associated worsening of safety results upon the application of increased operating pressure.

- Cavalier attitude toward safety – This factor is manifested in various risky behaviours, for example ignoring safety procedures, moving through watertight door openings when the door is still in motion, etc. These behaviours are particularly prevalent in industries popular with the more risk taking type of individual. It is likely that offshore oil and gas production would fall into this category. The authors suggested two methods for reducing the negative effects of this factor: (i) care taken at the hiring stage to avoid candidates who test high on "risk taker" personality tests, and (ii) the appropriate rewarding (and punishment) of safety *behaviours,* as opposed to safety *results.*
- Safety efficacy, defined as an employee's confidence that he or she has the skill to work safely in the context of a specific environment, must be considered in relation to the higher level factors which precede it in the model (i.e. hazards, safety climate, and pressure). The authors promoted the importance of *hands on* training in the development of a satisfactory level of safety efficacy.

Several versions of the model shown in Figure 2.4 were evaluated. For example, eliminating the relationships shown by dotted lines produces the "system-person sequence" model. Including those relationships produces the added effect whereby safety hazards, safety climate, and pressure, in addition to their existing role in the system-person model, also impinge directly on the final accident result. Removing the lines from pressure to cavalier attitude and safety efficacy removes the influence of corporate factors on personal behaviour.

Correlational analyses were performed on the data when considered within the three distinct model configurations. The analyses confirmed that the version best fitting the data was a direct relationship from hazards and climate through people to the accident, i.e. without the direct influence of safety hazards and climate on safety, but with the influence of pressure on personal behaviour.

Brown et al.'s view of "system-person sequence" as the major accident dynamic may be summarised as "although the individual performs the act, factors in the operating and social environment play a role in the person's disposition toward safe practices".

The authors' conclusions were similar in principle to the concept proposed by this research, i.e. that although accidents result directly from the acts of people, work environment plays a vital role in those acts. The authors recognised several limitations to their work, as below.

- The research was carried out within one firm in a single industry, resulting in a limited and biased dataset.
- The factors included were not exhaustive (others such as age, gender, and time on the job were mentioned).
- The work indicated correlation between factors, although the validity of directionality was questionable – for example they could not positively conclude that increased pressure necessarily produced negative safety climate.

The authors' conclusions included a reference to the "dearth of theory development and testing in the safety arena". They recommended that future researchers expand upon their methods by including multiple organisations, monitoring change over time, and considering a greater range of data sources. The present work addresses these recommendations in combination with its other objectives.

2.1.3.9) Cheyne's employee safety attitude model

Cheyne et al. (1999) have modelled employee attitudes to safety in three UK based industries: manufacturing, dairy produce, and transportation. Their model, shown in Figure 2.5, was similar to others described in this section, in that its elements dealt with the effect of management actions and training on employee attitudes.

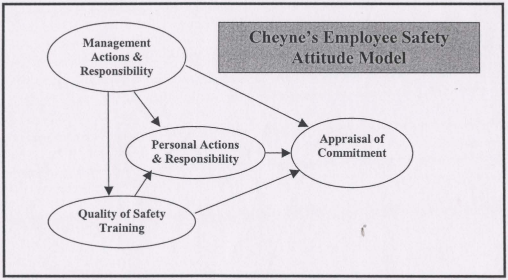


Figure 2.5 – Cheyne's employee safety attitude model

The authors' analysis included a statistical evaluation of nearly twenty-five hundred survey questionnaire responses. The questions were grouped according to their association with management actions, personal actions, and safety training quality. Analysis of variance (ANOVA) and Tukey's honestly significantly different (HSD) evaluations were used to study differences in the results. Relationship patterns were studied using a structural equation modelling (SEM) approach.

Some conclusions of the work were as follows:

- The main determinant of commitment to safety was the strength of employee attitude toward management actions.
- Attitude to management actions was related to quality of safety training.
- Surprisingly, an inverse relationship was found between safety training and personal safety actions. The authors proposed that this may be partially explained by personal actions compensating for training which was perceived negatively by workers.
- Managers were identified as the key group through which attitudes to safety could be influenced and improved.
- The model relationships were shown to be valid across the three industries studied.
- Contrary to those working in the other two industries, transport sector workers perceived no relationship between how their managers acted and how they, as individuals, acted in the context of safety.

The final two conclusions were important to the present research from two perspectives. Firstly, the validity of the model across the three industries studied indicates that the authors' general accident philosophy, which has similarities with the one presently proposed, correctly models accidents in many fields. Secondly, the inter-industry variance of *some* aspects reinforced the importance of industry-specific studies of safety behaviour, such as this one. Employee attitudes may differ between industries, as may corporate behaviours.

Cheyne et al.'s work offered further confirmation of the importance of corporate-personal relationships, such as the ones accounted for in the present research, but it did not include external influences, or offer a practical predictive model. Also, the study was specific to three industries distinct from the oil and gas sector comprising the arena for this work.

2.1.3.10) Pate-Cornell and Murphy's SAM approach

Pate-Cornell and Murphy (1996) have applied their "System-Action-Management (SAM)" approach to two catastrophic accidents, the Piper Alpha disaster and the space shuttle Challenger crash, and also to problems associated with anaesthetics during surgery. The authors proposed that while bad luck is a fact of life, the fraction of accidents involving some human and/or corporate responsibility ranges from 50% to 90%. Accordingly, the objective of the SAM approach was to facilitate the inclusion of corporate and human factors in a probabilistic risk analysis (PRA, which is defined as a risk assessment procedure that includes a probabilistic element), thereby improving it as a tool for managing and reducing risks. SAM offered a link between management approaches, the decisions and actions they affect, and system failures. The approach used basic conditional probability theory as defined by the following equation.

$$p(F) = \sum_i p(F \mid IE_i)p(IE_i) \tag{2.1}$$

where

$p(F)$ = probability of system failure

$p(F|IE)$ = conditional probability of system failure given an initiating event

$p(IE)$ = probability of occurrence of the initiating event

Management decisions and actions (DA) were included by using the following equation.

$$p(F) = \sum_i \sum_j p(F \mid IE_i, DA_j)\, p(IE_i \mid DA_j)\, p(DA_j) \tag{2.2}$$

where

$p(F \mid IE_i, DA_j)$ = conditional probability of failure given an initiating event and a specific management decision/action

$p(IE_i \mid DA_j)$ = conditional probability of an initiating event given a specific management decision/action

$p(DA_j)$ = probability of occurrence of the specific management decision/action

The SAM philosophy is illustrated in Figure 2.6.

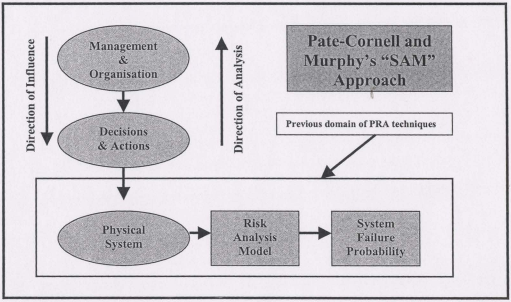


Figure 2.6 – Pate-Cornell and Murphy's "SAM" approach

A series of general observations emerged following the application of the SAM approach to the accidents mentioned above, which are listed here.

- In many organisations, "risk management" means "insurance".
- Too much emphasis is often put on technical rather than corporate risk mitigation measures.
- Operators are generally predictable, competent and well intentioned.
- People are basically rational (or at least intend to be).
- Under excessive constraints, people tend to cut corners in ways that are difficult to predict.
- General policies seem to receive lower priority than specific directives.
- Management is sometimes unaware of the hidden costs of the constraints it sets.
- Informal rewards seem at least as important as formal ones.
- Organisations seem to have difficulty in communicating the importance of safety.
- Informal organisational structure may be as important as formal channels.
- Physical systems change faster than the behaviours of their operators.
- Normal operations do not prepare people for crisis situations.
- In crises situations, it is essential that someone be clearly in charge.
- Trainers often receive insufficient supervision.
- People have difficulty understanding and communicating uncertainty.
- People tend to ignore information that conflicts with their beliefs and wishes.

The authors included an illustration of the specific organisational factors and related decisions and actions which were considered important in the Piper Alpha disaster, which is partially re-created in Figure 2.7. The diagram is interesting in that (i) it gives examples of specific organisational factors which may be important in the offshore industry, and (ii) it shows the complicated and multiple relationships between organisational factors and decisions/actions.

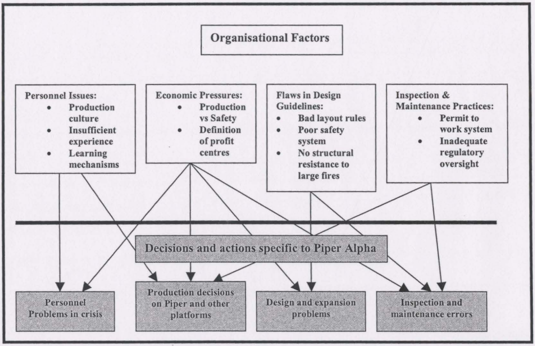


Figure 2.7 – Piper Alpha analysis

Pate-Cornell and Murphy's concepts were similar to the holistic approach to occupational accidents proposed by this research. There is no doubt that policies, procedures, and attitudes imprinted on an organisation by its senior management will affect the frequency of occupational accidents, as evidenced by the models reviewed in this chapter.

2.1.4) Summary

Accident models have been developed and tailored in reaction to the specific needs they attempted to address. Medicine and the nuclear industry have historically demanded overwhelming attention to accident causation, prevention, and mitigation. This has probably been due to the high emotional attachment associated with problems in these industries – medicine due to the obvious distress caused by the illnesses of loved ones, and the nuclear industry due to the many and varied catastrophic consequences of nuclear accidents. Because of these emotional issues it is no surprise that many of the earliest accident models originated in these industries. These early models provided a valuable philosophical foundation for subsequent work.

Other models have concentrated on direct or obvious causes, for example drawing from investigation results or zeroing in on elements such as personal protective equipment, number of shifts worked, effect of safety regulations, and the like. These models provided a vehicle to produce improvements in specific areas, such as protective helmets and boots, and working hour expectations for usually fatigued offshore staff, but they did not adopt a holistic view of the occupational accident problem.

Some models have taken a broader view of offshore accidents, but this approach has usually been applied to catastrophic accidents rather than *occupational* ones. Significant attention has been paid to holistic modelling of large accidents such as explosions, toxic releases, and boat collisions, a single occurrence of which can have dire consequences. These holistic models often included attempts to consider the effect of the overall organisation in the analysis and some also considered external factors, but, as mentioned, they concentrated on large accidents.

Human performance and personal reaction to dangerous situations has provided the basis for some models. The occurrence (or not) of the accident was essentially considered to be a question of how well individuals satisfactorily reacted to their environment in order to prevent, mitigate the results of, or recover from, the accident. These models offered insight into human aspects of the problem, but the present research considers the human element as just one of many different factors in a holistic analysis.

Other models have adopted a statistical approach, but they tended to use historical data to study existing relationships between factors, as opposed to offering a predictive model which can be used to help guide management decisions. In cases where predictive models have been proposed, the applications have either been in industries other than oil and gas, the factors have been limited to direct and corporate ones, or the regional coverage has been narrow. These models have provided valuable input to the present research, but the current proposal is to provide a quantitative holistic view of occupational accident prediction and causation within a specific industry, thereby offering the possibility of directing resources to maximise safety result improvements.

The literature also describes significant work which has provided a qualitative view on the process. Opinions and case studies have been used as input data to propose graded or ranked causes of offshore accidents. Suggestions for corrective/preventive actions were then offered to improve safety performance. The present work brings mathematical rigour to the analysis, thereby providing benefits unavailable in qualitative studies, such as

- sensitivity studies

- calibration to known results
- application to existing installations
- calculation of "maximum improvement per resource allocation"

The types of accident models studied have contributed expertise to the offshore occupational accident problem from a wide range of perspectives. Some models have dealt specifically with occupational accidents, some have taken a holistic approach to the other more catastrophic types of offshore accidents, and others have considered non-traditional elements (i.e. societal, human). However, no presently available model has adopted the holistic, quantitative approach to offshore occupational accidents proposed by this research.

Figure 2.8 illustrates the strengths and weaknesses of the various types of accident models available today. Blackened squares indicate that the model type complies with the element indicated.

Model Type	Offshore Specific?	Quantitative Appl.?	Time Tested?	Current?	Simple?	Detailed?	Gen. Framework?	Comments
Epidemiological			■		■			Very early (40's) – philosophical building block
Driving Force		■	■		■			Innovative attempt at quantification
Normal Operating State			■		■			New perspective at the time
Human Information Processing			■		■			Attempts to explore the human reaction to danger
Fault Tree		■	■			■		Brings classic methods to the problem
Event Tree		■		■		■		Complex algorithm – nuclear application
Quantitative risk assessment		■	■	■		■		
Socio Technical / Holistic				■			■	Broader, but possibly lacks quantitative / offshore appl.
Neural Networks		■		■		■	■	Possible candidate for model basis
MACHINE		■	■			■	■	Lacks application offshore / occupational accident
Accident Investigation			■		■			Retrospective analysis, essentially non-predictive
Comparison Analysis	■	■		■		■		Most applicable model of those considered
Thompson's confirmatory		■		■		■		Relational, not oil & gas related
Tomas' Structural equation		■		■		■		Relational, not oil & gas related
Brown's Sociotechnical model		■		■		■		Specific to the steel industry, no resulting practical model
Guastello's Cusp model		■		■		■		Relational, not predictive, not oil & gas related
Cheyne's safety attitude		■		■		■		Relational, not predictive, not oil & gas related
SAM approach		■		■		■		Retrospective, little attention outside the organisation

Figure 2.8 – Summary of accident models

2.2) Statistics associated with occupational accidents

A variety of sources of offshore occupational accident statistics and associated literature analysing the data have been investigated and are described in this section. These include internet based databases (for example the United Kingdom (UK) Health and Safety Executive (HSE) and the Norwegian Petroleum Directorate (NPD)), open literature offering statistical analyses, and company-supplied documentation.

2.2.1) Slips, trips and falls from height offshore

BOMEL (UK HSE, 2002a) has conducted a statistical study of slips, trips, and falls from height (STF) in the UK offshore industry. The objectives of the study were to establish a firm understanding of the causes of STFs and to develop a strategic plan to bring about a 15% reduction in these accidents over a three year period.

The study comprised the following elements:

- literature review
- accident data analysis
- interviews with HSE inspectors and trade union representatives
- focus groups, including offshore installation managers and safety representatives
- an offshore visit

Some conclusions of the accident data analysis were as follows:

- The rate of STF was seen to be dependent on the activity being undertaken, as illustrated in Table 2.2. The ratio of highest to lowest values (1500/325 = 4.6) was relatively higher than for other influencing factors, which leads to the conclusion that activity being undertaken is a strong factor in STF occurrence likelihood.

Table 2.2 – Slips, trips and falls by operation

Activity Being Undertaken	Rate of Slips, Trips and Falls (per 10^5 people), 1996-1999
Deck operations	1500
Drilling / workover	600
Production	600
Construction	600
Maintenance	525
Transport	425
Diving	325

- The rate was not as dependent on age, where the ratio of the rate (550) for the group (21-40 yrs) most likely to have an accident compared to that (450) for the group (41-50 yrs) least likely to have an accident, was only 550/450 = 1.2. This result, compared to the ratio associated with activity being undertaken, indicates that age related issues (perhaps capability, attitude, or experience), may be relatively less important than activity being undertaken.
- STF rates for work on fixed and mobile units were compared, and they differed by a relatively small ratio of 1.08, with the rate on fixed installations being greater. The similarity in results is not particularly surprising in light of the generally similar activities executed on each type of unit. If anything, the rate on mobile installations might have been expected to be slightly greater, owing to the continuous, albeit slight, wave induced motion present on floating units.

2.2.2) Multivariate analysis of injuries data

The University of Liverpool (UK HSE, 2001b) has conducted a statistical analysis of a database of more than one thousand offshore accidents, in an attempt to extract possible relationships between the accidents and the operations being undertaken at the time. Some results were as follows.

- The percentage of injuries categorised as fatal or major was greater on mobile installations than on fixed installations (23% vs 17%). Note this is an opposite trend to that suggested by the data in UK HSE (2002a), and may result from the additional complexity introduced to activities by vessel motion.
- 32% of injuries between 10am and 11am were categorised as fatal or major, compared to 19% for the remaining 23 hours.
- 27% and 33% respectively of injuries categorised as slips/trips/falls and lifting/crane operations, were fatal or major, compared to 12% for the remaining categories. This result supports the notion that occupational accidents are more dangerous than generally thought.

2.2.3) Health and safety performance of the global E & P industry 2000

Smith (2002) has analysed the global safety performance of the exploration and production industry. Some of Smith's results are summarised below.

- The dataset was extensive, including results from 39 companies operating in 71 countries over 10 years. Data from the latest year surveyed, 2000, represented over 1.6 billion hours worked.

- The data represented both onshore and offshore work, and little significant difference was seen when comparing safety performance onshore and offshore. However, since 30% of the onshore accidents were caused by driving incidents, it is reasonable to conclude that if vehicle accidents were disregarded to allow a "like for like" comparison, onshore safety performance results would have been superior.
- A regional analysis produced the following results.
    - Where fatal accident rate (FAR, defined as fatalities per 100 million hours worked) is concerned, the region performing poorest was South America, followed by Africa, the Middle East, Asia/Australia, North America, and Europe.
    - Considering lost time injury frequency (LTIF, defined as injuries per million hours worked), again the region performing poorest was South America, but in this case the next poorest was Europe, followed in turn by North America, Africa, the Middle East, and Asia/ Australia.
- In 2000, the overall FAR was 7.28, which was not appreciably different from the figures generally recorded over the preceding 10 years, during which the values ranged between 7 and 13, with no particular trend in either direction.
- The 2000 fatal incident rate (FIR – which eliminates the number of fatalities associated with each incident from the calculation) was 6.73 per 100 million hours worked. As was the case for FAR, there has been no particular directional trend in the statistic between 1991 and 2000.

- LTIF values showed significant inter-company variability. The worst performing company had an LTIF exceeding 30, and the best, lower than 1. Eight of the thirty nine companies performed *significantly* better than the average frequency of 1.88, and fifteen *significantly* worse than the average.

Smith's work supports the view that both cultural and corporate factors can affect safety performance. The ratio of worst to best FAR between regions approached five. The ratio of worst to best LTIF approached a similar figure. Results from different organisations indicate that corporate safety programmes can have a very significant effect, in that the ratio of worst to best company performance exceeded thirty.

Although not as consistent or obvious, Smith's work also showed that improvements in safety performance over time can be realised. LTIF in 2000 was less than one half of the figure achieved in 1990.

Smith's results and conclusions support the validity of the holistic approach proposed by this work, which considers cultural and corporate factors as inputs within a wide range of influencing elements affecting occupational accidents.

2.2.4) Safety and environmental performance measures in offshore E&P operations: empirical indicators for benchmarking

Iledare et al. (1998) have conducted a statistical analysis to test the hypothesis that the expanded role of small independent operators in the Gulf of Mexico poses an increased danger to personnel safety or the environment. The authors used several indicators to study the situation from 1987 to 1993, including the following.

- fire and explosion incident rate – the ratio of the total number of reported fires and explosions within a given time period to a weighted normalising factor (for example, number of installations for production companies, or number of wells for drilling contractors)
- blow-out incident rate – the ratio of total number of blowouts to total wells

Some results and conclusions associated with the analysis were as follows.

- Average fire and explosion incident rate for major operators was more than twice that for independents.
- Independents (especially smaller ones) had a higher average blow-out incident rate than the majors.
- From the general safety perspective, independents were seen to have performed marginally better over the period than the majors.
- Independents also bettered the majors when accidents of greater severity were studied.

Iledare's work suggests an interesting conclusion about the effect of company size on safety culture, and its subsequent effect on safety performance. Size and financial strength, usually associated with major operators, might be expected by some to be correlated with a high attention to safety culture, but some of the results indicate the reverse. A possible explanation may be associated with the family company atmosphere in smaller organisations, which may produce a more favourable safety culture than that existing in larger companies, and in turn, better safety results.

2.2.5) Risk perception and safety in the UK offshore oil and gas industry

Flin et al. (1996) have presented the results of a questionnaire-based survey which investigated the risk perceptions of a series of some 622 UK offshore oil and gas workers. Some of the results of the work were as follows.

Workers' perception of their risk

- 80% of the workers considered themselves basically safe while working on offshore platforms.
- Slipping was the individual hazard about which the highest percentage (14) of workers felt unsafe, outdistancing weather conditions (13), hit by a falling object (11), food poisoning (5), crushed by machinery (4), electric shock (4), fall to a lower level (4), medical problems (3), burns (3), and fall overboard (2).
- Vessel hitting platform was the installation hazard about which the highest percentage (11) of workers felt unsafe, outdistancing sabotage (8), helicopter crash (8), explosion (7), toxic gas leak (7), blow-out (6), fire (6), and structural failure (4).

Workers' views on accident causation and safety culture

- 60% or more of the workers disagreed with the following statements:
  - Sometimes it is necessary to take chances to get a job done.
  - The permit to work system is just a paperwork system.
  - Sometimes it is necessary to ignore safety issues to keep production going.
  - Accidents just happen, there is little one can do to avoid them.

    - The use of machines and technical equipment makes accidents unavoidable.
    - I never think about the risks now that I am used to the work.
- 60% or more of the workers agreed with the following statements:
    - Good proposals on how to improve safety are often stopped if they cost too much.
    - Whenever I see safety instructions being ignored, I point them out.
    - Lots of minor accidents and injuries are a sign that more serious accidents could also occur.
    - Most accidents could be prevented if a little care and attention was paid to preventive measures.
    - Accidents and near misses are often the result of bad planning and management.
    - Most accidents are due to human failure.

Some psychological aspects of risk perception were discussed by the authors. They suggested, for example, that people are generally too frightened of strange situations and too casual about familiar ones, and that people tend to underestimate the risks they choose to take and overestimate the risk associated with mandated activities. Because there was evidence that actual accident rates were higher in groups that underestimate risks, it is important to try to ensure that the workforce assesses risk as accurately as possible.

The results provided a consolidated picture of UK offshore workers' perspectives of the occupational accident situation. It is encouraging that the workers were aware of the relatively high risk associated with occupational accidents. Furthermore, the workers' responses to the agree/disagree statements indicated a mature safety culture. There seemed to be little fear of reporting safety violations, little cynicism regarding management attitudes and procedures, and a generally positive attitude with respect to the ability to avoid accidents.

2.2.6) Rig floor accidents: who, when and why? – an analysis of UK offshore accident data

Dobson (1999) has presented a summary of accidents on UK drilling rigs, subdivided by a range of categories, including activity at the time of the accident, occupation of the injured, age group, and type of injury. An analysis of the data was conducted, which led to the proposal of some causal factors associated with the accidents and a series of proposed remedies. Tables 2.3 – 2.5 present some of Dobson's results.

Table 2.3 – Accident occurrence by type

Accident Type	Number of Occurrences (Apr. 1997- Sept. 1998)
Manual handling	53
Trips and slips	29
Moving load	24
Dropped load	15
Dropped object	7
Pressure	4
Hand tools	4
Release of hazardous substance	1

Table 2.4 – Accident occurrence by occupation

Occupation	Number of Occurrences
Toolpusher	1
Driller	2
Assistant Driller	5
Derrickman	9
Floorman	57
Deck foreman and rigger	3
Roustabout	30
Subsea engineer	4
Service hands	3
Well service and wireline	8
Other	15

Table 2.5 – Accident rate by age

Age Group	Injuries/1000 Employees
< 21	80
21-25	62
26-30	66
31-35	22
36-40	30
41-45	8
46-50	8

Dobson has offered the following comments with respect to the results.

- The critical factors were shown to be the level of experience of those involved and the number of days they had been working offshore.
- A high proportion of accidents occurred in the first hour following a shift change.
- The accident rate for individuals was highest among those who had been offshore for six or seven days or for thirteen or fourteen days.

- A significant proportion of accidents happened to those with less than one year's offshore experience.
- Those with between seven and ten year's experience appeared more likely to be involved in accidents than some of their less experienced colleagues.

Dobson has suggested the following series of remedies to reduce accident occurrence.

- rigorous safety training for all new starts and follow-on training when promoted to another position
- provision of full information on hazards and how to avoid and mitigate them
- development of a safety culture with regular tool-box talks where hazards and risks are discussed
- commitment to good housekeeping on the rig floor
- assessment of material handling risks
- design of rigs to reduce human factors problems

Dobson's work offered valuable input to the present research. Statistical information was provided regarding drilling rig occupational accidents and their breakdown by various categories. The subdivision of the data helped to indicate which factors are important in the occupational accident problem. The suggested list of remedies added support to the view that accident causation must be considered on a multi-level basis (i.e. design, equipment, human factors, safety culture, etc.).

2.2.7) Organizational factors, safety attitudes and workload among offshore oil personnel

Rundmo et al. (1998) have conducted a statistical study comparing attitudes and perceptions of Norwegian offshore workers in 1994 with a similar group surveyed in 1990. The work made use of the following statistical techniques.

- a "*t*" test to show whether respondents' evaluation of the 1994 work environment differed significantly from their view in 1990, and to test for differences by employment status
- "Pearson's *r*" to quantify the association between dimensions of the working environment and the respondents' satisfaction with management and manning

The data analysis confirmed significant differences in perception between the two groups, even within this relatively short time span. Some results of the work were as follows.

- Personnel reported greater influence over decisions regarding their own work in 1994 than in 1990.
- Personnel reported a reduction in "experiencing workload", i.e. feeling the adverse effects of draft, cold, noise and vibrations in 1994 compared to 1990. Said differently, working conditions were considered better in 1994.
- Personnel were generally more satisfied with safety and contingency measures (protective and safety equipment, instructions, training) in 1994 compared to 1990.
- A reasonable correlation was shown between dissatisfaction with management and manning and perceived accident risk.

Rundmo et al.'s work showed that improvements in safety perception are possible over time, and also that a relationship exists between corporate factors and the risks perceived by personnel. Both of these concepts are important to the present work, the first because it confirms the worth of taking steps to improve safety, and the second because it confirms the existence of a link between corporate and direct factors in the accident process.

2.2.8) International Association of Oil & Gas Producers (OGP) safety performance indicators data

Comprehensive offshore oil and gas occupational accident data are available from the International Association of Oil & Gas Producers' (OGP) annually released "Safety Performance Indicators" reports (OGP, 2002, 2004, 2005). The data are supplied to the OGP by a significant (~ 35-40) group of oil companies, including both large multinationals such as ExxonMobil, Shell, BP, ConocoPhillips, and ChevronTexaco, and growing operators such as Petro-Canada, OMV, Occidental, Marathon, and Premier Oil. In 2003, the information was based on more than two billion hours worked in seventy four countries. The primary indicators used to benchmark safety performance are number of fatalities, fatal accident and incident rates, lost time injuries, and total recordable incident rate. The present research has drawn heavily from the OGP reports, particularly because the data have been subdivided by both region and company. As an example of the information provided, total recordable incident rate versus time from 1995 – 2003, subdivided by companies and contractors, is shown in Figure 2.9.

Figure 2.9 – OGP Total recordable incident rate versus time

2.2.9) The International Labour Organisation (ILO), Safety in numbers, global safety culture at work (2003)

The ILO (2003) has presented global workplace accident statistics, subdivided according to world bank regions, which were primarily defined not geographically, but instead by their respective degrees of commercial development. For example, one group has been referred to as "established market economies", and included both the United States and Europe. India and China were individually considered as separate markets, and others included the Middle Eastern crescent and sub Saharan Africa. This data, although not specific to oil and gas, gave an indication of the potential of local wealth to effect safety results. The model proposed by this work recognises this concept by including financial elements within the group of external influencing factors.

Takala (1999) has studied the ILO data with a view to evaluating the willingness to report accidents in different cultures and regions. The results are described in Section 3.2.4, and it is clear that the percentage of accidents actually reported varies regionally.

2.2.10) The Norwegian Petroleum Directorate (NPD) website

The NPD (2004) internet based database offers a year-by-year presentation of accident statistics covering operations on the Norwegian continental shelf. Whilst the data lack a global view and are not company specific, they do provide a detailed account of the relative results when conducting different activities, for example drilling, production, maintenance, catering, and administration. Additionally, the data are split between mobile and fixed installations, and between operators and contractors, which provided opportunities for statistical analysis, the results of which are presented in Chapter 3.

2.2.11) The United Kingdom (UK) Health and Safety Executive (HSE) database

The UK HSE maintains an extensive database of accident statistics, and several authors and organisations (for example UK HSE, 2001b, HSE, 2002a) have produced reports analysing the data in different ways (for example by activity and over time).

2.2.12) Company annual reports

Annual reports, containing limited safety performance data, are publicly available from all major oil companies and contractors involved in the oil and gas industry (for example TotalElfFina, 2002, Halliburton, 2003, ExxonMobil, 2003, ConocoPhillips, 2002). A selection of the data has been included in Appendix 1.

These documents provided opportunities to compare one company with another, albeit generally between companies (major operators) which tend to have very similar attitudes toward safety issues. The reported data lack detail, often comprising one or only a few data points per year – for example company-wide injury and illness rates. Since the results are typically reported slightly differently from one company to the next, a perfect like for like comparison is not always possible. Nevertheless, with some manipulation, a reasonable comparison is achievable.

2.3) Factors affecting occupational accidents

A primary goal of this research has been the development of a quantitative predictive model to study offshore occupational accidents. An essential step in the model development was the identification of constituent factors and the formulation of realistic interrelationships between them. The literature related to occupational accidents offered a variety of suggestions for factors and their relationships and groupings, a cross section of which is described in this section. In some cases, the work reviewed has been discussed in detail elsewhere in this document, in which case the comments in this section are brief.

2.3.1) Organisational factors: the SAM approach

Pate Cornell and Murphy's (1996) SAM approach was described in Section 2.1.3.10. The authors' proposed factors and their grouping is shown in Table 2.6. There is some similarity between the authors' proposal and the present model's structure at the direct and organisational levels.

Table 2.6 – Pate Cornell and Murphy's proposed factors

Top Levels	Level 2	Level 3
Organisational Factors	Economic Pressures	Production vs. safety
		Definition of profit centres
	Personnel issues	Production culture
		Insufficient experience
		Learning mechanisms
	Flaws in design guidelines	Bad layout rules
		Poor safety system
		No structural resistance to large fires
	Inspection and maintenance practices	Permit to work system
		Inadequate regulatory oversight
Decisions and Actions	Personnel problems in crisis	
	Production decisions	
	Design and expansion problems	
	Inspection and Maintenance Errors	

2.3.2) BOMEL Ltd, Slips, trips and falls from height (STF) offshore

Following an analysis of UK occupational accident statistics, BOMEL (UK HSE, 2002a) concluded that factors contributing to STF's could be grouped into four main levels, as shown in Table 2.7.

Table 2.7 – BOMEL factors

Main level	Sub levels	
Environmental	Political influence	Market influence
	Regulatory influence	Societal influence
Corporate	Company profitability	Organisational structure
	Ownership and control	Safety management
	Company culture	Labour relations
Organisational	Work organisation	Safety culture
	Inspection & maintenance process	Supervision
	Terms & conditions	Procedures
	Accident/incident management loop	Management
	Training	Equipment purchasing
Direct	Housekeeping	Quality of PPE
	Fatigue	Inspection/maintenance
	Quality of hardware	Attentiveness
	Physical fitness	Experience
	Weather	Motivation
	Risk perception	Compliance
	Communication	Visual environment
	Availability of suitable human resources	

Following factor identification, a process of prioritisation and weighting was conducted to identify (i) critical factors, and (ii) paths of influence, for STF. Table 2.8 shows the critical paths for the six direct causes deemed most influential. This process and result proposed, in a qualitative manner, a causal chain extending from external market influence, through corporate elements such as profitability and corporate culture, to the direct causes of accidents, for example housekeeping and experience. Corporate culture's importance to the occupational accident process was reconfirmed by its inclusion as an influencing factor of five of the six direct causes. The extension of the causal link to external factors is fundamental to the present research, which goes further still by taking a quantitative approach to accident frequency prediction.

Table 2.8 – BOMEL critical paths

Six Most Influential Direct Causes	Organisational factor(s) affecting direct cause	Corporate factor(s) affecting organisational factor	Environmental factor(s) affecting corporate factor
Housekeeping	Accident/incident management loop		
	Supervision		
	Safety Culture	Company Culture	Market Influence
Inspection/ maintenance	Inspection & maintenance process		
	Safety Culture	Company Culture	Market Influence
Quality of hardware	Equipment purchasing		
	Insp./ maintenance process		
	Safety Culture	Company Culture	Market Influence
Experience	Management		
	Training		
Weather	Work organisation	Safety management	
	Safety Culture	Company Culture	Market Influence
Risk Perception	Accident/incident information loop	Company Profitability	
	Training		
	Safety Culture	Company Culture	Market Influence

BOMEL then formulated a series of actions and strategies in the hope of reducing STF's. Some of the proposed strategies were as follows:

- safety case regulation re-focus
- more detailed review of STF (for example to understand how corporate factors influence STF frequency)
- STF database to be developed
- HSE inspectors to be more completely educated on STF
- coefficients of friction (decking, grating, stairs, etc.) to be re-evaluated
- workforce survey to be conducted
- human factors to be studied

BOMEL's work identified and grouped a series of the factors considered to affect STF frequency. The result provided one possibility for the present model's structural arrangements. The present research builds on BOMEL's suggestions for future work, for example with the inclusion of more untraditional elements, a more detailed examination of the influence of corporate factors, and by taking a quantitative approach to accident frequency prediction.

2.3.3) Balkey and Phillips, Using OSHA process safety management standard to reduce human error

Balkey and Phillips (1993) have categorised the fourteen sections of the United States Occupational Safety and Health Administration's (OSHA) Process Safety Management Standard into five governing sections as shown in Table 2.9. The categorisation was based upon the overall issues considered to affect process safety. There is some consistency between the authors' elements and those suggested by the present research, but, unlike Balkey and Phillips' proposal, the present model includes factors external to the organisation.

Table 2.9 - Balkey and Phillips' levels

Top Levels	Lower Levels	
Global	Employee participation	Training
	Contractor	
Design / Change	Process safety information	Analysis teams
	Process hazard analysis	Analysis follow-up
	Analysis methods	Management of change
	Analysis content	Trade Secrets
Work Planning	Pre-startup safety review	Hot work permits
Operations	Operating procedures	Compliance safety audits
	Mechanical integrity	
Release / injury	Accident investigation	Emergency planning and response

2.3.4) McCauley-Bell and Badiru, Fuzzy modelling and analytical hierarchy processing – means to quantify risk levels associated with occupational injuries – part II: the development of a fuzzy rule – based model for the prediction of injury

McCauley-Bell and Badiru (1996b) have proposed and grouped a series of factors (Table 2.10) considered to affect the likelihood of occurrence of occupationally-induced cumulative trauma disorders. The work was discussed in more detail in Section 2.1.2.4. Whilst the application was different from that presently studied, the factors and their grouping were reasonably consistent with the direct and corporate levels proposed in this work (i.e. a series of direct (or task related) elements, elements associated with the characteristics of the person, and the effect of the employing organisation).

Table 2.10 – McCauley-Bell and Badiru's levels

Top Levels	Lower Levels	
Organisational	Equipment	Training
	Production rate / layout	Cumulative trauma disorder (CTD) level
	Ergonomics programme	Awareness
	Peer influence	
Personal	Previous CTD	Thyroid problems
	Hobbies and habits	Age
	Diabetes	Arthritis
Task-related	Awkward joint posture	Force
	Repetition	Task duration
	Hand tool use	Vibration

2.3.5) Embrey, Incorporating management and organisational factors into probabilistic safety assessment

Embrey (1992) has proposed a model, named Model of Accident Causation using Hierarchical Influence Network, or MACHINE, which considered accident causation to be a three-level process, as illustrated in Table 2.11. Embrey included direct and corporate elements (training, procedures), which were similar to the direct and corporate factors of the present model, which additionally includes an external layer. Further comments on Embrey's approach were made in Section 2.1.2.6.

Table 2.11 – Embrey's levels

Top Levels	Lower Levels	
Level Two	Design Errors	Poor Human Resource Management
	Risk management Errors	
Level One	Incomplete definition of responsibilities	Ineffective training
	Unclear Procedures	
Direct Causes	Failure to conduct equipment checks	Failure to follow maintenance procedures

2.3.6) Kjellen and Hovden, Reducing risks by deviation control – a retrospection into a research strategy

Kjellen and Hovden (1993) viewed the accident process as having two levels – the accident sequence, and the underlying determining factors. The proposed underlying factors were grouped as shown in Table 2.12. The groups were not unlike those proposed by the present research, although the authors did not include external elements to the same degree.

