Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

According to the official accident statistics of the past ten years, obtained from the Department of Minerals and Energy, safety performance in the South African mining industry has been static at intolerable levels, if the new risk-based paradigm is utilised as a reference point. While the inevitable year-to-year fluctuations can be distinguished, there has been no discernible downward trend in injury and fatality rates in this decade. This indicates that no real improvement has been achieved in accident prevention by existing approaches. This fact is supported by an analysis of the accident statistics of the South African mining industry. This analysis follows later in this chapter.

Since gold was discovered on the Witwatersrand during 1886 very few major changes have been made to standard mining techniques, according to Futcher, the 1988 President of the Association of Mine Managers of South Africa. The same can be said about the way in which accidents have been investigated during this period.

In this chapter the author will attempt to critically analyse the available literature on accident investigation. To limit misunderstanding, a number of definitions of more important terms will follow. In order to put the research in the correct perspective, a historic overview of accident investigation will be provided. Various recommended accident investigation procedures will be considered and evaluated. A section covering the literature regarding existing accident investigation procedures will follow. Before the elements present in an accident are isolated for further research, the theory of accidents will be reviewed.

This chapter is concluded with a discussion of the perceptions and insights the researcher gained by studying the literature on accident investigations.

2.2 BACKGROUND TO THE RESEARCH

Some of the first recorded organised initiatives to prevent industrial accidents refer to the first factory laws adopted in Great Britain, and shortly after, in the United States of America and other industrialised countries in the 19th century. The first official effort to prevent accidents in South Africa was the promulgation of safety legislation for the mining industry in 1910. The large number of accidents in the industry at that time prompted this legislation, according to Taljaard (1995).

During the past 50 years safety has played an increasingly important role in defining operational standards in industries all over the world. The fact that safety now plays such an important role in legislative and operational standards is a reflection of the demand from society that all activities should be free from risk to the worker or at least kept at tolerable levels of risk according to Makin (1999).

A certain level of risk is inherent in every activity in the workplace. Tolerating some level of risk is necessary, but to protect against unwanted loss such as injury, property damage or production downtime, risks must be eliminated, transferred, controlled or tolerated (ILO convention C 176).

This worldwide trend is emphasised by the fact that the International Labour Organisation (ILO) first accepted a convention (C28) on protection against accidents on 21 June 1929. This convention was aimed at reducing accidents during work performed on shore or on board ships whilst loading or unloading any ship. This convention was revised twice since then, first in 1932 (C32) and again in 1997 (C152). The International Labour Organisation also accepted the following conventions relating to health and safety:

- A convention for safety provisions for buildings (C62) in 1937,
- A convention on the prevention of accidents associated with seafarers (C134) in 1970,

- A convention on occupational health and safety (C155) that applied to all branches of economic activity in 1981,
- A safety and health in construction convention (C167) in 1988,
- A convention on the prevention of major industrial accidents (C174) in 1993,
- A safety and health in mines convention (C176) in 1995.

In addition to these conventions, the International Labour Organisation also accepted a number of conventions dealing with occupational health and occupational medical examinations.

This international emphasis on safety and health is also reflected in the in the South African mining industry new Mine Health and Safety Act, 1996 (Act No. 29 of 1996).

In this Act the emphasis was altered to make it clear that reducing or eliminating risks would improve safety. Design, control or management could be used to reach the desired level of risk reduction for identified hazards. In practice a combination of these approaches is called for.

The decriminalisation of accident investigations was given direction with the inclusion of Section 63 in the Mine Health and Safety Act, 1996 (Act No. 29 of 1996) that attempted to increase the effectiveness of investigations by making it possible for the Chief Inspector of Mines, in consultation with the Attorney General, to issue a certificate of non-prosecution under certain circumstances. Despite the inclusion of this section the inspectors did not make use of it, as there was no formal accident investigation methodology in use in the mining industry that effectively identified the fundamental contributing factors of accidents.

Most industrial accidents result from factors that are constantly present for weeks, months, or even years. It is only a matter of time before the event will occur. This state of affairs urgently needs to be addressed by developing an analytical accident investigation model for the South African mining industry. It is anticipated that knowledge of fundamental contributing factors will influence decision-makers to seek to avoid taking the risk that such events may occur.

In companies where the culture is such that employees are allowed to take risks, it is likely that the attitude towards accidents is that "accidents just happen and there is nothing we can do about it." This type of attitude is not conducive to an effective safety culture. Employers with a healthy attitude towards risk will require the pro active correction of fundamental contributing factors.

To conduct an effective accident investigation, the factors contributing to an accident, as well as ways and means to prevent accidents, must be clearly understood.

2.3 RELEVANCE OF ACCIDENT INVESTIGATIONS TO MINING ACTIVITIES

Safety measures always cost money and the employer must foot the bill. A perpetual conflict of interest exists between employers and employees as to the type and magnitude of safety measures that could be considered reasonably practical and reasonably necessary.

According to Smith (1994:229-234), the long-term future of the South African gold mining industry is largely dependent on the effective extraction, in terms of safety and financial returns, of deep level ore reserves. Should either of these factors not be achieved, the long-term future of the South African gold mining industry may be jeopardised.

It is with the above in mind that a method needs to be developed to establish and isolate the fundamental contributing factors of accidents on mines. Once these factors are known, it would be possible to implement pro-active preventative actions. In addition it would also become possible to focus the risk assessment procedure on the factors identified during accident investigations.

2.4 PREVAILING ACCIDENT INVESTIGATION METHODOLOGY

Mining is probably the world's oldest industry and considered one of the most hazardous. Mining differs from almost all other industries in that the working environment continually changes as the work proceeds. Notwithstanding this, the management of mining safety has much in common with safety management in other industries.

One way mines can achieve a better competitive advantage is to control the cost caused by workplace accidents. This can be achieved by integrating an appropriate accident investigation management program into an overall business strategy, according to Powers and Arnstein (1995).

Most modern accident investigation systems aiming to determine factors contributing to the recurrence of accidents in order to prevent them, offer methods of safer design to ensure that risks will be eliminated or minimised by eliminating contributing factors. The traditional accident investigation approach in the South African mining industry is focused on blame-fixing rather than on these principles. Hermanus and Leger (1993) support this view in their submission to the Leon Commission of Inquiry into safety and health in the mining industry.

South African government mining inspectors investigate all fatal accidents and a large portion of other accidents. The procedure they follow is guided by means of a Chief Inspector of Mine's Directive (D1).

The inspector has to visit the scene of a fatal accident and collect information that would assist during the inquiry. In the majority of the cases the inspector requests the mine's surveyor to measure the area and produce a plan. During this so-called in loco inspection all stakeholders have the right to attend.

From interviews with inspectors and the experience this researcher gained during the investigation of more than one hundred and fifty accidents over nine years, utilising this system, the information that witnesses supply at the scene differ vastly from those given under oath, especially when someone was potentially implicated. The information obtained during informal interviews is not "admissible" during the formal part of the inquiry as the witness is said not to have been under oath.

The formal part of the inquiry is structured in a quasi-legal format where the inspector swears in witnesses and takes down statements from all persons associated with the accident. These statements are taken down in the presence of everybody involved in the accident. Any person present has the opportunity to cross-question the witness. But workers are often not willing to make statements that could implicate their seniors for fear that they may loose their jobs.

