



M PROPS (PTY) LTD

Risk Assessment of the Camlok Canopy

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Risk Assessment of the Camlok Canopy

1 Introduction

The methodology followed in compiling the Risk Assessment was reviewed, but no attempt was made to verify the values associated with the various aspects related to the canopy life-cycle.

The objective of the risk assessment is to logically describe the use of the Camlok Canopy in a systematic method in order to identify the hazards and their associated probability of occurrence so that the level of risk can be assigned to the hazards. By adopting this approach, it is hoped that reading of the document would not be onerous on the reader and the major hazards and their associated risks be clearly highlighted in the text with the full risk assessment as backup in the appendices. For this purpose the fault-event tree risk assessment method was selected as the most appropriate for this purpose. A brief description of the method can be found in Appendix A.

2 **Table 1: Risk Assessment Team Members**

Name	Designation	Experience
Mr Colin May	General Manager M Props	36 Years Research and Development & Sales

3 **Quality Assurance**

The consistency of the performance of the Camlok Canopy supplied to the mine is maintained through a quality assurance program implemented during manufacture by M Props and the high quality of materials supplied to the manufacturer by their accredited suppliers.

4 **Risk Assessment Process**

This risk assessment was based on a risk assessment carried out previously by M Props on the Camlok Prop. A workshop was held in which the risks to workers during the twelve stages of the life cycle of a typical Camlok Canopy were assessed. A probability of occurrence for each root cause was assigned by the risk assessment team on a subjective and judgemental basis. A probability of occurrence for each fault was calculated using the fault tree method. This probability of occurrence was used as the base to determine the probability of mining personnel being injured or fatally injured whilst using the Camlok Canopy. Finally a risk profile was compiled for the Camlok Canopy benchmarked against the life time probability of being fatally injured in a public place or on public transport (Cole, 1993).

4.1 Camlok Canopy Life Cycle

The life cycle of a Camlok Canopy starts when an order is received from a mine by M Props for delivery and ends when the canopy is declared not fit for purpose due to excessive ‘wear and tear’ and/or corrosion of the canopy and removed from the work place (Figure 1).