Table 2.12 Kjellen and Hovden's levels

Top Levels	Lower Levels	
Social/ individual	Work management, instructions	Individual norms and attitudes
	Informal information flow	Individual knowledge and experience
	Workplace norms	Special circumstances
Organisational/ economical	Routines of decisions, construction, or buying of equipment	
	Systems of remuneration, promotion, sanctioning	
	Controls of other type, e.g. economic, "third party"	
	Maintenance routines	Education, training
	Quality control	Organisation of work, manning
	Activity planning	Systems of shift, work-time
	Instructions, rules	Routines in safety work
	Organisation of first aid	
Physical/ technical	Workplace layout	Protective equipment
	Design of equipment	Intensity of work
	Physical hazard (energy)	Method of work
	Physical environment	Work material

2.3.7) International Labour Organisation, Safety in numbers, pointers for global safety culture at work

The International Labour Organisation (ILO) (2003) has investigated work related (all industries) deaths on a global basis. As part of the research, the ILO proposed a series of main contributing and preventable factors associated with occupational accidents, which can been grouped into those associated with the individual, the organisation, and originating outside the primary workplace environment, as illustrated in Table 2.13. As was the case with much of the literature discussed, these factors, though not chosen based on specific oil and gas experience, are similar to those proposed by the present work.

Table 2.13 ILO levels

Top Levels	Lower Levels
Organisational	[Lack of] Company safety and health policy
	[Lack of] Safety and health structure
	[Lack of] Worker/employer collaborative mechanism
	[Lack of] Occupational safety and health management system
	[Lack of] Available solutions
	[Lack of] Information centres
	[Lack of] Incentive based compensation system
	[Lack of] Training
	[Poor] Safety culture
Individual	[Lack of] Knowledge
	[Lack of] Awareness
External	[Lack of or poor] Government policies
	[Lack of or poor] Legal enforcement
	[Lack of or poor] Advisory system
	[Lack of or poor] Tripartite cooperation
	[Lack of or poor] Occupational health services
	[Lack of] Research and proper statistics for priority setting
	[Lack of] Training

2.3.8) BP – Getting HSE right – a guide for BP managers

As part of its primary safety programme, BP (2004) identified and utilised a series of key HSE processes, as shown in Table 2.14. There is some consistency between BP's collection of key processes and the factors proposed by the other literature and the present research, for example:

- external pressures (in the BP case, customers and community awareness)
- corporate factors (BP's training, documentation, and management)
- direct and individual elements (behaviours, people)

Table 2.14 – BP key processes

BP Key Processes	
Leadership and Accountability	Information and Documentation
Risk Assessment and Management	Customers and Products
People, Training and Behaviours	Community and Stakeholder Awareness
Working with Contractors and Others	Crisis and Emergency Management
Facilities Design and Construction	Incidents Analysis and Prevention
Operations and Maintenance	Assessment, Assurance and Improvement
Management of Change	

2.3.9) Hurst, Risk assessment – the human dimension

Hurst's (1998) analysis of the accident phenomena resulted in a model which had some philosophical similarities to the one proposed by the present research. Building on previous work by Reason (1990), Hurst concluded that accidents resulted from a breakdown in a three way (hardware-people-corporate) infrastructure described below and shown in Table 2.15.

Table 2.15 – Hurst's levels

Top Levels	Lower Levels	Lower Levels
Design	Reliability Engineering	Technical hardware failures
Ergonomics	Hierarchical task analysis	People failures
Human errors: Types: slips, lapses, mistakes, violations Causes: skill, rule, knowledge	Human reliability assessments	
Safety culture		Failure of safety management systems
Management control		
Socio-technical systems failures		
Assessment tools for safety management systems		

People failures are a constituent factor in Hurst's model, and their causes are subdivided according to the underlying nature of the errors, which are considered to fall into one of three categories (knowledge, rule, or skill). Knowledge based actions are based on knowledge worked out from first principles, rule based decisions or diagnoses are based on, as expected, rules, and skill based actions are simple, almost automatic behaviour patterns.

Supplementing the direct benefits of protective equipment such as boots and hard hats, Hurst suggested that the quality of design of technical hardware and equipment affected accident occurrence likelihood. He recognised that safe designs necessarily incorporated human factors and included such things as non-slip flooring and appropriately constructed handrails.

Corporate systems considered by Hurst to affect the accident process included both softer items such as safety culture, and more prescriptive items such as procedures, training, and management systems.

Hurst's philosophies were consistent with the multi-layer modelling approach adopted by this work, which takes a further step by including factors external to the organisation.

2.3.10) Thompson, Hilton, and Witt, Where the safety rubber meets the shop floor: a confirmatory model of management influence on workplace safety

Thompson et al.'s (1998) statistical study of the relationship between company culture and shop floor safety conditions is described in Section 2.1.3.5. For completeness, their proposed set of factors is shown in this section (Table 2.16). There is a degree of consistency between Thompson's philosophy and that proposed by this research, but the present work additionally includes an external view, a practical methodology for predicting accidents, and a cost element.

Table 2.16 – Thompson et al.'s levels

Top Levels	Lower Levels	Lower Levels
Organisational politics	Manager support for safety	Safety conditions
Goal congruence		
Supervisor fairness	Supervisor support for safety	Safety Compliance

2.3.11) Tomas, Melia, and Oliver, A cross-validation of a structural equation model of accidents: organisational and psychological variables as predictors of work safety

Tomas et al. (1999) have investigated a set of factors, shown in Table 2.17, believed to affect the accident process (also discussed in Section 2.1.3.6). Several of Tomas et al.'s elements have also been included in the present model, but the calculation methodology and industrial application are very different. Tomas et al.'s work provided further support to the concept that accidents are caused only partially by hazards, and that their occurrence is heavily influenced by individuals' behaviour and their work environment.

Table 2.17 – Tomas et al.'s levels

Top Levels		Lower Levels	Lower Levels
Climate	Co-workers response	Hazards	Accidents
Supervisors response	Worker attitude		
Safety behaviour	Actual risk		

2.3.12) Brown, Willis, and Prussia, Predicting safe employee behaviour in the steel industry: development and test of a sociotechnical model

Brown et al. (2000) have compared three different accident philosophies, one where system effects dominated, one where individual employee actions dominated, and the favoured choice, where corporate climate and hazards affected accident results through staff actions. Brown et al.'s work is described in more detail in Section 2.1.3.8, but for completeness, the proposed constituent factors, which have some consistency with the present model's direct and corporate factors, are shown in Table 2.18.

Table 2.18 – Brown et al.'s levels

Top Levels	Lower Levels		Lower Levels
Safety hazards	Cavalier attitude		Safe Behaviour
Safety climate	Pressure	Safety efficacy	

2.3.13) Cheyne, Tomas, Cox, and Oliver, Modelling employee attitudes to safety: a comparison across sectors

Cheyne et al.'s (1999) comparison of staff attitudes toward safety in three UK based industries is described in Section 2.1.3.9. For completeness, Cheyne's proposed factors are shown in Table 2.19. The approach had similarities with the present model's interaction between the corporate and direct levels, whereby management actions act through staff behaviours to affect safety results.

Table 2.19 – Cheyne et al.'s levels

Top Levels	Lower Levels	Lower Levels
Management actions and responsibility	Personal actions and responsibility	Appraisal of Commitment
Quality of safety training		

2.4) Other general literature on occupational accidents

This section offers a discussion of literature which, though relevant to model development, did not fit well in either of the three foregoing sections.

2.4.1) Safety culture

Safety culture, as defined by the Advisory Committee for Safety in Nuclear Installations (ACSNI, 2003) is "the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine commitment to, and the style and proficiency of, an organisation's health and safety management. Organisations with a positive safety culture are characterised by communications founded on mutual trust, by shared perceptions of the importance of safety and by the efficacy of preventive measures." Several papers related to corporate safety culture were reviewed. Some resulting comments are included below.

Fleming (UK HSE, 2001a) has evaluated corporate safety culture using a maturity model, which had been previously applied to software development, project management, human resources, and quality. The stages through which a competence was considered to mature are shown in Table 2.20. Fleming concluded that the model may be applicable to safety culture, but a practical demonstration was not offered.

Table 2.20 – Fleming's maturity stages

Maturity stage	Activity required to move to the next level
Emerging	Management commitment
Managing	Realisation of frontline staff importance; development of personal responsibility
Involving	Staff engaged to develop cooperation/commitment to improving safety
Cooperating	Develop consistency and fight complacency
Continually improving	Not applicable; maturity achieved

Both Olsen et al. (2004) and Tharaldsen et al. (2002) have conducted statistical evaluations of safety culture in the offshore industry. It was concluded that good safety culture could be defined by satisfactory performance in a series of key elements, examples of which are listed below. The present model includes variations of these elements.

- communication and awareness
- focus and involvement
- dangerous tendencies
- safety promoting behaviour
- information
- competence

Flin et al.'s (1996) work provided evidence of the level of safety culture achieved on some UK offshore platforms, as demonstrated by the results of a questionnaire-based survey of offshore workers. The results, discussed in more detail in Section 2.2.5, indicated that the maturity of the safety culture was more advanced than might have been expected.

2.4.2) Human factors

One challenge with the present research was to realistically include human factors in the analysis. This section discusses literature related to the influence of human factors on the accident process.

2.4.2.1) General comments

Wolfram (1993), in a paper describing the historical use of various types of models in the engineering profession, emphasised the importance of human factors as follows.

> "One area in particular has received scant attention from engineers given its importance: human behaviour. People are crucial components in most large engineering systems. They are also, historically, the most unreliable. People are the source of the vast majority of accidents that occur – not from malicious intent, but from ignorance, oversight, overstress, misinterpretation and fatigue, among other factors."

The importance of including human factors has also been recognised and reinforced by the UK HSE in their document "Good practice and pitfalls in risk assessment" (UK HSE, 2003b). It was suggested therein that 80% of accidents may be attributed, at least in part, to the actions or omissions of people.

2.4.2.2) The University of Aberdeen – Human factors study

The University of Aberdeen (UK HSE, 2003a) was contracted by the UK HSE to execute a human factors study, one goal of which was to better understand human and corporate factors in safety.

The work was comprised of the following three packages:

- a benchmarking study to identify, analyse, and share best practice on human factors safety-related issues
- a systematic analysis of trends in human factors causes of offshore accidents
- the development of a programme to train staff in human factors issues

The work concluded that several human factors significantly affect safety, including the following:

- propensity to report accidents and incidents
- communication about health and safety
- satisfaction with safety activities
- health and safety policy awareness

The authors' work confirmed the importance to the accident process of human factors, which are recognised by and included in the present model.

2.4.2.3) BAE Systems – Integration of human factors into offshore design

BAE Systems (UK HSE, 2002b) provided the UK HSE with guidance on the integration of human factors principles into the offshore design and development process. Some of the major conclusions of the study were as follows:

- Systems will operate safely only if they have been designed to support their operators.
- Human factors issues must be considered as a central part of design development.

- Guidance is needed on approaches that place human factors at the heart of system design and development.
- Good management is needed to address human factors comprehensively.
- The human factors discipline is considered to be comprised of the following domains.
    - staffing
    - personnel
    - training
    - human factors engineering
    - health hazards
    - system safety

The paper provided a comprehensive analysis of human factors and further confirmed the importance of their inclusion in predictive models such as the one proposed by this research.

2.4.2.4) Gordon et al.'s human factors investigation tool

Gordon et al. (2001) have proposed a model to describe how human factors affect the accident process. The model formed the basis of a tool used to systematically collect data on the subject. Illustrated in Figure 2.10, the Human Factors Investigation Tool (HFIT) was developed in consultation with the UK HSE and five participating oil companies.

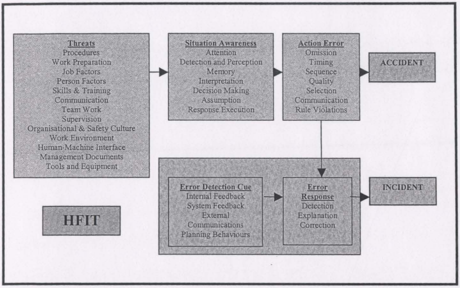


Figure 2.10 - Gordon et al.'s human factors integration tool

Human interaction within the accident process was considered to include four basic stages, or elements, as below.

- action errors, which occur immediately before an accident, and can be divided into the categories shown in Figure 2.10
- error recovery (referred to as error response in Figure 2.10), during which consequences of the accident can be prevented or at least mitigated
- situation awareness, which is a measure of the ability of individuals to accurately recognise and react to dangerous situations
- threats – factors (external or internal) which may initiate an accident or affect how serious it becomes

The HFIT structure provided the basis for the creation of a series of systematic questions posed to experts studying the human factors – accident interface. Gordon et al.'s methodology suggested a structured approach for the incorporation of a human factors capability in accident models, which was useful in the model development phase of the present work.

2.4.2.5) Strutt et al.'s quantification of human un-reliability

Strutt et al. (1998) have proposed a method for including human reliability in quantitative risk assessments. Probabilistic values were assigned to both task completion and resource consumption as execution was attempted. The likelihood of successful completion was then considered to be a matter of accomplishing a set of actions prior to exhausting the available resources. The overall probability of successful task completion was determined using joint probability distribution theory, i.e. the product of the probabilities of successfully completing the task and not consuming the resources.

The example chosen to illustrate the model was a diver attempting to salvage an asset from a submerged wreck before running out of air. As part of the presentation, the authors included a series of estimates of human unreliability while attempting to complete tasks, assuming different levels of experience, supervision, training, and time pressure. For illustration, the proposed values are shown in Table 2.21.

Table 2.21 – Quantification of human un-reliability

Task	Nominal Human Un-Reliability
Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55
Shift/restore system to new or original state on a single attempt without supervision or procedure	0.26
Complex task requiring high level of comprehension and skill	0.16
Fairly simple task performed rapidly or given scant attention	0.09
Routine highly practiced task involving relatively low level of skill	0.02
Restore or shift system to original or new state following procedures + checking	0.003
Completely familiar, well designed, highly practiced routine task occurring several times per hour, performed to the highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure with time to correct potential error but without the benefit of significant job aids.	0.0004
Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system state	0.000002
Miscellaneous task for which no description can be found	0.03

The authors considered the accident process to include four steps, as below.

- initiating event – most often human error or equipment failure - The authors supported the view that the underlying causes of accident–triggering events often include the interaction of human, corporate, and hardware factors.

- loss of safety barriers/defences – Triggering events need not necessarily lead to accidents, but the ability to control the situation depends on a robust and efficient control system.
- deterioration of conditions/escalation – usually the transformation point between minor and major accidents – This depends on such things as fuel inventory and over-design of structures.
- failure to escape or evacuate – usually the factor determining whether or not fatalities occur - This depends on the physical availability of escape possibilities combined with individuals' abilities to take advantage of them.

Strutt's et al.'s work illustrated one way of quantifying human reliability for inclusion in probabilistic analyses. The present model does include human reliability in the calculation methodology, although in a different way than proposed by Strutt et al.

2.4.2.6) Mosleh and Chang's comments on human reliability analysis

Mosleh and Chang (2004) have presented an ambitious approach to include the effects of human performance (human reliability analysis (HRA)) in probabilistic safety assessments, primarily as applied to nuclear power plant operators. They perceived the following limitations in current HRA models.

- failure to address the most common type of human error, errors of commission (as opposed to errors of omission)
- lack of confidence in the resulting numerical predictions, with respect to theoretical foundation and quality of existing data
- failure to cater for analyst-to-analyst variability

Moreover, the authors believed that the lack of a causal perspective on operator error was a fundamental flaw in existing models, and used this as the predominant element of their model, illustrated in Figure 2.11.

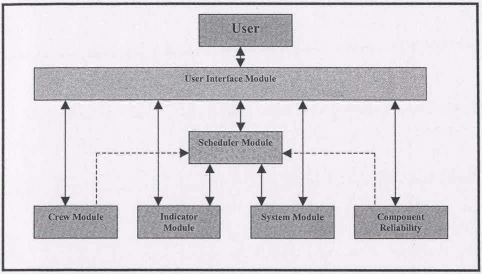


Figure 2.11 – Mosley and Chang's human reliability analysis

Mosleh and Chang believed that the future of human reliability modelling depended upon the capability of (i) understanding and (ii) properly modelling, the essential manner in which individuals receive information, and how and why they act upon it. While the approach seems reasonable, it may be slightly ambitious. For example, the authors themselves mentioned the following substantial list of limitations or needed enhancements.

- improvement or validation of essential assumptions inherent in the basic model
- the ability to inject a degree of memory or learning into the model
- the inclusion of crew interaction dynamics

- the need for an extensive knowledge base for the system under study, including
    - functional and physical characteristics
    - technological knowledge of associated scientific and engineering principles
    - database of past events
    - database of allowable rules of thumb or shortcuts
    - expected response of the system to perturbations
    - general guidance on knowledge of available options, preferences, and accepted practices
- the requirement for more quantitative and qualitative evidence and internal and external calibration of conditional probabilities
- the enhancement of overall model calibration
- calculation time may make the model impractical for many applications

This extensive list may lead to the conclusion that a practical application of this approach remains in the future. Nevertheless, it will be through ongoing efforts such as Mosleh and Chang's, that the accurate inclusion of human factors elements in probabilistic calculations will be realised.

2.4.2.7) Li et al.'s human factor event analysis

Li et al. (2003) have studied and reported on the use of a mathematical tool for incorporating human factors in system reliability analyses. The tool, called Human Factor Event Analysis (HFEA) relied on the following two analytical methods.

- Technique for Human Error Rate Prediction (THERP), which provided a human event tree model
- Human Cognitive Reliability (HCR), which determined human errors during the diagnosis stage of accidents

Although Li et al.'s research has been conducted within the nuclear industry, the concept of using a mathematical method to analyse human factors and behaviour has contributed to the present model development process.

2.4.3) Dealing with the cost and benefits of safety measures

Son et al. (2000) have proposed a method for optimising project safety spending. They suggested that the cost of project safety is composed of two elements, as below.

- the cost of accidents, in terms of lost time, reduction in productivity, payouts in compensation, etc.
- the cost of safety improvement measures, (or countermeasure costs) such as safety meetings, improved safety equipment, and additional safety personnel

For the former, the relationship between cost and degree of safety is inversely proportional; high accident costs are associated with a low degree of safety, and vice versa. For the latter, the relationship is proportional. High safety improvement costs are associated with a high degree of safety.

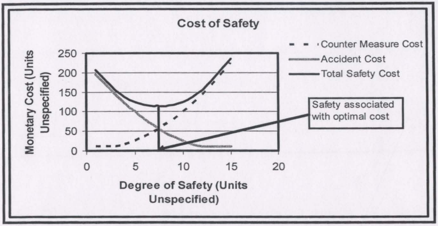


Figure 2.12 – The cost of safety

As illustrated in Figure 2.12, the summation of the two costs then produced a "u" shaped curve having a characteristic point of minimum cost. It was possible to determine parameters for the equations governing the two cost relationships and their sum, and thereby arrive at a value for the minimum cost and the associated degree of safety. The data used in Son et al.'s analysis were found in existing accident statistics, mainly in the onshore construction industry. For example, it was assumed that:

- The countermeasure cost is a direct function of contract value.
- The accident costs are determined by reviewing accident rates in the industry and combining with the costs (both direct and indirect) of typical accidents.

A theoretical example was presented, using a hypothetical construction company. It was concluded that the optimal overall safety investment is 1.2 – 1.3 % of total project cost.

The paper suggested a procedure for optimising safety expenditure from an economic perspective, albeit as applied to the onshore construction industry. One of the intentions of the work proposed here is to offer a similar analysis for the offshore occupational accident problem, and Son's concepts offered guidance. However, attention should be (and has been) paid to regulatory requirements and corporate culture when applying models such as this. Cost minimisation may suggest a level of safety that is unacceptable from other perspectives.

2.4.4 The effect of government policy on industry safety

The primary instrument through which public expectations are transferred to workplace safety results is government legislation. Brotherton (2003) has described some relationships, both current and historical, between regional societal cultures and workplace health and safety legislation. Some examples are described below.

- In the United Kingdom, a redirection in approach was described upon the 1979 election of a conservative government whose agenda included a rejection of welfare state attitudes and a commitment to privatisation. Under the newly installed government, new and more stringent safety related legislation was introduced which placed increased responsibilities on organisations for many workplace health and safety issues.
- Brotherton suggested that the central/national level of industrial regulation in the Nordic countries may be rooted in their geopolitical history. For many years these countries felt vulnerable to invasion, which produced a strong desire to avoid internal conflict, leading in turn to a philosophy of centralised control. Safety regulation received a significant injection of intensity in the region following a period of worker discontent in the 1970's. Wildcat strikes and survey results

indicating unhealthy working conditions characterised workplace relationships. Eventually, dissatisfied workers successfully demanded government legislation and programmes that transformed working conditions. Norway's safety reputation in the offshore oil and gas industry is today the envy of many other regimes, and societal pressures and history have played significant parts in this result.

- Brotherton discussed the United States' well-earned reputation as the global centre of capitalism. Competition has formed the cornerstone of the economic model at all levels of society. In this environment, efforts to encourage companies to voluntarily improve safety results have not proved completely successful. Consistent with the theme of competition as the driver of all improvements, the development and enforcement of national safety standards resulted from friction between company stakeholders and the workforce, groups with conflicting motivations. Eventually, the perception by workers of excessive company interest in profit at the expense of safety produced successful demands from workers for government intervention.

The present model accounts for societal expectations such as those described above. The model includes three layers (direct, corporate, external), and the external layer includes an element to handle regional value placed on life. In much the same philosophical manner as public expectations are directed to companies through government legislation, the overall model philosophy has the expectations of society directed through the companies to the workplace environment.

3

Data analysis

3) Data analysis

This chapter describes a review and analysis of offshore occupational accident data, including a discussion of both existing statistical information available in the literature and on databases, and results gathered specifically for this work.

The primary goal of the review of existing data was to confirm that significant differences exist between results achieved in different (i) regions and (ii) organisations. If, despite many years of effort, no real inter-regional or inter-company differences exist, then one might legitimately question the validity of the accident-reduction efforts expended by companies and regulators. If instead, a broad range of results is observable, it could be concluded that corporate and regulatory initiatives have produced real effects.

The results presented do confirm real corporate and regional differences in safety performance. A series of statistical tests supplementing and supporting graphical representations of the existing information has been presented, which shows that significant differences have already been achieved.

Extensive use has been made of the statistical method known as the "*t*" test to compare datasets representing different regions and companies. This test essentially compares the means of two datasets within the contexts of each sets' variance. Strict validity of "*t*" test results requires the data to have been distributed normally. However, in practice, an evaluation of normalcy requires more than fifteen or twenty observations (Johnson, 2005), and the data available for inter-company and inter-regional comparisons were typically in groups of between five and fifteen. In order to confirm the conclusions implied by the "*t*" tests, an alternative method, the Mann-Whitney test, which did not require normally distributed input data, was used to evaluate several of the data sets. In each case, the conclusions implied by the "*t*" tests were confirmed by the Mann-Whitney tests.

Other tests have been utilised in the analyses in addition to the "t" and Mann-Whitney tests, for example Tukey's honestly significantly different test and an analysis of variance (ANOVA) approach. The use of multiple tests provided two valuable benefits. First, the final conclusions could be proved despite any inherent weaknesses in individual methods, and second, educational benefit was gained by investigating the different methods and their respective strengths and weaknesses.

This section also describes the process and results associated with a survey questionnaire developed specifically for this work. The goal of the questionnaire was to obtain information required for the predictive model developed and described in Chapter 4. Expert opinion was needed on two topics: (i) the relative importance of factors influencing the accident process, and (ii) the degrees to which external factors affect corporate decisions, and to which the corporate decisions in turn affect the direct accident process. Every safety professional has a view of which elements are most important in the accident process, and also how the various layers (external, corporate, and direct) interact. The process undertaken here combined the opinions of more than forty safety professionals in a quantitative manner, thereby facilitating the direct injection of expert opinion to the model.

It is worth presenting here a series of definitions, as used by the International Association of Oil & Gas Producers, applicable to the analyses which follow.

Occupational injury – Any injury such as a cut, fracture, sprain, amputation, etc., which results from a work accident or from a single instantaneous exposure in the work environment. Conditions resulting from animal bites, such as insect or snake bites, and from one-time exposure to chemicals are considered to be injuries.

Fatal accident Rate (FAR) – The number of company/contractor fatalities per 100,000,000 hours worked.

Fatal incident rate (FIR) – The number of fatal incidents per 100,000,000 hours. Incidents involving a third party fatality are included (since 1998) provided they directly result from company or contractor operations.

Total recordable incident rate (TRIR) - The number of recordable incidents (fatalities + lost workday cases + restricted workday cases + medical treatment cases) per 1,000,000 hours worked

Lost time injury (LTI) – A fatality or lost workday case. The number of LTI's is the sum of fatalities and lost workday cases.

Lost time injury frequency (LTIF) – The number of lost time injuries (fatalities + lost workday cases) incidents per 1,000,000 hours worked.

The following sections discuss trends in occupational accidents from time, regional, and company perspectives. Before addressing these issues, however, it is worth reiterating the relative occupational accident risk faced by oil and gas workers compared to risks from other dangers, such as air transportation, drowning, and explosions. Figure 1.1 showed the subdivision by cause of significant injuries, and Figure 3.1 shows a similar breakdown for fatalities in the industry over the period 1998 - 2002.

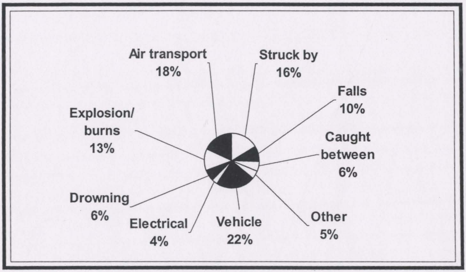


Figure 3.1 – Causes of oil and gas fatalities 1998 - 2002
(International Association of Oil & Gas Producers, 2004)

It is noteworthy that the sum of falls, struck by, and caught between (32%), is far greater than either of the more widely discussed dangers of explosions, drowning, and air transport.

3.1) Overall trends

3.1.1) Historical offshore accident performance

The trend in offshore occupational accident statistics over the past fifteen years has been generally downward, which is a testament to the efforts expended by offshore safety professionals. See for example Figures 3.2 - 3.4, generated from data presented in the International Association of Oil & Gas Producers (OGP) 2003 database (OGP, 2004). The curves show fatal accident rate (FAR), lost time injury frequency (LTIF), and total recordable incident rate (TRIR) as a function of time. Over the past four years there has been a levelling off trend in the FAR numbers. A similar effect is observable in the LTIF and TRIR numbers, though not to the same extent.

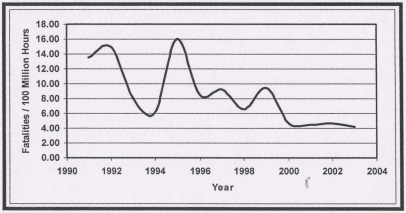


Figure 3.2 – Offshore oil and gas fatal accident rate versus time

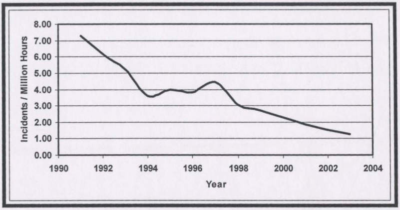


Figure 3.3 – Offshore oil and gas lost time injury frequency versus time

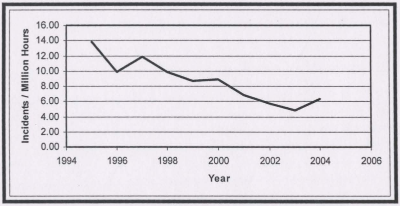


Figure 3.4 Offshore oil and gas total recordable incident rate versus time

3.1.2) Relationship between TRIR and price of oil

It is interesting to consider fluctuations in the price of oil over a similar period (1995 – 2003), shown in Figure 3.5. Had the price of oil showed a steady increase over the period one might be tempted to infer a relationship between increased available capital and safety improvements. On the other hand, lack of a significant relationship between the two parameters would lead to the conclusion that safety improvements have resulted from other factors such as improved safety culture, equipment, and/or motivation. The safety result/price of oil relationship has been evaluated by considering the correlation between the respective values, as described below.

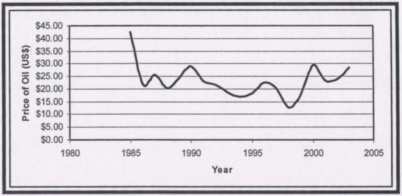


Figure 3.5 – Inflation adjusted price of oil versus time

A scatter plot of total recordable incident rate against price of oil is shown in Figure 3.6. Observation indicates a moderate negative correlation, which is investigated below.

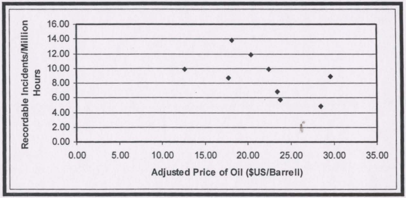


Figure 3.6 – Total recordable incident rate versus price of oil

The correlation coefficient (*"r"*), defined overleaf, has been calculated as -0.54 for the two variables between 1995 and 2003 (see Table 3.1). This result indicates a modest negative correlation, as we might expect.

$$CorrelationCoefficient(r) = \frac{N\sum XY - \sum X \sum Y}{\sqrt{\left[N\sum X^2 - \left(\sum X\right)^2\right] \times \left[N\sum Y^2 - \left(\sum Y\right)^2\right]}} \qquad (3.1)$$

Table 3.1 – Correlation coefficient between price of oil and offshore TRIR

Year	Price of Oil(X)	TRIR(Y)	X^2	Y^2	XY
1995	18.17	13.80	330.15	190.44	250.75
1996	22.40	9.90	501.76	98.01	221.76
1997	20.39	11.86	415.75	140.66	241.83
1998	12.66	9.83	160.28	96.63	124.45
1999	17.78	8.66	316.13	75.00	153.97
2000	29.54	8.84	872.61	78.15	261.13
2001	23.39	6.85	547.09	46.92	160.22
2002	23.78	5.77	565.49	33.29	137.21
2003	28.42	4.87	807.70	23.72	138.41
Sums >	196.53	80.38	4,516.95	782.81	1,689.73
	Correlation Coefficient	-0.54			

A test of significance can be conducted on this result, using the Fisher *Z* Transformation (Johnson, 2005) as shown below.

$$Fisher"Z"Transformation(Z) = \frac{1}{2} \times \ln\frac{1+r}{1-r} \qquad (3.2)$$

The statistic "z", defined below and derived from the Fisher "*Z*" value, can be shown to be distributed according to the standard normal distribution, and can therefore be used to test the null hypothesis that the two sets of data are not correlated.

$$z = \sqrt{n-3} \times Z \qquad (3.3)$$

where n = number of observations

The results are as follows:

$$Z(-0.54) = -0.6042$$

$$z = -1.48$$

Since the distribution of this statistic is normal, the null hypothesis can be rejected at the 0.15 level of significance. There is a reasonable basis to say that price of oil and TRIR are negatively correlated.

To investigate further, a Spearman rank order correlation coefficient analysis has been conducted. The Spearman coefficient is defined as follows:

$$r_s = 1 - \frac{6\sum_{i-1}^{N} d_i^2}{N^3 - N} \qquad (3.4)$$

where

d_i = the difference between ranks of the paired variables

N = number of observation pairs

In this case, we are investigating the hypothesis that a high price of oil will produce improved accident results, so a ranking of "1" is assigned to years when price of oil is highest and TRIR is lowest. The results are shown in Table 3.2.

Table 3.2 – Spearman rank-order correlation coefficient between price of oil and TRIR

Year	Price of Oil	TRIR(Y)	d_i	d_i^2
1995	7	9	2	4
1996	5	7	2	4
1997	6	8	2	4
1998	9	6	-3	9
1999	8	4	-4	16
2000	1	5	4	16
2001	4	3	-1	1
2002	3	2	-1	1
2003	2	1	-1	1
	r_s		Sum d_i^2	56
	0.53			

Tables are available (McCall, 1970) to evaluate the significance of the calculated Spearman rank-order coefficient. At the 0.10 level of significance, the acceptance value for $N = 9$ is 0.60, meaning the null hypothesis (no correlation) cannot be rejected with that level of certainty. Most tables do not offer a result for levels of significance greater than 0.10, but with a degree of extrapolation, we can conclude that the result suggests a level of confidence similar to that obtained for the "*z*" test discussed previously (0.15). Other sources (revision-notes.co.uk, 2005) would categorise this correlation (0.53) as "strong negative". The results imply a reasonable, but not definite, conclusion that price of oil and safety results are negatively correlated. This indicates that factors other than price of oil also play a significant role in the process. The result is entirely consistent with this work, which adopts a holistic view of occupational accident causation including direct, corporate, and external elements.

3.1.3) Conclusions

The efforts of offshore oil and gas safety professionals and workers have not been in vain. By almost any measure, when considered globally, offshore workers face less risk from occupational injuries today than they did fifteen years ago. Nevertheless, the danger from these accidents is greater than that associated with explosions and helicopter crashes and, in the general view of the industry, unacceptable.

The reasonably strong negative relationship between price of oil and TRIR demonstrated above may indicate that availability of capital combined with a willingness to spend it on safety measures can lead to improved safety results. An observation of superior safety results in prosperous regions would be consistent with this result, which will be explored in the next section.

3.2) Regional analysis

3.2.1) Graphical presentation of historical performance by region

The OGP 2003 (OGP, 2004) database offered regional breakdowns and analyses of occupational accident statistics. Figures 3.7 and 3.8 are based on data from this source. The FAR results were as generally expected by industry safety professionals, with Africa and South America having the largest FAR values, and Europe and North America the lowest. The LTI data provide an interesting surprise, however, in that Europe's performance was bettered by Africa, a region with a less attractive safety reputation. This effect may have something to do with the relative propensities to report accidents in the two regions. More will be said about this in Section 3.2.4.

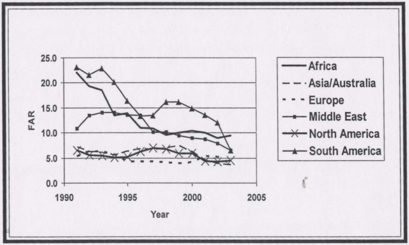


Figure 3.7 - Fatal accident rate versus time by region

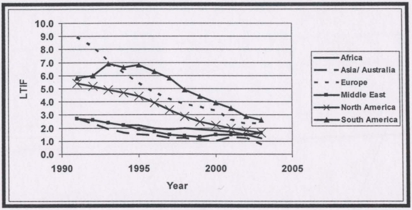


Figure 3.8 – Lost time injury frequency versus time by region

3.2.2) Statistical analysis of differences between regions

Observation of the above results indicates significant differences between regions. To evaluate this statistically, a "*t*" level of significance test (Smith, 1970) was conducted using the LTIF results for Africa and Asia/Australia. As can be seen from the analysis shown in Table 3.3, there is a statistically significant difference between the two datasets, with a probability less than 0.02 that the differences can be attributed to chance alone.

Table 3.3 – *"t"* significance test for differences in safety results in Africa and Australia

Africa	x^2	Asia-Australia	x^2
4.09	7.04	1.64	1.31
3.17	3.00	0.94	0.20
1.70	0.07	0.62	0.02
1.26	0.03	0.57	0.01
1.05	0.15	0.57	0.01
0.98	0.21	0.52	0.00
0.65	0.62	0.43	0.00
0.55	0.79	0.40	0.01
0.47	0.94	0.26	0.06
0.45	0.97	0.25	0.06
		0.24	0.07
		0.00	0.25
		0.00	0.25
n:	Sum x^2	n:	Sum x^2
10	13.82	13	2.22
Mean:		Mean:	
1.44		0.50	
s_{Diff}	t	Result (df = 21)	0.02
0.37	2.56		

In Table 3.3 the following definitions of "s_{diff}" and "t" apply.

$$s_{diff} = \sqrt{\left(\frac{\sum x_1^2 + \sum x_2^2}{n_1 + n_2 - 2}\right) \times \left(\frac{n_1 + n_2}{n_1 \times n_2}\right)} \tag{3.5}$$

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_{diff}} \tag{3.6}$$

where

n_1, n_2 = sample sizes of the two datasets

x_1, x_2 = difference between individual values and the dataset means

$\overline{X_1}, \overline{X_2}$ = dataset means

A rigorous definition of these statistical indicators is available in textbooks of basic statistics (e.g. Smith, 1970), but essentially the analysis involves an evaluation of the difference between the means of two datasets relative to the difference in their standard deviations. The larger the value of "t", the less likely it is that the two datasets originated from the same population. In this application, the large observed "t" means that it is extremely unlikely that the difference occurred due to chance alone and that both groups were working under equally efficient safety systems. Rather, it is extremely likely that there were real differences in the two safety regimes.

The "t" test has been applied in this instance without proving the required condition that the data were distributed normally (Refer to the comments made in the introduction to Chapter 3.). In order to confirm the conclusion above, a Mann-Whitney test has been conducted on the data, producing the result shown in Table 3.4 and below.