Very seldom are preventive measures identified during the accident investigation. In the few cases where preventive measures are identified, no evidence could be found that these measures were implemented in the business strategy of the mine or the industry.

In order to enhance the effectiveness of accident investigations, Section 63 (1) of the Mine Health and Safety Act empowers the Chief Inspector of Mines to decriminalise investigations held in terms of Section 60 of the Act by issuing a certificate of non-prosecution.

In the author's opinion, punishment should never be inflicted as the result of an accident investigation. Such action is shortsighted and counterproductive. Many more productive avenues exist to address shortcomings identified during accident investigations.

During this research some arguments against linking punishment with accident investigations will be presented. This researcher supports the decriminalisation of accident investigation, as this will ensure that the correct information is obtained for analysis.

According to Hermanus and Leger reporting to the Leon Commission (1993), should preventive measures be implemented as a matter of course, a great number of accidents could be prevented.

Unreliable accident information is an open invitation to certain disaster. Information pertaining to accidents may be used to make a wide range of operational, management and strategic decisions. One of the few ways to be sure that the accident information used as a basis for decisions are accurate, is to do an in-depth study of the fundamental contributing factors.

Accidents mostly occur as a result of a combination of factors, which must all be simultaneously or sequentially present. An unsafe act or situation does not give rise to an accident until someone is exposed to it and both physical and psychological factors, in combination with unsafe systems of work, trigger the accidents. Combining environmental hazards and human factor hazards multiplies accident potential. The larger the number of hazards, the more the accident potential will increase.

All the risks that were taken in leading up to an accident have to be evaluated during the investigation. The evaluation should result in identifying the inadequacies in the safety management programme, the standard procedures as well as non-compliance to standards.

2.5 ACCIDENT STATISTICS

The following analysis of accidents in the South African mining industry clearly places the relevance of this type of research in context.

The reportable accidents for all mines in South Africa for the period 1990 to 1997 are summarised in table 2.1, which is an extract from the statistical summary of accidents published annually by the Chief Inspector of Mines (1997). The statistical data is obtained from the South African Mines Reportable Accident Statistics System (SAMRASS).

The accidents statistics for coalmines for the same period is reflected in table 2.2 while the goldmine accident statistics are reflected in table 2.3. The statistics for all other mines such as platinum, diamonds, iron ore etc. combined makes up the difference between the totals, when compared with the totals reflected in the all-mines accident statistics table.

The first of the six columns indicates the year for which the statistics are reported. The columns titled "fatalities" and "injuries" reflect the number of persons fatally injured or reportably injured for each corresponding year. The columns labelled "fatality rate" and "injury rate" indicate the number of fatal injuries per 1 000 employees at work.

The rates are calculated by means of the following formula:

$$\textbf{Injury/fatality Rate} = \frac{\text{Number of injuries/fatalities X 1000}}{\text{Employees at work}}$$

The column labelled "Labour" indicates the average number of employees at work for each of the years in the table.

With reference to table 2.1 it can be seen that a total of 4 325 persons lost their lives and that 66 384 persons were reportably injured in the mining industry over this period. During the reporting period the number of persons reported to be at work dropped from a high of 697 658 during 1990 to a low of 483 981 during 1997.

The fatality and injury rates indicate the true change over the years, normalised against the number of employees at risk.

Table 2.1 - REPORTABLE ACCIDENTS: ALL MINES 1990 TO 1997

YEAR	FATALITIES	FATALITY RATE	INJURIES	INJURY RATE	LABOUR
1990	684	0.98	9 830	14.09	697 658
1991	602	0.95	9 058	14.24	636 096
1992	551	0.94	8 795	15.00	586 333
1993	586	1.08	8 524	15.66	544 317
1994	482	0.95	7 934	15.71	505 029
1995	533	1.02	7 717	14.76	522 832
1996	463	0.94	7 426	15.00	495 067
1997	424	0.88	7 100	14.67	483 981
Total	**4 325**		**66 384**		

The number of injuries seem to indicate a constant decline from 1990 (9 830 injuries) to 1997 (7100 injuries), an apparent improvement of 27,8 %, but this would be a complete misinterpretation as the employees at work, and therefore at risk, reduced from 697 658 to 483 981 over this period.

Had the number of employees at work stayed the same from 1990 to 1997 the injuries during 1997 would have been 10 225. The facts represent a deterioration of 4 % in the injury performance for this period.

One should therefore take cognisance of the number of injuries/fatalities in order to evaluate how well an industry is performing in accident prevention, as well as the number of persons exposed to the risk of being injured/killed. The injury/fatality rate is one way of taking cognisance of both these factors.

The discussion of the difference between the specific safety achievements of the gold and coal mining sectors respectively, on page 9 of this thesis, requires further discussion.

The reportable accidents for all mines in South Africa for the period 1990 to 1997 are summarised in table 2.1, which is an extract from the statistical summary of accidents (1997) published annually by the Chief Inspector of Mines. The statistical data is obtained from the South African Mines Reportable Accident Statistics System (SAMRASS).

The accidents statistics for coalmines for the same period are reflected in table 2.2, while the goldmine accident statistics are reflected in table 2.3. The statistics for all other mines such as platinum, diamonds, iron ore etc. combined, make up the difference between the totals of coal and gold and the totals reflected on the All Mines table (table 2.1).

An analysis of the accident trends in the two sectors clearly indicate that the fatality rate in the gold mining sector improved from a rate 1.25 per thousand per annum in 1990 to 0.95 in 1997. (table 2.3) This translates to a 31.57% reduction in the rate. On the other hand, the coal mining fatality rate worsened from 0.53 in 1990 to 0.72 in 1997 (table 2.2) which is a 35.85% regression.

In addition to this, the 1993 rate of 1.57 is worse than the worst of the gold mine performance (1995 – 1.27) in the period under review. This particularly bad performance in 1993 can be ascribed to the Middelbult coal mine disaster that occurred in that year. The injury rates tells a similar story with a regression of 17.31% for coal mining and only 1,72% for gold mining for the same period. Considering that gold mining is a labour intensive industry with very little mechanisation, compared to coal mining where the labour force are much lower and mechanisation much higher, the efforts of the gold mining industry is paying better safety dividends.

Table 2.2 - COAL MINES - ACCIDENT DATA 1990-1997

YEAR	FATALITIES	FATALITY RATE	INJURIES	INJURY RATE	LABOUR
1990	51	0.53	400	4.16	96 154
1991	43	0.48	370	4.09	90 465
1992	46	0.65	358	5.04	71 032
1993	90	1.57	279	4.87	57 290
1994	54	0.96	240	4.26	56 338
1995	31	0.53	235	4.00	58 750
1996	45	0.79	285	4.79	59 499
1997	40	0.72	270	4.88	55 328
Total	**400**		**2437**		

Table 2.3 - GOLD MINES - ACCIDENT DATA 1990-1997

YEAR	FATALITIES	FATALITY RATE	INJURIES	INJURY RATE	LABOUR
1990	531	1.25	8 183	19.21	425 976
1991	461	1.21	7 531	19.80	380 354
1992	407	1.13	7 587	21.04	360 599
1993	426	1.23	7 368	21.34	345 267
1994	371	1.08	6 888	20.00	344 400
1995	415	1.27	6 243	19.13	326 346
1996	319	1.06	5 911	19.57	302 044
1997	279	0.95	5 710	19.54	292 221
Total	**3 209**		**55 421**		

2.6 DISCUSSION OF TERMS

In order to conduct accident investigation properly, some critical terms from the literature and the appropriate laws and regulations should be clarified. In the next section some of the more critical terms will be discussed and explained. It is the aim of the researcher to endeavour not only to supply definitions, but also to explain the terms for the purposes of this research.