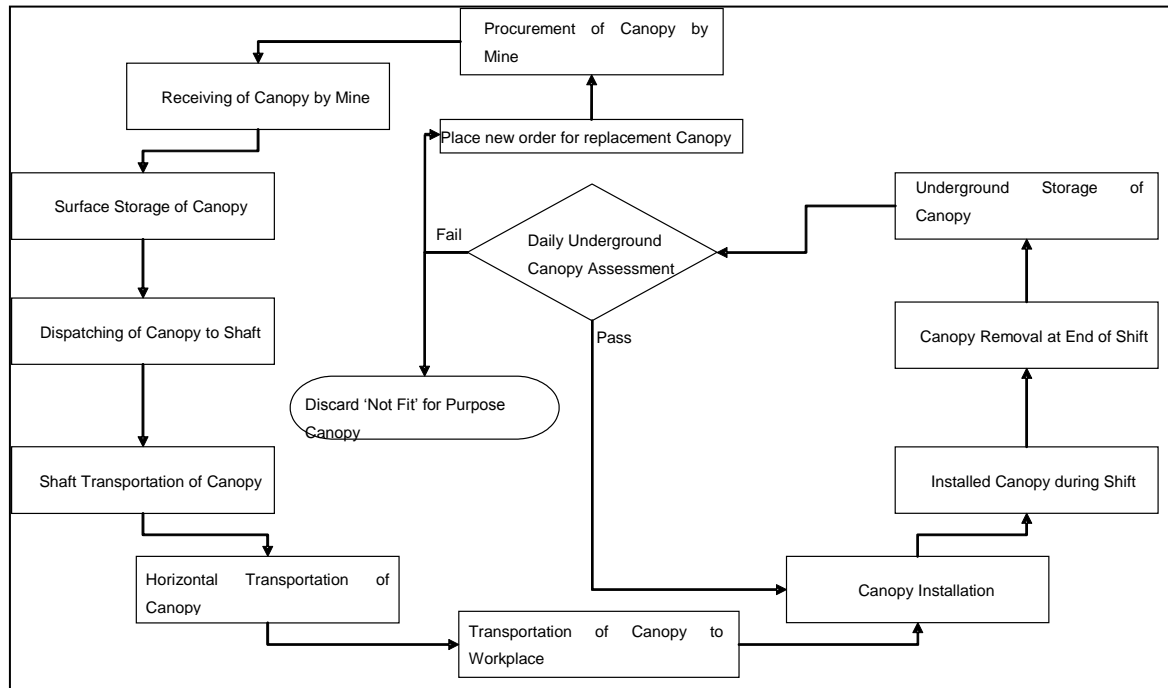


Figure 1: Life Cycle of the Camlok Canopy

The hazards associated with each stage of the life cycle of the Camlok Canopy were discussed and documented by the team during the workshops. Conclusions from these discussions are described for each stage of the life cycle, where the main risks associated with the use of the Camlok Canopy are highlighted. The full risk assessment can be found in Appendix B.

4.1.1 Procurement Procedure

The hazards with the highest probability of occurrence associated with procurement of the Camlok Canopy by the mine purchasing department is identified to be the following:

- **Incorrect quantity** of Camlok Canopy ordered for the current panel stopping length or excavation size with regards to development ends or large excavations is considered **“Low”** ~ **(1.00 x 10⁻⁰⁴)**.

The overall probability of occurrence of a threat of injury to mining personnel through the use of the Camlok Canopy due to poor procurement procedures is considered **“Low”** ~ **(3.31 x 10⁻⁰⁴)**.

However, the mine should ensure that the type of temporary support canopy ordered is appropriate for the general loading conditions experienced on the mine, through a detailed Rock Engineering design and underground assessment.

4.1.2 Receiving by Mine

The hazards associated with this cycle of the canopy's life were seen as mainly being the off-loading of the canopy at the stores from the delivery vehicle. The hazards identified are related to:

- **Lack of off-loading equipment** is considered “**Low**” ~ (5.00×10^{-04}) with the likelihood of hand and foot injuries to mine personnel due to falling or the dropping of Camlok Canopies while off-loading;
- The probability of injuries occurring while **handling Camlok Canopies** is also considered to be “**Low**” ~ (1.00×10^{-04}) ;
- **Late time of delivery** increases the probability of occurrence of a failure where labour may have already left for the day, leaving insufficient personnel to assist with the off-loading of the delivery vehicle. The probability of occurrence is considered “**Low**” ~ (1.01×10^{-04}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor receiving practice by the mine is considered “**Low**” ~ (7.07×10^{-04}) .

However, the mine should ensure that sufficient labour and off-loading equipment is available in the receiving yard to safely off-load and transport the Camlok Canopies to the storage yard. The availability of Personnel Protective Equipment (PPE) and training in correct handling of Camlok Canopies will reduce the risk of injury to mine personnel.

4.1.3 Surface Storage

The team identified the main hazard associated with storage of the Camlok Canopy at the mine's storage facility as **weathering of Camlok Canopies**, if stored out in the open. Weathering of Camlok Canopies can cause the following:

- **Sun damage to Camlok Canopies** can lead to U/V damage to the webbing net resulting in deterioration of the carrying capabilities of the net and the peeling off of the identification label which contains information on the type of canopy. Without this label the user may be unable to identify the correct type of canopy to be used. The probability of occurrence is considered “**Extremely Low**” ~ (1.00×10^{-06}) ;
- **Storage in mud / water** which may lead to premature corrosion of the canopy is considered “**Extremely Low**” ~ (2.00×10^{-06}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor surface storage by the mine is considered “**Low**” ~ (2.09×10^{-04}) .

However, the mine should ensure that the Camlok Canopies and accessories are stored under cover and are not exposed to sun and rain. A procedure should be implemented which ensures correct stock rotation.