Table 3.4 – Mann - Whitney test on Australia – Africa data

Data point	Rank	Originating from	Data point	Rank	Originating from
0.00	1.5	Australia	0.57	13	Australia
0.00	1.5	Australia	0.62	14	Australia
0.24	3	Australia	0.65	15	Africa
0.25	4	Australia	0.94	16	Australia
0.26	5	Australia	0.98	17	Africa
0.40	6	Australia	1.05	18	Africa
0.43	7	Australia	1.26	19	Africa
0.45	8	Africa	1.64	20	Australia
0.47	9	Africa	1.70	21	Africa
0.52	10	Australia	3.17	22	Africa
0.55	11	Africa	4.09	23	Africa
0.57	12	Australia			

$$W_{Aus} = 1.5 + 1.5 + 3 + 4 + 5 + 6 + 7 + 10 + 12 + 13 + 14 + 16 + 20 = 113$$

$$W_{Af} = 8 + 9 + 11 + 15 + 17 + 18 + 19 + 21 + 22 + 23 = 163$$

$$U_{Aus} = 113 - (13 \times 14)/2 = 22$$

$$U_{Af} = 163 - (10 \times 11)/2 = 108$$

$$\mu_{U1} = (n_1 \times n_2)/2 = 65$$

$$\sigma^2_{U1} = (n_1 \times n_2 \times (n_1 + n_2 + 1))/12 = (10 \times 13 \times 24)/12 = 260$$

$$Z = (U_1 - \mu_{U1})/\sigma_{U1} = (22-65)/\text{sqrt}(260) = -2.67$$

where W, U, μ, σ^2, and Z are as defined in Johnson (2005)

Since the resulting value of Z is less than -2.57, the null hypothesis can be rejected at the 0.01 level of significance. This test confirmed the conclusion drawn using the "*t*" test, i.e. that the samples are significantly different. The similar conclusions support the validity of using the "*t*" test for other comparisons conducted in this chapter.

As a further demonstration of the significance of the differences between regions, an analysis of variance (ANOVA) has been conducted. The datasets are shown in Table 3.5. The null hypothesis in this instance is that the samples all came from populations with identical means, and that differences between the sample results are due to chance alone.

Table 3.5 – Safety results in different regions

Africa	x^2	Asia-Australia	x^2	Europe	x^2
4.09	7.04	1.64	1.31	6.01	9.87
3.17	3.00	0.94	0.20	4.75	3.54
1.70	0.07	0.62	0.02	2.88	0.00
1.26	0.03	0.57	0.01	2.70	0.03
1.05	0.15	0.57	0.01	2.49	0.14
0.98	0.21	0.52	0.00	2.45	0.18
0.65	0.62	0.43	0.00	2.25	0.38
0.55	0.79	0.40	0.01	1.41	2.13
0.47	0.94	0.26	0.06	0.88	3.96
0.45	0.97	0.25	0.06		
		0.24	0.07		
		0.00	0.25		
		0.00	0.25		
Mean:	Sum x^2	Mean:	Sum x^2	Mean:	Sum x^2
1.44	13.82	0.50	2.22	2.87	20.22
n:		n:		n:	
10		13		9	

FSU	x^2	Middle East	x^2	North America	x^2
1.21	0.25	5.26	13.19	0.80	0.00
0.6	0.01	2.86	1.52	0.79	0.00
0.33	0.15	1.22	0.17		
		1.01	0.38		
		0.87	0.58		
		0.71	0.84		
		0.68	0.90		
		0.42	1.46		
Mean:	Sum x^2	Mean:	Sum x^2	Mean:	Sum x^2
0.71	0.41	1.63	19.03	0.80	0.00
n:		n:		n:	
3		8		2	

South America	x^2
2.82	2.53
2.64	1.99
2.52	1.66
0.67	0.31
0.53	0.49
0.35	0.77
0.31	0.85
0.00	1.51
Mean:	Sum x^2
1.23	10.12
n:	
8	

An ANOVA table has been constructed, shown in Table 3.6, where the following definitions are applicable.

$$T_{ss} = \sum_{i-1}^{k} n_i (\bar{y}_i - \bar{y})^2 \tag{3.7}$$

$$E_{ss} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (y_{ij} - \bar{y}_i)^2 \tag{3.8}$$

where

T_{ss} = treatment sum of the squares

E_{ss} = error sum of the squares

n_i = number of values in each sample

$\bar{y}$ = grand mean (overall mean of all values)

$\bar{y}_i$ = mean of each sample

y_{ij} = individual values

k = number of datasets

Mean squares = sum of squares / degrees of freedom

F = Mean treatment sum of squares/Mean error sum of squares

Table 3.6 – ANOVA table for safety results in different regions

Grand Mean	Treatment Sum of Squares	Error Sum of Squares	
1.38	32.85	65.81	"F"
Degree of Freedom>	6	46	3.83
Mean Squares >	5.47	1.43	

At the 0.01 level of probability, the "*F*" value for 6 and 46 degrees of freedom is 3.24, so the above result means that the null hypothesis (i.e. that the samples all came from the same population) can be rejected. There are significant differences in these safety results. Finally, Tukey "*t*", or "Honestly significantly different" (HSD) tests have been conducted to further evaluate the difference between means of selected regions. The definitions associated with the statistic are as follows:

Tukey "t_{hsd}" statistic is defined as follows

$$t_{hsd} = \frac{M_i - M_j}{\sqrt{\frac{MSE}{n_h}}} \tag{3.9}$$

where

M_i, M_j = means of the samples under consideration

MSE = mean error sum of the squares, as defined above for the ANOVA discussion

$$n_h\text{, or harmonic mean, } = n_h = \frac{k}{\frac{1}{n_1}+\frac{1}{n_2}+\frac{1}{n_3}+\ldots\ldots\frac{1}{n_k}} \tag{3.10}$$

The results, comparing several pairs of countries, are shown in Table 3.7.

Table 3.7 – Tukey test for safety results in different regions

Africa - Australia
Harmonic Mean
11.30
MSE
0.76
t_{hsd}
3.62

Australia - Europe
Harmonic Mean
10.64
MSE
1.12
t_{hsd}
7.31

Africa - South America
Harmonic Mean
8.89
MSE
1.50
t_{hsd}
0.50

Europe - Middle East
Harmonic Mean
8.47
MSE
2.62
t_{hsd}
2.23

The relative significance of the results is shown in Table 3.8, which again confirms significant differences between many regions (Africa – South America is an exception).

Table 3.8 – Significance of Tukey results

Regions compared	Degrees of Freedom	P = 0.05 level of significance for "t" statistic	Result	Significant?
Africa - Australia	21	2.08	3.62	Yes
Australia - Europe	20	2.09	7.31	Yes
Africa – South America	16	2.12	0.50	No
Europe – Middle East	15	2.13	2.23	Yes

3.2.3) Company protection across regions

In order to evaluate the degree to which corporate culture and processes provide a degree of protection for their employees, a brief analysis of safety results within a single (unnamed major operator) company in several different regions has been conducted. The results of this are presented in Tables 3.9 and 3.10.

Table 3.9 – Injury frequency in different regions within a single company

Region	Mean recordable injury frequency	Sample size	Sum of squares of difference from mean
North America	0.99	16	4.0
Europe	0.81	29	13.3
Latin America	0.61	4	0.13
Australasia	0.54	5	0.85

Table 3.10 – Significance of "*t*" result comparing safety results in different regions within a single company

Comparison of North America with…	Degrees of Freedom	"t" statistic	Significant at the 0.1 level?
Europe	43	0.91	No
Latin America	18	1.41	No
Australasia	19	1.71	No

The conclusion might be drawn that regional deviations, when viewed under the umbrella of a large company with a substantial corporate safety programme, are not as significant as the general industry deviations. This is as might be expected, and reflects the philosophy of a chain of influence that includes both regional *and* corporate factors.

The above analysis compared the result from the region with the largest mean recordable injury frequency (North America) with those from the other three. To provide consistency with analyses done previously in this chapter, results from Europe and Australia were also compared. The resulting "*t*" value for this comparison, 0.82, was also not significant, which again contrasts with the general industry result obtained in Tables 3.7 and 3.8.

3.2.4) Likelihood of reporting accidents

Takala (1999) has conducted an investigation into the likelihood of individuals to report occupational accidents in different regions. The reported country-specific accident rate was multiplied by the number of workers comprising the country's workforce to give an expected number of accidents. This was compared to the number of accidents actually reported to the International Labour Organisation, thereby giving a potential indicator of propensity to report accidents. The results are shown in Figure 3.9 for a cross section of countries involved in the oil and gas industry. The results are approximately aligned with both the safety results and general safety reputations of the countries. It is noted that the calculation was unavailable for China, due to lack of data.

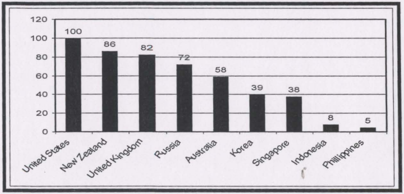


Figure 3.9 – Percentage of accidents reported versus country

3.2.5) Conclusions

As expected and commonly believed, there are significant regional differences in safety performance. This has been shown in five distinct ways:

- by observation of graphically presented results
- by "*t*" level of significance tests
- by Mann-Whitney evaluations
- by an analysis of variance
- by a Tukey HSD test

Company processes and procedures provide a degree of consistency in safety approach across regions, and thereby attenuate the effect of regional variations.

The likelihood of workers to report accidents differs on a regional basis, which may itself affect the resulting safety statistics.

In general, safety results were approximately aligned with regional prosperity, which is consistent with the relationship between price of oil and safety results discussed in Section 3.1.3. The fact that this result was not so in every case supports the holistic philosophy of the model developed in this research, which includes financial issues as just one of a number of elements.

3.3) Organisational analysis

3.3.1) Variability in data sources

Data are available from many sources to compare safety performance between companies. For various reasons, companies often report different statistics in their publications, in some cases reporting lost time injury frequency, and in others total recordable injury frequency or days away from work. The situation is further complicated by the inclusion of illnesses in some company statistics. Data which include illness will not be considered in the present analyses, since they are outside the scope.

Company comparisons are therefore more conveniently made using data compiled by and available from government agencies and industry organisations such as the UK Health and Safety Executive (HSE), the Norwegian Petroleum Directorate (NPD), and the International Association of Oil & Gas Producers (OGP). A difficulty with such data, however, is its associated condition of anonymity. The anonymity does not prevent the evaluation of statistical differences between companies, but it does present difficulties when attempting to match company specific safety initiatives, spending, and culture, to results.

Some of the differences in statistical presentation are easily accounted for, for example data reported in occurrences per 200,000 hours are easily translated to occurrences per 1,000,000 hours. As a general rule, it has been chosen to use, where available, the measure of total recordable incidents per 1,000,000 hours worked, both because it is the measure most often reported, and because it is most appropriate to this research.

3.3.2) Organisational variability in OGP data

The OGP 2001 (OGP, 2002) database included lost time injury frequency for the thirty-nine organisations which participated in the study, albeit on an anonymous basis. "*t*" test comparisons of data from two pairs of companies are shown in Table 3.11. The analysis shows that the difference in safety performance between the companies is statistically significant. Note that for Table 3.11, the definitions of "s_{diff}" and "*t*" are identical to those presented in Section 3.2.2.

Table 3.11 – Comparison of company specific safety results (LTIF)

Compare "C" with "JJ"			
C	x^2	JJ	x^2
13.06	28.84	0.63	0.01
9.13	2.07	0.67	0.02
6.89	0.64	0.43	0.01
4.69	9.00	0.55	0.00
4.68	9.06	0.38	0.02
Mean	Sum x^2	Mean	Sum x^2
7.69	49.61	0.53	0.06
s_{Diff}	t		
1.58	4.54		
Result (d.f. = 8)		0.002	
< 1 chance in 500 these came from the same distribution.			

Compare "G" with "CC"			
G	x^2	CC	x^2
4.27	0.27	1.09	0.04
3.08	0.45	0.98	0.01
4.94	1.42	0.76	0.02
2.97	0.61	0.83	0.00
3.48	0.07	0.79	0.01
Mean	Sum x^2	Mean	Sum x^2
3.75	2.82	0.89	0.08
s_{Diff}	t		
0.38	7.51		
Result (d.f. = 8)		0.002	
< 1 chance in 500 these came from the same distribution.			

A Mann-Whitney test has also been conducted on the data from companies C and JJ. The result, shown in Table 3.12 and described below, confirms the conclusion resulting from the "*t*" test.

Table 3.12 – Mann - Whitney test on company JJ versus company C data

Data point	Rank	Originated from	Data point	Rank	Originated from
0.38	1	JJ	4.68	6	C
0.43	2	JJ	4.69	7	C
0.55	3	JJ	6.89	8	C
0.63	4	JJ	9.13	9	C
0.67	5	JJ	13.06	10	C

$W_{JJ} = 1 + 2 + 3 + 4 + 5 = 15$

$W_C = 6 + 7 + 8 + 9 + 10 = 40$

$U_1 = W_1 - (n_1 \times (n_{1+}1))/2$

$U_{JJ} = 15 - (5 \times 6)/2 = 0$

$U_C = 40 - (5 \times 6)/2 = 25$

$\mu_{U1} = (n_1 \times n_2)/2 = 12.5$

$\sigma^2_{U1} = (n_1 \times n_2 \times (n_1+n_2+1))/12 = (5 \times 5 \times 11)/12 = 22.9$

$Z = (U_1-\mu_{U1})/\sigma_{U1} = (0\text{-}12.5)/\text{sqrt}(22.9) = -2.61$

where W, U, μ, σ^2, Z have the standard definitions as defined in Johnson (2005).

Since the value of Z is less than -2.57, the null hypothesis can be rejected at the 0.01 level of significance. This test further confirms that the samples are significantly different.

3.3.3) Graphical and statistical comparison of results presented in company annual reports

A second useful group of sources is oil and gas companies' annual reports, which generally include safety statistics as part of their public information. A graphical demonstration of organisational differences in safety results is shown in Figure 3.10, where total recordable incident rates for Shell, ConocoPhillips, Halliburton, and ChevronTexaco are plotted against time over the past several years.

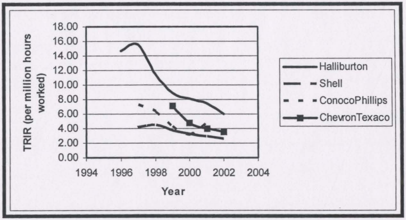


Figure 3.10 – Total recordable incident rate versus time by company

Observation of the results indicated, for example, that Shell and ConocoPhillips were outperforming Halliburton where occupational accidents were concerned.

Some would suggest that workers employed by operator companies (Shell, ConocoPhillips, ChevronTexaco) would, by the nature of their relatively more office based activities on an offshore platform, face a lower likelihood of accident than those employed by contractor companies such as Halliburton, since they are more likely to be engaged in deck operations. This line of thinking suggests that the differences in performance between Halliburton and the operators had more to do with accident likelihood than an inferior safety programme. There may be some validity to this suggestion, but the level of effort expended by oil and gas companies performing a variety of roles indicates a strong preference for the view that accident likelihood can be controlled with similar efficiency whether in an office or heavy equipment environment. It is noted that there were apparently significant differences between the performances of the individual operator companies as well. For example, in 1999 ChevronTexaco's TRIR was approximately 75% greater than Shell's or ConocoPhillips'.

To confirm that the differences in the results did not occur by chance alone, the statistical analysis shown in Table 3.13 has been conducted. The analysis confirms a significant difference between the Shell and Halliburton results. The hypothesis that the two sets of results came from the same population, i.e. from companies operating equally effective safety systems, is rejectable with a probability of 0.998.

Table 3.13 – "*t*" test for comparison of Shell and Halliburton safety results

Halliburton	x^2	Shell	x^2
14.65	13.26	4.10	0.38
15.60	21.08	4.40	0.84
11.40	0.15	3.70	0.05
8.85	4.66	3.20	0.08
8.15	8.17	2.90	0.34
7.40	13.02	2.60	0.78
Mean	Sum x^2	Mean	Sum x^2
11.01	60.35	3.48	2.47
s_{Diff}	t		
1.45	5.20		
Result (d.f. = 10)		0.002	
< 1 chance in 500 these came from the same distribution			

Figure 3.11 gives an indication of company variability in lost time incident frequency statistics. No mathematical analysis has been conducted on these data, but the observable differences in the curves suggest significant differences in results.

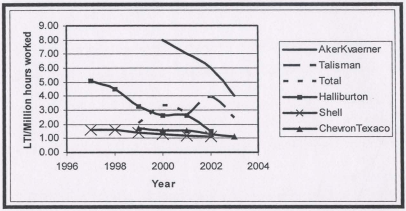


Figure 3.11 – Lost time incidents versus time by organisation

3.3.4) Norwegian Petroleum Directorate (NPD) comparison between operator and contractor groups

The Norwegian Petroleum Directorate has compiled statistics which, among other things, compared accident rates for operator and contractor staff while conducting similar activities. Curves representing the results are shown in Figures 3.12 and 3.13. Analyses of the significance of differences between the two datasets are presented in Tables 3.14 and 3.15. It can be concluded that for Norwegian offshore staff involved in both production and maintenance activities, operators' staff had a significantly lower accident rate than their contractor employed colleagues.

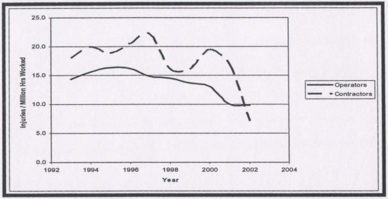


Figure 3.12 – Injury rate versus time for Norwegian production workers – operators versus contractors

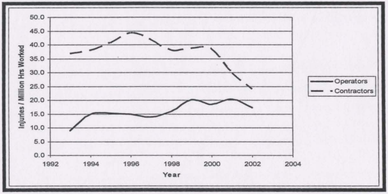


Figure 3.13 - Injury rate versus time for Norwegian maintenance workers – operators versus contractors

Table 3.14 – "*t*" test for comparison of safety results of Norwegian production operators and contractors

	Production Operators		Production Contractors	
Year	Rate	x^2	Rate	x^2
1993	14.3	0.2	18.0	0.2
1994	15.6	3.1	19.9	5.8
1995	16.3	6.1	18.8	1.7
1996	16.2	5.6	20.5	9.0
1997	14.8	0.9	22.2	22.1
1998	14.5	0.4	16.2	1.7
1999	13.7	0.0	16.1	2.0
2000	13.1	0.5	19.4	3.6
2001	10.0	14.7	16.8	0.5
2002	9.8	16.2	7.1	108.2
	Mean	Sum x^2	Mean	Sum x^2
	13.8	4.8	17.5	15.5
	n		n	
	10		10	
	s_{Diff}	t		
	0.5	7.7		

Table 3.15 - "*t*" test for comparison of safety results of Norwegian maintenance operators and contractors

	Maintenance Operators		Maintenance Contractors	
Year	Rate	x^2	Rate	x^2
1993	9.0	49.1	36.7	0.1
1994	15.0	1.0	38.0	1.0
1995	15.2	0.7	40.6	12.8
1996	15.0	1.0	44.2	51.6
1997	13.9	4.5	41.8	22.8
1998	15.9	0.0	37.9	0.8
1999	20.1	16.7	38.7	2.8
2000	18.4	5.7	38.4	1.9
2001	20.3	18.4	29.8	52.1
2002	17.3	1.7	24.1	166.9
	Mean	Sum x^2	Mean	Sum x^2
	16.0	9.9	37.0	31.3
	n		n	
	10		10	
	s_{Diff}	t		
	0.7	31.1		

3.3.5) Conclusions

There are significant differences in safety performance between companies, and between classes of companies, for example the operator and contractor groups. This result should be viewed positively, since it reinforces the importance to the accident process of corporate factors such as company culture, training, and procedures, and confirms the improvements achievable with the implementation of effective corporate safety programmes.

3.4) Analysis by activity

The activity being undertaken affects accident likelihood. Figures 3.14 and 3.15 show relationships between activities and STF (slip, trip, and fall) accident rate in the UK offshore region (UK HSE, 2002a). Whilst some would consider drilling activities to be more dangerous than production work, the accident rates per person reported here for these two activities (as well as construction) were identical. The most dangerous activity appeared to be deck operations, where the accident rate per person was more than double the others.

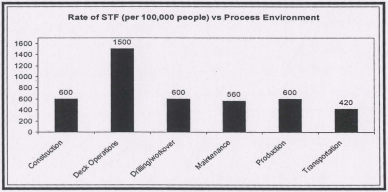


Figure 3.14 – STF rate versus process environment

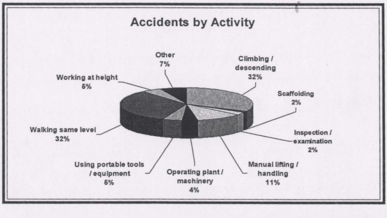


Figure 3.15 – Percentage of accidents versus activity

"*t*" - test level of significance analyses (methodology described elsewhere) of accident frequency versus activity, based on data in UK HSE (2000), have been conducted and are presented in Tables 3.16 and 3.17.

Table 3.16 - "*t*" test comparing safety results for production and drilling activities

Production	**x^2**	**Drilling**	**x^2**
0	1055551	14706	118840522
0	1055551	2474	1770496
730	88447	4231	181817
2688	2757592	4231	181817
893	18063	3761	1901
1393	133663	2564	1539088
1384	127164	1449	5548851
1648	385144	4630	681285
1538	260712	0	14474981
0	1055551	0	14474981
Mean	**Sum x^2**	**Mean**	**Sum x^2**
1027	6937438	3805	157695740
s_{Diff}	**t**		
1353	2.05		
Result (d.f. = 18)		0.1	
therefore null hypothesis (both sets from same distribution)			
can be rejected at the 0.1 level			

Table 3.17 - "*t*" test comparing safety results for maintenance and deck operations

Maintenance	**x^2**	**Deck Ops.**	**x^2**
0	1098723	0	3146366
1848	639680	2041	71396
947	10241	1923	22261
1062	190	952	675355
868	32472	2365	349517
613	189399	2062	83059
878	28968	3509	3010919
1453	163863	939	696891
730	101251	3947	4722798
2083	1070811	0	3146366
Mean	**Sum x^2**	**Mean**	**Sum x^2**
1048	3335600	1774	15924930
s_{Diff}	**t**		
463	1.57		
Result (d.f. = 18)		0.2	
therefore null hypothesis (both sets from same distribution)			
can be rejected at the 0.2 level			

It is noted that the individual data points in the tables represented results for different age groups, i.e. one pair of points for the 21 - 25 age group, another for 26 - 30, and so on. The analysis must be considered to be somewhat weakened by this process, as any effects actually related to age were ignored. This is similar to other analyses where, for example, company comparisons utilise data points from different years, thereby ignoring any temporal effects which act across all companies. For the present analysis, however, Figure 3.16 indicates no significant trend with age for the activities under consideration.

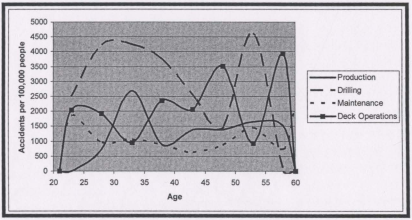


Figure 3.16 – Accident frequency versus age

The results indicate with a *reasonable* probability that a significant difference exists in likelihood of accident occurrence depending on the activity being undertaken. However, many approaches require the null hypothesis to be rejected only if the calculated "t" value exceeds the value indicated for chance occurrence at the 0.01 or 0.05 probability levels. In the two cases above, however, rejection was only at the 0.1 level for the comparison of production with drilling, and at the 0.2 level for the comparison of maintenance with deck operations. This means that the probability that there are real differences is of the order of

90% and 80% respectively. This leads to the conclusion that, whilst activity is clearly an important factor, other elements have a significant impact on the likelihood of an accident. This result is in line with the holistic philosophy proposed by this work.

Stronger conclusions could be drawn from the personal injury data shown in Figures 3.17 and 3.18, from the Norwegian offshore sector (NPD, 2004). The results of associated "*t*" test analyses are presented in Tables 3.18 and 3.19. In both these cases, the null hypothesis was rejectable at the 0.002 level. In this case, however, as mentioned above, individual data points represented year by year data, so time related effects were ignored. The time series charts shown below, however, did not show a strong consistent long-term trend, so this was not considered to be a significant problem.

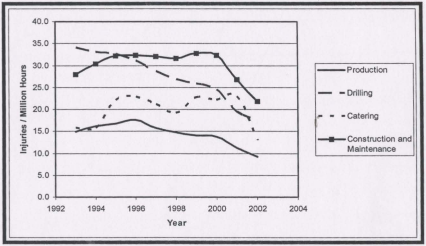


Figure 3.17 – Injuries on Norwegian permanently located installations versus time, by activity

Table 3.18 – "*t*" test comparing safety results for production and maintenance activities on Norwegian permanently located installations

Production	x^2	Maintenance	x^2
14.9	0.2	28.0	4.1
16.2	3.2	30.3	0.1
16.7	5.2	32.2	4.7
17.6	10.2	32.4	5.6
15.8	1.9	32.1	4.3
14.7	0.1	31.7	2.8
14.1	0.1	32.7	7.1
13.7	0.5	32.3	5.2
11.2	10.3	26.8	10.4
9.2	27.1	21.8	67.7
Mean	**Sum x^2**	**Mean**	**Sumx^2**
14.4	58.9	30.0	112.0
s_{Diff}	**t**		
1.4	11.3		
Result (d.f. = 18)		0.002	
Therefore null hypothesis (both sets from same distribution) can be rejected at the 0.002 level			

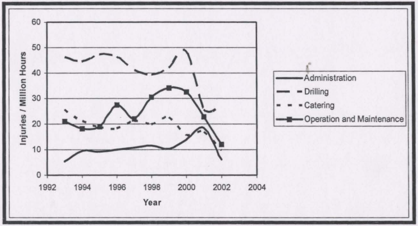


Figure 3.18 – Injuries on Norwegian mobile installations versus time, by activity

Table 3.19 "*t*" test comparing safety results for drilling and maintenance activities on Norwegian mobile installations

Maintenance	x^2	Drilling	x^2
20.9	9.2	46.2	30.4
18.1	34.0	44.3	13.0
18.9	25.3	47.2	42.4
27.5	12.7	46.3	31.5
22.0	3.7	41.0	0.1
30.4	41.9	39.2	2.2
34.1	103.4	42.0	1.7
32.6	75.2	48.5	61.0
22.7	1.5	25.6	227.7
12.1	139.9	26.6	198.5
Mean	**Sum x^2**	**Mean**	**Sum x^2**
23.9	446.9	40.7	608.5
s_{Diff}	**t**		
3.4	4.9		
Result (d.f. = 18)		0.002	
Therefore null hypothesis (both sets from same distribution) can be rejected at the 0.002 level			

It can be concluded from the data and analyses presented in this section that the activity being undertaken plays a significant, though not the only, role in occupational accident likelihood.

3.5 Questionnaire results

3.5.1 General

Several aspects of the model proposed by this work and described in Chapter 4 required the inclusion of offshore industry expert opinion. Various methods were available to obtain this, for example direct interview, or review and interpretation of existing documentation. Whilst direct interviews provide a significant degree of detailed and qualitative opinion, the present need was for experience-based quantitative measures of relative factor strengths and inter-dependencies. This, together with the requirement to gather a broad range of input in a reasonable period of time, led to the choice of a survey questionnaire* as the data gathering method, which was consistent with the method used by other researchers (Mearns et al., 2003, Brown et al., 2000, Flin et al., 1996) studying variations of the occupational accident process. Questionnaires (See Appendix 2 for the questionnaire form and a completed example.) were sent to a series of offshore safety professionals. A breakdown of the respondents is shown in Table 3.20.

Table 3.20 – Respondent profile

Respondent Profile					
	Region				
Category	Americas	Europe, Midddle East, & Africa	Asia	Total	Response %
Operator	4	5	1	10	24%
Contractor	1	6	1	8	24%
Regulator	10	9	3	22	50%
Researcher	4	1	0	5	100%
Total	19	21	5	45	
Response %	50%	26%	83%	36%	

---

* Attwood, D, Khan, F, and Veitch, B, 2005b. Offshore oil and gas occupational accidents – what is important? *Journal of Loss Prevention in the Process Industries*, October, pp 1-13.

The primary purposes of the survey were

- to quantify the *relative* strengths of the various factors thought to affect occupational accidents
- to assess the degree of influence imposed by external elements (e.g. royalty regime, value placed by society on life) on corporate decisions and actions (e.g. company safety culture, provision of training), and the influence of these elements on factors directly affecting the accident process (e.g. staff attitude, behaviour, design of workplace safety arrangements, etc.)

Within the model structure, the factors are organised into a series of subgroups. Because relative importance between group members was sought, rather than absolute importance, the first section of the questionnaire comprised a series of nine questions, each requesting an opinion of the importance of all members of a specific group. It was felt that the commonly used 1-10 scale would be most familiar to respondents and was therefore the chosen option. However, this system created a difficulty in comparing responses from different individuals. For example, a score of "9" for each of two factors within a group would indicate that the respondent considered the factors to be of equal importance, as would a pair of "1" responses. The respondent answering with the "9's" clearly considered both factors more important *overall* to the accident process than did the respondent who answered "1". To cope with this and ensure a like-for-like comparison between respondents, a common scale of intra group relative importance was needed, in effect, a "normalisation" of the responses. The normalisation process, illustrated in Table 3.21, effectively decoupled the overall importance assigned to an element from the relative importance within the group, for example producing scores of 0.5 for each element of a two-member group when they were assigned any equal scores.

Table 3.21 – Example of normalisation process

	Raw Score	Fraction of total points = normalised score
Element 1	7	0.47
Element 2	5	0.33
Element 3	3	0.20
Total	15	1.00

Questions ten and eleven gauged expert opinion regarding the influence of senior elements on junior factors. Respondents completed matrices for both sets of interfaces (external - corporate and corporate - direct) and thereby provided information on all relationships realistically expected to contain a degree of influence. As before, a normalisation process was used, again producing sets of results summing to 1 as required by the model.

The use of the normalised survey results within the model is described more fully in Sections 4.1.2.2 and 4.1.2.3. However, the untreated (i.e. not normalised) results provided significant and interesting information concerning experts' views on the occupational accident process, and were therefore not disregarded. The untreated results and their analysis are discussed in Sections 3.5.2 through 3.5.6.

3.5.2 Overall safety performance

The literature (Thompson et al., 1998, Tomas et al., 1999) included the concept that pure accident statistics may not, as is usually assumed, be the best measure of corporate safety performance. This is essentially because, thankfully, accidents remain relatively rare. The conclusion that an organisation experiencing one accident in a year involving many hundreds of thousands of man-hours worked had implemented a safety programme twice as effective as one having two accidents while working a similar number of hours, is questionable. Another possibility for measuring safety programme performance is internal staff perception of its effectiveness.

The questionnaire asked the respondents to comment on the safety performance of their respective organisations via the question "*On a scale of 1 to 10, how well do you consider your organisation's safety programme to be operating*?" Figure 3.19* and Table 3.22 show the results in graphical and tabular format respectively. The results showed that most experts felt their organisations' programmes were working relatively well, with averages in all regions and in all industry organisational types ranging between 7.0 and 7.5 on the 1-10 scale. The lower average score (5.8) reported from the researcher group was based on a small (5) sample, but no specific explanation for this result is offered.

* It is recognised that the data collected in this exercise would be most correctly presented as series of bar graphs, as opposed to continuous curves, which are usually associated with frequency distributions. However, the results were most clearly illustrated by series of smooth curves drawn through values representing the number of responses for each score, as presented for safety performance in this section, for relative importance in Section 3.5.3, and for relative influence in Section 3.5.6.

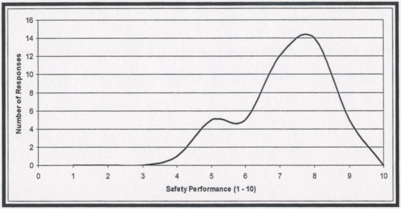


Figure 3.19 – Expert opinion of organisational safety performance

Table 3.22 - Tabulation of self-reported safety programme performance

	Safety Performance										
Score	1	2	3	4	5	6	7	8	9	10	Average
Combined	0	0	0	1	5	5	12	14	5	0	7.1
Americas	0	0	0	0	3	3	4	5	3	0	7.1
Europe	0	0	0	1	2	1	6	8	1	0	7.1
Asia	0	0	0	0	0	1	2	1	1	0	7.4
Operator	0	0	0	1	1	1	2	3	2	0	7.1
Contractor	0	0	0	0	1	1	2	3	0	0	7.0
Regulator	0	0	0	0	1	2	7	8	3	0	7.5
Researcher	0	0	0	0	2	1	1	0	0	0	5.8

3.5.3 Ranking of all factors

The respondents were not offered detailed information regarding the intra-group normalisation process which would be applied to their responses. Ignoring for the moment the grouping of the questions, the responses they gave to the request to "*rate, on a scale of one (not important at all) to ten (crucial), the importance of each element in the accident process*" could reasonably be assumed to offer an indication of the elements judged most important in the process, regardless of group. The five elements which received the highest overall average scores were:

1 Behavioural

2 Organisational safety culture

3 Organisational safety activities (i.e. versus direct and external factors)

4 Mental capability

5 Safety knowledge

The five elements receiving the lowest average scores were:

1 Royalty regime

2 Price of oil

3 External elements (i.e. versus direct and organisational factors)

4 Physical capability

5 Financial elements

It was not surprising to see safety behaviour, corporate culture, and organisational factors at the top of the list. These elements receive significant attention in the safety literature and are universally considered to be crucial to the accident prevention process. Similarly, it was interesting and also not surprising to see that physical capability (compared to the stronger mental capability) and financial elements received a relatively lower rating.

The appearance of "organisational factors" in the top five solidified its reputation as outweighing either external elements or direct factors as a critical issue. This indicated that most respondents felt that the organisation could influence safety results more than either individual behaviour or external events, which was an encouraging and empowering result for safety professionals.

Tables and curves representing (by subgroup) the untreated scores are shown in Appendix 3. A few of the curves considered particularly worthy of discussion are shown in Figures 3.20 and 3.21. For completeness, all group elements have been included on the graphs.

Figure 3.20 shows the number of responses by importance value (1-10) for the "overall" elements – direct factors, organisational elements, and external factors. The result was encouraging for safety professionals and workers in the offshore business. Direct and organisational factors were considered more important than external elements. This implied a degree of control over the process, in effect indicating that the ability to reduce accidents is more in the hands of workers and companies than depending exclusively on external elements.

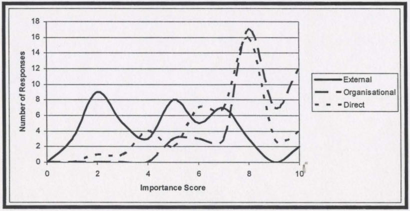


Figure 3.20 Questionnaire responses - overall importance

Figure 3.21 shows the result for importance of financial factors versus value placed by society on life. Safety experts considered the region-specific value placed by society on life to be more important in the occupational accident process than the combined financial factors (i.e. price of oil, shareholder pressure, and royalty regime).

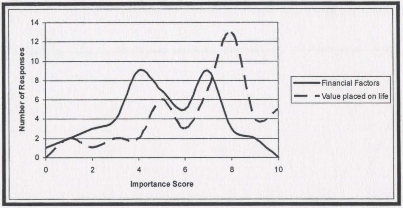


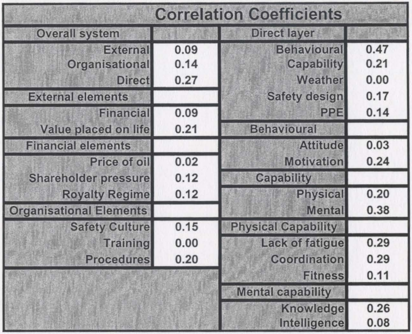
Figure 3.21 Questionnaire responses - financial factors and value placed on life

3.5.4 Correlation between various factors and overall safety performance

The correlation (Refer to equation 3.1) between self-reported safety performance (see Section 3.5.2 for a discussion) and importance score for each individual factor has been studied. It was hypothesized that good organisational safety performance would correlate with the recognition of certain key factors as having relatively greater importance than others in the accident process. The correlation coefficients between importance score and self-reported safety performance for each element have been calculated and are presented in Table 3.23.

Only two factors showed a correlation higher than 0.35, those being behavioural (0.47), and mental (0.38). One might conclude from this result that those who believe in the effectiveness of their safety programmes also believe that good worker behaviour and mental capabilities are crucial to its success. Upon reflection, this result seems reasonable.