The explanations results from interpretations and a combination of explanations from a number of sources listed in the references. The words and phrases may have other meanings in general or scientific use, but for the purpose of this research the meaning of these words will be as explained below.

2.6.1 ACCIDENT v INCIDENT

In publications such as Loss Control Management by Bird and Germain (1996) and National Occupational Safety Association (NOSA) publications, the term incident is used in preference to accident. In order to ensure consistency the following references have been consulted.

The South African Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) defines the term **incident** in Section 24 (1) to include:

> *"Any person who dies, becomes unconscious, suffers the loss of a limb or part of a limb or otherwise becomes ill to such a degree that he is likely to die or suffer a permanent physical defect or likely to be unable for a period of at least 14 days either to work or to continue with activities for which he was employed or is usually employed."*

Despite the definition used by this Act, no other reference could be found of incident having a meaning that includes injury to people.

The following sources all support the use of the term accident whenever injury to people are meant:

The ILO convention concerning the prevention of major industrial accidents adopted on 22 June 1996 (Convention C174:3) states the following:

> *For the purposes of this convention the term major* ***accident*** *means a sudden occurrence such as a major emission, fire or explosion in the course of an activity within a major hazard installation, involving one or more hazardous substances and leading to a serious danger to workers, the public or the environment, whether immediate or delayed.*

Article 5 (2) of the ILO convention concerning safety and health in mines that were adopted on 22 June 1998 (Convention C176:3) requires national laws and regulations to provide for:

> *(c) The procedures for reporting and investigating fatal and serious* ***accidents****, dangerous occurrences and mine disasters, each as defined by national laws or regulations;*
>
> *(d) The compilation and publication of statistics on* ***accidents****, occupational diseases and dangerous occurrences, each as defined by national laws or regulations;*

In Chapter 16 of the Canadian Workplace Safety and Insurance Act, 1997, the use of the term accident for work-related injuries indicate that Canada makes extensive use of the term accident and does not utilise the term incident at all.

The US military standard MIL-STD-882C dealing with system safety program requirements dated 19 January 1993, defines the term mishap or accident to be:

> *An unplanned event or series of events resulting in death, injury, occupational illness, or damage to or loss of equipment or property, or damage to the environment.*

The British Standard with the title "Guide to occupational health and safety management systems" BS 8800:1996 defines the following terms:

> ***Accident:***
>
> *Unplanned event giving rise to death, ill health, injury, damage or loss.*
>
> ***Incident:***
>
> *Unplanned event which has the potential to lead to accident*

The occupational health and safety assessment series OHSAS 18001:1999 draft 4 dated 18 February 1999 defines the terms as follows:

> ***Accident:***
>
> *Undesired event giving rise to death, ill health, injury, damage or other loss.*
>
> ***Incident:***
>
> *Undesired event, which has the potential to lead to accident.*

The USA code of federal regulations part 30 (Mineral Resources) defines **accident** extensively in section 50.2 (g). In summary the term is defined to include death and injury to an individual as well as a number of conditions that relate to loss without injuries being associated with the condition. The term incident is not found in this legislation.

The definition of accident, included in the US Federal Government Employees Compensation Act, is interpreted by the appeal commission to encompass both accidental cause and accidental result.

The Queensland Mines Regulation Act of 1964 as in force on 21 March 1997 does not define the term accident, but from Section 39(4) it can be concluded that a reportable accident is an accident that has resulted in loss of working time by any person on or about the mine.

The Victorian (Australian) Accident Compensation Act of 1985 does not define the term accident but from the text it is clear that injuries are compensated by this Act indicating that the term accident is acceptable.

The South African Mine Health and Safety Act, 1996 (Act No. 29 of 1996) does not specifically define the term accident but it is extensively used throughout the Act.

In the light of the above, it is clear that there is overwhelming evidence for the use of the term accident when an event results in the death, ill health or injury to workers. In cases where property damage and/or loss is referred to, most agree that the use of the term incident is acceptable.

For the purpose of this research the term accident will therefore be used and will include the meaning of incident. The motivation for this is that the research will focus primarily on accidents resulting in the death, ill health or injury to workers.

Based on the above definitions obtained from the literature the researcher developed the definitions below.

2.6.2 ACCIDENT

An occupational accident can be described as follows:

The final event in an undesirable, unexpected and unplanned event sequence that interrupts an activity, and directly or indirectly results in immediate or delayed injury or illness to an employee, and may or may not result in property damage or loss in production.

The definition utilises certain words that could have different interpretations and it is therefore necessary to define some of these terms.

2.6.2.1 FINAL EVENT

The final event is the simultaneous, interconnected, cross-linked occurrence that takes place when the last of the fundamental contributing factors interact dynamically with other contributing factors in a four-dimensional space-time continuum.

2.6.2.2 FUNDAMENTAL CONTRIBUTING FACTORS

A fundamental contributing factor is a feature or condition required before and/or during an accident that plays a part during the dynamic interaction of the fundamental contributing factors in such a way that it plays a primary part in the accident sequence.

2.6.3 ACCIDENT INVESTIGATION

An accident investigation is the first step in a fact-finding process aimed at avoiding future accidents. It should determine what, why and how the accident happened. Its purpose should not be to blame someone. A good accident investigation will establish the failure modes of the fundamental contributing factors.

Appropriate accident investigations often confirm that many small, less serious accidents occurred earlier as a result of similar system failures. An accident investigation offers the chance to learn a great deal about the fundamental contributing factors present during an accident and thereby increase the opportunity to intervene in the interest of safety. To be useful, accident investigations must be an honest attempt to establish the facts.

2.7 RISK ASSESSMENT AND ACCIDENT INVESTIGATION IN CONTEXT

Risk Assessment as defined in the South African mining context is the pursuit of managing the future safety of workers. It involves a detailed and systematic examination of any activity, location or operational system to identify risks, understand the likelihood and potential consequences of the risks, and review the current or planned approaches to controlling the risks, resulting in the instituting of additional controls where required.

Successful risk control can include outcomes such as improved safety, health, production, environmental protection or community acceptance.

From this explanation it is clear that essentially there are no differences between the accident prevention risk assessment and accident investigation processes as both aim to prevent unwanted incidents and both have the same components: hazard identification, consequence or impact, controls and failure modes. The consequence or impact stems from hazards being realised. Controls are active management interventions to eliminate or reduce the risks. Failure modes are the primary reasons for controls failing.

Despite the similarities in the two processes some procedural differences do exist. The main distinction is the timing within the management cycle of activation. Risk assessment occurs at the beginning of a management system cycle (pro-active) and accident investigation occurs after accidents (re-active) in the management cycle. However, the information contained in the outcome of accident investigations is fed into the risk assessment process and the cycle is repeated. A graphic representation of the main components of the two processes is given in Figure 2.1.