4.1.4 Dispatching to the Shaft

The team agreed that the hazards associated with dispatching of the Camlok Canopies to the shaft by the mine stores are similar to those identified during receiving by the mine. Although time of delivery is not an issue as the stores operate during set times and the hazards associated with rushing of loading may not exist.

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor dispatching procedures by the mine is considered “**Low**” ~ (7.07×10^{-04}) .

4.1.5 Shaft Transport

This stage of the canopy’s life cycle includes the transportation of the Camlok Canopies in vertical and/or inclined shafts. The hazards identified by the team are:

- **Poor packing and stacking of Camlok Canopies in material cars** could lead to canopy handling injuries while unpacking is “**Medium**” ~ (2.05×10^{-03}) ;
- **Poor slinging practice of Camlok Canopies** also poses the hazard of material falling down the shaft or catching on shaft steel work while in transit. Although the probability of occurrence is considered “**Extremely Low**” ~ (2.00×10^{-06}) , the consequences could be disastrous;
- **Lack of shaft time availability** was also highlighted as a potential problem as this would delay the arrival of the Camlok Canopies at the designated workplace and lack of support units in the workplace increases the risk of injury to mine personnel or lost production. The probability of occurrence is considered “**Very Low**” ~ (2.00×10^{-05}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor shaft transport procedures by the mine is considered “**Medium**” ~ (2.07×10^{-03}) .

The mine should ensure that appropriate procedures are in place regarding the packing and transportation of Camlok Canopies, with emphasis on long Camlok Canopies and slinging if required.

4.1.6 Horizontal Transport

This section of the risk assessment workshop focused on the hazards associated with the transportation of Camlok Canopies in material cars in mine haulages to the work place. The team identified the two main hazards as being:

- **Poor packing of material cars** which may lead to Camlok Canopies falling off material cars or protruding from the material car and able to strike mine personnel while being transported is considered to be “**Medium**” ~ (2.05×10^{-03}) ;
- **Poor handling of Camlok Canopies** which may lead to protruding or falling of loose Camlok Canopies from the material car is considered to be “**Medium**” ~ (2.00×10^{-03}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopies due to poor horizontal transport procedures by the mine is considered “**Medium**” ~ (4.24×10^{-03}) .

The mine should ensure that correctly sized material cars are available and correct packing and transport procedures are in place to ensure that this task is performed safely.

4.1.7 Transport in the Workplace

The team agreed that this was one of the important cycles of the canopy’s life, as the Camlok Canopies are transported manually by mine personnel or attached to monorope winches for transportation into the place of work. The main hazards identified and the associated values are:

- Injury while **transporting the Camlok Canopies to the workplace** is identified as having a “**Medium**” ~ (7.25×10^{-03}) probability of occurrence with the following two categories:
 - Injury to mine personnel and damage to equipment whilst the canopy is being **transported by the monorope winch system** is considered to be “**High**” ~ (1.72×10^{-02}) ;
NB. Due to the high risk of injury and potential damage to equipment and infrastructure it is regarded as unsafe practice to transport the Camlok Canopy by the monorope system.
 - Injury to mine personnel whilst **manually transporting** the canopy to the workplace is considered to be “**Medium**” ~ (6.03×10^{-03}) .
- Poor **underground storage** in the timber bay **may** result in injury due to tripping and falling or falling Camlok Canopies due to poor stacking is considered to be “**Medium**” ~ (4.40×10^{-03}) ;
- When transporting Camlok Canopies in tunnel developments, **inclined excavations** are identified as having a slightly higher probability of occurrence (3.92×10^{-03}) than transporting in **horizontal excavations** (1.72×10^{-03}) . This is due to the higher probability of injury caused by slipping and falling due to **poor footwall conditions** in inclined excavations.

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor transportation to the workplace is considered “**High**” ~ (1.72×10^{-02}) .