Table 3.23 - Correlation between perceived element importance and safety performance



Correlation Coefficients			
Overall system		Direct layer	
External	0.09	Behavioural	0.47
Organisational	0.14	Capability	0.21
Direct	0.27	Weather	0.00
External elements		Safety design	0.17
Financial	0.09	PPE	0.14
Value placed on life	0.21	Behavioural	
Financial elements		Attitude	0.03
Price of oil	0.02	Motivation	0.24
Shareholder pressure	0.12	Capability	
Royalty Regime	0.12	Physical	0.20
Organisational Elements		Mental	0.38
Safety Culture	0.15	Physical Capability	
Training	0.00	Lack of fatigue	0.29
Procedures	0.20	Coordination	0.29
		Fitness	0.11
		Mental capability	
		Knowledge	0.26
		Intelligence	0.08

3.5.5 Significance of the differences

To evaluate the significance of differences between the respective rated strengths of pairs of elements within their subgroups, statistical "t" tests were conducted for both normalised and untreated results (see equations 3.5 and 3.6 for methodology). The results are shown in Tables 3.24 and 3.25. As can be seen, there were significant perceptions of importance for 22 of the 26 pairs evaluated. It is not surprising that some pairs (price of oil versus royalty regime, training versus procedures, capability versus safety design, and attitude versus motivation) were judged very similar in importance, and this is accurately reflected in the model through the use of average values of strength and influence. However, it was noted that for the most part, safety experts saw real differences in the importance of the respective groups of factors.

Table 3.24 – Significance of differences between pairs – normalised results

"t" tests	Sum of Squares	sdif	t	df	Significant? (.05 - 2.00)
External vs Organisational	66.4	0.2	10.7	88	Yes
External vs Direct	72.9	0.2	6.8	88	Yes
Organisational vs Direct	64.7	0.2	3.7	88	Yes
Financial vs Value of Life	207.9	0.3	4.5	88	Yes
Price of Oil vs Shareholder Pressure	155.6	0.3	4.7	88	Yes
Price of Oil vs Royalty Regime	121.9	0.2	1.7	88	No
Shareholder Pressure vs Royalty Regime	141.4	0.3	6.5	88	Yes
Safety Culture vs Training	13.3	0.1	3.3	88	Yes
Safety Culture vs Procedures	18.9	0.1	3.3	88	Yes
Training vs Procedures	13.8	0.1	0.7	88	No
Behavioural vs Capability	11.0	0.1	5.2	88	Yes
Behavioural vs Weather	14.0	0.1	12.3	88	Yes
Behavioural vs Safety Design	12.6	0.1	5.5	88	Yes
Behavioural vs PPE	17.2	0.1	7.6	88	Yes
Capability vs Weather	11.5	0.1	8.5	88	Yes
Capability vs Safety Design	10.2	0.1	0.8	88	No
Capability vs PPE	14.8	0.1	3.7	88	Yes
Weather vs Safety Design	13.2	0.1	7.2	88	Yes
Weather vs PPE	17.8	0.1	3.4	88	Yes
Safety Design vs PPE	16.4	0.1	2.9	88	Yes
Attitude vs Motivation	179.2	0.3	0.4	88	No
Physical vs Mental	146.4	0.3	10.7	88	Yes
Lack of Fatigue vs Coordination	19.2	0.1	5.9	88	Yes
Lack of Fatigue vs Fitness	22.9	0.1	8.6	88	Yes
Coordination vs Fitness	21.4	0.1	3.3	88	Yes
Knowledge vs Intelligence	55.1	0.2	4.6	88	Yes

Table 3.25 - Significance of differences between pairs – untreated results

"t" tests Factors	Sum of Squares	sdif	t	df	Significant? (.05...2.00)
External vs Organisational	350.9	0.4	8.6	88	Yes
External vs Direct	413.6	0.5	5.2	88	Yes
Organisational vs Direct	249.2	0.4	3.5	88	Yes
Financial vs Value of Life	445.7	0.5	3.7	88	Yes
Price of Oil vs Shareholder Pressure	486.8	0.5	3.0	88	Yes
Price of Oil vs Royalty Regime	440.8	0.5	1.3	88	No
Shareholder Pressure vs Royalty Regime	420.3	0.5	4.5	88	Yes
Safety Culture vs Training	140.8	0.3	2.3	88	Yes
Safety Culture vs Procedures	155.5	0.3	2.8	88	Yes
Training vs Procedures	154.0	0.3	0.6	88	No
Behavioural vs Capability	133.2	0.3	5.0	88	Yes
Behavioural vs Weather	219.2	0.3	10.5	88	Yes
Behavioural vs Safety Design	135.0	0.3	5.8	88	Yes
Behavioural vs PPE	255.4	0.4	6.4	88	Yes
Capability vs Weather	243.6	0.4	6.3	88	Yes
Capability vs Safety Design	159.4	0.3	0.8	88	No
Capability vs PPE	279.8	0.4	2.7	88	Yes
Weather vs Safety Design	245.4	0.4	5.6	88	Yes
Weather vs PPE	365.8	0.4	2.7	88	Yes
Safety Design vs PPE	281.6	0.4	2.1	88	Yes
Attitude vs Motivation	355.6	0.4	0.5	88	No
Physical vs Mental	248.9	0.4	9.5	88	Yes
Lack of Fatigue vs Coordination	187.6	0.3	3.9	88	Yes
Lack of Fatigue vs Fitness	160.0	0.3	7.0	88	Yes
Coordination vs Fitness	149.6	0.3	2.9	88	Yes
Knowledge vs Intelligence	180.2	0.3	3.6	88	Yes

Note that in this case there were sufficient observations to evaluate the normalcy of the data. As examples, evaluations (Johnson, 2005) were conducted of the normalcy of the untreated results associated with personal protective equipment and coordination, resulting in the plots shown in Figures 3.22 and 3.23. The relatively linear result indicates that the data were distributed approximately according to the normal distribution.

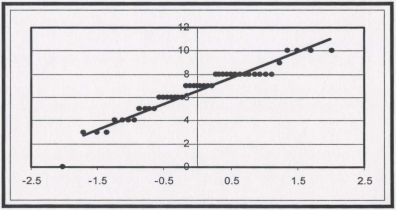


Figure 3.22 – Normalcy evaluation – PPE - untreated results

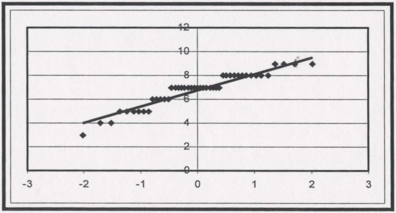


Figure 3.23 – Normalcy evaluation – coordination – untreated results

3.5.6 Levels of inter-layer influence

One of the foundations of this research is that external elements affect corporate decisions and that these in turn affect the direct accident process. The questionnaire results provided a means to quantify experts' perceptions of the relative degree to which each external and corporate factor affects the lower level layers. In order to establish the relative total impact of the influencing elements at both interfaces, the effects of each senior element on all of its respective influenced junior factors have been combined. For example, the effects of royalty regime on safety culture, safety training, and safety procedures were combined to give an indication of royalty regime's total power as an influencing factor. The results for the external - corporate and corporate - direct interfaces are shown in Figures 3.24 and 3.25 respectively, and Table 3.26.

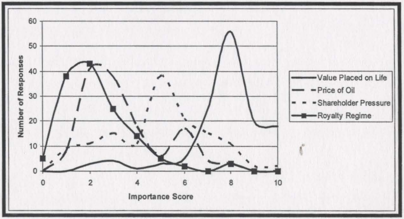


Figure 3.24 – Effect of external elements on organisational decisions

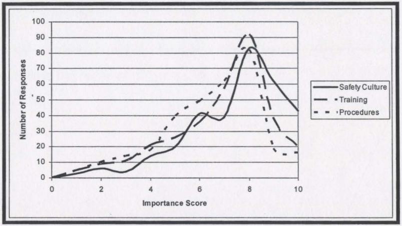


Figure 3.25 – Effect of organisational decisions on the direct accident process

Table 3.26 – Combined measure of influence on all lower level elements

Combined average	
Value placed on life	7.77
Price of oil	3.41
Shareholder pressure	4.94
Royalty regime	2.34
Training	6.87
Procedures	6.52
Safety culture	7.47

The results shown in Figure 3.24 and Table 3.26 indicated a clearly dominant factor at the external – corporate interface. Value placed on life is considered to affect corporate behaviour to a significantly greater degree than any of the three financial elements. Shareholder pressure was considered to be the most prominent of the financial factors, followed in turn by price of oil and royalty regime. It is interesting to note again that amongst the financial factors, the one "closest" to the organisation itself (shareholder pressure) was considered most prominent. This is in line with conclusions drawn elsewhere, i.e. that the organisation holds more "power" in the accident process than do external elements.

The results of the corporate – direct analysis were not as clear - cut as for the external – corporate interface. All three elements were perceived to be significantly important (average values 6.3 - 7.4), but the *differences between* their respective influencing powers on the direct factors were not very large. As expected, though, the experts viewed safety culture to be more influential than either training or procedures.

4

Model development

4) Model development

This chapter is comprised of four sections, structured as follows.

1. In Section 4.1 the overall premise and model structure are described, followed by a discussion of the choice of calculation methodology and associated details.
2. Section 4.2 includes a description of the process whereby the model is calibrated and subsequently run for specific cases.
3. The effect of component changes on overall output is described in a parametric analysis included as Section 4.3.
4. The final section, 4.4, includes a series of demonstrations of the model, describing accident likelihood as hypothetical offshore assets experience changes in operating conditions, for example during mobilization.

4.1) Basic premise, model structure, and calculation methodology

This section describes the model developed to study the accident process*. The overall premise and model structure are described, followed by a discussion of the choice of calculation methodology. Subsequent sections describe specific aspects of the model, for example:

- how the relative importance of individual factors is accounted for
- the method for inclusion of the influences of (i) external factors on corporate behaviour and (ii) corporate behaviour on the direct accident process

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* Attwood, D, Khan, F, and Veitch, B, 2005c. Can we predict occupational accident frequency? *Process Safety and Environmental Protection, Trans IChemE*, Part B, 84(B2), March, pp 1 - 14.

- the details of the reliability calculation
- the method for calculating accident frequencies using system reliability values
- the inclusion of a cost element

An illustration of the spreadsheet used for the calculation has been included at the end of the section as Figure 4.12.

4.1.1) Overall premise and model structure

The basic premise of the model may be stated as follows:

> *Occupational accidents result from an unsatisfactory direct interaction between worker and the workplace environment, but the workers' actions were influenced and the workplace environment provided by an organisation whose actions were, in turn, influenced by external elements.*

A schematic of the model philosophy is shown in Figure 4.1. More details of the basic premise are presented in this section.

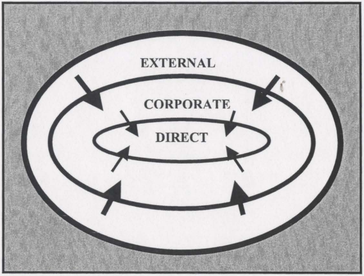


Figure 4.1 – Basic schematic of model

Factors directly affecting accident likelihood include worker behaviours and capabilities, weather conditions, safety related design of the workplace, and quality of protective equipment. Most of the direct factors are heavily affected by the safety culture and programmes provided by the employer.

Worker motivation, attitude and resulting behaviours are influenced by corporate safety culture. Senior management, through its words, and more importantly, through its actions, will foster safety attitudes ranging from the cavalier to the overly cautious. Employee capability and knowledge can be positively affected by things such as effective safety training programmes and procedures and facilities to encourage physical fitness.

Organisations prescribe the quality of safety design applied to the workplace environment. Historically, safety groups have sometimes felt marginalised from the other design departments, at times trying to "hang on to" or "keep up with" the rest of the group. Modern offshore design programmes, however, usually require that safety representatives participate in all elements of the design, and also that they be heavily involved in periodic overall design reviews.

Corporate decisions also determine the quality of basic safety equipment provided to workers. On modern oil and gas platforms in most regions, provision of the very best quality safety equipment has become the norm.

Other researchers (for example Pate-Cornell and Murphy, 1996, Cheyne et al., 1999, Thompson et al., 1998, and Tomas et al., 1999) have considered the effect of corporate actions on the accident process. The present model, however, extends the analysis by considering an external (to the organisation) level. Essentially, pressures imposed by societal culture and financial realities are considered to influence the organisational actions and decisions mentioned above, which in turn affect the direct accident process.

It has become accepted that the value placed by society on human life differs between regions. Populations routinely experiencing large scale mortality due to unstable political situations are more likely to accept death as a potential part of daily work life than groups having little first hand experience with unnatural death. Governments, as represented by their regulatory agencies, act as conduits of the attitudes of the populations they represent. The degree of governmental pressure to enhance safety measures applied to operators will therefore be proportional to the value placed on life by the region's population.

Financial drivers are also considered to affect accident frequency through organisational behaviour. Corporate profitability affects how much available capital exists, which *partially* determines safety spending (only *partially* because companies have different views on how much of the available capital is directed to safety issues). Three financial elements have been included in the model to represent this effect: price of oil (or gas, for gas production installations), shareholder pressure, and royalty regime.

The following sections describe in more detail the components of the different levels, or layers, which are shown in Figure 4.2. These components were chosen based on (i) discussions with offshore oil industry colleagues, (ii) personal experience in the industry and (iii) the literature review described in Chapter 2.

External Layer		Corporate Support Layer	Direct Layer		
Value placed on life by society		**Corporate safety culture**	**Individual behaviour**		**Attitude**
Financial Drivers	**Price of oil**	**Safety training programme**			**Motivation**
	Shareholder pressure	**Safety procedures**	**Individual capability**	**Mental**	**Knowledge**
	Royalty regime				**Intelligence**
				Physical	**Coordination**
					Fitness
					Lack of fatigue
			Weather		
			Safety design		
			Personal Protective Equipment		

Figure 4.2 – Specific elements of model

With respect to the literature review, it was felt worthwhile to introduce a degree of rigour to the review of factors suggested by others. Therefore, the groupings proposed in the literature (see Section 2.3) were reviewed and the number of occurrences of specific factors in the direct, corporate, and external categories counted. The result of this exercise is shown in Table 4.1, with the numbers in brackets indicating the total number of times the factors were proposed. Because researchers use slightly different terms to describe the factors, the process required a degree of interpretation. However, the factors proposed most frequently by others have been included in the present model, which provides confirmation and validation to the choices. The relative scarcity of factors outside the organisation proposed by previous researchers confirms the novelty of the present approach, which includes external societal and economic forces.

Table 4.1 – Frequency of mention of factors affecting safety results

Factors affecting occupational accidents (frequency of mention in brackets)		
External	**Corporate**	**Direct**
Political influence (2)	Economic pressure (3)	Personnel experience (3)
Regulatory influence (1)	Corporate Culture (11)	Staff knowledge/learning (5)
Market influence (1)	Procedure/Permit syst. (8)	Safety design/layout (10)
Societal influence (2)	Corporate supervision/ audit programme (3)	Staff errors (2)
	Safety management (2)	Safety behaviour (6)
	Labour relations (2)	Fatigue (2)
	Accident management (3)	Housekeeping (1)
	Training (10)	Physical fitness (1)
	Human resources (4)	Weather (2)
		Quality of PPE(3)
		Attentiveness (2)
		Motivation (2)
		Compliance (1)
		Visual environment (1)
		Personnel attitude (4)

4.1.1.1) The direct layer

Occupational accidents result directly from the actions and choices of workers as they operate within a specific environment. Individuals' actions are driven by (i) chosen behaviours and (ii) capabilities. **Behaviours** are personal choices, considered to be heavily influenced by general attitude and motivation.

It is recognised that individual attitudes can sometimes be difficult to significantly change and are probably best influenced at the hiring stage. However, this does not (and should not) stop responsible organisations from encouraging good attitudes and discouraging poor ones such as risk taking and mocking of staff considered overzealous in their concern for safety. Corporate encouragement of good safety attitudes will produce both direct benefits and a general improvement of overall corporate safety culture.

Motivation to operate in a safe manner must be clearly provided by management and supervisors. Positive reinforcement is the more frequent option and usually takes the form of safety awards, financial or otherwise. Penalties for poor safety behaviour are less common, but may become more so in reaction to increasing corporate penalties for inferior safety performance. Some would question the effectiveness of the safety award/penalty system, citing the encouragement of inappropriate non-reporting of accidents. Nevertheless, the system probably, on balance, encourages behaviour beneficial to both workers and the organisation.

Capabilities may be subdivided into mental and physical. Mental capabilities are of two categories, knowledge based, and intelligence based (Hurst, 1998). The knowledge component comprises the safety related information retained by the worker following training sessions, which, if effective, cover both general safety issues and specific requirements of the particular work environment. The intelligence component allows the worker to cope with safety issues not specifically covered by training and procedures. Physical capabilities associated with avoiding occupational accidents are considered to be good coordination, a reasonable degree of fitness, and lack of fatigue.

To summarise, a worker with a good chance of avoiding an accident will have good common sense, a sound knowledge of the safety procedures under which he should have been trained to work, and be coordinated, reasonably fit, and not fatigued.

Three other factors not related to personal behaviour or capability are considered to directly affect the accident process and have therefore been included in the analysis. They are (i) the **weather conditions** at the time when the work is performed, (ii) the **safety related design** (which would take into account the type of facility – oil or gas) of the work environment and equipment (i.e. non-slip floor coverings, ergonomically designed ladders) and (iii) the supplied **personal protective equipment (PPE)** (i.e. hat, boots, safety glasses, and earplugs).

4.1.1.2) The corporate layer

The second fundamental layer is the safety related support provided by the organisation. This support is considered to be comprised of the **corporate safety culture** nurtured by the organisation, the specific **safety training** delivered to staff, and the **procedures** offered to reduce accident risk.

Safety culture is difficult to quantify. Almost all operators today promote a commitment to safety as their foremost concern. Annual reports and other promotional materials repeat phrases and promises such as "safety takes precedence over production", "safety is job one", and similar. Corporate policy statements carrying signatures from top executives reinforce the statements. Senior executives use many approaches during "town-hall" meetings to encourage attention to safety – for example, by displaying pictures of families with an accompanying plea to "get home to them safely", or through a request to staff to not burden the manager with the guilt associated with an employee injury or death "under his watch". Further motivation for staff to support good corporate safety culture is often added by a public implementation of a reward/penalty scheme, as discussed in Section 4.1.1.1.

Corporate safety culture tends to be a fragile thing which can quickly collapse if the workforce senses that the safety system has been created for political reasons only instead of resulting from genuine concern for the workers. A common example of this is subtle management encouragement to bend safety rules when doing so might mean avoiding financial loss, for example, when continuous production is in jeopardy. Similarly, motivations can be questioned when managers fail to encourage safety attention away from the work environment, instead taking the view that risks taken during non-work time are "none of my (the manager's) business".

In addition to nurturing an organisation-wide safety culture, offshore operators today take many practical steps to ensure that the basic elements required for safe work activities are in place. These include the development and enactment of impressive **safety training** programmes and the distribution of **safety procedures** and guidance notes. The frequency and content of safety training meetings can be immediately adjusted to reflect the most recent performance, and the style and location of the meetings is sometimes changed to react to problem areas within the organisation. An example would be replacing office-based meetings with "tool-box" talks held on the shop floor to raise awareness of specific potential hazards.

It is important to develop and maintain an appropriate balance in the intensity and quantity of training sessions and procedures. Too little of either can produce a work force ill equipped to face work activities in a safe manner, and one which feels unsupported by those responsible for its ongoing safety. However, excessive and overly restrictive safety procedures can create an unfortunate and unexpected negative result. Workers can feel immune to dangers when armed with an overabundance of instructions, which can lead to unsafe actions. Or, staff can occasionally find safety procedures so restrictive that they lose their will to comply, cut corners, and become injured. Experience is gradually producing the *appropriate* level of safety training and procedure.

A supportive safety culture combined with suitable training programmes and procedures comprises the corporate layer of safety protection. Taken together, they form a safety system that can be very effective.

4.1.1.3) The external layer

The view that safety results can be fundamentally and significantly improved solely by changing elements at the direct level is not supported by this or previous research. Better safety boots, a series of more visible warning signs, and similar initiatives may prevent an accident or two, but fundamental change requires improvement at least at the corporate level, which is usually driven by external factors such as the relative societal value placed on life or market financial pressures. These external factors are discussed in this section.

Oil companies need to operate in regions where hydrocarbon reserves are discovered. Cultural expectations differ enormously throughout the world, and region-specific societal forces will affect corporate safety results in several ways. For example, certain regions place a higher **value on a human life** than others. In regions where the value is high, operators will receive, usually through the regulatory process, a relatively high pressure to impose a strict safety programme. This pressure will take many forms – for example requirements for high expenditure on safety equipment through demanding and prescriptive regulation, stiff penalties for injuries, both in terms of fines and public embarrassment, and lengthy and expensive pre-project public safety performance forums. The opposite relative effect will manifest in regions with a comparatively lower societal value placed on life.

Financial pressures on oil companies originate from several sources, including global price of oil, corporate shareholder pressure, and regionally based royalty regime. The latter two are significantly driven by regional public opinion. Some examples of the manifestation of public views on pressures felt by organisations were described by Brotherton (2003) and discussed in Section 2.4.4. An additional hypothetical example would be the election of a government whose campaign policy included a commitment to oppose hydrocarbon development and impose a restrictive and lucrative (for the population) royalty regime.

A reasonably strong inverse correlation has been shown (Section 3.1.2) between **price of oil** and accident frequency. This is likely due to an effect which is more easily seen from a negative perspective – when money is scarce, i.e. when the price of oil (or gas, for gas production facilities) is low, there is an increased pressure to cut corners everywhere, and this includes, unfortunately, the quality of the safety programmes enacted by operators.

Shareholder pressure is primarily organisation specific, and is related to the degree to which an organisation feels pressure from its ultimate owners to improve bottom line performance. When they buy specific companies' shares, purchasers have certain expectations related to corporate history and reputation. Organisational objectives to return industry leading dividends can be felt throughout the organisation, often in ways not popular with all employees, for example in a reduction of safety programme spending.

A secondary regional influence on shareholder pressure has arisen as companies continue to divide themselves into regional legal entities. Some cultures support a greater degree of capitalistic corporate philosophy than others, and shareholders in such regions will likely exert a proportionally greater pressure to return high dividends.

Unduly high pressure to return dividends or retain money within corporate coffers rather than spending it on what some shareholders perceive to be an unnecessary expense lacking an obvious payback, such as the safety programme, will negatively affect safety results.

The final financial factor considered is the **royalty regime**, which, similar to the value placed on human life discussed above, is heavily region-specific. It is interesting to watch the dynamic of different government and public behaviour following the euphoria of the first oil or gas discovery in an area. Usually the initial reaction is to make life very attractive for the companies, and a lucrative (for the organisation) royalty scheme is discussed and proposed in general terms. Then, usually over a period of one to two years, the historical values of the region are brought to bear on the process. If the region's long term economics have been acceptable or excellent, and the environment is of high importance to the public (usually due to valuable tourism or fishing industries), pressure is placed on government to enforce a strict royalty regime, which erodes project profitability, increases financial pressure, and has the potential to produce a negative knock-on effect on safety results. On the other hand, in areas where the population has suffered from poor long-term economics, it is more likely that the public will encourage government to ensure that oil and gas operators are made to feel welcome in every possible way, including financially. This will have a positive effect on disposable corporate cash, which has a good likelihood of being translated to increased safety spending and improved performance.

4.1.2) Calculation methodology

This section includes descriptions of both the general methodology and specific calculations used within the model to predict accident frequency, based on the effectiveness of the influencing factors described in the previous section.

4.1.2.1 General method of analysis

Many methods are available to study probabilistic events such as offshore accidents. These have been discussed in Chapter 2 (literature review), and include fault tree analyses, event tree analyses, and others.

Tabachnick and Fidell (2001) have described several methods available to analyse relationships between statistical data, including for example multiple regression analysis and, most promising for application to the occupational accident issue, structural equation modelling, or SEM. SEM uses statistical techniques to evaluate the strength of the relationships between variables associated with a given hypothesis. A diagrammatical representation of the output of a typical SEM analysis is shown in Figure 4.3 (from Tabachnick and Fidell, 2001).

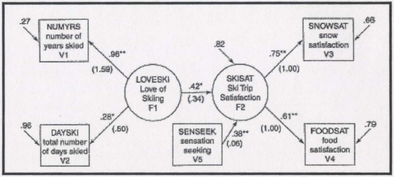


Figure 4.3 – Structural equation modelling – skiing example

The authors employed the following protocol in their representations of SEM analyses:

- Squares or rectangular shapes indicate measured variables, also known as observed variables, indicators, or manifest variables.
- Round or oval shapes represent factors, also known as latent variables, constructs, or unobserved variables.
- The collection of hypothesized relationships between the constructs is referred to as the structural model.
- Sections of the model which relate unobserved variables to measured ones are referred to as measurement models.
- Relationships between variables are represented by lines – no line symbolises a prediction of no relationship; a line with one arrow indicates a direct relationship,

with the arrow pointing to the dependent variable; and a line with two arrows indicates a relationship with no implied direction of effect.

In the example shown in Figure 4.3, the authors evaluated the premise that two elements, love of skiing (LOVESKI) and propensity for sensation seeking (SENSEEK), would heavily influence satisfaction on a subsequent ski trip (SKISAT).

Love of skiing was *represented by* the participants' total number of days skiing (DAYSKI) and total years during which skiing formed part of the respondents' leisure activities (NUMYRS). Furthermore, love of skiing was also *considered to influence* both of the latter variables (NUMYRS, DAYSKI).

Satisfaction with the trip was *measured by* satisfaction with snow conditions (SNOWSAT) and food (FOODSAT). In addition, higher ski trip satisfaction was proposed by the authors to *predict* greater satisfaction with the food and ski conditions, but a case could be made that the direction of causality could be reversed, in other words that food and snow condition satisfaction would predict overall trip satisfaction.

An analysis of the covariance of responses to a questionnaire on the subject was combined with a regression analysis to optimise regression coefficients between the variables. The coefficients were adjusted until the difference between predicted and actual results could be shown to have reached a minimum. The results of the process are shown in Figure 4.3, with the strength of the relationships indicated by the relative size of the numbers.

SEM was given serious consideration for this work, since, as can be seen from the discussion and figure above, similarities exist between the skiing example and the current study of offshore occupational accidents. Specifically, in the same way that satisfaction on a ski trip is thought to be influenced by love of skiing and level of sensation seeking, it is proposed here that accidents are influenced by a series of direct elements, corporate decisions, and external drivers. Figure 4.4 shows a SEM representation of the offshore occupational accident process.

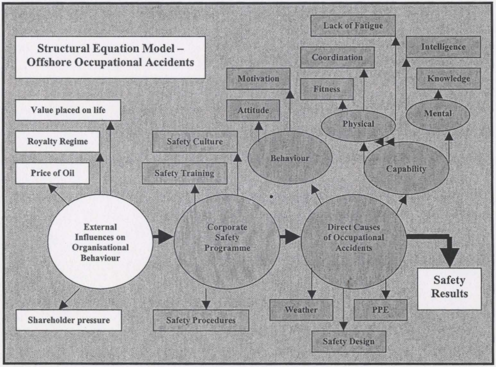


Figure 4.4 – SEM analysis of offshore occupational accidents

The following points are made with respect to the application of SEM to the occupational accident process.

- This application of SEM is significantly more complex than those described in the literature.
- Some factors, such as safety procedures, weather, and price of oil can be directly measured, for example by the number of safety procedures, days of good weather per year, and daily price of oil, respectively.
- Other items, such as physical capability and behaviour, cannot be measured directly, and would therefore need to be quantified by an evaluation of the measurable elements with which they are associated. For example, physical capability would be quantified by evaluating the more easily measurable physical fitness and lack of fatigue.
- The primary structural model in this application is composed of the lines connecting external influences, corporate safety programme, direct causes of occupational accidents, and safety results.
- An example of a measurement model would be the measurement of a corporate safety programme using a quantification of safety training, procedures, and safety culture indicators. This measurement model sub-set is shown in the middle portion of Figure 4.4.

To understand the issues surrounding the application of SEM to the general accident process, several related papers (for example Brown et al., 2000, Tomas et al., 1999, Cheyne et al., 1999) were reviewed. It was noted that SEM and, indeed, most of the other statistical approaches considered, are primarily observational and static – they study the situation as it is currently measured. There are advantages to an alternative method offering the capacity to predict accident frequency and grow and change to account for improved information.

Following individual reflection, experimentation, and discussion with colleagues, it was decided that the accident process would be best modelled using a modified reliability network. Using this approach, the relationships between direct layer factors are similar to those of a physical system, and, consistent with the general philosophy, their reliabilities are influenced by the performance of the corporate and external elements. More detail will be offered on the actual model in subsequent sections. It is emphasised that whilst the reliability model was considered to be the best option, no particular problem is perceived with using either SEM, the previously mentioned fault tree and event tree methods, or other approaches.

The notion to model the accident process as a reliability network originated with the recognition of several similarities between the components and interconnections of a mechanical/electrical engineering system and the elements considered to affect safety programmes and accidents, as mentioned below.

- Similar to an engineering system, success of accident reduction programmes depends on the reliability of individual components.
- Individual components perform at different levels of reliability.
- System improvements are produced by improving component performance.
- The overall system can be realistically subdivided into sub-systems.

- Some subsets of components in engineering systems are configured in series setups having the fundamental properties that (i) the reliability of the subset is the product of individual component reliabilities and (ii) the subset reliability is always less than the reliability of the least reliable component (see Figure 4.5). This corresponds to the concept that, for some subsets of a safety programme/accident process, all elements must be operating relatively efficiently to produce a satisfactory result.
- Other elements in engineering systems are configured in parallel setups having the fundamental properties that (i) the reliability of the subset is calculated by subtracting the product of individual component probabilities of failure from one and (ii) the subset reliability is always greater than the reliability of the most reliable component (see Figure 4.5). This corresponds to the concept that, for some subsets of a safety programme/accident process, poor performance in some elements can be compensated for by superior performance by others within the subset.

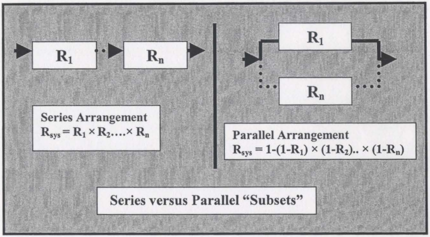


Figure 4.5 – Series versus parallel subsets

A mathematical example can be used to illustrate the final two points above, with reference to the equations in Figure 4.5 (see also Table 4.2). Consider two subsets of elements, each containing two elements, one connected in series, the other in parallel. Assume a situation where each system reliability is approximately equal, produced when, for example, component reliabilities of the series subset are 0.6 and 0.7, giving a system reliability of ($0.6 \times 0.7 = 0.42$), and component reliabilities of the parallel subset are 0.2 and 0.3, producing a system reliability of ($1 - (1-0.2) \times (1-0.3) = 0.44$). Suppose system failure is proposed to occur when overall reliability falls below approximately 0.35. In the series arrangement, this occurs if the first component reliability falls below 0.5, a drop of only 17% from the original value of 0.6. However, in the parallel arrangement, a fall below system reliability of 0.35 would require the first component reliability to drop from 0.2 to approximately 0.06, a fall of 70%. A failure of the parallel system requires a much greater percentage component reliability drop than is the case for the series system. This example shows how the effect of compensation by elements in the safety system is modelled by the parallel arrangement of components in the reliability network.

Table 4.2 – Comparison of series and parallel arrangements

Configuration	**Original Individual Component Reliabilities**	**System Reliability**	**New Component Reliabilities**	**System Reliability**	**% Reduc. in Comp.1 Reliability**
Series	Comp.1=0.6 Comp.2=0.7	(=0.6 × 0.7 =) =**0.42**	Comp.1=0.5 Comp.2=0.7	(=0.5 × 0.7=) =**0.35**	(0.6-0.5) =**17%**
Parallel	Comp.1=0.2 Comp.2=0.3	(=1-(1-0.2) × (1-0.3))= **0.44**	Cmp.1=0.06 Comp.2=0.3	(=1-(1-0.06) × (1-0.3))= **0.34**	(0.2-0.06) =**70%**

Some other advantages of the modified reliability network over other approaches are as follows.

- One of the primary tenants of this thesis is that the higher level (i.e. external and corporate) layers of the system *affect* the lower level layers. The proposed model includes a function to spread the effect of the higher levels to the lower layers.
- The relative importance of individual elements has been included, heavily relying on industry expert opinion.
- The model can be easily modified. Importance of individual elements, strength of relationships and even individual component location within the structure are easily updated with improved information or revised philosophy.

The modified reliability system based model of the accident process is shown in Figure 4.6. A few points to note are as follows:

- The direct layer elements (behaviour, capability, weather, safety design, PPE, and their subcomponents) are connected in a reliability network. The reliability of the system is calculated in much the same way as would be done for a physical network (Billinton and Allan, 1983). The only departure from formal system reliability calculation methodology is the necessary inclusion of relative strength factors, which is discussed in Section 4.1.2.2.
- The external elements *influence* corporate factors, and these in turn *influence* the direct components, as shown in Figure 4.6. The mathematics of this process is described in Section 4.1.2.3.
- The main direct elements (behaviour, capability, weather, safety design, and PPE), are connected in a series configuration, reflecting the belief that all must contribute effectively in order to achieve satisfactory safety results.
- Some element subsets, for example (i) coordination, fitness, and lack of fatigue, and (ii) knowledge and intelligence, are connected in parallel arrangements. This reflects the belief that a degree of compensation is available in the process. Examples of this would be when a high level of coordination and fitness allowed a fatigued worker to successfully avoid an accident, or when good intelligence facilitated accident avoidance for a worker having a less than ideal knowledge of safety procedures.

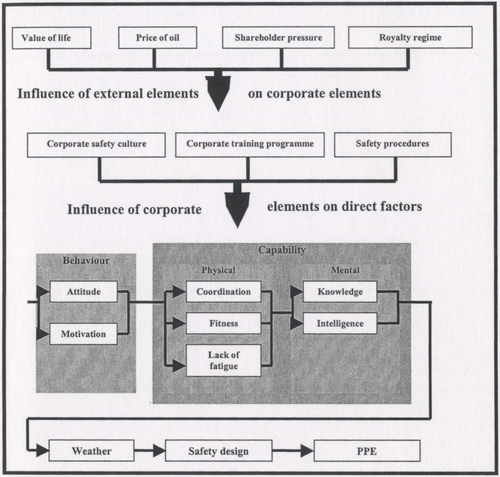


Figure 4.6 – Model structure

In the following sections several of the main features of the model are discussed, specifically:

- the ability to apply varying strengths to individual components based on their relative importance in the process
- the method by which the influence of external elements on corporate factors and corporate factors on direct elements is modelled
- the exact method of reliability calculation

- the method for predicting accident frequency once reliability has been established
- the inclusion of a cost element in the model

4.1.2.2 Strength of individual elements

The model accounts for the fact that not all elements affect overall safety performance to the same degree. Expert opinion, as obtained from a survey (Section 3.5) of safety professionals, has been used to quantify each element's relative effect (or "strength") on accident frequency. The process used to transfer experts' opinions to values having the form required by the model is described in this section.

Decisions needed to be made regarding relative importance of all subgroups and individual elements within the model's direct layer. First, a decision was made regarding the relative importance of the five overall elements (behaviour, capability, weather, safety design, and PPE). Moving to the next level, within the group of capability elements, the relative importance of physical and mental capability was assessed. Moving down still further in the structure, the relative importance of the physical capability elements (coordination, fitness, and lack of fatigue) was determined. Similar quantitative choices were also required for all the other direct elements. Relative strength of the corporate and external elements was handled by their relative degrees of influence on lower levels, which was also determined by expert survey and is discussed in Section 4.1.2.3.

As mentioned, quantified decisions regarding the relative importance of specific elements was based on information gained via an industry expert survey. A questionnaire was used for this purpose in which experts were asked to rate the relative importance of elements using a one (not very important at all) to ten (crucial) scale. A discussion of the choice of a questionnaire as a method of gauging expert opinion is included in Section 3.5.1. Table 4.3 shows the resulting average values for the normalised importance of each element. The normalisation process was described in Section 3.5.1. Curves showing the spread (based on the questionnaire responses) of normalised results for each element are included in Appendix 4. As an example, curves showing the relative response frequencies for mental and physical capability are shown in Figure 4.7. Note the perceived higher importance of mental compared to physical aspects.

Table 4.3 – Element strengths

Element	Strength value	Element	Strength value
Main elements		Capability	
Behavioural	0.25	Mental	0.64
Capability	0.21	Physical	0.36
Weather	0.15	Mental capability	
Safety design	0.21	Knowledge	0.54
PPE	0.18	Intelligence	0.46
Behavioural		Physical capability	
Attitude	0.49	Coordination	0.33
Motivation	0.51	Fitness	0.29
		Lackof fatigue	0.38

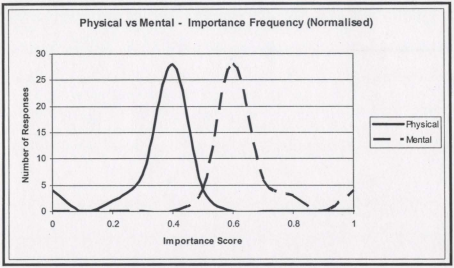


Figure 4.7 – Normalised importance of physical versus mental factors

The relative importance information is then transformed to the mathematical model by a process of strengthening or weakening the various elements in the reliability network. This is best explained by considering the effect of individual component reliability on overall system reliability in a mechanical or electrical engineering system composed of sub-groups of components, some arranged in parallel, others in series. Consider the series arrangement shown in Figure 4.8.