Accident investigation has a defined re-active outcome (specific information after a once-off activity) as opposed to risk assessment that pro-actively attempts to prevent incidents.

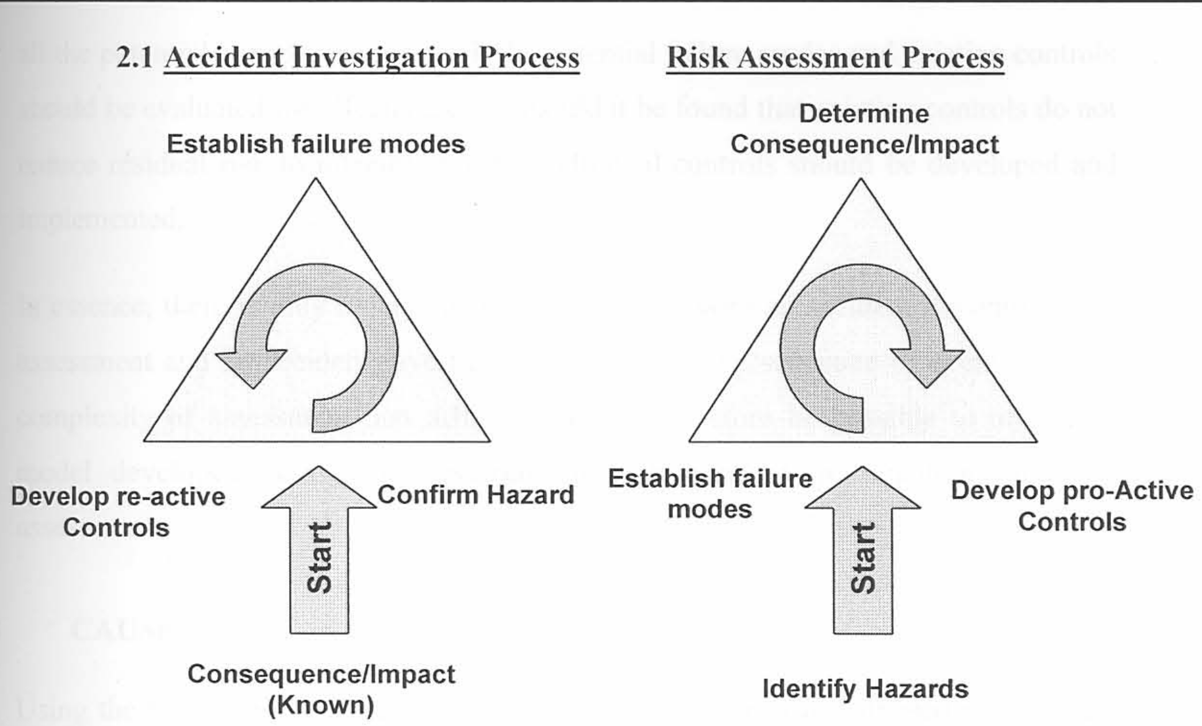

Figure 2.1: Accident investigation and risk assessment processes in context

During the accident investigation process (left triangle in Figure. 2.1) the starting point is after the impact when the consequences are known. The first step is to confirm the hazard responsible for the accident. The next step is to determine the failure modes in order to reactively develop additional controls to prevent a re-occurrence. Since the consequences are known it is reasonably easy to identify the hazards. The challenge is to correctly identify the failure modes and then develop control measures to eliminate, minimise or control the risk at source, as personal protective equipment should only be issued in response to risks remaining after instituting controls.

A risk assessment process (right triangle in figure 2.1) starts before the impact and potential consequences are known. The first step is therefore to identify the risks in each step of the process. The next step is to identify the potential failure modes for all the identified hazards. The aim of this process is to identify and ascertain the consequences pro-actively to develop controls that will prevent the various potential failure modes. It goes without saying that this process is much more complex since all the potential consequences and all the potential failure modes and existing controls should be evaluated for effectiveness. Should it be found that existing controls do not reduce residual risk to tolerable levels, additional controls should be developed and implemented.

In essence, there is only a very small difference between an accident prevention risk assessment and an accident investigation. It is only the sequence of events and the complexity of assessment that differ. It would therefore be possible to utilise the model developed during this research for both accident investigations and risk assessment.

2.8 CAUSE

Using the term cause as an exclusive reason for an accident is criticised by Saunders (1991). They are of the opinion that there are no accidents with a single cause and that the expression should be seen as a general term, including many factors related to the occurrence of an accident.

From the Western Australian Department of Minerals and Energy accident and incident investigation manual (1997) it is clear that they are also of the opinion that accidents mostly occur as a result of a combination of factors which must simultaneously or sequentially be present. They go further to state, "an unsafe situation does not give rise to an accident until someone is exposed to it" and conclude that both physical and psychological factors, in combination with unsafe systems of work, result in accidents.

According to the USA Department of Energy's workbook on conducting accident investigations (1997), during all accidents human consideration or a human-made object, or both, play a significant role. They continue to state that generally any accident can be attributed to a human activity or response. This researcher is of the opinion that this wide definition of "human factors" in accidents will continue to contribute to incorrect approaches during accident investigations that seek to establish blame during accident investigations.

Combining environmental hazards and human factor hazards, would multiply accident potential. The larger the number of hazards, the quicker the accident potential will increase, according to Curtis (1995).

According to the Workers Compensation Board of British Columbia's Worksafe publication, Investigation of Accidents and Diseases: An Overview (1996) the multiple factors associated with accidents include unsafe acts, personal factors, unsafe environmental conditions, unsafe acts by other persons and deficiencies for which others are responsible.

In a work environment several levels of barriers may be used in an effort to prevent accidents. Accidents occur when one or more barriers in a work system, including procedures, standards and requirements intended to control the actions of workers, fail to perform as intended, according to the U S A Department of Energy's workbook on conducting accident investigations (1997). Barriers that protect objects against loss can be physical barriers such as machine guards, administrative barriers such as procedures and policies, and supervisory or management barriers such as work instructions, line management supervision and effective communication strategies.

According to Minerisk Africa (1998) an accident is the result of a combination of parallel and sequential events and conditions, again indicating that accidents are deemed to be the result of multiple factors.

The factors contributing to an accident are equated to the fable about the straw that broke the camel's back, according to Kuhlman (1977). He is of the opinion that each straw contributed as much as the last one. The last substandard act in an accident sequence tells very little by itself. All the risks tolerated in the lead-up to the accident have to be evaluated during the investigation. The evaluation should result in identifying inadequacies in the safety management programme, in standard procedures as well as shortcomings in compliance with standards.

According to Albert Einstein (1961) the world we live in is a four-dimensional space-time continuum and therefore this researcher is of the opinion that it is important that equal significance be allocated to physical and temporal dimensions when isolating factors underlying or contributing to accidents.

From the above it is clear that most leading authors on accident investigation are in agreement that no accident can be attributed to one single factor.

This researcher supports the view that an accident will always be the result of multiple factors interacting, but strongly recommends that the use of the term cause or causes, in so far as it relates to accidents, be replaced by the term contributing factors. This may assist in establishing a caring culture not focussed on apportioning blame.

Where existing literature refers to cause or causes of accidents it is taken to refer to fundamental contributing factors. This researcher will therefore refrain from using the term cause or causes of accidents in the thesis.