The mine should ensure that adequate procedures are in place for transportation of the Camlok Canopy to the workplace via a monorope winch system. [If the Camlok Canopies are to be manually transported to the workplace, the mine is to ensure that the travel distance is not excessive, is adequately ventilated, and there is sufficient clearance in which to travel.]

4.1.8 Installation

The installation of the canopy in the workplace has the highest probability of incident occurrence of all the stages of the Camlok Canopy life cycle. This stage is sub-divided into the following hazards:

- **Poor “making safe”** which can result in a fall of ground accident due to disturbing a weak hangingwall whilst installing the canopy is considered **“High”** ~ (1.99×10^{-02}) ;
- **Poor footwall conditions** may cause the user to slip and fall while installing the canopy as well as providing an unstable footing for the installed canopy, which will reduce the canopy’s performance capabilities is considered **“High”** ~ (1.99×10^{-02}) ;
- **Poor permanent support installation** as a result of the permanent support not being installed to mine standard or already having worked beyond its capabilities, the installation of the Camlok Canopy becomes more hazardous and is considered **“High”** ~ (1.00×10^{-02}) ;
- **Failure to examine canopy condition** may result in unsafe work conditions by increasing the probability of fall of ground occurrences as the canopy will not perform to the specified level or may not be installed due to being completely inoperable. The probability of occurrence is considered **“High”** ~ (1.99×10^{-02}) ;
- **Poor positioning of the canopy** will result in insufficient support resistance being applied to the hangingwall or incorrect canopy orientation which will increase the risk of removing the canopy safely is considered **“Very High”** ~ (1.80×10^{-01}) ;
- **Failure to extend the adjusting tube and tension correctly** will result in poor performance of the canopy due to an insufficient preload and the canopy being easily dislodged is considered **“High”** ~ (3.95×10^{-02}) ;
- **Failure to install the canopy cross brace correctly and pre-load** will result in failure of the canopy, allowing it to easily dislodge is considered **“Very High”** ~ (1.80×10^{-01}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy during installation in the workplace is considered **“Very High”** ~ (2.71×10^{-01}) .

The mine should ensure that all mine personnel required to use the Camlok Canopy are trained correctly according to the lesson plan provided by M Props.

4.1.9 Installed Canopy

This stage of the Camlok Canopy covers the period when the canopy is installed and acting as temporary support in the workplace. The major hazards with the highest probability of occurrence are identified as:

- **Falls of ground** which may occur due to poor ground conditions or when the canopy is dislodged as a result of block rotation of loose hangingwall, structural failure of the canopy due to excessive loading, or lateral loading caused by a fall of ground. The probability of occurrence for this is considered “**High**” ~ (3.55×10^{-02}) ;
- **Inappropriate support design** which may result in canopy failure due to inappropriate canopy use or insufficient load bearing capacity of the canopy is considered “**High**” ~ (1.12×10^{-02}) . This hazard also includes lateral loading due to the installation of safety nets which may result in Camlok Canopies being dislodged during a fall of ground;
- **Illegal removal** of an installed canopy which normally occurs when the canopy is deemed to be in the way, normally by the rock drill operator, is considered” **High**” ~ (1.12×10^{-02}) . This illegal removal of a canopy **increases the probability of falls of ground** due to the **increased support span or extra loading on the remaining Camlok Canopies**;

The overall probability of injuries occurring to mining personnel through the correct use of the Camlok Canopy during the shift is considered to be “**Medium**” ~ (4.75×10^{-02}) .

The mine should ensure that all stope and development mine personnel are trained in the correct use of the Camlok Canopy. The mine is to ensure that appropriate support design is in place and that the Camlok Canopy is used for the purpose that it is intended. If safety nets are to be implemented by the mine as a safety initiative, the mine must ensure that the lateral load capacity of the canopy can comply with the maximum load bearing capacity of the safety net.