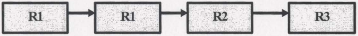


Figure 4.8 – Series reliability

In this case, the reliability of the system is:

$$R_{sys} = R1 \times R1 \times R2 \times R3 = R1^2 \times R2 \times R3 \qquad (4.1)$$

Now consider the effect on system reliability if a 10% improvement is made in the component reliability of the two *R1* elements, as compared to the system improvement if the same 10% improvement is made in the single *R2* component. Table 4.4 shows that the % improvement in system reliability associated with the 10% improvement in the two *R1* components is greater than the case when a 10% improvement is made to the single *R2* component.

Table 4.4 – Effect of component reliabilities – series configuration

Case	Component Reliabilities				System Reliability	% Improvement in system reliability
	R1	*R1*	*R2*	*R3*		
Base	0.70	0.70	0.70	0.70	0.240	Not Applicable
10% Improvement *R1*	0.77	0.77	0.70	0.70	0.291	21.3%
10% Improvement *R2*	0.70	0.70	0.77	0.70	0.264	10.0%

Note that the absolute reliabilities in this discussion are not as important as the percentage changes. This is because before the model is used to predict accident frequency for a specific case, a calibration process is undertaken whereby component reliabilities are preset to ensure that the starting point for the analysis will produce base case results (usually industry average). Therefore, absolute individual component reliabilities are not important, but changes in them are.

Consider now a similar analysis applied to the parallel arrangement shown in Figure 4.9.

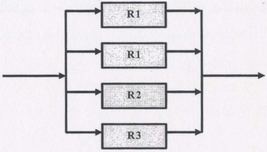


Figure 4.9 – Parallel reliability

In this case, the reliability of the system is:

$$R_{sys} = 1 - (1\text{-}R1)^2 \times (1\text{-}R2) \times (1\text{-}R3) \qquad (4.2)$$

As before, the effect of component improvements on system reliability is greater when more components are involved. As shown in Table 4.5, when the reliability of the two *R1* components increases by 10%, system reliability improves by 2.7%, but when the reliability of the single *R2* component (or, indeed *R3*) increases by 10%, system reliability improves by only 1.4 %.

Table 4.5 - Sensitivity to number of elements, parallel system

Case	**Component Reliabilities**				**System Reliability**	**% Improvement in system reliability**
	R1	***R1***	***R2***	***R3***		
Base	0.30	0.30	0.30	0.30	0.76	Not Applicable
10% Improvement *R1*	0.33	0.33	0.30	0.30	0.78	2.7%
10% Improvement *R2*	0.30	0.30	0.33	0.30	0.77	1.4%

These effects are used to apply relative strengths to the elements in the model. In the foregoing system reliability equations, the exponents correspond to the number of physical units. Similarly, the strength values in Table 4.3 are used as exponents in the model reliability equations (described in more detail in Section 4.1.2.4). Those with higher than average importance are therefore treated similarly to a physical subgroup of components having relatively more units, and those with lower than average importance like a group having relatively fewer units. Unlike the analysis of a physical system, however, it is not necessary to use whole numbers for the strength values in the model. The strength of each element is then directly proportional to its relative importance, as derived from the results of the safety expert survey.

4.1.2.3 Influence of senior elements on junior factors

The model philosophy proposes that external elements affect corporate decisions and actions, and these, in turn, influence items which directly affect the accident process. An example would be the multiple positive effects of operating in a regime with a higher than average value placed on life. The effects of operating in such a region would include increased pressure on the organisation to improve safety culture and training procedures, which in turn would result in improvements in such things as staff attitude and motivation, safety design, and personal protective equipment.

The inter-layer influencing effects have been accounted for in the calculation. Using an approach similar to that proposed by Sadiq (2003), matrices of influence coefficients have been developed (see Table 4.6, external – corporate interface matrix), which cause lower level elements to be appropriately adjusted whenever the higher level elements change.

For example, the reliability of safety culture is automatically increased with increases in the values associated with either value placed on life, price of oil, shareholder pressure, or royalty regime. The values in the influence coefficient matrices have been determined on the basis of the expert survey questionnaire (See Section 3.5 for further comments).

Table 4.6 – Influence coefficients

External – Corporate Influencing Coefficients			
	Normalised Scores		
	Training	Procedures	Safety Culture
Value placed on life	0.43	0.43	0.44
Price of oil	0.18	0.19	0.18
Shareholder pressure	0.27	0.26	0.25
Royalty regime	0.12	0.12	0.12

The specific calculation is as follows. Each more junior element's reliability is the sum of the products of (i) the reliability and (ii) the associated influencing coefficient of those more senior elements considered to have an influence on the junior element. For example, safety training, as shown in Table 4.6, is considered to be affected by value placed on life (43%), price of oil (18%), shareholder pressure (27%), and royalty regime (12%). Assuming, for the purposes of this example only, the reliabilities of those factors to be 0.60, 0.50, 0.40, and 0.60, safety training reliability would be calculated as shown in Table 4.7.

Table 4.7 – Method of element influence on junior elements

Safety Training Reliability	Component reliability	Influencing coefficient	(Component reliability) × (influencing coefficient)
Value of life	0.60	0.43	0.26
Price of oil	0.50	0.18	0.09
Shareholder pressure	0.40	0.27	0.11
Royalty regime	0.60	0.12	0.07
Sum of the products = reliability value			0.53

This process is repeated for all elements at the external – corporate interface and most at the corporate – direct interface. Whilst all of the corporate factors are considered to be influenced to some degree by each of the external elements, three of the direct elements (intelligence, coordination, and weather) are considered to be independent variables and hence require direct input.

Note that this process does not preclude the adjustment of any element reliability based on stand alone specific changes made in the respective area. For example, improvements in personal protective equipment may be made in isolation of any changes in the corporate or external elements.

4.1.2.4) The reliability calculation

Overall system reliability is a function of the direct layer components' reliabilities. If the direct element reliabilities are known, the overall system reliability can be calculated directly. Otherwise, external or corporate component reliabilities can be used to determine the direct component values using the method described in Section 4.1.2.3. The latter is consistent with the work's general philosophy of accidents being caused directly at the workplace, but being affected by corporate and external elements. Once values for component reliabilities have been determined (discussed elsewhere), the equation for calculating system reliability is as follows.

$$R_{sys} = (R_b)^{sb} \times (R_c)^{sc} \times (R_w)^{sw} \times (R_{sd})^{ssd} \times (R_{ppe})^{sppe} \qquad (4.3)$$

where:

$R_b =$ Reliability of behaviour $\quad sb =$ strength of behaviour

$R_c =$ Reliability of capability $\quad sc =$ strength of capability

$R_w =$ Reliability of weather $\quad sw =$ strength of weather

$R_{sd} =$ Reliability of safety design $\quad sd =$ strength of safety design

$R_{ppe} =$ Reliability of personal protective equipment $\quad sppe =$ strength of personal protective equipment

R_w (reliability value for weather conditions) is a ***direct input*** (i.e. it is an independent variable not based on the values of other elements). Reliabilities of the other elements are calculated as follows:

Behaviour: $$R_b = (1 - (1-R_a)^{sa} \times (1-R_m)^{sm}) \qquad (4.4)$$

composed of:

Attitude : $$R_a = R_t \times I_{ta} + R_{pr} \times I_{pra} + R_{sc} \times I_{sca} \qquad (4.5)$$

and

Motivation: $$R_m = R_t \times I_{tm} + R_{pr} \times I_{prm} + R_{sc} \times I_{scm} \qquad (4.6)$$

where:

$R_t =$ Reliability of training (defined below)

$R_{pr} =$ Reliability of safety procedures (defined below)

$R_{sc} =$ Reliability of safety culture (defined below)

$I_{ta} =$ Influence coefficient of safety training on attitude

$I_{pra} =$ Influence coefficient of safety procedures on attitude

$I_{sca} =$ Influence coefficient of safety culture on attitude

$I_{tm} =$ Influence coefficient of safety training on motivation

$I_{prm} =$ Influence coefficient of safety procedures on motivation

$I_{scm} =$ Influence coefficient of safety culture on motivation

$sa =$ Strength of attitude

$sm =$ Strength of motivation

Safety Training : $$R_t = R_{po} \times I_{pot} + R_{sp} \times I_{spt} + R_{rr} \times I_{rrt} + R_{vl} \times I_{vlt} \tag{4.7}$$

Safety Procedures: $$R_{pr} = R_{po} \times I_{popr} + R_{sp} \times I_{sppr} + R_{rr} \times I_{rrpr} + R_{vl} \times I_{vlsp} \tag{4.8}$$

Safety Culture: $$R_{sc} = R_{po} \times I_{posc} + R_{sp} \times I_{spsc} + R_{rr} \times I_{rrsc} + R_{vl} \times I_{vlsc} \tag{4.9}$$

where :

$R_{po} =$ Reliability of price of oil (***direct input***)

$R_{sp} =$ Reliability of shareholder pressure (***direct input***)

$R_{rr} =$ Reliability of royalty regime (***direct input***)

$R_{vl} =$ Reliability of value of life (***direct input***)

$I_{pot} =$ Influence coefficient of price of oil on safety training

$I_{spt} =$ Influence coefficient of shareholder pressure on safety training

$I_{rrt} =$ Influence coefficient of royalty regime on safety training

$I_{vlt} =$ Influence coefficient of value of life on safety training

I_{popr} = Influence coefficient of price of oil on safety procedures

I_{sppr} = Influence coefficient of shareholder pressure on safety procedures

I_{rrpr} = Influence coefficient of royalty regime on safety procedures

I_{vlpr} = Influence coefficient of value of life on safety procedures

I_{posc} = Influence coefficient of price of oil on safety culture

I_{spsc} = Influence coefficient of shareholder pressure on safety culture

I_{rrsc} = Influence coefficient of royalty regime on safety culture

I_{vlsc} = Influence coefficient of value of life on safety culture

Capability: $R_c = (R_p)^{sp} \times (R_{me})^{sme}$ (4.10)

composed of:

Physical capability: $R_p = (1 - (1-R_f)^{sf} \times (1-R_{lf})^{slf} \times (1-R_c)^{sc})$ (4.11)

composed of:

Fitness : $R_f = R_t \times I_{tf} + R_{pr} \times I_{prf} + R_{sc} \times I_{scf}$ (4.12)

Lack of fatigue: $R_{lf} = R_t \times I_{tlf} + R_{pr} \times I_{prlf} + R_{sc} \times I_{sclf}$ (4.13)

and

Coordination: $R_c = \textit{direct input}$

where :

I_{tf} = Influence coefficient of safety training on fitness

I_{prf} = Influence coefficient of safety procedures on fitness

I_{scf} = Influence coefficient of safety culture on fitness

I_{tlf} = Influence coefficient of safety training on lack of fatigue

I_{prlf} = Influence coefficient of safety procedures on lack of fatigue

I_{sclf} = Influence coefficient of safety culture on lack of fatigue

$sp =$ Strength of physical capability

$sme =$ Strength of mental capability

$sf =$ Strength of fitness

$slf =$ Strength of lack of fatigue

$sc =$ Strength of coordination

Mental capability : $R_{me} = (1 - (1-R_k)^{sk} \times (1-R_i)^{si})$ (4.14)

composed of :

Knowledge : $R_k = R_t \times I_{tk} + R_{pr} \times I_{prk} + R_{sc} \times I_{sck}$ (4.15)

and

Intelligence: $R_i = \textit{direct input}$

where :

$I_{tk} =$ Influence coefficient of safety training on knowledge

$I_{prk} =$ Influence coefficient of safety procedures on knowledge

$I_{sck} =$ Influence coefficient of safety culture on knowledge

$sk =$ Strength of knowledge

$si =$ Strength of intelligence

Safety Design : $R_{sd} = R_t \times I_{tsd} + R_{pr} \times I_{prsd} + R_{sc} \times I_{scsd}$ (4.16)

where :

$I_{tsd} =$ Influence coefficient of safety training on safety design

$I_{prsd} =$ Influence coefficient of safety procedures on safety design

$I_{scsd} =$ Influence coefficient of safety culture on safety design

PPE : $R_{ppe} = R_t \times I_{tppe} + R_{pr} \times I_{prppe} + R_{sc} \times I_{scppe}$ (4.17)

where :

I_{tppe} = Influence coefficient of safety training on PPE

I_{prppe} = Influence coefficient of safety procedures on PPE

I_{scppe} = Influence coefficient of safety culture on PPE

4.1.2.5) Expected number of accidents

Once system reliability has been calculated, the expected number of accidents for a unit time (usually taken as one year) is calculated according to the reliability formula (Billinton and Allan, 1983) shown below.

$$R(t) = \exp\left[-\int_0^t \lambda dt\right] = e^{-\lambda t}, \qquad t > 0 \tag{4.18}$$

where

R = system reliability at time t

λ = average failure (accident) rate

Taking natural logarithms of both sides and setting $t = 1$, we get:

$$\lambda = -\ln(R) \tag{4.19}$$

This approach, in principle, assumes a relatively constant failure rate over the period. The typical relationship between failure rate and time for physical components (Billinton and Allan, 1983) is illustrated in Figure 4.10. The failure rate is usually initially relatively high, until such time as initial inherent problems have been resolved. Following this, a period of constant failure rate is experienced, until component wear-out results in an increasing rate. It is during the middle period (sometimes called useful life) of constant failure rate that the foregoing equation is valid.

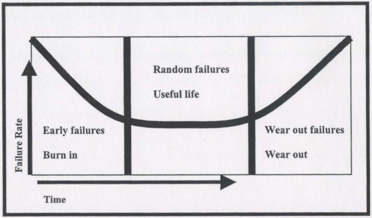


Figure 4.10 – Failure rate versus time – the "bathtub" curve

Applying this philosophy to the offshore occupational accident situation, the analogy could be drawn that, before accident causation became relatively well understood, the accident rate was relatively high. However, evidence exists to confirm that the industry accident rate has reached a relatively constant state. There is an obvious flattening of the FAR curve between 1999 and 2003, as shown in Figure 4.11, and the average slope of the TRIR curve from 1999-2003 is 26% less than the average between 1995 and 1999. These results support the constant failure rate assumption required above.

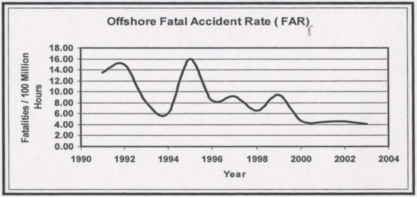


Figure 4.11 – Overall oil and gas fatal accident rate versus time

4.1.2.6) The cost of accidents – input to management decisions

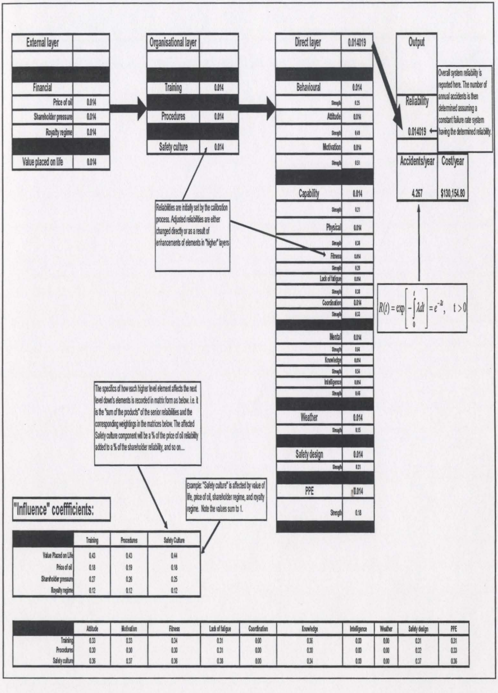
Accidents are costly – this is a well known fact in the offshore oil and gas industry which has been discussed in Section 2.4.3. The model provides an easy method to evaluate cost savings associated with accident frequency reduction, and, conversely, costs associated with accident frequency increase. Incremental financial rewards can be immediately observed upon improvements made in individual components, facilitating safety spending optimisation.

This feature offers a tool to aid sound management decision-making related to safety programmes. For example, the model could be run several times, with each scenario assuming a different relative improvement in various components' performance, for example a 20% improvement in safety design effectiveness or a 10% improvement in safety training effectiveness. The model would predict, for each scenario, the associated accident frequency improvement, and the cost associated with that level of accident frequency. The operator will have gained, through experience, a good idea of the costs of making the respective component improvements, and will thereby be able to make decisions in full knowledge of both the implementation and effect sides of the equation. Similarly, model runs can be used to show the costs associated with increased accident frequency upon relaxation of various safety initiatives. It is understood that a cost benefit analysis such as this will be just one input to decisions related to safety, which may affect worker well being.

The model assumes that an average offshore accident will have costs as detailed in Table 4.8 (Attwood, 2005). It has been assumed that the injured worker remains unable to work for an average period of two weeks. The cost element is determined by multiplying the cost of an accident by the expected number of accidents.

Table 4.8 – Occupational accident cost

Element	Cost ($ Canadian)
First Aid	500.00
Procure and provide replacement worker	2500.00
Salary cost of replacement worker	7000.00
Management time in replacement	3500.00
Accident investigation costs	4500.00
Rehabilitation costs	2500.00
Reputational cost	10,000.00
Total	**30,500.00**



External layer	
Financial	
Price of oil	0.014
Shareholder pressure	0.014
Royalty regime	0.014
Value placed on life	0.014

Organisational layer	
Training	0.014
Procedures	0.014
Safety culture	0.014

Direct layer	0.014019
Behavioural	0.014
Strength	0.25
Attitude	0.014
Strength	0.49
Motivation	0.014
Strength	0.51
Capability	0.014
Strength	0.21
Physical	0.014
Strength	0.36
Fitness	0.014
Strength	0.29
Lack of fatigue	0.014
Strength	0.38
Coordination	0.014
Strength	0.33
Mental	0.014
Strength	0.64
Knowledge	0.014
Strength	0.54
Intelligence	0.014
Strength	0.46
Weather	0.014
Strength	0.15
Safety design	0.014
Strength	0.21
PPE	0.014
Strength	0.18

Output	
Reliability	
0.014019	
Accidents/year	Cost/year
4.267	$130,154.80

Overall system reliability is reported here. The number of annual accidents is then determined assuming a constant failure rate system having the determined reliability.

$$R(t) = \exp\left[-\int_0^t \lambda dt\right] = e^{-\lambda t}, \quad t > 0$$

Reliabilities are initially set by the calibration process. Adjusted reliabilities are either changed directly or as a result of enhancements of elements in "higher" layers

The specifics of how each higher level element affects the next level down's elements is recorded in matrix form as below. i.e. it is the "sum of the products" of the senior relaibilities and the corresponding weightings in the matrices below. The affected Safety culture component will be a % of the price of oil reliability added to a % of the shareholder reliability, and so on...

Example: "Safety culture" is affected by value of life, price of oil, shareholder regime, and royalty regime. Note the values sum to 1.

"Influence" coeffficients:

	Training	Procedures	Safety Culture
Value Placed on Life	0.43	0.43	0.44
Price of oil	0.18	0.19	0.18
Shareholder pressure	0.27	0.26	0.25
Royalty regime	0.12	0.12	0.12

	Attitude	Motivation	Fitness	Lack of fatigue	Coordination	Knowledge	Intelligence	Weather	Safety design	PPE
Training	0.33	0.33	0.34	0.31	0.00	0.36	0.00	0.00	0.31	0.31
Procedures	0.30	0.30	0.30	0.31	0.00	0.30	0.00	0.00	0.32	0.33
Safety culture	0.36	0.37	0.36	0.38	0.00	0.34	0.00	0.00	0.37	0.36

Figure 4.12 – Model spreadsheet

4.2) Model calibration and specific case analysis

The accident frequency prediction process requires the model to be run in two distinct modes. First, a calibration run is executed, where known accident rates (in a situation where the safety conditions are also known) are used to determine base case component reliabilities. Second, the model is run in predictive mode following adjustment of the base case component reliabilities. The degree of adjustment is determined using a quantified comparison of safety conditions in the specific and base cases, which requires expert input from safety personnel familiar with both situations. In many applications, the global average safety situation, with documented results and generally known conditions, is used as the base case. This section details the process of running the model in both calibration (base case) and predictive (specific case) modes.

4.2.1) Calibration

The goal of the calibration process is to determine base case component reliabilities. Any situation where both safety results and safety conditions are known can be chosen as the base case. However, because the subsequent predictive model run requires a comparison of specific and base cases, a convenient base case option is the average global offshore industry. Global average safety results are available, and in most cases experienced safety experts can offer a reasonable comparison of specific case conditions for any factor with the global average situation for that element. The remainder of the discussion in Section 4.2 is based on the assumption of global average conditions as the base case.

The type of accident statistic used for calibration depends on which output statistic is desired. For example:

- If a particular (total recordable, lost time) accident *rate* in a region or industry sector is sought, then the corresponding global average value of that particular rate is used for calibration.
- If the expected annual *number* of a specific kind of accident (total recordable, days away from work) on an installation having a given POB (persons on board) is required, then the global average rate of that type of accident is combined with the POB to determine accident numbers expected had the facility been operating under average safety conditions.

An example of the latter type of calibration calculation is presented here. The most all-encompassing (and therefore most appropriate for calibration) data source for global average results is the annually released International Oil & Gas Producers (OGP) database. Table 4.9 shows data for several types of accidents for 2003.

Table 4.9 – OGP 2003 average accident rates

Statistic	Value
Offshore fatal accident rate (per 100,000,000 hours)	4.16
Offshore lost time injury frequency (per 1,000,000 hours)	1.27
Offshore total recordable incident rate (per 1,000,000 hours)	4.87

In this example it is assumed that the desired model output is installation specific annual number of recordable incidents. Therefore, the global average TRIR value (4.87) is used for calibration. Had we been interested in fatalities or lost time injuries, then the value 4.16 or 1.27 respectively would have been used (remembering that fatal accident rate, contrasting with the others, is reported per *100 million* hours worked).

On a 200 POB installation operating twenty four hours per day, as most do, approximately 100 persons will be working at any given time, while their counterparts rest. The number of person-hours worked per year for the platform is then calculated as below.

Person-hours worked = (100 persons) × (24 hours/day) × (365.25 days/year) =

876,600 person-hours

Based on the 2003 TRIR (4.87/1,000,000 hours), the expected number of installation specific annual recordable cases under average safety conditions is then calculated as follows.

Expected number of recordable cases =

(876,600 person-hours) × (4.87/1,000,000 person-hours) = 4.27 cases

This figure is then used to calibrate the model for average safety conditions. An iterative process is used to determine the individual component reliabilities required for the model to have predicted this number of annual accidents. Software tools (goal-seek function in Microsoft Excel) are available to make the exercise a quick and easy affair.

It is worth mentioning that the calibration process results in the assignment of equal base case reliabilities to all components. This result is based on two issues – the choice of the input component reliabilities used to initiate the calibration process, and the mechanics of the subsequent calculation of the remaining components' reliabilities. These issues, and their implications for the prediction process, are discussed below.

- In calibration mode, the model takes as its inputs those components which are independent of other (higher level) components, namely (i) the four external elements, and (ii) those direct elements (weather, intelligence, and coordination) which are not influenced by either corporate or external factors. Because the calibration run is typically concerned with global average conditions, there is no basis for setting these inputs at values different from one another. It cannot be confidently or precisely established, for example, that the global average royalty regime reliability indicator should be set at a different value than the global average shareholder pressure indicator. Assigning equal values to all calibration input reliabilities is a valid starting premise, considering the global average nature of the calibration run.

- Turning to the second issue mentioned above, and recalling the discussion of Section 4.1.2.3, the reliabilities of junior elements are dependent upon, indeed made up of, the values of their next higher level counterparts. Therefore, once the input external elements (and the independent direct elements) are set at equal values, the dependent corporate and direct components, which are based on them, become equal also.

Many sets of component reliabilities could produce the output required for *calibration* purposes. However, since model execution is based on a quantified *comparison* of specific and base cases, the absolute values of base case component reliabilities are not important. What is crucial, though, is the scale of their subsequent expert judgement based adjustments applied for the predictive run. The establishment of different component reliabilities at calibration would be an unnecessary complication to the process. This would be the case even if the base case was not global average conditions. The model requires a comparison of specific case to base case, not absolute reliability values.

An exception to the requirement to perform a base case calibration is when a prediction of the effect of *iterative change* is required. A good example of this would be when a prediction of year on year safety result changes on a specific installation or within the same region is desired. Assuming a comparison to global average conditions was used to make the initial prediction, and (different) component reliabilities for subsequent years had been established (The method for doing this is described in the next section.), the following year's predictions can be made by simply adjusting the previous year's component reliabilities to reflect the new conditions.

4.2.2) Specific case runs

To predict accident frequency for a specific case, the model is run following adjustment of the base case component reliabilities in line with the safety environment of the installation or sector under study.

The degree of component reliability adjustment is based on the opinion of experts familiar with both base (average global) and specific case safety conditions. The experts assign scores from one to ten for each factor, representing the component's specific case conditions, compared to global average, which is represented by a score of five. Higher scores, in all cases, represent situations more favourable to safety results – for example a high score on royalty regime corresponds to a situation where the government takes relatively less money in royalties, thereby leaving more free cash for operators to spend on everything, including safety measures. Likewise, a lower score (i.e. less than five) corresponds to a regime where more than average cash is taken by the government, leaving relatively less for safety spending. A high score on PPE would indicate that the specific case's quality of safety equipment was considered superior to global average.

At first glance it would seem reasonable to adjust component reliabilities in direct proportion to the experts' assigned scores. Using this system, a score of 6 for a given component would result in the base case reliability being multiplied by 6/5, or 1.2, whilst a score of 10 would result in a doubling of base case reliability (10/5 = 2). However, other functions can be used to transform the expert panel's subjective observations to factors used to adjust the base case reliabilities. The literature (Ott, 1978) describes the design of several alternative mechanisms for transforming subjective observations such as these to useful indices. For example, the use of power functions to generate indices for water quality, based on pollutant variables, is proposed.

For the present application, results were seen to be improved (Chapter 5 describes model accuracy) by considering the importance of scores further away from the mean to be greater than that for more centralised results, in effect magnifying extreme values' effects beyond that applied when using a directly proportional approach. This is done by using a "power 2" function, in other words making the changes (in component reliability in this case) proportional to the square of the ratio of specific case to average case score (5). For example, an assigned score of 6 would produce a component reliability increase of $(6/5)^2 = 1.44$ and a score of 10 would produce a component reliability increase of $(10/5)^2 = 4$. Note that the difference between squared increases and the directly proportional approach is only 20% (1.44/1.2) for values relatively close to the mean (6), but the difference is 100% (4/2) at the extreme value (10). This process has the effect of making the importance directly proportional to the magnitude of the score. The use of powers greater than 2 makes the process overly sensitive to extreme values and is therefore to be avoided.

Once a panel has been established to determine specific case component reliabilities (using the method described above), accident frequency predictions can be made by running the model in either of three distinct ways.

- Direct layer component reliabilities can be input and system reliability and accident frequency calculated directly.
- Corporate component reliabilities can be input and allowed to determine the direct layer values using the process described in Section 4.1.2.3. (remembering that weather, intelligence and coordination are independent from corporate or external effects and require direct input). Following determination of the direct layer reliabilities, the calculation proceeds as in the previous method.
- External reliabilities can be input and allowed to determine the corporate values and, in turn, the direct values, facilitating the calculation as previously.

In general, if specific case expert scores are known for all components, the model is run using all three methods, with the final prediction taken as the average of the three results.

4.3) Parametric analysis

In order to evaluate and illustrate the *relative* importance of individual elements to accident frequency, runs have been executed with several individual component base case reliabilities increased by the same amount (30%). A spreadsheet showing the runs has been included as Figure 4.15. It is not surprising that the most influential factor is value placed on life, since, as can be seen in the influencing coefficient matrix shown in Table 4.6, it heavily affects all three corporate elements, which in turn affect most of the direct layer elements. The effects produced by improvements in individual direct layer elements such as lack of fatigue are not as great, as would be expected.

Figure 4.13 shows the effect on base case accident frequency as several individual component reliabilities are increased by 30%. The greatest reduction is seen with improvements in value placed by society on life, which is explained by the knock-on effect mentioned above. The next most important elements of those presented are safety culture and safety design. Safety culture significantly influences the direct level elements, and safety design improvements prove more influential than price of oil, weather, and lack of fatigue. The latter is due to the following considerations.

- Safety design (0.21) carries a higher strength value than weather (0.15) as derived from the survey of safety experts.
- Lack of fatigue is one of three components of physical capability, which in turn is one of two components of the main direct factor "capability". Safety design, however, is a main direct factor all on its own. Therefore, a given improvement in safety design will produce a greater effect on accident frequency than a similar

improvement in lack of fatigue. Furthermore, physical capability, which includes lack of fatigue, has been assigned a relatively lower strength value (0.36) than mental capability (0.64).

- Price of oil was assigned lower influencing coefficients (reference Table 4.6) than two of its three external layer competitors. Its ability to influence lower layer elements is therefore relatively low.

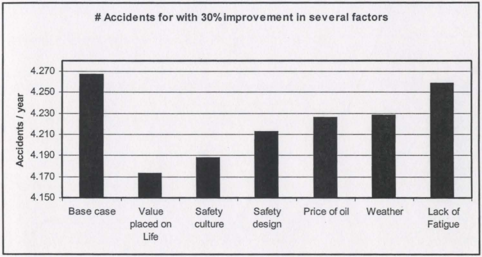


Figure 4.13– Number of accidents with 30% improvement in several factors

The results show how the assigned component strengths and influencing values heavily affect individual components' abilities to affect system output reliability, in much the same way that changing the characteristics of individual safety elements having varying importance within a real safety programme will produce different accident frequencies.

These results confirm the significant safety benefits operators could expect when moving to a region with a comparatively higher societal value placed on life. In some cases, powerful operators may try, for many reasons, to actually change societal attitudes in the regions in which they operate, especially when the area suffers from considerable poverty and its associated social problems. However, attempts to do this represent a reversal in the natural direction of influence proposed by the model. In general, external factors affect companies, not the other way around. Furthermore, even the most powerful operator would likely struggle to produce a 30% change in this factor. On the other hand, organisations have it within their power to produce a 30% enhancement in things such as safety design, safety culture, and (lack of) worker fatigue.

The results also emphasize the difficulties organisations face when oil and gas reserves are discovered in regions where societal value of life is lower than that in more developed locations. This will continue to be a challenge for operators as reserves in more safety conscious areas are gradually depleted.

Figure 4.14 shows cost savings realised with 30% reliability improvements in the same six individual components. In the current financial environment where the price of a barrel of oil exceeds USD $50, possibly the only value which would get the attention of a major operator is that obtained with a 30% improvement in the value placed on life element. Under the assumptions made here, the financial benefits are not compelling arguments for improvements. Still, there appears to be a higher value attached to excellent safety outcomes than would be explained by these modest financial rewards. The value of political goodwill and other intangible benefits are not included in the model output, although they may be valued significantly more than the financial ones.

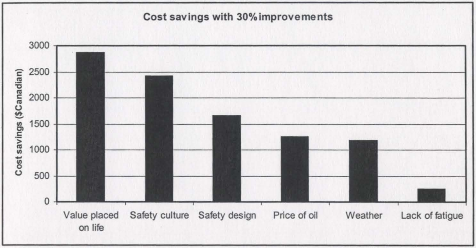
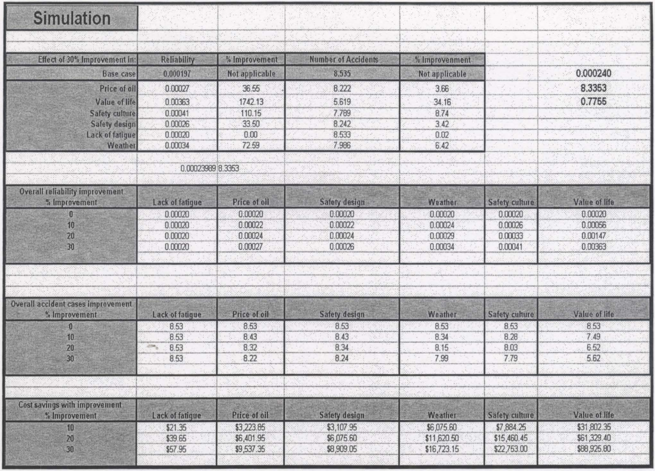


Figure 4.14 – Cost savings versus individual component reliability improvement



Simulation

Effect of 30% Improvement in:	Reliability	% Improvement	Number of Accidents	% Improvenment		
Base case	0.000197	Not applicable	8.535	Not applicable		0.000240
Price of oil	0.00027	36.55	8.222	3.66		8.3353
Value of life	0.00363	1742.13	5.619	34.16		0.7755
Safety culture	0.00041	110.15	7.789	8.74		
Safety design	0.00026	33.50	8.242	3.42		
Lack of fatigue	0.00020	0.00	8.533	0.02		
Weather	0.00034	72.59	7.986	6.42		

0.00023989 8.3353

Overall reliability improvement % Improvement	Lack of fatigue	Price of oil	Safety design	Weather	Safety culture	Value of life
0	0.00020	0.00020	0.00020	0.00020	0.00020	0.00020
10	0.00020	0.00022	0.00022	0.00024	0.00026	0.00056
20	0.00020	0.00024	0.00024	0.00029	0.00033	0.00147
30	0.00020	0.00027	0.00026	0.00034	0.00041	0.00363

Overall accident cases improvement % Improvement	Lack of fatigue	Price of oil	Safety design	Weather	Safety culture	Value of life
0	8.53	8.53	8.53	8.53	8.53	8.53
10	8.53	8.43	8.43	8.34	8.28	7.49
20	8.53	8.32	8.34	8.15	8.03	6.52
30	8.53	8.22	8.24	7.99	7.79	5.62

Cost savings with improvement % Improvement	Lack of fatigue	Price of oil	Safety design	Weather	Safety culture	Value of life
10	$21.35	$3,223.85	$3,107.95	$6,075.60	$7,884.25	$31,802.35
20	$39.65	$6,401.95	$6,075.60	$11,620.50	$15,460.45	$61,329.40
30	$57.95	$9,537.35	$8,909.05	$16,723.15	$22,753.00	$88,925.80

Figure 4.15 – Model simulation data

4.4) Model demonstration

The model can be used for many purposes. Three hypothetical examples are presented in this section. The first compares safety results in an ideal situation to those obtained in a worst case scenario. Two subsequent examples show how the model can be used to predict changes in occupational accident probability as an asset moves through different stages in its operational life, i.e. from off hire to operating in a given regime, or during the de-mobilisation process.

4.4.1) Example 1 – Ideal situation versus worst case scenario

This case considers a drilling contractor interested in comparing predicted safety results under the opposite extremes described below:

Ideal Case:

- The society in the operating region places a high value on life.
- The client demands, and is offered, the very best safety equipment, procedures, and training schemes.
- The weather conditions are benign.
- The available workforce has a generally cautious attitude toward safety issues.
- The price of oil is at a relatively high level.

Worst Case:

- The society in the operating region places a less than average value on life.
- The client is interested in developing a marginal field and is therefore satisfied with safety equipment, procedures, and training schemes which (only) comply with regulatory requirements.

- The weather conditions are extreme.
- The workforce is categorised as generally more risk-taking than average.
- The price of oil is at a relatively low level.

The model can be used to predict the number of accidents under these two extremes, as compared to average conditions. To do this the model is run three times:

1. a base case with all factor reliabilities set at average value
2. an ideal case where all factor reliabilities are set at average value + 20%
3. a worst case scenario where all factor reliabilities are set at average value – 20%

The result is shown in Figure 4.16.

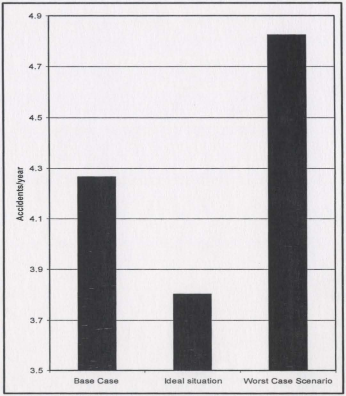


Figure 4.16 – Opposite extremes

The actual figures resulting from these extremes (4.8 for worst case versus 3.8 for ideal) indicate that for a 200 POB (persons on board) platform, one less accident per year is predicted for the ideal situation than for the worst case scenario. Assuming an average accident (Attwood, 2005), the cost saving associated with this would be about CAD $30K, which is not very significant in today's world of oil company finance. Things would be very different, however, from many perspectives, if the accident which was avoided turned out to be a fatality. On a percentage basis, a 21% improvement in safety results is achieved when the change from worst to best case conditions is made.