2.9 SAFETY MANAGEMENT SYSTEMS

The main objective of any safety management system should be to support better management decision-making that will lead to improved safety outcomes for the workforce, in addition to indirect management benefits that may result. A correctly implemented safety management system can be used to improve the safety performance of any organisation by utilising improved control and accountability mechanisms.

An effective safety management system will include the setting of safety objectives as well as performance review against those objectives. In a safety management system, performance may be measured by using simple and transparent indicators as well as more complex measurement systems. Measurement should however always be from the point of view of the safety of workers and the impact of potential accidents on efficiency, effectiveness, service quality and financial results.

All parts of a safety management system are based on good management principles and it is increasingly seen as an integrated part of daily management activities, rather than isolated from these.

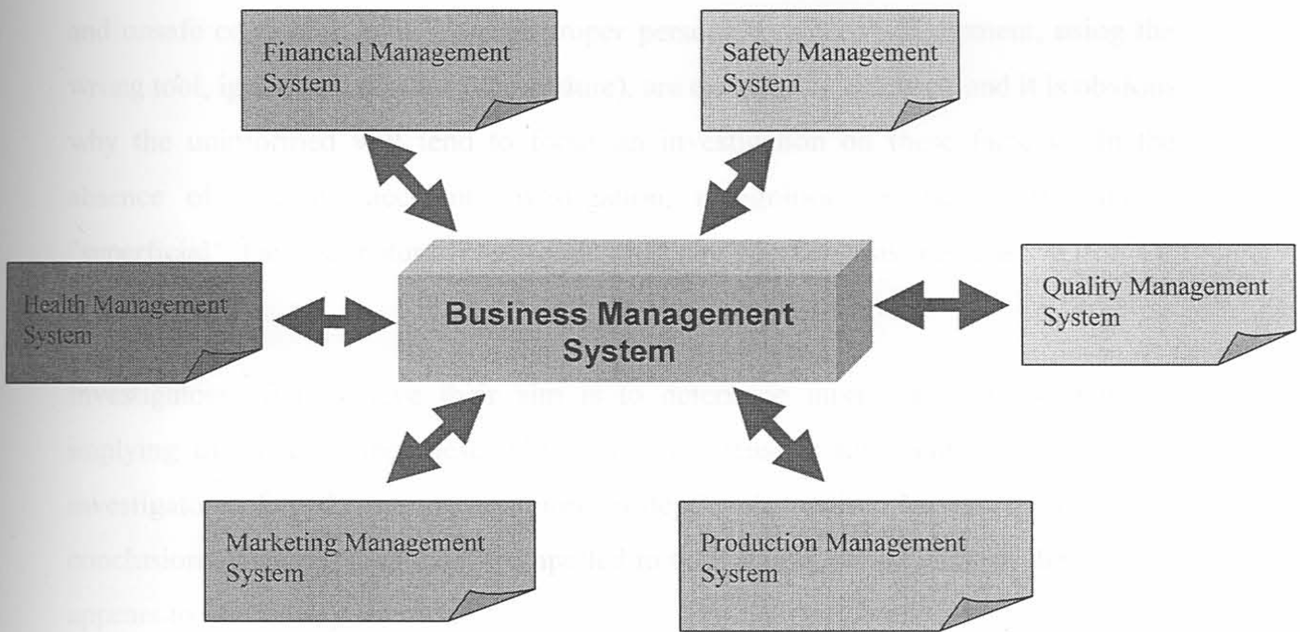

Figure 2.2 – The relationship between a safety management system and other management activities in a business management system. (Adapted from The South African Excellence Model)

2.10 THE EFFECT OF A BLAME-APPORTIONING CULTURE

Accidents are symptoms of problems within an organisation. By addressing only these symptoms, a company may find itself with an accident rate intolerable to all. Accident prevention methodologies focussed only on the symptoms are doomed. Proper accident investigation is the primary tool to establish the information required to effectively reduce accidents on a fundamental level. According to the American Society of Safety Engineers (1999) a punishment-orientated culture ignores this information and is counterproductive to effective accident investigations.

Rather than punishing, management should try to determine what motivates employees to act unsafely, or why workers do not understand what they are supposed to do. Managers often settle for punishment because it is easier than searching for fundamental contributing factors.

The focus of the so-called immediate or proximate causes, often called unsafe acts and unsafe conditions (not wearing proper personal protective equipment, using the wrong tool, ignoring established procedure), are on tangible elements and it is obvious why the uninformed will tend to focus an investigation on these factors. In the absence of in-depth accident investigation, recognition of these symptomatic, "superficial" factors, naturally suggests that the worker was responsible for the accident.

Investigators often believe their aim is to determine unsafe acts and conditions, implying that uncovering these will expose the reasons for accidents. Therefore, investigators often do not pry for more in depth information, leaving them to base conclusions on superficial data. Compelled to take action, punishment of the "guilty" appears to be the only solution.

Another general problem is agitated supervisors who want to complete the accident investigation as soon as possible. Punishment is normally the way of least resistance.

According to Bakker, Chief Inspector of Mines of South Africa, accident investigations should be performed to ascertain the reasons for accidents in order to establish and implement appropriate remedial action(s) to prevent a recurrence (Personal interview, January 1998).

According to Minerisk Australia (1995), accidents frequently occur as a result of deficiencies in the management system and as such they decrease performance and production. This publication informs that accidents should be used as a window through which the existing management system is viewed. The deficiencies revealed and benefits derived should go far beyond rectification of the so-called immediate causes of the accident. The investigation needs to identify the areas where managers or supervisors have unsuccessfully assumed responsibility.

In Practical Loss Control Leadership (1996), Bird and Germain describe Ferdinand Fournie's survey of 4 000 managers, supervisors and company presidents. Thirteen factors were cited for subordinates' failures to follow rules, most of which were not "punishable offences." Clearly, workers who face "obstacles beyond their control, ... think they are performing a task properly" or are "personally unable to do it", do not deserve punishment (Bird and Germain 1996: 423-425).

Management should strive to correct management systems. Inappropriate management systems normally do not anticipate or discover factors before they contribute to accidents. It is believed by some, that with few exceptions, accidents are ultimately the result of management system failures, not employee infractions. This researcher believes that this is too simplistic an approach and that a combination of factors contributes to accidents.

The outcomes of many modern industrial accident investigations do not achieve the desired effect, as the focus is limited to establishing only some of the fundamental contributing factors. Some systems in use maintain a focus on establishing blame.

In many cases, management or the authorities utilises an investigation system that only lends itself to punishing the so-called "guilty party", who may well already have experienced personal injury.

To achieve some sense of justice for a breach of standard or regulation, this type of investigation is still justified by the ill informed.

On many mines the employees involved in causing accidents are still being suspended, demoted, dismissed or otherwise punished for the "crime" of being involved in occupational accidents, according to Speir and Richard (1998).

Invariably companies complain about ineffective or unsatisfactory accident investigation programmes. In the author's opinion, they are doomed to repeat the same investigation for the same transgression again and again, with no hope of resolving the fundamental contributing factors that may lead them to preventing future accidents. The tragedy is that these firms mean well, they are trying to gain control over the factors contributing to accidents, but do not understand enough about accident prevention theory to react properly.