4.1.10 Canopy Removal

The risk assessment process showed that canopy removal is ranked third after canopy installation and the installed canopy during the shift. The major hazards identified for this cycle with values are as follow:

- **Falls of ground** which may occur during the release of the Camlok Canopy, where the probability of injury to mine personnel is significantly increased. The probability of occurrence is considered “**High**” (1.99×10^{-02}) ;
- Injury due to **canopy falling on a person** is considered “**High**” ~ (1.10×10^{-02}) ;

- **Strain** injuries to person when releasing the canopy or due to heat exhaustion are considered to be “**Low**” ~ (3.03×10^{-04}) .
- **In the event of a FOG having occurred and the Camlok Canopy is supporting the FOG.** Only **remote release** of the **supporting Camlok Prop** should be considered, allowing the **complete collapse of the supporting Camlok Prop and Camlok Canopy.** This condition requires extreme caution and is considered “**Very High**” ~ (2.71×10^{-01}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy while removing the canopy after the shift is considered to be “**High**” ~ (1.27×10^{-02}) .

The mine should ensure that all mine personnel required to use the Camlok Canopy are trained correctly according to the lesson plan provided by M Props.

4.1.11 Underground Storage

The main hazard associated with underground storage of the Camlok Canopy is incorrect storage conditions leading to damage which may cause premature failure of the canopy and its accessories. The potential types of damage which can lead to poor canopy performance are:

- The probability of **blast damage** to the canopy if stored in close proximity to the face area is considered to be “**Medium**” ~ (1.00×10^{-03}) ;
- The probability of **canopy corrosion** when stored in wet muddy conditions, which may lead to defective operation and premature corrosion of the canopy is considered to be “**Medium**” ~ (1.00×10^{-03}) ;
- **Poor storage practice** may lead to injury to mine personnel through tripping and falling or falling Camlok Canopies if the Camlok Canopies are stored haphazardly. The probability of occurrence is considered to be “**Medium**” ~ (1.20×10^{-03}) ;
- **Scraper damage to the canopy** may occur if the canopy is stored in the path of the scraper or in contact with scraper ropes. The probability of occurrence is considered to be “**Medium**” ~ (1.00×10^{-03}) ;

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor underground storage is considered “**Medium**” ~ (6.38×10^{-03}) .

The mine should ensure that correct underground storage procedures are in place.

4.1.12 Daily Underground Canopy Assessment

This is an important aspect of the Camlok Canopy’s life cycle, as the performance of the canopy depends on its condition and level of corrosion. The assessment should be done on a daily basis before canopy installation to guard against the following:

- **Poor assessment of the physical condition** of the **canopy** is considered “**Medium**” ~ (2.60×10^{-03}) ;
- **Poor assessment of the physical condition** of the tensioning mechanisms on the canopy support arms and cross brace is considered “**Medium**” ~ (2.30×10^{-03}) .

The overall probability of injuries occurring to mining personnel through the use of the Camlok Canopy due to poor canopy performance as a result of poor daily underground canopy assessment is considered to be “**Medium**” ~ (4.89×10^{-03}) .

The mine should ensure that a checklist is included in the daily assessment of the Camlok Canopy.

4.1.13 Removal of ‘not fit for purpose’ Camlok Canopies

This is the final stage of the canopy’s life cycle, when the daily canopy assessment indicates that the canopy is no longer fit for purpose. The canopy should be removed from the workplace and transported to surface to be discarded. **Refurbishment of ‘not fit for purpose’ Camlok Canopies by the mine or a contractor is only to be undertaken with the approval and or involvement of M Props.**

5 **Risk Profile**

The probability of occurrence of the top fault, the threat to mine personnel while using the Camlok Canopy is calculated for each identified stage of the life cycle. From this, the probability of a mine employee being injured or fatally injured can be calculated taking into account their exposure time and the potential severity of the hazard (Figure 2).

From this risk profile, it is clear that the risk of injury to mine personnel increases as the canopy progresses through its life cycle towards the workplace and decreases after the canopy has been removed from the workplace and stored for the next shift.