4.4.2) Example 2 – Rig hired and moved to location

The model can be used to predict changes in safety results as an asset moves through stages in its life cycle. For mobile drilling units (MDU), a typical cycle includes idle time, hiring, mobilisation, operating, and de-mobilisation. The corresponding stages for a fixed installation include construction, installation, commissioning, operating, and decommissioning. The examples in this and the next section concern an MDU.

Upon hire of an idle MDU, an operator will specify things such as operational and training requirements, safety targets, etc., all of which will affect safety results. The drilling location will be specified, and this will determine the reliability values assigned to weather, value placed by society on life, and royalty regime. Furthermore, crew make-up will affect safety results. In most cases operators will be required by national legislation to employ local workers for most jobs. If this is not the case, however, some operators prefer to avoid the perceived risk associated with using a local workforce that may, for many reasons, be more likely to experience accidents than a group more familiar with the operator, the unit, and the offshore business. Alternately, occasionally operators prefer to replace an underperforming crew with one having the benefit of working under a more positive safety culture. Either way, crew make-up will affect safety results.

The specific case studied considers an MDU as it transforms from an idle condition to one where enhanced safety procedures and training programme are implemented, a workforce with superior safety attitude is hired, better PPE is purchased, and the vessel moves to a harsh weather area where societal value placed on life is lower than average. To predict changing accident frequency under this scenario, the model is run seven times - once for each of the changes in situation indicated below. The changes are sequential, and factor reliabilities are not reset to average values between runs.

1. base case – all factors set at average value
2. improve safety procedures – this factor adjusted to base case + 20%
3. improve safety training process – this factor adjusted to base case + 20%
4. take on staff with superior safety attitude – this factor adjusted to base case + 20%
5. purchase enhanced PPE – this factor adjusted to base case + 20%
6. move to region with lower than average value placed on life – this factor adjusted to base case – 20%
7. move to area with poor operating (weather) conditions – this factor adjusted to base case – 20%

The results are shown in Figure 4.17.

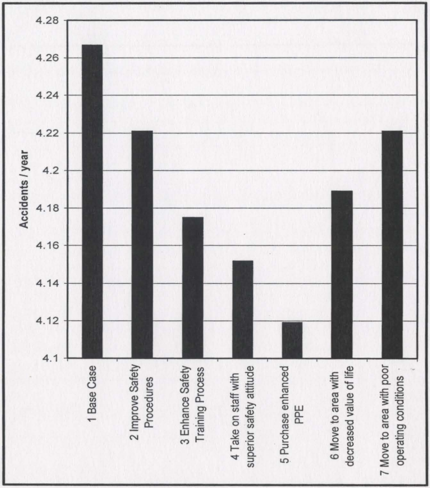


Figure 4.17 – Accidents versus position in hiring /operational cycle

Note that the number of predicted accidents reduces with each positive change, but moving to an area with lower than average value placed on life and harsh weather conditions returns the value close to the original prediction.

4.4.3) Example 3 – Rig taken off-hire

This case studies accident probability as a rig is taken off hire. The scenario includes the replacement of a local crew with one more familiar with the rig and its safety arrangements (and accordingly exhibits improved capability and behaviour), rig movement from harsh to calmer weather conditions, and a company decision to abandon enhanced safety training and procedures.

To predict changing accident frequency, the model is run five times - once for each of the changes indicated below. The base case in this scenario is taken to be the on hire condition – subsequent runs predict incremental changes in accident rate from this base case. As before, the changes are sequential, and factor reliabilities are not reset to average values between runs.

1. base case – all factors set at average value
2. replace unfamiliar crew with one more familiar with rig – behaviour and capability factors adjusted to base case + 20%
3. return to benign weather conditions - this factor adjusted to base case + 20%
4. abandon enhanced safety training - this factor adjusted to base case - 20%
5. abandon enhanced safety procedures – this factor adjusted to base case - 20%

The results are shown in Figure 4.18.

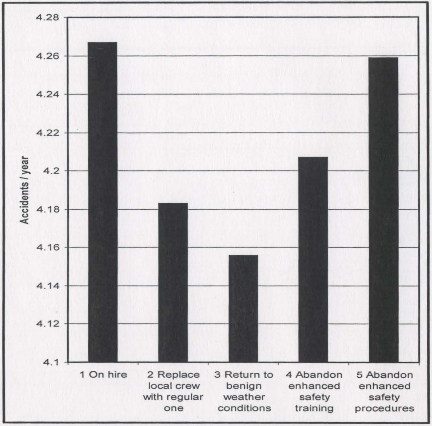


Figure 4.18 – Rig taken off hire

The number of predicted occupational accidents is reduced upon crew replacement and weather improvement, but again approaches the on-hire levels with the abandonment of the enhanced safety training and procedures.

5

Application to the Canadian and Gulf of Mexico offshore oil and gas industries

5) Application to the Canadian and Gulf of Mexico offshore oil and gas industries

Application of the model to two producing Canadian offshore oil and gas installations and the Gulf of Mexico drilling business is described in this chapter*. The data (and its sources) required to run and validate the model for these cases are discussed. Required input data included both published accident statistics, used to calibrate the model for base cases, and quantified expert opinion, used to run the model for actual cases. Published data were also used to evaluate the accuracy of outputs and thereby validate the model. The general methodology for the case studies is detailed, followed by a discussion of each case.

5.1) Model input and validation data

Application of the model to real situations requires input data. Evaluation of the resulting predictions requires actual results for comparison. The specific data requirements were as follows.

- global average accident rates - to calibrate the model
- installation or sector specific expert opinion with respect to existing safety programmes – to appropriately adjust base case component reliabilities and thereby facilitate the model prediction process
- region specific accident rates - to estimate safety results on specific installations or within industry sectors, which are used to evaluate model prediction accuracy

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* Attwood, D, Khan, F, and Veitch, B, 2005d. Predicting offshore occupational accident frequency – a practical demonstration using case studies. Accepted for publication in *Process Safety Progress*, AIChE.

This section provides summaries of (i) the databases from which accident data were extracted and (ii) the qualifications of the panel members used to score the elements of the specific safety programmes under consideration (compared to global average conditions).

5.1.1) Data sources

Data for the calibration portion of model application were publicly available. For model validation, the ideal data would have been installation specific accident frequencies, since they would have provided an opportunity to directly compare predictions with specific platform results. However, operators are reluctant to release this information. In general, the data are released only when operators are legally obliged to do so, and only to those parties authorised to have it. For this research, all operators of producing installations in eastern Canada were requested to provide installation specific data. Despite an offer to keep installation and operator names confidential, all operators refused the request. In the absence of operator-supplied platform specific data, the next best thing was to use statistics published by the provincial petroleum boards to estimate accident frequencies on the installations. Because there is but a single operating project in Nova Scotia and two in Newfoundland, these data provide a good approximation to installation specific values.

Listed below are the data sources which have been used to (i) calibrate the model for average conditions and (ii) evaluate the subsequent predictions.

- The International Association of Oil and Gas Producers (OGP, 2005) global TRIR statistics.
- The Canada-Nova Scotia Offshore Petroleum Board (CNSOPB, 2005) and the Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOPB, 2005) annual TRIR values for the Nova Scotia and Newfoundland offshore areas respectively. The Nova Scotia data are split into installations, vessels, and aviation, but the Newfoundland and Labrador data cover all offshore activity.
- The International Association of Drilling Contractors (IADC, 2005) LTIR data for offshore drilling activities for several regions (for example USA, Canada, Africa).

A summary of the data used for calibration and validation is shown in Table 5.1.

Table 5.1 – Accident rates

	2000	**2001**	**2002**	**2003**	**2004**	**2005**
Global Offshore TRIR (OGP)	8.84	6.85	5.77	4.87	6.36	
Nfld Offshore TRIR (CNLOPB)	10.16	9.49	8.04	11.45	4.36	
NS Installations TRIR (CNSOPB)	5.60	3.35	6.40	3.35	5.95	
Gulf of Mexico LTIR (IADC)		3.35	2.52	2.57	2.11	1.96
Global Drilling LTIR (IADC)		3.09	2.71	1.81	1.56	1.92

5.1.2) The panel

Satisfactory model output accuracy requires a quality comparison of the specific case's safety situation with global average conditions. This can be provided only by qualified safety professionals having both specific project or region experience, and a significant international offshore background. The present panel had both project-specific and general experience in safety design, project management, and offshore surveying. The members averaged eighteen years of oil and gas industry experience, ensuring that the group could draw from a sufficient depth of relevant knowledge. Details of the panel's experience are as follows:

- surveyor one – thirty-five years oil and gas experience, the past eight surveying Canadian oil and gas projects
- surveyor two – ten years oil and gas experience, the past five surveying Canadian oil and gas projects
- project manager one – twenty three years oil and gas experience, most of the past fourteen spent surveying and project managing Canadian and US projects
- project manager two – eighteen years oil and gas experience, the past three spent surveying and project managing Canadian oil and gas projects
- project manager three – three years oil and gas experience, all spent project managing Canadian and US oil and gas projects
- safety design appraisal specialist – twenty five years oil and gas experience, the past eight partially spent appraising safety designs on Canadian and US projects

5.2) Case studies

Three case studies are described in this section, as follows:

- A comparison of predicted and actual annual accident occurrence on a Nova Scotia based production installation
- A comparison of predicted and actual annual accident occurrence on a Newfoundland based production installation
- A comparison of predicted and actual lost time incident (LTI) rate in the Gulf of Mexico drilling business

5.2.1 General methodology

The general process for running the model was discussed in Section 4.2. The specific methodology for these case studies was as follows.

1. In cases one and two, published global average accident rates (OGP) were used to estimate how many accidents would have occurred on the installations had they been operating under average conditions. In case three, the global average accident *rate* was directly available from the published data (IADC).
2. Using the results obtained in Step 1, a calibration run was executed to calculate component reliabilities which would have produced the average conditions, thereby producing base values for the component reliabilities.
3. Each component reliability was then adjusted according to the location-specific scoring assigned to each factor by the expert panel as the members compared the specific situation to global average (using a 1-10 scale and assuming 5 = global average).

4. The model, using the updated component reliabilities, then predicted accident occurrence numbers or rate for the specific situations.
5. For cases one and two, published, region specific accident rates (CNSOPB, CNLOPB) were used to estimate the number of accidents likely to have been experienced on installations in the areas covered by the data. For case three, the region specific accident *rate* was directly available from published data (IADC). These were taken to be the actual values against which the predictions generated in Step 4 were evaluated.

A few additional details on the process are noteworthy, as follows.

Because of the subjective nature of the component scoring process, an analysis was conducted to study the sensitivity of output predictions to changes in individual component scorings. It was discovered that the greatest percentage change in prediction with a single step change (for example from 7 to 8) in any one component's score was less than 3%. This means that if the panel erred (Perhaps erred is too strong a word for this subjective activity.) by a single digit in its scoring of a specific component, the effect on accident frequency prediction would be relatively small. Furthermore, since (i) the *directions* (i.e. overrating versus underrating) of individual component scoring errors are expected to be equally divided and (ii) the prediction process relies on the scoring of multiple components, the effect of the errors is expected to cancel out. It was important for the panel to have an accurate general view of the overall situation, but a precise measure on each and every individual component is not essential. The opinion-based nature of the scoring process likely made such precision impossible in any event. Within the context of using expert opinion to produce a quantitative prediction of accident frequency, the effect of component scoring errors is considered to be acceptably small.

Three separate methods of using the model to determine accident frequency were discussed in Section 4.2.2. For these case studies, the experts' opinions allowed the calculation to be performed using either method. For comparison purposes, all three were used. The final accident prediction (Step 4) was taken as the average of the results from the three runs, which are described in principle below.

- Run 1 – the external element reliabilities were adjusted (from base case values) according to the assigned scores. The effect of this change spread through the corporate elements to the direct elements, thereby facilitating accident prediction.
- Run 2 - the corporate elements were adjusted according to the assigned scores. The effect of this change spread through the direct elements, thereby facilitating accident prediction.
- Run 3 – The direct elements were adjusted according to the assigned scores, thereby facilitating accident prediction

It is noted that three direct factors (weather, coordination, and intelligence) are not influenced by either corporate or external elements. Therefore, in all three runs, their adjusted reliabilities were determined by the expert panel's assigned scores.

5.2.2) Nova Scotia production installation

A Nova Scotia based 70 POB (persons on board) installation was chosen as a case study for the model. The data in Table 5.2 are discussed in this section.

Table 5.2 – Nova Scotia case study

		2000	2001	2002	2003	2004	Average
1	**Global average TRIR**	8.84	6.85	5.77	4.87	6.36	6.54
2	**Nova Scotia TRIR**	5.60	3.35	6.40	3.35	5.95	4.93
3	**Number of accidents (based on global average TRIR)**	2.71	2.10	1.77	1.49	1.95	2.00
4	**Number of accidents predicted by model**	2.26	1.65	1.32	1.03	1.50	1.55
5	**Number of accidents (based on Nova Scotia TRIR)**	1.72	1.03	1.96	1.03	1.83	1.51
6	**% Error**	32	61	-33	0	-18	3

Step 1 – Accidents under global average conditions

The number of accidents expected on a 70 POB installation operating under global average conditions was calculated by combining the annual global average accident rates (TRIR) available from the OGP database (Table 5.2, Row 1), with the POB. The assumption was made that, as is the norm on offshore oil and gas installations, at any given time, 50% of the workers are on shift, whilst their opposite numbers rest. This produced the same numerical result as if 50% of the POB were working continuously. As an example, the expected number of accidents for the 2004 data was calculated as follows.

$$\text{Expected accidents} = 6.36 \text{ accidents} / 1{,}000{,}000 \text{ manhours} \times 70 \text{ persons} \times 0.50 \text{ working} \times 24 \text{ hours/day} \times 365.25 \text{ days/year} = 1.95$$

The results of this by year are presented in Table 5.2, Row 3.

Step 2 – Calibration Run

In order to set base case component reliabilities, the model was run for each year with the results preset to the number of accidents expected under global average conditions, shown in Table 5.2, Row 3.

Step 3 – Component reliability adjustment

Table 5.3 shows the component scores assigned by the expert panel to the Nova Scotia installation, as mentioned, on a scale of 1-10 compared to an industry average value of 5. These scores were used to adjust the base component reliabilities calculated in Step 2.

Table 5.3 – Component ratings for Nova Scotia installation

Factor	Expert Score	Factor	Expert Score
External factors		**Direct factors**	
		Attitude	7
Value placed on life	9	Motivation	6
Price of oil	10	Lack of fatigue	8
Shareholder pressure	3	Coordination	5
Royalty regime	4	Fitness	6
Corporate factors		Knowledge	7
		Intelligence	5
Safety culture	7	Safety design	7
Safety training	7	Weather	3
Safety procedures	8	Personal protective equipment	8

Step 4 - Prediction

The results for the three model runs conducted for 2004 are shown in Table 5.4.

Table 5.4 – Nova Scotia installation - results of 2004 model runs

		Number of accidents
Actual (based on published Nova Scotia accident rate		1.83
Base Case (based on published global average accident rate)		1.95
Model predictions	Run 1 – Based on changing external elements only	1.44
	Run 2 – Based on changing organisational elements only	1.50
	Run 3 – Based on changing direct elements	1.56
	Average prediction (average of three runs)	1.50

It is noteworthy that accident predictions resulting from the three independent runs were relatively consistent (Note the three results 1.44, 1.50, and 1.56, represent a spread of only 8%). The experts offered a view on factors at all levels, and did so by considering the existing situations associated with each factor in isolation of their views on other factors and levels. Despite the independent nature of the individual element scoring process and irrespective of the level at which change was initiated, the results were consistent with one another, which indicates that (i) the panel provided a consistent view of the safety situation at all levels, and (ii) the model accurately handles the external-corporate-direct layer influencing processes.

The predicted numbers of accidents per year by year are shown in Table 5.2, Row 4.

Step 5 – Comparison of predictions with estimates of actual numbers of accidents

Actual number of accidents expected on the platform were estimated by repeating the calculation in Step 1, but, instead of using global average values, substituting the annual accident rates (TRIR) available from the CNSOPB (Table 5.2, Row 2). The results for 2000 - 2004 are shown in Table 5.2, Row 5. The errors between the predicted and actual results (i.e. using Nova Scotia accident statistics) are shown in Table 5.2, Row 6.

A graphical comparison of actual and predicted results by year is shown in Figure 5.1.

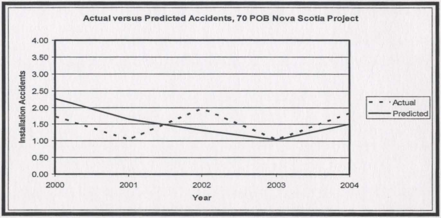


Figure 5.1 – Predicted versus actual accidents, Nova Scotia installation

The good agreement between the actual and predicted results served to validate the model. Some specific points follow.

- It could be argued that results for any specific year have questionable reliability, and that five year rolling averages are more appropriate. The five year average number of accidents was predicted with a very small (3%) error.
- The result for 2003 was excellent (0% error), and that for 2004 (-18% error) was very good.
- Trend matching on the basis of five data points may be of limited value, but it was interesting to note that with the exception of the 2001 – 2002 transition, the

directions of year on year changes in actual accident frequency were matched by the predicted values.

With some assumptions, predictions of expected number of annual accidents can be used to give an operator an idea of the probability of experiencing specific numbers of accidents around the mean value. The Poisson distribution (Billinton and Allan, 1983) represents the probability of an isolated event occurring a specified number of times in a given time interval when the average rate of occurrence is fixed. The assumption of constant failure rate for the present application was discussed in Section 4.1.2.5. Assuming a constant failure rate (λ) then, the Poisson distribution proposes the equation below to calculate the probability of "x" occurrences in a unit time (one year in this example).

$$P_x = \frac{\lambda^x e^{-\lambda}}{x!} \tag{5.1}$$

where

P_x = Probability of "x" occurrences;

λ = Average or expected number of occurrences

As reported in Table 5.2, in 2004, the model predicted the expected number (λ) of occupational accidents on the installation for one year to be 1.50. Using the Poisson assumptions, the operator could expect his probability of having 0, 1, 2.... accidents to be as shown in Figure 5.2.

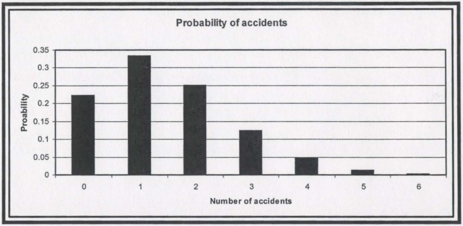


Figure 5.2 – Probability of accidents, Nova Scotia installation

The operator could conclude from this, for example, that assuming no safety related changes are made, his probability of having zero accidents would be 0.22, of having zero or one accident would be 0.55, of having two or fewer would be 0.80, and so on. Similar calculations could be made for other years, or assuming the five year average value to be applicable over the long term.

Many companies and managers, possibly as a result of moral pressure, publicly proclaim a goal of zero accidents. However, such a target is an extremely difficult one to achieve. An analysis such as this could be used by an operator to make reasonable safety challenges to its workforce or set key performance indicator (KPI) targets for itself or its contractors. Calculations such as these, however, would provide managers with more achievable, yet challenging, targets. Staff could be asked, for example, to improve on the number of accidents expected on a platform with a probability of, say, 60%. Or, contractors could earn scaled rewards based on beating the number of accidents expected with probability of 80%, 70%, and so on.

5.2.3) Newfoundland production installation

The model has been applied to a Newfoundland installation, specifically a 100 POB facility. The data in Table 5.5 are discussed in this section.

Table 5.5 – Newfoundland case study

		2000	2001	2002	2003	2004	Average
1	Global average TRIR	8.84	6.85	5.77	4.87	6.36	6.54
2	Newfoundland TRIR	10.16	9.49	8.04	11.45	4.36	8.70
3	Number of accidents (based on global average TRIR)	3.87	3.00	2.53	2.13	2.79	2.86
4	Number of accidents predicted by model	3.68	2.80	2.33	1.93	2.59	2.67
5	Number of accidents (based on Newfoundland TRIR)	4.45	4.16	3.52	5.02	1.91	3.81
6	% Error	-17	-33	-34	-62	36	-30

Step 1 – Accidents under global average conditions

The number of accidents expected on a 100 POB installation operating under global average conditions was calculated by combining the annual global average accident rates (TRIR) available from the OGP database (Table 5.5, Row 1), with the POB (and assuming that 50% of them are working continuously). As an example, the expected number of accidents for the 2004 data was calculated as follows.

Expected accidents = 6.36 accidents / 1,000,000 manhours × 100 persons ×

0.50 working × 24 hours/day × 365.25 days/year = 2.79

The results of this by year are presented in Table 5.5, Row 3.

Step 2 – Calibration Runs

To set base case component reliabilities, the model was run for each year with the result set at the number of accidents expected under global average conditions, shown in Table 5.5, Row 3.

Step 3 – Component reliability adjustment

Table 5.6 shows the scores assigned to model components by the expert panel for the Newfoundland installation.

Table 5.6 – Component ratings for Newfoundland installation

Factor	Expert Score	Factor	Expert Score
External factors		**Direct factors**	
		Attitude	6
Value placed on life	9	Motivation	7
Price of oil	10	Lack of fatigue	8
Shareholder pressure	3	Coordination	5
Royalty regime	4	Fitness	6
Corporate factors		Knowledge	8
		Intelligence	5
Safety culture	8	Safety design	7
Safety training	7	Weather	1
Safety procedures	9	Personal protective equipment	9

Step 4 – Predictions

The predicted numbers of accidents per year by year are shown in Table 5.5, Row 4.

Step 5 – Comparison of predictions with estimates of actual numbers of accidents

Actual number of accidents expected on the platform were determined by repeating the calculation in Step 1, but, instead of using global average values, substituting the annual accident rates (TRIR) available from the CNLOPB (Table 5.5, Row 2). The results for 2000 - 2004 are shown in Table 5.5, Row 5. The errors between the predicted and actual results (i.e. using Newfoundland accident statistics) are shown in Table 5.5, Row 6.

A comparison of actual and predicted results for each year is shown in Figure 5.3.

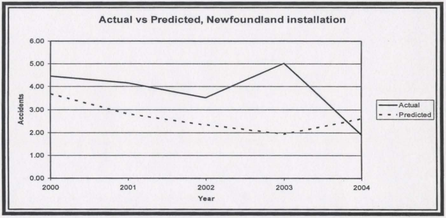


Figure 5.3 – Predicted versus actual accidents, Newfoundland installation

These results were less encouraging than those obtained in the Nova Scotia case study. A possible explanation for this follows.

The Newfoundland published (actual) TRIR results, compared in Figure 5.4 with global average values, were, from 2000 - 2003, consistently and significantly worse than industry average.

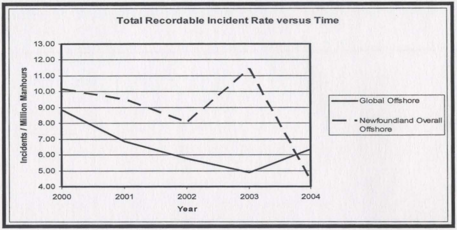


Figure 5.4 – Newfoundland and global average TRIR

However, as discussed elsewhere, (Section 3.5.2, Thompson et al., 1998, Tomas et al., 1999) safety experts' views can offer an alternative (some say better) indicator of safety performance to the more commonly used accident statistics. The panel rated the Newfoundland offshore safety environment equal or superior to the average global situation in more than 86% (44/51) of the elements considered. This is consistent with the 2004 results, when Newfoundland's statistics bettered the global values, but not with those from the previous four years. It could be argued that because the evaluation took place in mid-2005, it was most heavily influenced by the situation over the most recent few years. However, in the absence of an explanation for why Newfoundland safety performance would be significantly worse than global average from 2000 – 2003, and then suddenly better in 2004, and based on the panel's views, it is probably more likely that the Newfoundland offshore industry has in fact been performing better than global average over the entire 2000-2004 period. This conclusion requires explanations of (i) why the relationship between global and Newfoundland published TRIR values from

2000-2003 was opposite from the expert panel's views and (ii) why this effect was not evident in the Nova Scotia case study. Two possibilities are offered here.

- The Newfoundland data included accidents on supply boats, which are not usually included in oil and gas statistics. This made the Newfoundland data less applicable than the Nova Scotia data for the present exercise, which was concerned with activities on installations. The five-year average TRIR for vessels in Nova Scotia was 38% higher than for installations, so the inclusion of the supply boat data may have inflated the Newfoundland TRIR results.
- The Newfoundland statistics *may* have suffered from a greater propensity to over-report occupational accidents than the Nova Scotia results. A possible explanation may be associated with the different union status of workers in the regions. Unlike the Nova Scotia sector, both of the Newfoundland projects' workforces are unionised. A successful union certification vote for one project was held in late 2001 (Hatfield, 2003), and for the other in 2002 (CBC, 2003). In situations where a struggle to unionise has recently been won, the workforce can sometimes be characterised by both an exaggerated and newfound perception of job security, and significant anger with the employer. In such situations, a healthy and appropriate *willingness* to report accidents can gradually turn into a *desire* to do so, resulting in trivial accidents finding their way into the statistics. Following a three year downward trend in the Newfoundland published accident rate from 2000 – 2002, an upward spike occurred in 2003, in the first full year when both installations were operating with a unionised workforce. It is noted that the 2004

value could have been predicted by approximately continuing the 2000 – 2002 downward trend.

The panel's view of safety performance in the Newfoundland offshore industry (relative to global average), contrasting as it does with the published TRIR values, explains why, with the exception of 2004, the model under-predicted the Newfoundland installation accident frequency.

The model can be used as a diagnostic tool to investigate unexpected safety results. In this case, for example, a trial and error exercise was conducted to determine some component scorings necessary for the model to have accurately predicted the actual results. Figure 5.5 shows the comparison of predicted and actual values when external elements were scored as three, instead of the values in Table 5.6. Under this scenario, predictions matched actual values quite well for the years 2000 – 2002. The 2003 prediction implied a continuation of the trend for the previous three years, which did not compare well with the rise experienced in the 2003 published data. Replacing both the 2003 and 2004 "actual cases" (5.02, 1.91) by their average (3.47) removed the 2003 - 2004 fluctuations and produced even better matching (see circles in Figure 5.5).

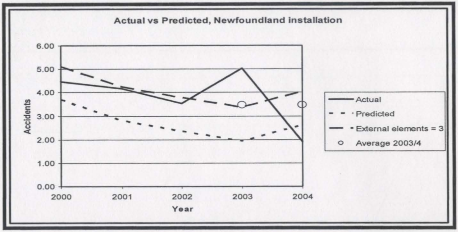


Figure 5.5 – Predicted versus actual accidents, Newfoundland installation, external elements set below global average

5.2.4) Gulf of Mexico drilling sector

In this case the model has been used to predict lost time incident (LTI) *rate* in the Gulf of Mexico drilling business. This application showed that the model can be used in different modes, in this case to predict accident *rate* in a given region rather than previously where it was used to predict number of accidents on a specific platform. The data in Table 5.7 are discussed in this section.

Table 5.7 – Gulf of Mexico case study

		2001	2002	2003	2004	2005	Average
1	Global average LTIR	3.09	2.71	1.81	1.56	1.92	2.22
2	Gulf of Mexico LTIR	3.35	2.52	2.57	2.11	1.96	2.50
3	Predicted LTIR	3.19	2.81	1.91	1.66	2.02	2.32
4	% Error	-5	12	-26	-21	3	-7

Step 1 – Average global LTI rate

Global average drilling LTI rates are shown in Table 5.7, Row 1.

Step 2 – Calibration Run

To set base case component reliabilities, the model was run for each year with the result set at the global average accident rates shown in Table 5.7, Row 1.

Step 3 – Component reliability adjustment

Table 5.8 shows the scores assigned to the Gulf of Mexico offshore drilling industry by an expert panel. Note that, in general, the values in this table are lower than those presented in the Newfoundland and Nova Scotia cases. This reflects the panel's view that safety climate in the Gulf of Mexico is, on balance, of poorer quality than that existing in eastern Canada.

Table 5.8 – Component ratings for Gulf of Mexico drilling business

Factor	**Expert Score**	**Factor**	**Expert Score**
		Direct factors	
External factors		Attitude	4
Value placed on life	4	Motivation	4
Price of oil	7	Lack of fatigue	5
Shareholder pressure	1	Coordination	5
Royalty regime	6	Fitness	4
		Knowledge	4
Corporate factors		Intelligence	5
Safety culture	3	Safety design	4
Safety training	5	Weather	8
Safety procedures	4	Personal protective equipment	5

Step 4 – Prediction

The results by year of predicted accident rate are shown in Table 5.7, Row 3.

Step 5 – Comparison of predictions with actual accident rate

Annual Gulf of Mexico drilling sector LTI rates are available from the IADC website and are presented in Table 5.7, Row 2. The errors between the predicted and actual results (i.e. using Gulf of Mexico accident statistics) are shown in Table 5.7, Row 4.

A comparison of actual and predicted results for each year is shown in Figure 5.6.

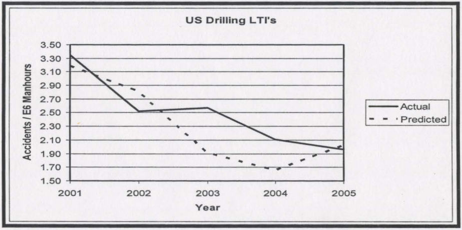


Figure 5.6 – Predicted versus actual LTIR results, Gulf of Mexico business

The predictions matched the actual results well. In all cases error percentage was less than 27%, and in three of the five years studied it was less than 13%. With the exception of the 2004 – 2005 transition, the year-to-year trends were matched, and the five year average predicted value was within 7% of the actual value.

This case demonstrated the versatility of the model. The previous cases considered accidents expected on specific production platforms in different regions, whereas this case considered accident rate in a region specific drilling sector.

5.3) Conclusions

The model has been validated against actual accident results. Results were most accurate in the Nova Scotia installation case study, and were very good in the Gulf of Mexico drilling sector analysis. Results in the Newfoundland study were less accurate than the other two, but the published accident data in this case may be unreliable. Potential explanations for this were described in more detail in Section 5.2.3.

It was demonstrated that the model can be used as a diagnostic tool to study unexpected safety results. For example, by adjusting input scores, we can simulate situations that would have been required to match actual results. If the theoretical input ratings are clearly at odds with reality, we may have possible grounds to question the reliability of the reported data. An example of this process was the exercise of assigning scores of 3 to all external factors for the Newfoundland case, when this was clearly not the case, as described in Section 5.2.3.

The versatility of the model has been demonstrated. It can be used to predict accident numbers on a single specific platform or accident rates in a specific sector.

6

Conclusions

6) Conclusions

By most measures, an offshore oil and gas worker's likelihood of suffering an occupational accident is relatively low. However, the level of risk continues, for many reasons, to be considered unacceptable by industry stakeholders. The offshore occupational accident process has been studied, and a holistic, quantitative model capable of predicting accident frequency has been developed and validated. The model's approach combines concepts favoured by safety representatives from the engineering, psychology, and management disciplines. The conclusions of the work are presented here, subdivided according to its main components.

Literature Review

The literature review revealed that industrial accidents have been studied for more than half a century. Many and varied approaches have been developed and applied within different industries. Early models originated in the nuclear and medical industries. Model philosophy then showed a progression from a concentration on direct causes, to holistic views of major accidents, to statistical approaches. However, a gap in the knowledge was confirmed, specifically the absence of a holistic, quantitative approach to oil and gas occupational accidents.

The choice of component influencing factors used in the current model was based partially on the elements receiving significant attention in the literature. A quantitative review of the factors mentioned in the literature was conducted to confirm a degree of continuity between factors proposed by previous researchers and those presently used.

The present work has built upon previous concepts, drawing from both the statistical methods suggested by some researchers and the holistic view taken by others to offer a unique offshore oil and gas - specific approach to the occupational accident process.

Data Analysis

An analysis of existing offshore oil and gas occupational accident data was conducted. The work included both observation of graphical representations and a series of statistical analyses, including level of significance tests, Mann – Whitney tests, analyses of variance, and Tukey HSD (honestly significantly different) tests. The analyses led to the following specific conclusions.

- Following a relatively continuous and steady improvement in accident frequency through the 1990's, a levelling trend is observable over the past four to five years.
- A reasonably strong negative correlation exists between price of oil and accident frequency. This indicates that financial factors play a partial role in accident likelihood. This conclusion is consistent with the additional observation that, in general, regional safety performance is approximately aligned with the associated local level of prosperity.
- Safety results vary significantly between regions. This indicates that cultural and societal issues play a part in accident frequency.
- The likelihood of workers to report accidents differs on a regional basis, which may itself affect safety statistics.

- Safety results vary significantly between companies and between types of companies. This indicates that corporate culture and organisation-specific safety programmes and hardware also affect accident frequency.
- Safety results between regions within individual projects tend to vary less than for the general inter-regional case, which implies a degree of corporate protection and, combined with the forgoing conclusions, suggests that a holistic approach including direct, corporate and cultural elements is most appropriate.
- Safety results varied significantly with activity being undertaken (for example production, drilling, construction), which supports the importance of direct factors in determining accident likelihood.

The data analysis confirmed real differences in safety results between regions and companies, and according to activity being undertaken. This supports the holistic philosophy of accident causation proposed by this research.

Questionnaire

To provide numerical input to specific aspects (relative component strength, inter-layer relationships) of the accident model, a survey of safety experts was conducted which extracted quantitative views on the accident process. Some of the conclusions of the survey exercise follow.

- Safety professionals believe that the combined effect of corporate elements (e.g. safety culture and programmes) is more influential in the accident process than the combined effects of either direct elements (e.g. PPE, staff behaviour), or external elements (e.g. price of oil, royalty regime).

- Of the external elements, the respondents considered value placed by society on life to be more influential than financial elements such as shareholder pressure.
- The factor receiving the highest individual score was staff behaviour, followed by organisational safety culture and general organisational elements (safety culture, training, and procedures).
- The respondents considered their organisations' safety programmes to be operating relatively well, reporting an average efficiency score of 7.1 on a one to ten scale.

Model Development

A model to predict occupational accident frequency has been developed, which provides a quantitative representation of the layered, holistic view of the process proposed by the research. The approach is based on a chain of influence originating with external factors, which act through corporate elements to affect factors directly influencing the accident process. A calculation determines overall safety system reliability based on the component reliabilities of the elements considered to directly affect accident frequency. The direct elements' reliabilities are influenced by the effectiveness of the corporate elements, which are, in turn, affected by external factors. The degrees to which the layers influence one another, and the relative importance of the elements directly affecting accident frequency, are based on the results of the safety expert survey mentioned above.

A parametric analysis has been conducted to demonstrate the effect of component efficiency changes on accident frequency. Example runs have been conducted to demonstrate model use in three realistic hypothetical scenarios – comparison of worst case and ideal conditions, drilling rig hire / mobilization, and drilling rig demobilisation.

Model Application

The model has been validated by using it to hindcast accident results on oil and gas installations in Nova Scotia and Newfoundland, and in the Gulf of Mexico drilling business. Since platform specific results were not made available by operators, the Canadian "actual" results were based on data published by the respective provincial petroleum boards. For the Gulf of Mexico drilling example, the actual accident frequencies under study were publicly available.

A panel of experts with both project/region specific and general industry experience was assembled to score the model elements according to the actual installation/regional situations compared to average global conditions. Model runs based on the inputs were able to hindcast actual accident frequencies with good accuracy in the Nova Scotia and Gulf of Mexico examples. The results for the Newfoundland example were less encouraging, but this might be explained by the inclusion of supply boat data in the published accident statistics, or some potential over-reporting of accidents.

The versatility of the model was demonstrated by using it to predict both accident numbers on specific installations (in the Canadian examples) and accident rates in regional industry sectors (for the Gulf of Mexico example).

Further work

Suggestions for future work are proposed here, specifically associated with probabilistic analyses, fuzzy approaches, multilevel analysis, and model adjustment with industry knowledge improvement.

Probabilistic analysis – Several aspects of the model rely on averaged values of subjective expert opinion (i.e. strength of components, relationships between layers). Model output is a prediction of an expected number of accidents or an expected accident rate. The model could be enhanced by adopting a probabilistic approach to inputs, for example assuming distributions for inputs having the calculated mean but assuming appropriate distribution parameters. Such an approach would more realistically represent the uncertainty associated with subjectively judging the safety conditions on specific installations or in specific regions compared with the global industry. Monte-Carlo style analyses could then be carried out to establish a probability distribution of output results, rather than a prediction of mean value only.

Fuzzy approaches – Instead of taking experts' individual component scoring as single values, fuzzy methods could be used, including experimentation with different membership functions. Similar to the probabilistic approach mentioned above, fuzzy methods offer a means to handle the uncertainty associated with input subjectivity.