2.11 ACCIDENT INVESTIGATION TECHNIQUES

In this section some of the more typical accident investigation techniques will be discussed individually with a view to evaluating and extracting the best parts from each. The factors so isolated will be combined to develop an analytical accident investigation model for the South African mining industry.

2.11.1 HEINRICH'S TRIANGLE

According to Heinrich, (1980), a well-managed loss control strategy provides an operational strategy that contributes to the improvement of overall management. While Heinrich's triangle is illustrative of the ratio of types of accidents, it implies that the same contributing factors are at work throughout the triangle. Of course, this cannot be the case. Despite being a groundbreaking publication for the era, the basic approach has many flaws and cannot be implemented without major changes.

The triangle clearly indicates that a very specific ratio exists between various levels of severity. This can be very useful when analysing accidents, however, it does not provide any failure modes that may be utilised during pro-active prevention activities.

In Figure 2.3 Heinrich's triangle depicts the ratio between various levels of accident severity. This clearly indicates that every serious or major injury is preceded by ten minor injuries and thirty property damage accidents. Heinrich established no explanation of the reasons for the accidents, and therefore this cannot be viewed as a formal investigation method. The ratios established does however provide invaluable information to investigators regarding accidents that may be unreported.

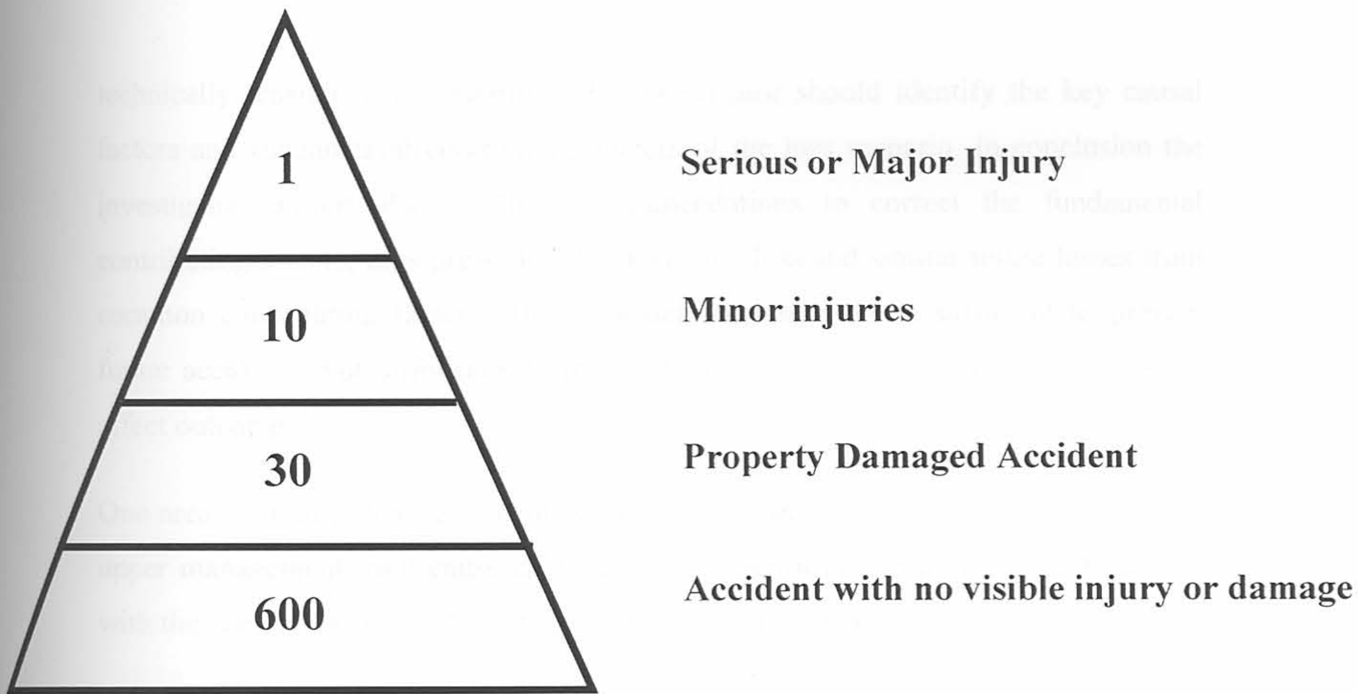

Figure 2.3 - Heinrich's triangle depicting the ratios between the various levels of accident severity.

2.11.2 ROOT CAUSE ANALYSIS

One of the more modern types of accident investigation systems is the root cause analysis, sometimes called the root cause failure analysis. The procedure consists of a set of processes through which the underlying causes of adverse outcomes may be identified. The goal of the investigation is preventing the reoccurrence of such events, according to the United States of America's Joint Commission on Accreditation of Health Care Organizations (JCAHO) (1996).

There are many different processes by which root cause analyses can be performed and the engineering and industrial risk management literature is rife with arguments for and against the different approaches. It is not the purpose of this research to explore those differences.

Root Cause Analysis is designed to systematically evaluate the possible ways that a loss (or series of losses) could have occurred. During the process the investigator collects and arranges factors in such a way as to rule out possibilities and develop a technically feasible loss scenario. The investigator should identify the key causal factors and fundamental contributing factors of the loss scenario. In conclusion the investigator should also produce recommendations to correct the fundamental contributing factors, thus preventing the recurring loss and similar future losses from common contributing factors. This approach may seen to be sufficient to prevent future accidents, but unfortunately the methodology focuses only on a singe cause-effect outcome.

One area of undisputed agreement is the observation that without strong support by upper management, root cause analyses will be performed in a mechanical manner, with the singular purpose of meeting regulatory requirements.

Most real-world events do not follow a simple cause-effect trail. A single factor may have multiple consequences. A combination of factors may bring about a single result, or they may initiate multiple effects. Causes can themselves have causes, and effects can have subsequent downstream effects. The failure mode should also be considered in all of these models.

2.11.3 FAULT TREE ANALYSIS (FTA)

Fault tree analysis is a widely used method in analysing the behaviour of failures in complex systems and is a method used in estimating the probability of occurrence for a particular failure mode. The main purpose of fault tree analysis is to evaluate the probability of a top event using analytical or statistical methods. This approach is most useful when several factors play a role in the occurrence of the failure mode.

Fault tree analysis is a systematic method of analysing contributing events that may lead to accidents. Fault trees can be used to determine the probability of failure of a system (or top event), to compare design alternatives, to identify critical events that will significantly contribute to the occurrence of a top event and to determine the sensitivity of the probability of a top event to the contributions of various fundamental events.

Fault trees describe a sequence of events that lead to system failure. The leaves of the tree can be used to represent the initial causes of the accident (Leplat, 1987). The author would however rather refer to the network of roots of a tree as this more accurately describes the network of events leading to an accident. The logical dependencies at each level of the tree is specified by using so-called AND and OR gates. The AND gate (Indicated by the symbol in figure 2.4) indicates that the output occurs if only if all of the input events occur. The OR gate (Indicated by the symbol in figure 2.4) indicates that the output occurs only if at least one of the input events occur. Basic tree nodes can make reference to any dependability model element such as LRU class, hardware configuration, reliability graph, embedded fault tree, or Markov model. Reliability and availability values are calculated for each node and logic gate and are expressed as probability numbers. In figure 2.4 these values are reflected on each of the nodes and logical gates. Vesely *et al* (1981).