Risk Value (log (probability of occurrence))

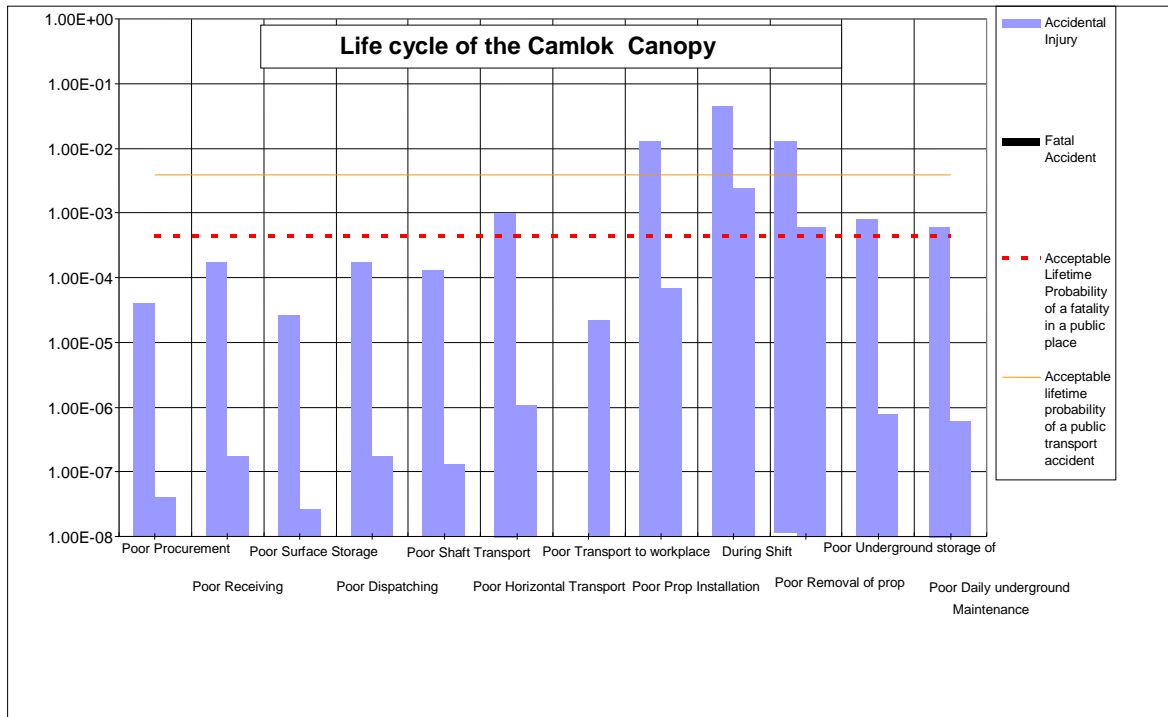


Figure 2: Risk profile of the Camlok Canopy

Figure 2 shows a significant increase in the risk profile as the Camlok Canopy enters the workplace. The indicated benchmarks are the acceptable lifetime probability of total loss in a public place and while using public transport (Cole, 1993). The probability of a fatal injury to mine personnel while using a Camlok Canopy remains within acceptable limits, except for the installation, during the shift and removal of the canopy. However, a mine employee trained in the correct use of the Camlok Canopy should be aware of the hazards and risks associated with his/her daily tasks underground, making them more vigilant and thus reducing the risk to themselves when compared to a general member of the public with a low awareness and little ability to reduce the risk of being fatally injured in a public place or on public transport.

6 Conclusions

The threat of injury to mine personnel through the use of the Camlok Canopy was assessed during the study with the typical life cycle of the canopy described and documented in thirteen definable stages.

The probabilities of injuries occurring during each stage of the Camlok Canopy's life cycle are determined, providing an overall probability of occurrence for the top risk, threat of injury to mine personnel through the use of a Camlok Canopy.

A risk profile is compiled for the life cycle, where the threat of injury to mine personnel is determined by calculating the probability of injuries or fatal injuries occurring to mine personnel, taking into account the exposure of mine personnel to the hazards and the severity of the hazard.