Multilevel analysis – A recent approach to the statistical analysis of situations involving complex data sets including units of more than one type is known as multilevel analysis. Lewis-Beck et al. (2003) suggest as an example studies on educational achievement, in which pupils, teachers, classrooms and schools might all be important units of analysis. There are clear parallels in principle between this example and the safety performance of an offshore installation, where workers, supervisors, the primary work environment, the operator, and external factors would be important factors. Future researchers may be interested in applying the multilevel analysis method to the oil and gas safety process.

Model structure refinement – The oil and gas industry has a significant thirst for accident knowledge. Through steady work, approaches are improved year on year, although the majority of the advancements have originated in mature operating regions. As activity in frontier regions increases, accident knowledge there will increase along with it. The present model can be easily adjusted to cope with new information or philosophies, either by appropriately adjusting element strengths, layer relationship matrices, or even component makeup and location.

Overall

Because occupational accident frequency on offshore oil and gas installations remains at a level unacceptable to industry stakeholders, further effort is required to understand the process and improve results. The present work offers a contribution. Accident likelihood is affected by direct, corporate, and external factors. Drawing from engineering, safety, psychology, and management philosophies, a validated, holistic, quantitative occupational accident frequency prediction model has been proposed.

7) References

ACSNI, 2003. Human factors study group third report: Organising for safety, *London:HMSO.*

AkerKvaerner, 2004. Annual Report 2003, *AkerKvaerner.*

Attwood, D, 2005. Personal discussion with LR Aberdeen verification and classification manager, 28 January.

Attwood, D, Khan, F, and Veitch, B, 2005a. Occupational accident models – where have we been and where are we going? Accepted for publication in the *Journal of Loss Prevention in the Process Industries.*

Attwood, D, Khan, F, and Veitch, B, 2005b. Offshore oil and gas occupational accidents – what is important? *Journal of Loss Prevention in the Process Industries,* October, pp 1 - 13.

Attwood, D, Khan, F, and Veitch, B, 2005c. Can we predict occupational accident frequency? *Process Safety and Environmental Protection, Trans IChemE* , Part B, 84(B2), March, pp 1 - 14.

Attwood, D, Khan, F, and Veitch, B, 2005d. Predicting offshore occupational accident frequency – a practical demonstration using case studies. Accepted for publication in *Process Safety Progress, AIChE.*

Balkey, J P, and Phillips, J H, 1993. Using OSHA process safety management standard to reduce human error, PVP Vol. 251, *Reliability and Risk in Pressure Vessels and Piping, ASME*, pp 43 - 54.

Billinton, R and Allan, R N, 1983. Reliability evaluation of engineering systems: concepts and techniques, *Plenum Press, New York, London.*

BP, 2003. Environmental - social - health and safety, *BP.*

Brotherton, C, 2003. The role of external policies in shaping organisational health and safety, from Health and Safety in Organisations, A Multilevel Perspective, Hofmann, D A, and Tetrick, L E, Editors, *John Wiley & Sons.*

Brown, K A, Willis, P G, Prussia, G E, 2000. Predicting safe employee behaviour in the steel industry: development and test of a sociotechnical model, *Journal of operations management*, 18, pp 445 - 465.

Canada - Newfoundland and Labrador Offshore Petroleum Board, 2005. Website www.cnlopb.nf.ca.

Canada - Nova Scotia Offshore Petroleum Board, 2005. Website www.cnsopb.ns.ca.

Canadian Broadcasting Corporation (CBC), 2003. Terra Nova workers have a union, *Website www.cbc.ca*, 16 April.

ChevronTexaco, 2004. 2003 Annual Report, *ChevronTexaco.*

Cheyne, A, Tomas, J M, Cox, S, and Oliver, A, 1999. Modelling employee attitudes to safety: a comparison across sectors, *European Psychologist*, Volume 4, No. 1, March, pp 1 - 10.

ConocoPhillips, 2002. Sustainable growth report, *ConocoPhillips*.

Dobson, J D, 1999. Rig floor accidents: who, when and why? - an analysis of UK offshore accident data, *Society of Petroleum Engineers / International Association of Drilling Contractors Conference*, Amsterdam, The Netherlands, pp 293 - 298.

Embrey, D E, 1992. Incorporating management and organisational factors into probabilistic safety assessment, *Reliability Engineering and System Safety* 38, pp 199 - 208.

ExxonMobil, 2003. 2002 Safety, health & environment progress report, *ExxonMobil.*

Flin, R H, Mearns, K, Gordon, R P E, Fleming, M T, 1996. Risk perception in the UK offshore oil and gas industry, *International conference on health, safety & environment*, New Orleans, Louisiana, 9-12 June, pp 187 - 197.

Geyer, T A W, and Bellamy, L J, 1991. Pipework failure, failure causes and the management factor, *The Institute of Mechanical Engineers*, London.

Gordon, J E, 1949. The epidemiology of accidents, *The American Journal of Public Health*.

Gordon, R, Flin, R, and Mearns, K, 2001. Designing a human factors investigation tool to improve the quality of safety reporting, *Proceedings of the 45th Annual meeting of the Human Factors and Ergonomics Society,* pp 1519 - 1523.

Guastello, S J, 1989. Catastrophe modelling of the accident process: evaluation of an accident reduction program using the occupational hazards survey, *Accident Analysis & Prevention*, Volume 21, No. 1, pp 61 - 77.

Haddon, W, 1973. Energy damage and the ten countermeasure strategies, *Human Factors*.

Halliburton, 2003. 2002 HSE performance around the world; health, safety and environment annual report, *Halliburton.*

Hatfield, R, 2003. Extreme organising: A case study of Hibernia, *JUST LABOUR*, Volume 2, Spring.

Houston, D E L, 1971. New approaches to the safety problem, *Major Loss Prevention*.

Hurst, N W, 1998. Risk assessment – the human dimension, *The Royal Society of Chemistry*, ISBN 0-85404-554-6.

Iledare, O O, Pulsipher, A G, and Mesyazhinov, D V, 1998. Safety and environmental performance measures in offshore E&P operations: empirical indicators for benchmarking, *The Society of Petroleum Engineers Annual Technical Conference and Exhibition,* New Orleans, 27 – 30 September, pp 47 - 56.

International Association of Drilling Contractors, 2005. Website: www.iadc.org.

International Association of Oil & Gas Producers, 2002. OGP Safety performance of the global E&P industry 2001, Report Number 6.59/330, *International Association of Oil & Gas Producers.*

International Association of Oil & Gas Producers, 2004. OGP Safety performance indicators 2003, Report Number 353, *International Association of Oil & Gas Producers.*

International Association of Oil & Gas Producers, 2005. OGP Safety performance indicators 2004, Report Number 367, *International Association of Oil & Gas Producers.*

International Labour Organisation (ILO), 2003. Safety in numbers, global safety culture at work, *The International Labour Organisation*, Geneva.

Johnson, R, 2005. Miller & Freund's probability and statistics for engineers, Seventh Edition, *Pearson Prentice Hall,* Upper Saddle River, NJ 07458.

Johnson, W G, 1980. MORT safety assurance systems, *Basel: Dekker.*

Khan, F I, Sadiq, R, and Veitch, B, 2004. Life cycle IndeX (LInX): a new indexing procedure for process and product design and decision-making, *Journal of Cleaner Production* 12, pp 59 - 76.

Kjellen, U, 1983. The deviation concept in occupational accidents control: theory and method, Occupational Accident Group, *Technological University of Stockholm.*

Kjellen, U, 1995. Integrating analyses of the risk of occupational accidents into the design process. part II: method for predicting the LTI rate, *Safety Science*, 19, pp 3 - 18.

Kjellen, U and Hovden, J, 1993. Reducing risks by deviation control; a retrospection into a research strategy, *Safety Science* 16, pp 417 - 438.

Kjellen, U, Sklett, S, 1995. Integrating analyses of the risk of occupational accidents into the design process. part I: a review of types of accident criteria and risk analysis methods, *Safety Science*, 18, pp 215 - 227.

Klir, G J, St Clair, U, and Yuan, B, 1997. Fuzzy set theory: foundations and applications, *Prentice Hall.*

Le Bot, P, 2004. Human reliability data, human error and accident models - illustration through the Three Mile Island accident analysis, *Reliability Engineering and System Safety*, 83, pp 153 – 167.

Lees, F P, 1996a. Loss prevention in the process industries, Volume 1, 2nd Edition, *Butterworth Publications.*

Lees, F P, 1996b. Loss prevention in the process industries, Volume 2, 2nd Edition, *Butterworth Publications.*

Lewis-Beck, M, Bryman, A E, and Liao, T F, 2003. The SAGE encyclopedia of Social Science Research Methods (Volume II), *Sage.*

Li, Z, Shu-dong, H, and Xiang-rui, H, 2003. THERP+HCR-based model for human factor event analysis and its application, *Hedongli Gongcheng/Nuclear Power Engineering*, v 24, n 3, June, pp 272 - 276.

McCall, R B, 1970. Fundamental statistics for psychology, *Harcourt, Brace & World,* New York, Chicago, San Francisco, Atlanta.

McCauley-Bell, P, and Badiru, A B, 1996a. Fuzzy modelling and analytic hierarchy processing to quantify risk levels associated with occupational injuries – part I: the development of fuzzy-linguistic risk levels, *IEEE Transactions on Fuzzy Systems*, Volume 4, Number 2, May.

McCauley-Bell, P, and Badiru, A B, 1996b. Fuzzy modelling and analytic hierarchy processing – means to quantify risk levels associated with occupational injuries – part II: the development of a fuzzy rule-based model for the prediction of injury, *IEEE Transactions on Fuzzy Systems*, Volume 4, Number 2, May.

Mearns, K, Flin, R, and Fleming, M, 1997. Human and organisational factors in offshore safety, *HSE Books,* Norwich, United Kingdom

Mearns, K, Whitaker, S M, Flin, R, 2003. Safety climate, safety management practice and safety performance in offshore environments, *Safety Science* 41, pp 631 - 680.

Mosleh, A, and Chang, Y H, 2004. Model-based human reliability analysis: prospects and requirements, *Reliability Engineering and System Safety*, 83, pp 241 - 253.

Munteanu, I, and Aldemir, T, 2003. A methodology for probabilistic accident management, *Nuclear Technology*, Volume 144, October, pp 49 - 62.

Norwegian Petroleum Directorate (NPD), 2004. Website, *NPD.*

Olsen, E, Eikeland, T, and Tharaldsen, J, 2004. Development and validation of a safety culture inventory, to be presented at the *EA-OHP conference*, Berlin, 20-21 November.

Ott, W, 1978. Environmental indices: theory and practice, *Ann Arbour Science Publishers.*

Owen, D, and Raeburn, G, 1991. Developing a safety, occupational health, and environmental (SOHE) program as part of a total quality program, *Offshore Technology Conference*, May 6 – 9, Houston, Texas, pp 33 – 37.

Pate-Cornell, M E, Murphy, D M, 1996. Human and management factors in probabilistic risk analysis: the SAM approach and observations from recent applications, *Reliability Engineering and System Safety*, 53 pp 115-126.

Pietersen, C M, and Engelhard, W F J M, 1991. Offshore safety assessment, *Proceedings of the first international conference on health, safety, and the environment*, The Hague, The Netherlands, 10 – 14 November, pp 765 - 768.

Reason, J, 1990. Human Error, *Cambridge University Press,* New York

Revisionnotes.co.uk, 2005. *Website www.revision-notes.uk.*

Richardson, R, and Watkiss, R, 2003. The influence of leadership and behaviours on safety performance, *The Society of Petroleum Engineers,* Presented at Offshore Europe, Aberdeen, 2 - 5 September.

Rundmo, T, Hestad, H, and Ulleberg, P, 1998. Organizational factors, safety attitudes and workload among offshore oil personnel, *Safety Science* 29, pp 75 - 87.

Sadiq, R, Kleiner, Y, and Rajani, B, 2003. Forensics of water quality failure in distribution systems – a conceptual framework, *Journal of Indian Water Works Association*, v. 35 No. 4, October – December, pp 1 - 23.

Shell, 2004. 2003 Annual report, *Shell.*

Sinclair, J and Andrews, G, 2004. Comparative review of HSE requirements for specified offshore fabrication activities, report for the *Atlantic Canada Opportunities Agency,* April, Aberdeen.

Smith, D, 2002. Health & safety performance of the global E&P industry 2000, *Offshore Technology Conference, Houston, 6-9 May.*

Smith, G M, 1970. A simplified guide to statistics for psychology and education, *Holt, Rinehart and Winston.*

Son, K S, Melchers, R E, and Kal, W M, 2000. An analysis of safety control effectiveness, *Reliability Engineering and System Safety* 68, pp 187 - 194.

Strutt, J E, Wei-Whua, L, and Allsopp, K, 1998. Progress towards the development of a model for predicting human reliability, *Quality and reliability engineering international*, 14, pp 3 - 14.

Tabachnick, B G and Fidell, L S, 2001. Using multivariate statistics, *Allyn & Bacon.*

Takala, Jukka, 1999. Global estimates of fatal occupational accidents, Epidemiology, September, Volume 10 Number 5, from the *Occupational Safety and Health Branch, Working Conditions and Environment Department, International Labour Office*, 4 Route des Morillons, CH-1211 Geneva 22, Switzerland.

Talisman Energy Incorporated, 2004. 2003 Health, Safety, and Environmental Performance

Tharaldsen, J, Olsen, E, and Eikeland, T, 2004. A comparative study of safety culture, ABB offshore systems compared with other companies on the Norwegian Continental Shelf, *Work life and business development, Rogaland Research*, Norway.

Thompson, R C, Hilton, T F, and Witt, L A, 1998. Where the safety rubber meets the shop floor: a confirmatory model of management influence on workplace safety, *Journal of Safety Research*, Vol. 29, No. 1, pp 15 - 24.

Tomas, J M, Melia, J L, and Oliver, A, 1999. A cross-validation of a structural equation model of accidents: organisational and psychological variables as predictors of work safety, *Work & Stress*, Vol. 13 No. 1, pp 49 - 58.

TotalElfFina, 2002. 2001 Environment and safety report, *TotalElfFina.*

Trontin, T, and Bejean, S, 2004. Prevention of occupational injuries: moral hazard and complex agency relationships, *Safety Science*, 42, pp 121 - 141.

UK HSE (Health & Safety Executive), 1992. UK offshore installations (Safety Case) regulations 1992 (Number 2885, Health and Safety), ISBN 011025869X, *HSE.*

UK HSE, 1996. Preventing slips, trips and falls at work, *HSE.*

UK HSE, 2000. Offshore accident rates for April 1996 to March 1998, Offshore Technology Report # OTO 2000/12, *HSE.*

UK HSE, 2001a. Safety culture maturity model, Offshore Technology Report 2000/049, Prepared by Dr Mark Fleming of The Keil Centre for the *HSE.*

UK HSE, 2001b. Multivariate analysis of injuries data, Offshore Technology Report 2000/108, Prepared by the University of Liverpool for the *HSE.*

UK HSE, 2002a. Slips, trips and falls from height offshore, Offshore Technology Report 2002/001, Prepared by BOMEL Limited for the *HSE.*

UK HSE, 2002b. Human factors integration: implementation in the onshore and offshore industries, Research Report 001, Prepared by BAE Systems Defence Consultancy for the *HSE.*

UK HSE, 2003a. Factoring the human into safety: translating research into practice, Volumes 1-3, Research Report 062 Prepared by the University of Aberdeen for the *HSE.*

UK HSE, 2003b. Good practice and pitfalls in risk assessment, prepared by Drs Sandra Gadd, Deborah Keeley, and Helen Balmforth of The Health & Safety Laboratory for the *HSE.*

Wang, J, 2001. Liverpool John Moores in safety-based decision support design project, *Journal of Offshore Technology*, v 9, n 2, March, pp 37.

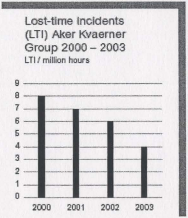
Wells, G L, Phang, C, Wardman, M, and Whettan, C, 1992. Incident scenarios: their identification and evaluation, *Process Safety Environment*.

Witt, L A , Hellman, C, and Hilton, T F, 1994. Management influences on perceived safety, presented at the annual meeting of the *American Psychological Society*, San Francisco, California.

Wolfram, J, 1993. Safety and risk: models and reality, *Journal of Process Mechanical Engineering*, IMechE, pp 3-11.

Appendix 1 – Company information

Appendix 1.1 AkerKvaerner (AkerKvaerner, 2004)



Appendix 1.2 BP (BP, 2003)

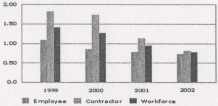
Long-term improvement in safety performance (DAFWCF)

Footnote: DAFWCF is the annual frequency (per 200,000 hours) of injuries or illness that resulted in person (employee or contractor) being unable to work for a day (shift) or more. The data from 1992 is both employee and contractor. 2002 data excludes Castrol and Veba employees.

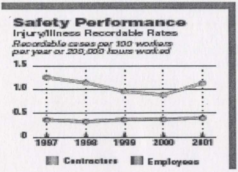
Fatality accident rate per million hours

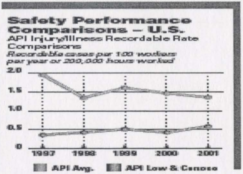
Days away from work case frequency per 200,000 hours

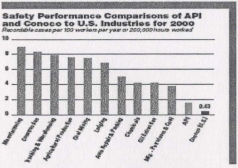
Recordable injury and illness frequency per 200,000 hours

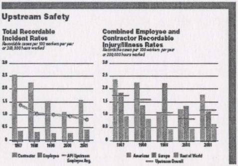


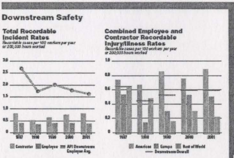
Appendix 1.3 ConocoPhillips (ConocoPhillips, 2002)

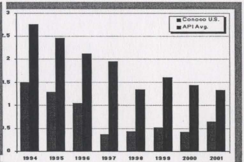


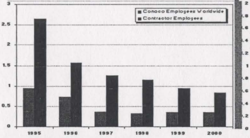


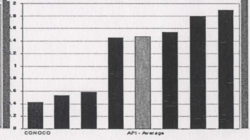




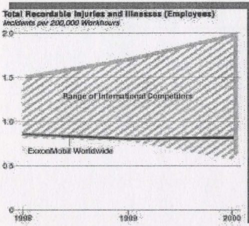




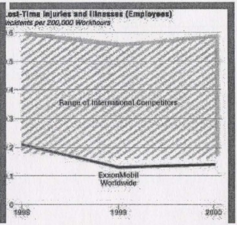




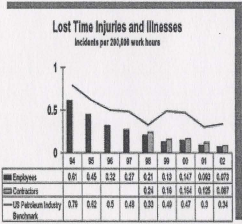
Appendix 1.4 ExxonMobil (ExxonMobil, 2003)



Total Recordable Injuries and Illnesses (Employees)
Incidents per 200,000 Workhours

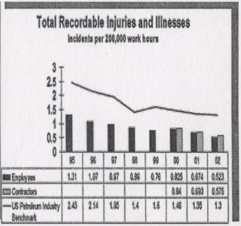


Lost-Time Injuries and Illnesses (Employees)
Incidents per 200,000 Workhours



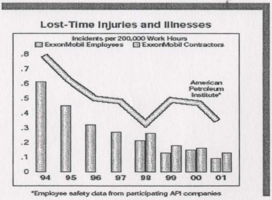
Lost Time Injuries and Illnesses
Incidents per 200,000 work hours

	94	95	96	97	98	99	00	01	02
■ Employees	0.61	0.45	0.32	0.27	0.21	0.13	0.147	0.093	0.073
▨ Contractors					0.24	0.16	0.164	0.125	0.087
— US Petroleum Industry Benchmark	0.79	0.62	0.5	0.48	0.33	0.49	0.47	0.3	0.34



Total Recordable Injuries and Illnesses
Incidents per 200,000 work hours

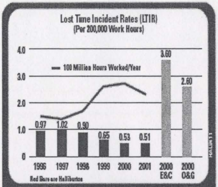
	95	96	97	98	99	00	01	02
■ Employees	1.31	1.07	0.97	0.88	0.76	0.825	0.674	0.523
▨ Contractors						0.84	0.693	0.575
— US Petroleum Industry Benchmark	2.45	2.14	1.95	1.4	1.6	1.46	1.35	1.3



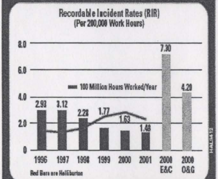
Lost-Time Injuries and Illnesses
Incidents per 200,000 Work Hours

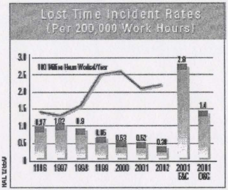
*Employee safety data from participating API companies

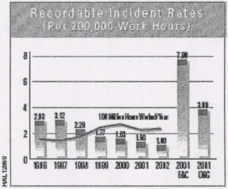
Appendix 1.5 Halliburton (Halliburton, 2003)



>> Based on U.S. Occupational Safety and Health Association (OSHA) criteria and recorded globally for Halliburton. Industry sector comparisons are U.S. based only using most current data available. Both LTIR and RIR have declined for the fourth consecutive year and are 50% lower than the 1997 rates.

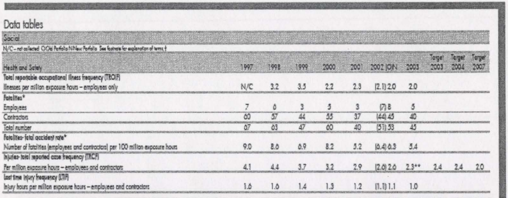






Based on U.S. Occupational Safety and Health Association (OSHA) criteria and recorded globally for Halliburton. Industry sector comparisons are U.S.-based only, using most current data available. Both LTIR and RIR have declined for the fifth consecutive year and are over 60 percent lower than 1997 rates.

Appendix 1.6 Shell (Shell, 2004)

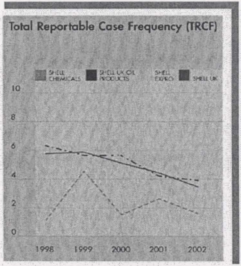


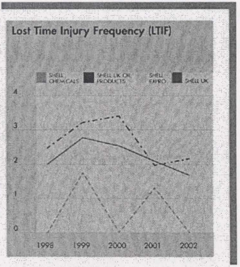
Data tables

Social

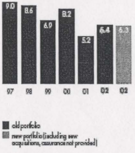
N/C – not collected O Old Portfolio N New Portfolio See footnote for explanation of terms †

Health and Safety	1997	1998	1999	2000	2001	2002 (O)N	2003	Target 2003	Target 2004	Target 2007
Total reportable occupational illness frequency (TROIF)										
Illnesses per million exposure hours – employees only	N/C	3.2	3.5	2.2	2.3	(2.1) 2.0	2.0			
Fatalities*										
Employees	7	6	3	5	3	(7) 8	5			
Contractors	60	57	44	55	37	(44) 45	40			
Total number	67	63	47	60	40	(51) 53	45			
Fatalities- fatal accident rate*										
Number of fatalities (employees and contractors) per 100 million exposure hours	9.0	8.6	6.9	8.2	5.2	(6.4) 6.3	5.4			
Injuries- total reported case frequency (TRCF)										
Per million exposure hours – employees and contractors	4.1	4.4	3.7	3.2	2.9	(2.6) 2.6	2.3**	2.4	2.4	2.0
Lost time injury frequency (LTIF)										
Injury hours per million exposure hours – employees and contractors	1.6	1.6	1.4	1.3	1.2	(1.1) 1.1	1.0			

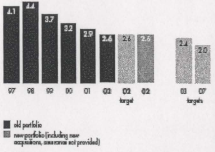




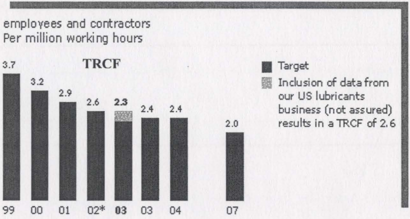
15 Fatal accident rate – company employees and contractors
per 100 million exposure hours

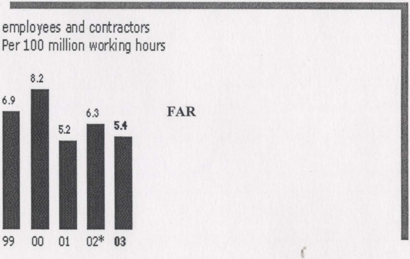


16 Total reportable case frequency – company employees and contractors*
per million exposure hours

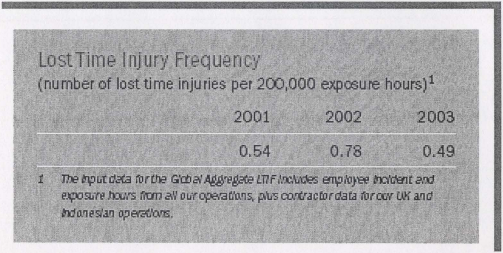


* see Safety


employees and contractors
Per million working hours
TRCF
3.7
3.2
2.9
2.6
2.3
2.4
2.4
2.0
99
00
01
02*
03
03
04
07
Target
Inclusion of data from our US lubricants business (not assured) results in a TRCF of 2.6


employees and contractors
Per 100 million working hours
FAR
6.9
8.2
5.2
6.3
5.4
99
00
01
02*
03

Appendix 1.7 Talisman (Talisman Energy Incorporated, 2004)



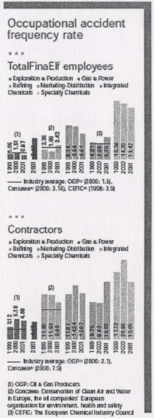
Lost Time Injury Frequency

(number of lost time injuries per 200,000 exposure hours)[1]

2001	2002	2003
0.54	0.78	0.49

[1] *The input data for the Global Aggregate LTIF includes employee incident and exposure hours from all our operations, plus contractor data for our UK and Indonesian operations.*

Appendix 1.8 Total (TotalElfFina, 2002)



Occupational accident frequency rate

* * *

TotalFinaElf employees

- Exploration & Production ▨ Gas & Power ▨ Refining ▨ Marketing-Distribution ▨ Integrated Chemicals ▨ Specialty Chemicals

—— Industry average: OGP(1) (2000: 1.5), Concawe(2) (2000: 3.16), CEFIC(3) (1998: 3.5)

* * *

Contractors

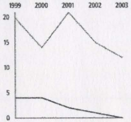
▨ Exploration & Production ▨ Gas & Power ▨ Refining ▨ Marketing-Distribution ▨ Integrated Chemicals ▨ Specialty Chemicals

—— Industry average: OGP(1) (2000: 2.1), Concawe(2) (2000: 7.9)

(1) OGP: Oil & Gas Producers
(2) Concawe: Conservation of Clean Air and Water in Europe, the oil companies' European organization for environment, health and safety
(3) CEFIC: The European Chemical Industry Council

Appendix 1.9 ChevronTexaco (ChevronTexaco, 2004)

Work-Related Fatalities

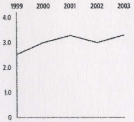


	1999	2000	2001	2002	2003
— Employees	4	4	2	1	0
– Contractors	20	14	21	15	12
Total	24	18	23	16	12

1999–2001 data are combined Chevron and Texaco. 2002 and 2003 data are ChevronTexaco.

Motor Vehicle Safety

Motor vehicle crashes per million miles driven (company vehicles)

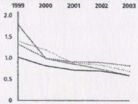


	1999	2000	2001	2002	2003
— Employees	2.52	2.99	3.29	2.94	3.31

1999–2000 data are Chevron, 2001 data are combined Chevron and Texaco, and 2002 and 2003 data are ChevronTexaco.

Total Recordable Injury Rate

Recordable incidents per 200,000 work hours

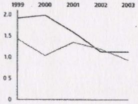


	1999	2000	2001	2002	2003
— ChevronTexaco: Employees	1.04	0.82	0.72	0.68	0.60
— ChevronTexaco: Contractors	1.80	1.08	0.88	0.74	0.59
···· Benchmark: Employees	1.37	1.04	0.93	0.90	0.84
···· Benchmark: Contractors	1.40	1.22	0.90	0.84	0.76

1999–2001 data are combined Chevron and Texaco. 2002 and 2003 data are ChevronTexaco. Data use American Petroleum Institute as industry benchmark.

Lost Time Injury Frequency

Injuries per million work hours



	1999	2000	2001	2002	2003
— ChevronTexaco: Employees	1.93	2.00	1.70	1.26	1.26
— ChevronTexaco: Contractors	1.47	1.06	1.37	1.30	0.95

1999–2001 data are combined Chevron and Texaco. 2002 and 2003 data are ChevronTexaco.

Appendix 2 – Survey questionnaire

Questionnaire

Factors that influence offshore occupational accidents

As part of a university research programme, we are performing a quantitative study of offshore occupational accidents (i.e. this research is **not related to major accidents such as explosions**). Part of the research involves the development of a mathematical model of the accident process. A description of the basic model premise is included at the end of the questionnaire for those interested. The questionnaire's goal is to ensure that the model accurately reflects expert opinion/judgement in two essential areas, specifically:

1. the relative importance of certain factors in the accident process; and
2. the degree (causal strength) to which external forces and organisational factors influence the direct causes of accident

The whole exercise should take no longer than 10 minutes to complete

Your responses will be combined with others and used in the model – the identities of individual respondents and their organisations will be kept strictly confidential

Importance of elements

This section concerns the relative importance of elements. You are asked, for each subset below, to rate, on a scale of one (not important at all) to ten (crucial), the importance of each element in the accident process.

Question 1		Rating (1-10)
Rate the relative importance of direct issues, the company, and external drivers	External effects (i.e. price of oil, value placed by society on life, etc)	
	Company effects (i.e. safety culture, procedures, training programme, etc)	
	Direct effects (i.e. Personal Protective Equipment, weather, etc)	

Question 2		Rating (1-10)
Which external driver is more important: financial pressures, or the value placed by society on life	Financial drivers (i.e. price of oil, royalty regime, shareholder pressure)	
	Value placed by society on life (specific to the operating region)	

Question 3		Rating (1-10)
Rate the relative importance of the external financial drivers	Price of oil	
	Shareholder pressure (consider its effect on decision making through "boards of directors" to senior and middle managers)	
	Royalty regime	

Question 4		Rating (1-10)
Rate the relative importance of the following organisational elements	Corporate safety culture	
	Training programme	
	Safety procedures	

Question 5		Rating (1-10)
Rate the relative importance of these factors directly affecting the accident process	Individual behaviour (i.e. attitude and motivation)	
	Individual capability (includes physical and mental)	
	Weather conditions	
	Design of safety arrangements at the workplace	
	Personal protective equipment	

Question 6		Rating (1-10)
Is general staff attitude toward safety or the level of motivation more important?	Attitude	
	Motivation (i.e. the degree of incentive felt by staff to avoid accidents)	

Question 7		Rating (1-10)
Which is more important, physical capability or mental sharpness?	Physical	
	Mental (i.e. knowledge of procedures, ability to deal with unexpected situations)	

Question 8		Rating (1-10)
Rate the relative importance of the following physical factors	Lack of fatigue	
	Coordination	
	General physical fitness	

Question 9		Rating (1-10)
Which of the following mental capabilities is more important	Knowledge (of safety procedures, practices, and equipment)	
	Intelligence (i.e. ability to cope with situations not covered by procedure)	

Influence of external factors on organisations, and organizational factors on individuals

This section comprises two "affecting matrices". You are asked to place scores from one (light influence) to ten (heavy influence) in each box corresponding to how heavily you think the element ***heading*** each column is ***affected by*** each of the elements ***along the left side*** of the matrix.

For example, if you think the ***likelihood*** of an organisation to enact an effective safety training programme is affected relatively heavily by the region-specific value placed by society on life, but less so by the three financial factors mentioned (price of oil, shareholder pressure, royalty regime) then you might place the values "8", "3", "5", and "2" in the appropriate boxes, as shown below (please replace these example values with ones reflecting your actual belief). The chosen values should indicate the relative degree with which you believe each factor along the left side affects the factors at the top of the columns. This process should be repeated for each column in the following two matrices.

Question 10

The effect of external drivers on organisations

	Company safety training programme	Company safety procedures	Company safety culture
Value placed on life by society	8		
Price of oil	3		
Shareholder pressure	5		
Royalty regime	2		

Question 11

The effect of organisational elements on individual behavior

	Staff attitude towards safety	Staff motivation to improve safety results	Staff fitness	Staff lack of fatigue	Staff knowledge concerning safety	Safety design	Provision of Personal Protective Equipment
Company safety training programme							
Company safety procedures							
Company safety culture							

General

Please indicate:

Country in which your primary activities are carried out	
The nature of your organisation's business (e.g.) operator, contractor, regulatory agency, etc)	
On a scale of 1 to 10, how well do you consider your organisation's safety programme to be operating?	
Company name (Optional)	
Other general comments you may wish to include	

Model Basic Overall Premise

Occupational accidents result from an unsatisfactory interaction between workers and their environment. At the most direct level, accidents occur when people perform tasks in an unsafe manner. At this level, the definition of "an unsafe manner" needs to consider things such as weather conditions at the time of task execution, quality of protective equipment used, safety design of the immediate workplace, and the behaviour and capabilities, both physical and mental, of the worker.

Moving to a "higher", or organisational level, many of the aspects at the direct level are heavily influenced by the work environment provided by the organisation. For example, worker attitudes and resulting behaviours can be heavily influenced by the "safety culture" developed by the organisation. Senior management, through its words, and more importantly, through its actions, will foster within the workplace, attitudes toward safety which can range from the cavalier to the excessive.

More directly, the organisation will decide on the level to which safety design is applied to the workplace environment. In years past, safety group sometimes tended to feel marginalised from the remaining elements of the design team, at times trying to "hang on" or "keep up" with the rest of the group. Recent design processes, however, have required that representatives from the safety group participate in all elements of design, and also that they be heavily involved in the periodic design reviews which have become a part of all offshore design processes.

The quality of safety training and procedures is also a matter of organisational choice. Providing an appropriate level of effort, resource, and quality is at the same time a difficult and crucial matter. Too little of either can produce a work force both ill equipped to face daily work activities in a safe manner, and also feeling unsupported by those responsible for their ongoing safety. But excessive and overly restrictive safety procedures can produce a negative effect as well. Workers can feel immune to dangers in the face of an overabundance of safety procedures, which can lead to unsafe actions. Or, workers can occasionally find safety procedures so restrictive that they lose their will to comply completely, cut corners, and become injured. Experience is gradually producing the *appropriate* level of safety training and procedure.

Organisational decisions will also determine the quality of basic safety equipment provided to workers. Thankfully, on modern oil & gas platforms, provision of the very best quality safety equipment has become the norm.

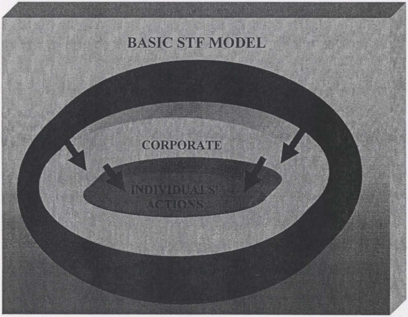
Previous work in other industries by other researchers, discussed elsewhere, has considered the effect of company actions on accident occurrence. The model proposed here, however, takes a further outward step by considering an external (to the organisation) level affecting the accident process. Essentially, pressures imposed by societal culture and regional or global financial realities are considered to influence the organisational actions and decisions mentioned above which, in turn, affect the direct accident process.

The value placed on a human life is an extremely uncomfortable concept for anyone to consider, but it has become accepted that this implied value differs from one region to another. Governments act on the implied or direct wishes of the populations they represent, and the degree of pressure applied to oil & gas operators to enhance safety environments will be proportional to the value placed on safety by the region's population.

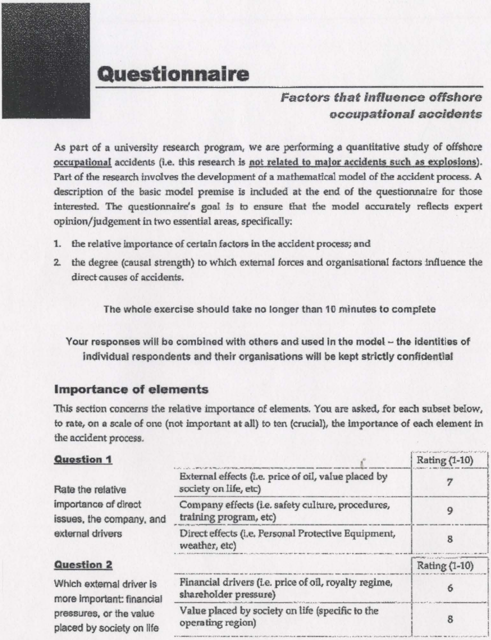
Similarly, the profitability of an organisation's operation in a region will affect how much available capital exists, which *partially* determines available capital for safety programmes (only *partially* because organisations will have different views on how much of the available capital is directed to safety issues). The profitability is in turn heavily dependant on such things as the current price of oil and existing royalty regime, which, as in the case of safety, is indirectly determined by the views of the public. Regions experiencing tough financial times will be more likely to encourage an attractive (to the organisation) royalty regime than areas where the economic situation is more positive.