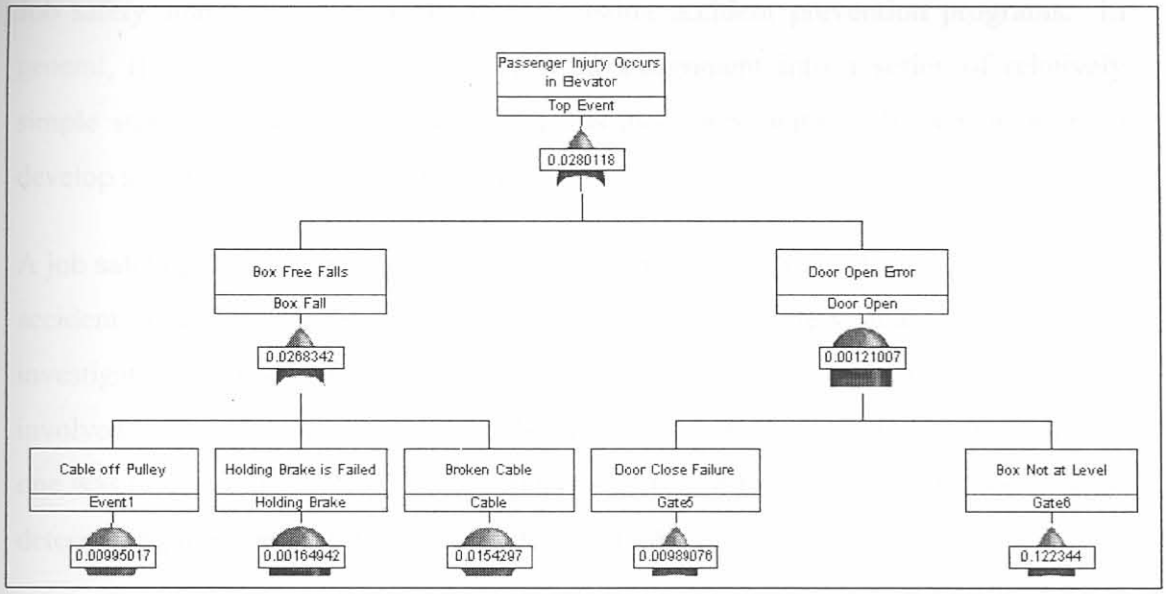

Figure 2.4 – Typical layout of a fault tree with NODES as well as AND & OR gates.

This author is of the opinion that the major disadvantage of fault tree analyses is that it does not recognise fundamental contributing factors as independent contributors to accidents. The fault tree approach is a quantitative system only aimed at establishing the probability of an accident re-occurring rather than establishing failure modes.

2.11.4 CHANGE ANALYSIS

As its name implies, this technique emphasises change. To solve a problem, an investigator must look for deviations from a norm. The investigator must consider all problems that could result from some unanticipated change.

This system requires that an analysis of changes be made to determine the potential consequences, thereby identifying the contributing factors.

Change analysis is an attempt to determine deviations from a pre-determined norm or standard, however, the system fails to provide the investigator a framework on where to expect deviations, according to Bird and Germain (1996).

2.11.5 JOB SAFETY ANALYSIS (JSA)

Job safety analysis forms part of many existing accident prevention programs. In general, it separates a specific job or work assignment into a series of relatively simple steps and then identifies the hazards associated with each step in order to develop solutions to control each hazard.

A job safety analysis consists of a chart listing these steps, hazards and controls. The accident investigation requires the review of the job safety analysis during the investigation, provided that a job safety analysis has been conducted for the tasks involved in an accident. This implies that a job safety analysis should be performed if one was not available. A job safety analysis therefore forms part of an investigation determining the events and conditions that led to the accident.

The main aim of a job safety analysis is to prevent accidents by trying to anticipate and then eliminate the associated hazards. This may be possible in an environment where the jobs and work assignments are well described and reasonably standard, however, in the mining industry the jobs and work assignments are of such a diverse nature that the use of this system will be very difficult to implement (National Safety Council, 1994).

2.11.6 SYSTEMATIC CAUSE ANALYSIS TECHNIQUE (SCAT)

The Systematic Cause Analysis Technique (SCAT) is a method that has been developed by the International Loss Control Institute (ILCI), which can be used to determine the root causes of an incident once a description of the sequence of events has been determined. (International risk control Africa – undated)

The systematic cause analysis technique is based on a five-step fault tree that leads the investigator through a set of pre-determined questions. The yes/no questions are designed so that the investigator is led to a next set of questions. In the first step the investigator is required to collect evidence in five categories, namely people evidence, position evidence, paper evidence, parts evidence and re-enactment of the accident.

Once the evidence has been collected, this step requires the investigator to evaluate the loss potential if the accident is not controlled. This is one of the few accident investigation models that attempt to introduce risk assessment principles into the investigation, however, the loss potential or severity of an accident used here, is only one of the factors considered during a typical risk assessment.

Step two of the investigation requires the investigator to identify the agency from a list of general agencies such as equipment, machinery, electricity or explosive devices, to mention only four of the twenty-five common agencies. If the agency cannot be found here, a further list of sixteen occupational hygiene agencies, that include dust, fumes, noise and radiation, can be consulted. This would appear to be an attempt to identify the energy source, however, some of the general agencies given here cannot be classified as energy sources.

In step three the investigator is required to identify the so-called immediate or direct causes from two lists, one for sub-standard acts and the other for sub-standard conditions. These lists respectively contain twenty-one and sixteen options and include items such as "operate equipment without authority" and "use of unsafe/sub standard equipment" under acts, with "inadequate warning systems" and "sub-standard material" under conditions.

Step four requires the investigator to identify the so-called underlying or basic causes of the accident. In this step the system divides the underlying/basic causes into three categories namely personal factors, job factors and natural factors. The investigator is required to answer a list of two hundred and one questions in thirteen categories.

It is unclear why the system differentiates between the so-called immediate or direct causes and the so-called underlying or basic causes. It would appear that the system attempts to try and isolate more than one contributing factor by differentiating in this way.

During step five the investigator is required to identify control actions needed. The guiding questions take the investigator back to the safety management system elements and require him to make recommendations that will impact on these.

2.11.7 HAZARD AND OPERABILITY STUDY (HAZOP)

The operability study was developed for use in the chemical and petroleum industries. It is based on the theory that most hazards are missed because the system is complex, rather than a lack of knowledge during design. Operability studies identify hazardous or unacceptable situations, according to Knowlton (1985).

Hazard analysis provides a quantitative examination of a serious hazard that has been identified, either by an operability study or by some other hazard identification method. It quantifies the effect of hazards as well as unacceptable situations.

During hazard and operability studies (HAZOP) the two methods are brought together, according to the hazard and operability studies training manual published by International Risk Control Africa under licence of Det Norske Veritas of Sweden.

During hazard and operability studies the plant is examined line-by-line, vessel-by-vessel. The participation of a team of process experts is necessary to evaluate the consequences of hazards that may result from various failures or errors they have identified.

2.11.8 STRUCTURED WHAT IF CHECKLIST (SWIFT)

The Structured What If checklist study technique has been developed as an efficient alternative to the hazard and operability studies for providing effective hazard identification, when it can be demonstrated that conditions do not warrant the rigor of a hazard and operability study.