These probabilities are benchmarked against acceptable lifetime probabilities of being fatally injured in a public place or on public transport (Cole, 1993).

The risk profile for the Camlok Canopy shows that the risk value for all the identified stages of the life cycle are within acceptable limits, except for the stages involving the installation of the canopy i.e. the installation of the canopy during the shift and removal of the canopy after the shift.

The mine should ensure that strategies are in place to reduce or eliminate the risks associated with the identified hazards associated with the use of the Camlok Canopy.

Appendix A

General Description of the Risks Assessment Method

**GENERAL DESCRIPTION OF THE FAULT-EVENT TREE
ANALYSIS TECHNIQUE**

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GLOSSARY OF TERMS AND DEFINITIONS

Event, consequence	Potentially damaging consequences. It denotes the effects of the causative hazards, for example, injury to people or damage to machines and equipment.
Event tree analysis	An analysis that describes the possible range and sequence of the outcomes which may arise from an initiating event or top fault. The probability of occurrence of events is determined by considering the probability of occurrence of the top fault together with the relative weighting for the associated potentially adverse events.
Exposure	How often and for how long employees are exposed to a hazard.
Fatality accident rate (FAR)	The risk of death per 100 million hours of exposure to a dangerous activity. This is approximately the same as the probable number of fatalities from 1000 people involved in the activity for the whole of their working lives, each about 100 000 hours (50 years x 250 days/year x 8 hours/day).
Fault	Is a more general term than failure and can include the correct operation of an item at an inopportune time as well as the failure of an item to operate properly.
Fault Tree Analysis (FTA)	Is a technique, either qualitative or quantitative, by which sets of circumstances, which would need to co-exist, and can contribute to a specified undesired event (called the top event) are deductively identified, organised in a logical manner, and represented pictorially.
Gates	Show the relationships of faults needed for the occurrence of a higher fault. The higher fault is the output of the gate and the lower faults are the inputs to the gate. OR gates are used to show that the output fault occurs only if one or more of the input faults occur. AND gates are used to show that the output fault occurs only if all the input faults occur.

Harm	Injury or loss
Hazard, cause, fault, threat	Something that has the potential to cause harm; e.g. Fall of ground from the hangingwall.
Lifetime probability of occurrence	The probable unit number of times to which any person would be exposed to a detrimental event during his/her whole life. It is directly related to the fatality accident rate, FAR. Expressed as a percentage, the lifetime probability of occurrence of an event is therefore equal to $FAR \times 100/1000 = 0,1 \times FAR$.
Primary faults	The primary categories in which the hazards to safety and health are considered e.g. threat of fall of ground due to bord collapse or threat of fall of ground due to pillar failure.
Probability of occurrence	The likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes. It is expressed as a number between 0 and 1, with 0 indicating an impossible outcome and 1 indicating an outcome is certain.
Risk	Is the product of the probability of occurrence of a hazard and the consequence of the hazard (severity of the damage of an event).
Risk analysis	A systematic use of available information to determine how often specific events may occur and the magnitude of their likely consequences (often interchangeably used for 'risk assessment').
Risk assessment	The decision making process whereby a level of risk is compared against criteria and risks are prioritised for action.
Risk management	The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring risk.

Secondary faults

The component hazards that can be identified in each of the primary categories of hazards/faults e.g. with regard to the threat of a fall of ground due to bord collapse would be fall of ground originating from the hangingwall and fall of ground originating from the sidewall.

Tertiary faults

The component hazards that can be identified in each of the secondary categories of hazards/faults e.g. with regard to fall of ground from the hangingwall would be fall of ground from the hangingwall in the face area, fall of ground from the hangingwall in the back area, or fall of ground from the hangingwall at intersections.

1 INTRODUCTION

The failure of any system, e.g. a fall of ground in an underground excavation, is seldom the result of a single **cause** or **fault**. Failure usually results after a combination of faults occur in such a way that the factor of safety of the system falls to below unity. A disciplined and systematic approach is therefore required to determine the correct logic that controls the failure of the system and to analyse the potential consequences of failure. One such approach, the **Fault-Event Tree Analysis**, is discussed here.