To reiterate the general premise, occupational accidents may well occur through the direct interaction between worker and workplace, but the workers' actions were influenced and the workplace environment provided by an organisation whose actions were in turn influenced by external elements.

A schematic of the model philosophy is as shown below.



Example of a completed questionnaire (3 pages)



Questionnaire

Factors that influence offshore occupational accidents

As part of a university research program, we are performing a quantitative study of offshore <u>occupational</u> accidents (i.e. this research is <u>not related to major accidents such as explosions</u>). Part of the research involves the development of a mathematical model of the accident process. A description of the basic model premise is included at the end of the questionnaire for those interested. The questionnaire's goal is to ensure that the model accurately reflects expert opinion/judgement in two essential areas, specifically:

1. the relative importance of certain factors in the accident process; and
2. the degree (causal strength) to which external forces and organisational factors influence the direct causes of accidents.

The whole exercise should take no longer than 10 minutes to complete

Your responses will be combined with others and used in the model – the identities of individual respondents and their organisations will be kept strictly confidential

Importance of elements

This section concerns the relative importance of elements. You are asked, for each subset below, to rate, on a scale of one (not important at all) to ten (crucial), the importance of each element in the accident process.

Question 1

Rate the relative importance of direct issues, the company, and external drivers

	Rating (1-10)
External effects (i.e. price of oil, value placed by society on life, etc)	7
Company effects (i.e. safety culture, procedures, training program, etc)	9
Direct effects (i.e. Personal Protective Equipment, weather, etc)	8

Question 2

Which external driver is more important: financial pressures, or the value placed by society on life

	Rating (1-10)
Financial drivers (i.e. price of oil, royalty regime, shareholder pressure)	6
Value placed by society on life (specific to the operating region)	8

Question 3

Rate the relative importance of the external financial drivers

	Rating (1-10)
Price of oil	6
Shareholder pressure (consider its effect on decision making through "boards of directors" to senior and middle managers)	9
Royalty regime	2

Question 4

Rate the relative importance of these organisational elements

	Rating (1-10)
Corporate safety culture	9
Training programme	7
Safety procedures	5

Question 5

Rate the relative importance of these factors directly affecting the accident process

	Rating (1-10)
Individual behaviour (i.e. attitude and motivation)	9
Individual capability (includes physical and mental)	8
Weather conditions	7
Design of safety arrangements at the workplace	7
Personal protective equipment	8

Question 6

Is general staff attitude toward safety or the level of motivation more important?

	Rating (1-10)
Attitude	9
Motivation (i.e. the degree of incentive felt by staff to avoid accidents)	9

Question 7

Which is more important, physical capability or mental sharpness?

	Rating (1-10)
Physical	7
Mental (i.e. knowledge of procedures, ability to deal with unexpected situations)	9

Question 8

Rate the relative importance of the following physical factors

	Rating (1-10)
Lack of fatigue	8
Coordination	7
General physical fitness	6

Question 9

Which of the following mental capabilities is more important

	Rating (1-10)
Knowledge (of safety procedures, practices, eqpt.)	9
Intelligence (i.e. ability to cope with situations not covered by procedure)	7

Influence of external factors on organisations, and organisational factors on individuals

This section comprises two "affecting matrices". You are asked to place scores from one (light influence) to ten (heavy influence) in each box corresponding to how heavily you think the element ***heading*** each column is ***affected by*** each of the elements ***along the left side*** of the matrix.

For example, if you think the *likelihood* of an organisation to enact an effective safety training program is affected relatively heavily by the region-specific value placed by society on life, but less so by the three financial factors mentioned (price of oil, shareholder pressure, royalty regime) then you might place the values "8", "3", "5" and "2" in the appropriate boxes, as shown below (please replace these example values with ones reflecting your actual belief). The chosen values should indicate the relative degree with which you believe each factor along the left side affects the factors at the top of the columns. This process should be repeated for each column in the following two matrices.

Question 10

The effect of external drivers on organisations

	Company safety training programme	Company safety procedures	Company safety culture
Value placed on life by society	8	9	8
Price of oil	6	6	6
Shareholder pressure	8	9	9
Royalty regime	2	2	2

Question 11

The effect of organisational elements on individual behaviour

	Staff attitude towards safety	Staff motivation to improve safety results	Staff fitness	Staff lack of fatigue	Staff knowledge concerning safety	Design of safety arrangements at the workplace	Provision of Personal Protective Equipment
Company safety training programme	8	9	7	8	9	8	10
Company safety procedures	7	7	6	7	6	8	9
Company safety culture	10	9	8	8	8	9	8

Appendix 3 – Survey responses - untreated results

Appendix 3.1 – Actual survey responses

Appendix 3.2 – Histogram data of responses

Appendix 3.3 – Curves showing number of responses by score

Appendix 3.1 - Actual survey responses

Key:

A: Americas
S: Asia
E: Europe, Middle East, and Africa

R: Regulator
U: Researcher
C: Contractor
O: Operator

Notes:

1. Appendix 3.1 contains nine tables.
   - Tables 3.1.1 – 3.1.3 show the results of questions 1 - 9 of the survey, concerning the relative importance of model elements and groups of elements.
   - Tables 3.1.4 – 3.1.6 show the results of question 10 of the survey, concerning the influence of external elements on corporate elements.
   - Tables 3.1.7 – 3.1.9 show the results of question 11 of the survey, concerning the influence of corporate elements on direct elements.
2. The indicators A_1,A_2,A_3...etc. refer to the first, second, and third respondents from the Americas, and so on.

Table 3.1.1

Respondent characteristics	Respondent region	A_{1}	A_{2}	A_{3}	A_{4}	A_{5}	A_{6}	A_{7}	A_{8}	A_{9}	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
	Category	R	R	R	R	R	R	R	R	R	R	U	U	U	U	C
Overall layer	External	6	4	7	8	5	5	4	6	3	7	6	1	7	5	7
	Corporate	10	8	9	10	10	5	10	7	9	9	8	6	5	8	9
	Direct	7	8	6	10	8	8	6	8	2	8	10	10	3	8	8
External elements	Financial	9	4	7	5	5	7	4	4	7	7	5	1	7	7	6
	Value placed on life	7	8	5	6	8	8	5	7	2	9	7	1	5	9	8
Financial elements	Price of oil	6	5	7	6	5	6	1	7	7	7	1	1	7	4	6
	Shareholder pressure	7	5	8	5	8	4	7	6	5	6	5	1	5	4	9
	Royalty regime	4	5	2	4	8	7	1	4	2	7	1	1	5	7	2
Corporate layer	Safety culture	10	6	9	10	10	9	10	8	8	10	9	6	5	9	9
	Training	9	7	9	9	7	10	8	8	9	8	6	7	7	8	7
	Safety procedures	9	8	9	9	6	10	8	7	8	7	7	8	9	7	5
Direct layer	Behavioural	10	8	8	10	10	9	10	10	9	9	10	8	5	7	9
	Capability	7	7	8	9	8	8	6	8	7	9	8	7	7	6	8
	Weather	5	5	6	8	6	6	5	8	4	7	7	7	4	7	7
	Safety design	9	8	8	8	8	10	8	8	8	7	7	8	8	8	7
	PPE	8	8	6	10	8	7	6	6	3	8	7	10	4	7	8
Behavioural elements	Attitude	10	7	9	10	10	10	10	9	9	7	10	8	8	8	9
	Motivation	9	8	9	9	7	8	7	7	7	8	8	8	5	6	9
Capability elements	Physical	5	5	7	5	7	8	5	7	7	6	5	7	5	6	7
	Mental	10	8	9	7	8	10	8	8	9	8	9	8	5	8	9
Physical capability	Lack of fatigue	10	7	8	9	9	10	8	9	8	8	9	4	5	8	8
	Coordination	7	5	9	7	7	8	7	8	6	7	7	4	3	8	7
	Fitness	5	7	6	8	5	9	5	7	7	7	5	6	6	5	6
Mental capability	Knowledge	10	8	9	9	6	10	10	8	8	8	8	8	8	8	9
	Intelligence	9	7	7	6	7	8	8	7	7	9	10	8	5	5	7
Safety program performance		9	8	5	9	6	8	7	6	8	8	7	5	5	6	7

Table 3.1.2

Respondent characteristics	Respondent region	A_{16}	A_{17}	A_{18}	A_{19}	S_1	S_2	S_3	S_4	S_5	E_1	E_2	E_3	E_4	E_5	E_6
	Category	O	O	O	O	R	R	R	C	O	R	R	R	R	R	R
Overall layer	External	3	4	5	10	8	3	2	2	5	2	2	1	10	5	6
	Corporate	8	6	9	10	8	7	10	5	8	7	8	8	10	8	10
	Direct	5	8	9	9	9	8	7	8	4	7	8	8	10	7	5
External elements	Financial	5	6	4	4	6	7	3	9	2	2	3	1	8	4	4
	Value placed on life	4	5	7	10	8	1	7	9	7	5	8	10	10	8	6
Financial elements	Price of oil	5	0	3	3	5	5	3	2	2	2	3	1	6	4	8
	Shareholder pressure	4	7	5	8	7	9	7	8	2	3	3	5	10	6	5
	Royalty regime	2	5	3	3	4	3	1	2	2	1	3	5	8	2	5
Corporate layer	Safety culture	8	8	8	8	8	10	9	8	9	7	7	8	10	7	8
	Training	6	8	9	7	7	10	8	9	7	8	7	8	9	4	8
	Safety procedures	7	6	9	7	9	10	5	10	4	8	9	8	9	8	6
Direct layer	Behavioural	10	9	9	9	9	9	9	8	9	9	8	8	10	9	9
	Capability	8	8	9	8	8	5	9	8	8	10	6	8	9	7	9
	Weather	4	8	9	2	6	5	4	2	5	7	4	2	9	4	4
	Safety design	6	7	8	7	7	9	7	4	7	6	8	8	10	3	6
	PPE	5	7	10	8	8	0	6	4	4	10	8	8	8	5	6
Behavioural elements	Attitude	10	8	9	8	9	0	9	8	7	8	8	8	10	7	6
	Motivation	8	6	7	5	9	10	7	8	8	8	8	8	9	9	10
Capability elements	Physical	7	5	6	5	4	0	5	6	3	5	5	2	8	5	6
	Mental	9	8	8	10	9	9	8	9	9	8	8	8	10	9	8
Physical capability	Lack of fatigue	7	8	8	8	8	7	9	8	7	9	8	8	10	7	8
	Coordination	5	7	7	7	7	9	8	9	7	5	7	8	9	5	8
	Fitness	6	7	7	6	6	4	7	6	4	5	5	4	8	4	8
Mental capability	Knowledge	8	6	8	10	8	9	8	10	6	8	9	6	10	7	5
	Intelligence	7	8	7	7	9	5	7	2	6	7	5	8	10	8	8
Safety program performance		8	7	8	9	7	9	7	8	6	8	8	7	8	8	8

Table 3.1.3

Respondent characteristics	Respondent region	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}	E_{18}	E_{19}	E_{20}	E_{21}
	Category	R	R	R	U	C	C	C	C	C	C	O	O	O	O	O
Overall layer	External	2	5	6	8	7	3	7	3	7	2	5	2	2	2	1
	Corporate	8	10	8	8	8	9	10	9	10	8	8	8	6	8	10
	Direct	8	8	7	8	7	6	4	6	6	7	4	6	8	6	4
External elements	Financial	3	8	6	6	2	4	8	5	4	7	7	3	5	5	1
	Value placed on life	7	8	8	8	10	10	6	3	9	3	8	8	5	8	4
Financial elements	Price of oil	3	8	5	0	3	3	5	4	6	9	5	2	2	0	1
	Shareholder pressure	4	8	7	2	3	2	8	3	7	7	8	1	3	8	5
	Royalty regime	2	4	3	2	3	3	7	3	5	5	3	1	1	5	0
Corporate layer	Safety culture	9	10	8	8	8	10	10	9	10	9	9	10	6	9	8
	Training	8	10	6	9	6	8	8	9	8	9	9	9	9	6	8
	Safety procedures	7	7	7	9	7	8	8	8	8	9	7	8	10	6	8
Direct layer	Behavioural	10	10	9	6	10	9	10	7	9	10	8	9	10	9	8
	Capability	9	10	6	7	5	6	8	7	8	7	8	8	10	6	4
	Weather	6	2	3	3	3	7	5	5	5	6	8	6	8	6	3
	Safety design	7	7	8	5	7	8	8	6	8	7	8	8	9	8	5
	PPE	7	8	7	9	3	5	8	5	7	7	4	6	8	6	3
Behavioural elements	Attitude	7	10	8	0	8	9	10	9	8	10	7	8	10	0	8
	Motivation	7	8	5	9	6	7	10	9	5	10	6	9	10	10	6
Capability elements	Physical	5	7	4	0	5	6	8	0	6	2	4	6	7	0	3
	Mental	7	10	8	7	9	8	10	9	8	7	9	9	10	7	7
Physical capability	Lack of fatigue	7	10	8	10	10	9	10	8	6	7	9	9	8	7	3
	Coordination	6	7	4	6	7	8	8	7	6	8	5	8	8	6	5
	Fitness	5	6	4	7	7	6	6	7	6	6	5	7	6	6	6
Mental capability	Knowledge	9	10	8	8	8	9	8	8	9	8	9	9	9	7	7
	Intelligence	8	6	8	9	10	6	8	5	8	7	5	8	5	9	6
Safety program performance		7	7	7	5	7	9	8	6	8	5	4	7	9	8	5

Table 3.1.4

Respondent characteristics	Respondent region	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
	Category	R	R	R	R	R	R	R	R	R	R	U	U	U	U	C
Influence on training	Value placed on life	7	8	9	8	9	9	8	7	7	10	7	4	8	8	8
	Price of oil	6	3	5	2	4	3	2	6	2	3	1	1	3	3	6
	Shareholder pressure	8	5	6	4	8	5	6	5	4	6	5	1	5	5	8
	Royalty regime	4	2	2	1	8	2	1	3	1	3	1	1	2	4	2
Influence on procedures	Value placed on life	7	9	8	7	8	6	9	7	8	10	8	5	7	8	9
	Price of oil	6	3	7	2	2	8	2	6	2	3	1	1	4	4	6
	Shareholder pressure	8	3	7	3	6	7	6	5	4	6	6	1	7	4	9
	Royalty regime	4	3	2	3	8	5	1	4	1	3	1	1	4	6	2
Influence on Safety culture	Value placed on life	7	9	9	7	8	6	10	6	8	10	9	5	8	10	8
	Price of oil	6	3	5	2	7	8	2	6	2	3	1	1	2	5	6
	Shareholder pressure	8	3	7	3	2	7	6	4	5	6	6	1	6	4	9
	Royalty regime	4	3	2	3	8	5	1	4	1	3	1	1	4	6	2

Table 3.1.5

Respondent characteristics	Respondent region	A_{16}	A_{17}	A_{18}	A_{19}	S_1	S_2	S_3	S_4	S_5	E_1	E_2	E_3	E_4	E_5	E_6
	Category	O	O	O	O	R	R	R	C	O	R	R	R	R	R	R
Influence on training	Value placed on life	7	8	7	9	8	8	7	10	8	7	8	8	8	9	10
	Price of oil	5	3	3	3	3	3	3	2	6	2	5	2	2	5	4
	Shareholder pressure	6	5	5	7	7	5	5	8	4	5	5	4	5	6	5
	Royalty regime	1	2	3	3	2	2	4	2	1	1	2	2	2	3	5
Influence on procedures	Value placed on life	8	7	7	9	7	10	7	9	8	8	8	10	8	9	10
	Price of oil	3	4	3	3	2	3	3	2	5	2	3	2	2	4	4
	Shareholder pressure	6	5	5	7	7	5	5	8	4	5	3	2	5	5	5
	Royalty regime	1	2	3	3	2	0	4	2	1	1	1	2	2	2	5
Influence on safety culture	Value placed on life	9	7	8	9	7	10	7	9	8	8	8	10	10	9	10
	Price of oil	3	4	3	3	3	3	3	2	4	2	3	2	2	4	8
	Shareholder pressure	6	5	5	7	7	5	7	8	4	2	3	2	5	5	8
	Royalty regime	1	2	3	3	3	0	4	2	1	1	1	2	2	4	5

Table 3.1.6

Respondent characteristics	Respondent region	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}	E_{18}	E_{19}	E_{20}	E_{21}
	Category	R	R	R	U	C	C	C	C	C	C	O	O	O	O	O
Influence on training	Value placed on life	8	8	8	8	8	10	8	3	8	8	8	2	8	8	3
	Price of oil	3	3	6	2	2	6	3	6	3	2	2	2	2	3	2
	Shareholder pressure	5	5	7	2	2	4	7	3	5	3	6	1	3	5	1
	Royalty regime	2	2	3	1	2	2	3	3	2	1	1	1	1	2	0
Influence on procedures	Value placed on life	8	8	8	8	8	10	8	3	8	7	7	2	8	9	3
	Price of oil	3	6	4	2	2	7	3	6	4	6	2	1	2	4	2
	Shareholder pressure	5	10	6	2	2	5	8	3	5	3	5	1	3	7	1
	Royalty regime	2	4	2	1	2	2	3	3	2	2	1	1	1	3	0
Influence on safety culture	Value placed on life	7	8	8	9	8	10	8	5	10	6	6	2	8	8	6
	Price of oil	3	7	4	2	2	3	3	6	4	4	2	1	2	4	2
	Shareholder pressure	6	10	6	2	2	3	8	3	6	2	5	1	3	6	1
	Royalty regime	2	2	3	1	2	2	3	3	2	1	1	1	1	4	0

Table 3.1.7

Respondent characteristics	Respondent region	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
	Category	R	R	R	R	R	R	R	R	R	R	U	U	U	U	C
Influence on attitude	Training	8	8	8	9	9	8	7	8	9	8	5	6	7	9	8
	Procedures	8	8	8	9	8	6	6	7	8	7	6	7	6	8	7
	Safety culture	9	8	9	9	8	4	10	9	9	10	8	7	6	6	10
Influence on motivation	Training	8	8	5	8	4	8	7	7	8	9	5	6	5	8	9
	Procedures	8	8	7	8	2	5	5	7	7	7	6	7	6	6	7
	Safety culture	9	8	9	8	6	3	10	7	8	10	8	7	4	6	9
Influence on fitness	Training	2	6	5	8	5	7	3	3	7	8	2	4	4	7	7
	Procedures	2	6	5	8	5	5	2	3	6	4	2	4	6	8	6
	Safety culture	6	6	7	8	6	4	4	4	6	7	2	4	5	6	8
Influence on lack of fatigue	Training	2	6	5	9	10	8	2	4	6	6	1	4	3	7	8
	Procedures	2	6	5	9	10	8	1	4	6	8	3	4	7	6	7
	Safety culture	6	6	8	9	10	8	5	4	6	8	4	4	4	6	8
Influence on knowledge	Training	9	8	9	7	8	6	9	8	8	8	7	6	5	8	9
	Procedures	9	8	8	7	8	5	8	5	7	10	5	7	6	6	6
	Safety culture	6	8	8	7	8	7	10	7	6	9	6	7	4	6	8
Influence on safety design	Training	4	8	4	8	9	7	4	5	8	8	7	7	5	8	8
	Procedures	4	8	8	8	10	5	8	7	8	10	8	7	7	8	8
	Safety culture	8	8	8	8	10	8	10	6	7	9	8	7	5	4	9
Influence on PPE,	Training	6	8	4	10	10	7	8	4	7	7	8	8	5	7	10
	Procedures	6	8	9	10	8	6	7	9	7	10	8	8	5	6	9
	Safety culture	6	8	9	10	8	5	9	8	7	9	8	9	5	6	8

Table 3.1.8

Respondent characteristics	Respondent region	A_{16}	A_{17}	A_{18}	A_{19}	S_1	S_2	S_3	S_4	S_5	E_1	E_2	E_3	E_4	E_5	E_6
	Category	O	O	O	O	R	R	R	C	O	R	R	R	R	R	R
Influence on attitude	Training	8	6	9	9	8	10	7	9	6	8	8	10	10	5	10
	Procedures	7	5	8	6	8	7	6	10	6	9	3	10	8	6	10
	Safety culture	9	8	8	9	9	10	10	10	8	10	8	10	8	8	10
Influence on motivation	Training	8	6	9	9	6	10	7	8	8	8	8	10	8	4	4
	Procedures	7	5	8	6	7	7	6	9	7	8	3	8	8	5	10
	Safety culture	9	8	8	9	8	10	7	9	8	9	8	8	8	9	10
Influence on fitness	Training	8	5	3	8	6	5	6	4	6	5	2	2	5	4	4
	Procedures	7	5	3	6	6	5	5	2	5	5	2	2	5	4	4
	Safety culture	9	5	3	9	6	5	6	2	5	6	5	2	5	6	5
Influence on lack of fatigue	Training	8	6	3	8	7	7	6	8	7	2	2	8	8	7	4
	Procedures	7	7	7	6	7	7	5	8	7	7	2	8	5	7	4
	Safety culture	9	7	7	9	8	7	6	8	7	8	5	8	5	8	8
Influence on knowledge	Training	9	7	8	8	7	10	8	9	8	10	9	8	10	6	10
	Procedures	8	5	7	6	7	10	5	9	7	5	7	8	7	7	6
	Safety culture	7	7	6	9	8	10	8	9	7	7	7	8	8	9	8
Influence on safety design	Training	7	6	5	8	7	10	7	9	8	8	8	8	10	4	3
	Procedures	8	5	8	6	7	10	5	8	5	8	8	8	9	4	1
	Safety culture	9	7	8	9	6	10	8	8	7	8	8	8	9	6	10
Influence on PPE	Training	7	7	9	8	8	10	9	9	4	5	8	8	8	6	1
	Procedures	8	8	9	7	7	10	5	9	4	8	8	8	5	6	5
	Safety culture	9	8	8	9	7	10	9	9	4	9	8	8	5	6	8

Table 3.1.9

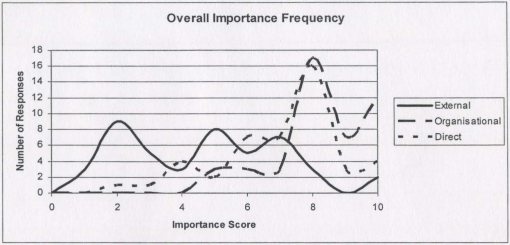
Respondent characteristics	Respondent region	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}	E_{18}	E_{19}	E_{20}	E_{21}
	Category	R	R	R	U	C	C	C	C	C	C	O	O	O	O	O
Influence on attitude	Training	8	8	8	8	8	9	10	9	8	10	7	7	8	7	7
	Procedures	6	6	7	9	8	9	10	7	8	8	7	6	8	7	5
	Safety culture	7	10	8	7	10	9	10	9	10	10	9	9	10	9	9
Influence on motivation	Training	7	8	7	7	8	7	10	9	8	8	7	7	8	7	7
	Procedures	6	6	5	7	8	8	10	6	8	8	5	6	8	7	4
	Safety culture	8	10	8	7	10	9	10	9	9	10	8	9	8	10	9
Influence on fitness	Training	1	8	1	7	3	5	5	5	7	2	6	5	6	5	6
	Procedures	1	6	1	7	3	4	5	3	7	2	4	4	6	5	3
	Safety culture	1	10	1	7	3	6	5	6	7	2	5	6	6	7	2
Influence on lack of fatigue	Training	3	6	1	8	3	8	6	5	6	5	6	4	8	7	4
	Procedures	3	8	1	8	3	6	6	3	8	5	4	4	8	7	3
	Safety culture	5	10	1	7	3	6	8	6	8	5	5	4	8	9	2
Influence on knowledge	Training	9	9	7	9	8	9	8	9	8	7	9	8	9	8	6
	Procedures	7	8	6	9	8	8	6	7	8	7	4	5	9	6	3
	Safety culture	8	10	6	9	10	6	10	9	8	9	7	9	9	8	7
Influence on safety design	Training	7	9	7	6	8	7	6	7	7	5	4	8	9	8	3
	Procedures	8	10	7	8	8	8	6	8	8	4	3	5	9	8	7
	Safety culture	8	8	7	6	10	7	10	7	8	7	7	9	9	8	6
Influence on PPE	Training	7	9	7	9	8	6	6	6	6	7	7	8	8	6	3
	Procedures	9	8	8	9	8	8	7	8	7	6	7	5	8	7	8
	Safety culture	6	10	6	9	10	8	10	9	8	5	8	9	8	8	9

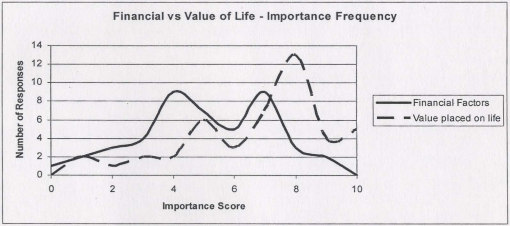
Appendix 3.2 - Histogram data of importance results

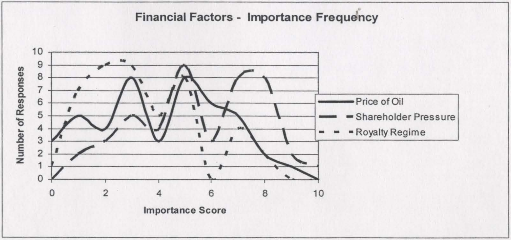
The results of survey questions 1 – 9, included in Appendix 3.1, are placed in categories in this table.

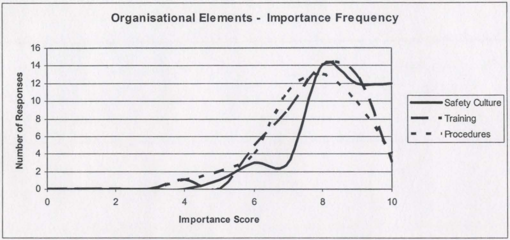
	0	1	2	3	4	5	6	7	8	9	10	Check Total
External	0	3	9	5	3	8	5	7	3	0	2	45
Organisational	0	0	0	0	0	3	3	3	17	7	12	45
Direct	0	0	1	1	4	2	7	7	16	3	4	45
External elements												
Financial	1	2	3	4	9	7	5	9	3	2	0	45
Value placed on life	0	2	1	2	2	6	3	7	13	4	5	45
Financial elements												
Price of oil	3	5	4	8	3	8	6	5	2	1	0	45
Shareholder pressure	0	2	3	5	4	9	3	8	8	2	1	45
Royalty Regime	1	7	9	9	5	8	0	4	2	0	0	45
Organisational Elements												
Safety Culture	0	0	0	0	0	1	3	3	14	12	12	45
Training	0	0	0	0	1	0	5	9	14	13	3	45
Procedures	0	0	0	0	1	2	4	11	13	10	4	45
Direct layer												
Behavioural	0	0	0	0	0	1	1	2	8	19	14	45
Capability	0	0	0	0	1	2	6	9	17	7	3	45
Weather	0	0	4	4	7	8	8	7	5	2	0	45
Safety design	0	0	0	1	1	2	4	12	20	3	2	45
PPE	1	0	0	3	4	4	7	8	13	1	4	45
Behavioural												
Attitude	3	0	0	0	0	0	1	6	14	9	12	45
Motivation	0	0	0	0	0	4	5	8	12	10	6	45
Capability												
Physical	4	0	2	2	3	14	8	9	3	0	0	45
Mental	0	0	0	0	0	1	0	6	17	14	7	45
Physical Capability												
Lack of fatigue	0	0	0	1	1	1	1	8	17	9	7	45
Coordination	0	0	0	1	2	6	5	16	11	4	0	45
Fitness	0	0	0	0	5	9	16	11	3	1	0	45
Mental capability												
Knowledge	0	0	0	0	0	1	4	3	19	11	7	45
Intelligence	0	0	1	0	0	7	5	12	12	5	3	45

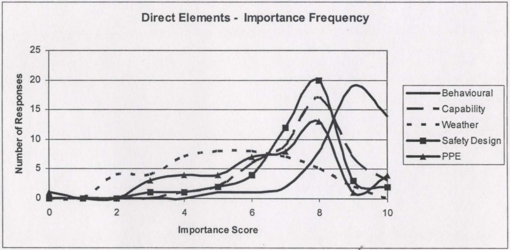
Appendix 3.3 – Curves showing number of responses by score

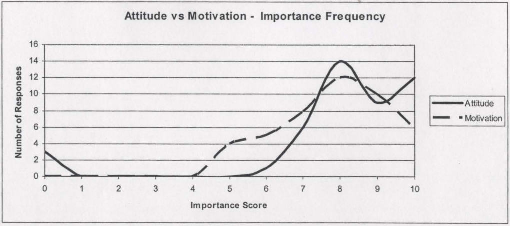

Overall Importance Frequency
Number of Responses
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
Importance Score
External
Organisational
Direct

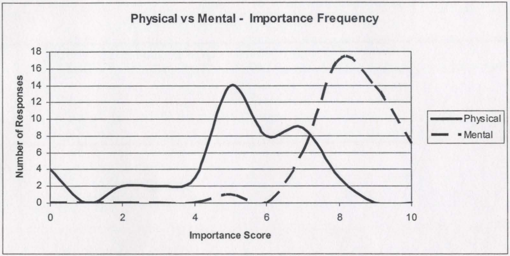

Financial vs Value of Life - Importance Frequency
Number of Responses
14
12
10
8
6
4
2
0
0
2
4
6
8
10
Importance Score
Financial Factors
Value placed on life

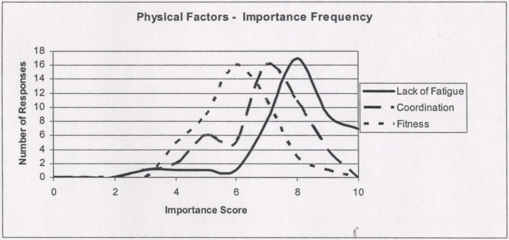

Financial Factors - Importance Frequency
Number of Responses
10
9
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
Importance Score
Price of Oil
Shareholder Pressure
Royalty Regime

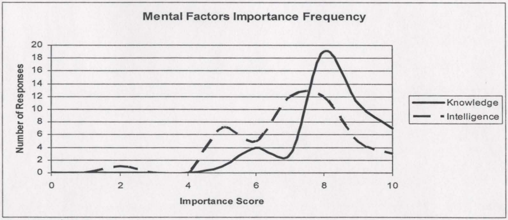

Organisational Elements - Importance Frequency
Number of Responses
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
Importance Score
Safety Culture
Training
Procedures


Direct Elements - Importance Frequency
Number of Responses
25
20
15
10
5
0
0
2
4
6
8
10
Importance Score
Behavioural
Capability
Weather
Safety Design
PPE


Attitude vs Motivation - Importance Frequency
Number of Responses
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
Importance Score
Attitude
Motivation

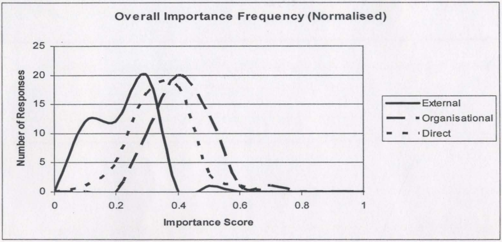

Physical vs Mental - Importance Frequency

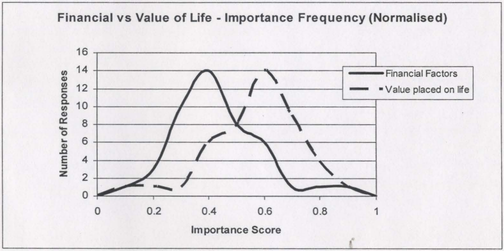

Physical Factors - Importance Frequency

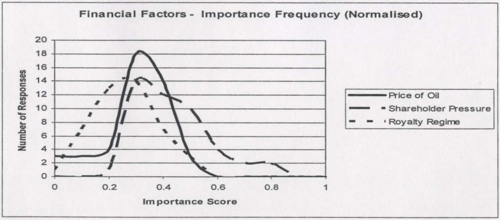

Mental Factors Importance Frequency

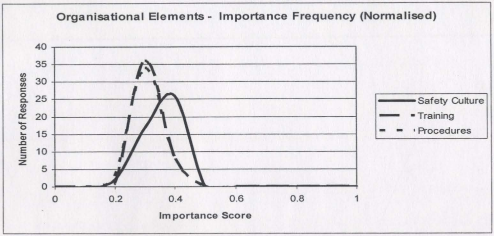
Appendix 4 – Survey responses - normalised results

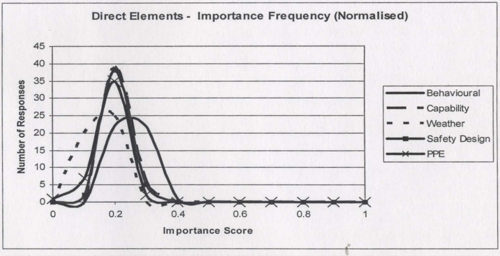
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
External	0	12	12	20	0	1	0	0	0	0	0
Organisational	0	0	0	10	20	13	1	1	0	0	0
Direct	0	1	5	17	18	3	1	0	0	0	0
External elements											
Financial	0	1	3	10	14	8	6	1	1	1	0
Value placed on life	0	1	1	1	6	8	14	9	4	1	0
Financial elements											
Price of oil	3	3	4	18	14	3	0	0	0	0	0
Shareholder pressure	0	0	1	14	12	10	4	2	2	0	0
Royalty Regime	1	7	13	14	7	3	0	0	0	0	0
Organisational Elements											
Safety Culture	0	0	2	17	26	0	0	0	0	0	0
Training	0	0	1	36	8	0	0	0	0	0	0
Procedures	0	0	3	34	8	0	0	0	0	0	0
Direct layer											
Behavioural	0	0	22	22	1	0	0	0	0	0	0
Capability	0	0	39	6	0	0	0	0	0	0	0
Weather	0	20	25	0	0	0	0	0	0	0	0
Safety design	0	2	38	5	0	0	0	0	0	0	0
PPE	1	7	35	2	0	0	0	0	0	0	0
Behavioural											
Attitude	3	0	0	0	2	21	19	0	0	0	0
Motivation	0	0	0	0	19	21	2	0	0	0	3
Capability											
Physical	4	0	2	7	28	4	0	0	0	0	0
Mental	0	0	0	0	0	4	28	6	3	0	4
Physical Capability											
Lack of fatigue	0	0	1	6	34	4	0	0	0	0	0
Coordination	0	0	1	33	10	1	0	0	0	0	0
Fitness	0	0	7	34	4	0	0	0	0	0	0
Mental capability											
Knowledge	0	0	0	0	5	24	15	0	1	0	0
Intelligence	0	0	1	0	15	23	6	0	0	0	0

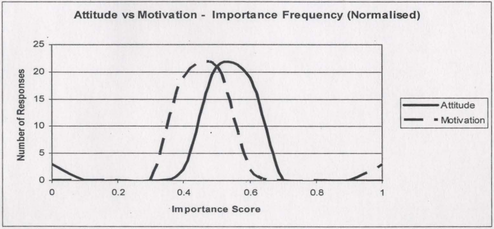

Overall Importance Frequency (Normalised)

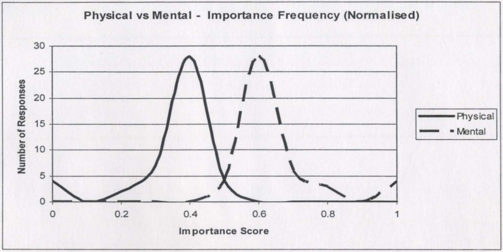

Financial vs Value of Life - Importance Frequency (Normalised)

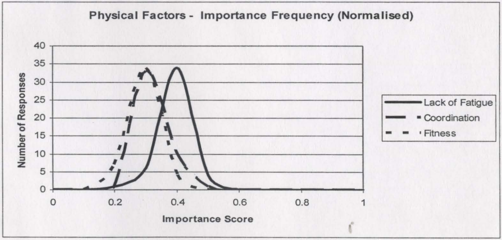

Financial Factors - Importance Frequency (Normalised)

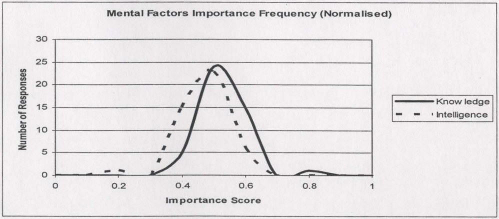

Organisational Elements - Importance Frequency (Normalised)
Number of Responses
40
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
Importance Score
Safety Culture
Training
Procedures


Direct Elements - Importance Frequency (Normalised)
Number of Responses
45
40
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
Importance Score
Behavioural
Capability
Weather
Safety Design
PPE


Attitude vs Motivation - Importance Frequency (Normalised)
Number of Responses
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
Importance Score
Attitude
Motivation


Physical vs Mental - Importance Frequency (Normalised)


Physical Factors - Importance Frequency (Normalised)


Mental Factors Importance Frequency (Normalised)