According to Dougherty (1999) the What If analysis is a structured brainstorming method of determining what could go wrong and judging the likelihood and consequences of those situations occurring. The answers to these questions form the basis for making decisions regarding the tolerability of the risks. This is then used in determining a recommended course of action for the risks judged to be intolerable.

The Structured What If checklist is a comprehensive, methodical, multidisciplinary team orientated analytical technique. It is also a system-orientated technique, which scrutinises complete systems or sub-systems. The Structured What If checklist system relies on a structured brainstorming effort by a team of knowledgeable process experts with complementary questions from a checklist.

When responding to all the questions about reasonable variations from the normal, planned function of a process unit, the team considers the probability of an accident, the possible consequences and the adequacy of safeguards to prevent it. The questions that may be posed by members of the team are structured according to specific categories.

This technique relies a great deal on the experience and insight of the assessment team and if all the appropriate What If questions are not asked, this technique can result in an incomplete conclusion and miss some significant hazards.

2.11.9 FAILURE MODE AND EFFECTS ANALYSIS (FMECA)

The failure mode and effects analysis discipline was developed in the United States military. The military procedure MIL-P-1629, titled "Procedures for performing a failure mode, effects and criticality analysis", dated 09 November 1949 is believed to be the first document describing this process. It was used as a reliability evaluation technique to determine the effect of system and equipment failures. Failures were classified according to their impact on mission success and personnel/equipment safety.

A failure mode and effects analysis is a bottom-up approach utilised to analyse the design of a product or process. The process starts by defining the bottom levels of the system. For each bottom level activity, a list of potential failure modes is generated. Effects of each potential failure mode are then determined.

Unfortunately this system only focuses on system and equipment failure and does not address the potential impact of management failure on the probability of an accident.

2.12 INVESTIGATION PROCEDURE

According to Minerisk Africa (1998), accident investigation procedure requires an impartial investigation team who utilises a systematic, logical and thorough process. They also advocate the use of systems safety analytical techniques to reveal what happened and why.

The International Risk Control Africa hazard and operability studies training manual (1994) requires that hazard and operability studies are embarked upon through the use of formal, systematic and critical examinations of process and engineering intentions of a process design. They also expect that a team with the required technical experience be utilised.

The procedure that Kuhlman (1977) supports is a controlled, methodical process of examination to ascertain how, when, and where an accident took place, aiming to establish why the accident occurred. He identifies four sub-systems to be examined, namely people, equipment, material and the environment.

The University of South Australia (1995) also promotes the use of a team to investigate accidents. Their process involves the inspection of the accident scene, the interviewing of witnesses, the collection of physical evidence and the review of relevant policies, work procedures, workplace inspection reports, maintenance records, etc. In addition to this they also advise on the recording of environmental conditions.

The Western Australian Department of Minerals and Energy's Accident and Incident Investigation manual (1997) states that accident investigation procedures need to be systematic.

They are also of the opinion that the investigation should identify trends, problem areas, basic factors that contributed directly and indirectly to the accident, and deficiencies in the management system. Their procedure allow for teams as well as individuals to investigate accidents. Accidents are categorised by making use of a risk matrix where probability and consequence are used to establish the number of investigators to be involved.

The most important part of any accident investigation is an investigation plan, according to Bird and Germain (1996). In order to ensure effectiveness a pre-developed organisational procedure is encouraged. They further advise that successful investigations will include at least six common activities. These are:

- Go to the accident scene as soon as possible
- Collect pertinent information about the accident
- Analyse all significant contributory factors
- Develop and implement remedial actions
- Review the findings and recommendations on the next level of leadership
- Follow up on the implementation and effect of remedial steps.

The US Department of Energy (1997) prescribes a specific process for conducting accident investigations, including specific tools and techniques that need to be followed under these main sections:

- Appointing the investigation board
- Implementing site readiness
- Managing the accident investigation
- Collecting data
- Analysing data
- Developing conclusions and judgements of need
- Reporting results.

It is clear that there is no consistency in investigation procedures by the different authors, but there is consensus that a systematic procedure should be followed.

A factor neglected by most accident investigation systems in use, is an objective methodology to ensure that resources are allocated appropriately to investigate accidents.

2.13 THE ELEMENTS OF AN ACCIDENT

After careful consideration of the different existing models that try to isolate individual elements of accidents, the researcher came to the conclusion that not one of the existing accident investigation methodologies adequately addresses the issue.

The most appropriate way to conduct an accident investigation will be to isolate fundamental contributing factors based on an analytical accident investigation model for the South African mining industry.

A review of what different authors have to say about fundamental contributing factors will be verified by means of a questionnaire that will be sent out to a broad spectrum of role-players in the mining industry.

A number of the accident investigation systems analysed above do not attempt to isolate fundamental contributing factors, however the study of these systems assist in ensuring that all bases are covered.

Analysing the accident investigation systems that do aim to isolate fundamental contributing factors, the following factors are present in one way or another (mostly hidden), in at least one of the methodologies:

- Who was at fault
- Substandard physical conditions
- Imperfect procedures
- Latent design defects of the equipment or the mine layout
- Breakdown in communication
- Energy source
- Hazardous materials
- Safety management system failure
- Training deficiency
- The policy of the mine
- Inappropriate maintenance
- Unsuitable task directives
- Human factors
- Environmental factors
- Engineering factors
- Unsafe acts
- Barrier failure

The relevant importance of each of these fundamental factors will be confirmed by using a questionnaire. The results obtained are evaluated in Chapter 3 of this research.

2.14 CONCLUSION

Despite the use of highly complex investigation procedures, some investigators still come to the conclusion that the injured are responsible for their own demise.

It is a well-known fact that flawed accident information can prompt the wrong management decisions. If management makes a decision on information they believe to be true, but in reality the information is not a true reflection of the facts, it will most certainly lead to more accidents in the long run.

Unreliable accident information is an open invitation to certain disaster. Information pertaining to accidents may be used to make a wide range of operational, management and strategic decisions. One of the few ways to be sure that the accident information used as a basis for decisions are accurate is to do an in depth study of the fundamental contributing factors of accidents.

Incorrect safety information can place any organisation on a crisis course from which it may never recover. This may lead to problems the organisation can ill afford in today's competitive environment. It may focus line management on the wrong priorities resulting in them solving problems in the incorrect priority.

Enterprises the world over suffer enormous losses as a result of accidents. To survive and develop in a very competitive world market, losses must be prevented as far as possible (NOSA:1995).

Notwithstanding the existence of numerous accident investigation methodologies discussed and described in the literature, not one of these successfully convey what should be done in order to permanently eliminate the fundamental contributing factors, since they fail to instruct the investigator on the importance of these factors.

Accidents are deemed to represent problems primarily associated with management systems, that must be solved through accident investigation. Several formal investigation procedures are recommended to solve problems of varying degrees of complexity. These systems will only have the desired effect if they identify the fundamental contributing factors correctly in order to recommend appropriate remedial action.

Sadly most accident investigations fail to uncover the fundamental contributing factors as the investigation is terminated once the investigator believes that a "cause" was determined.

In the next chapter the methodology followed during the empirical investigation will be discussed.