2 CAUSE/FAULT TREE ANALYSIS

Fault Tree Analysis (FTA) is a quantitative or qualitative technique by which conditions and factors that can contribute to a specified undesired incident (called the **top fault**) are deductively identified, organised in a logical manner, and presented pictorially. It can also be defined as a deductive failure analysis which focuses on one particular undesired fault and which provides a method for determining causes of the fault.

FTA affords a disciplined approach that is highly systematic, but at the same time sufficiently flexible to allow analysis of a variety of factors. The application of the top-down approach focuses attention on those effects of failure that are directly related to the top fault. FTA is especially useful for analysing systems with many interfaces and interactions. The pictorial representation leads to an easy understanding of the system behaviour and the factors included, but as trees are often large, processing of fault trees may require computer systems.

Starting with the top fault, the possible causes or failure modes (**primary faults**) on the next lower system level are identified. Following the step-by-step identification or undesirable system operation to successively lower levels, **secondary faults**, **tertiary faults**, etc. are identified.

In order to determine the correct logic that controls the failure of the system, the faults are not initially given probabilities of occurrence. In this form the “tree” is referred to as a “**cause tree**”. Once the cause tree is considered to correctly reflect the combinations of faults necessary to result in failure, probabilities are either calculated or assigned to the faults. In this form, the “tree” is referred to as a “**fault tree**”.

Thus, a fault tree represents a quantitative or qualitative evaluation of the probabilities of various faults leading to the calculation of the **top faults**, which result in failure of the system. The objective of the fault tree is to identify and model the various system conditions that can result in the top fault (e.g. threat of FOG in East Block due to bord collapse).

3 **PROBABILITY EVALUATION IN FAULT TREE**

The fault tree is a complex of entities known as **gates** which serve to permit or inhibit the passage of fault logic up the tree. The gates show the relationships of faults needed for the occurrence of a higher fault. **AND** gates and **OR** gates denote the type of relationship of the input events required for the output event.

- AND gates are used where faults are statistically dependent. If it is necessary for n secondary faults to occur in order for a primary fault to result, then the probability of occurrence, p , is represented by:

$$p[\textit{primary fault}] = p[\textit{secondary fault 1}] \times p[\textit{secondary fault 2}] \times \dots \times p[\textit{secondary fault n}]$$

- OR gates are used where faults are statistically independent. If a primary fault can result as a consequence of the occurrence of any n secondary faults, then the probability of occurrence is determined from the calculation as follows:

$$p[\textit{primary fault}] = 1 - (1 - p[\textit{secondary fault 1}]) \times (1 - p[\textit{secondary fault 2}]) \dots (1 - p[\textit{secondary fault n}])$$

4 **EVENT TREE ANALYSIS**

The potential damaging consequences of a top fault is known as **events** and the systematic display of the events is referred to as an **event tree**. The probability of occurrence of a top fault together with relative weighting for the associated potentially adverse events, enable their likely occurrence to be determined. The product of the probability of occurrence and severity of the damage of an event is defined as the **risk**.

The systematic nature of the fault event tree enables the sensitivities of the potentially adverse consequences to any of the causative hazards to be evaluated. This enables the most threatening causative hazards to be identified and eliminatory measures to be defined.

5 **ALLOCATION OF PROBABILITIES OF OCCURRENCE**

Three measures are available for measuring reliability in engineering design, viz:

- the factor of safety;
- the reliability index, and;
- the probability of failure.

The factor of safety is a clearly understood and a numerically sensitive measure. It is, however, not a consistent measure and is not determined in terms of consistent processes. The reliability index is a consistent measure and is based on consistent processes for determining operational values. Its meaning is, however, not clearly understood. It is also not numerically sensitive, especially not with regard to higher orders of reliability.

The probability of failure is a consistent and numerically sensitive measure and is based on consistent processes for the determination of operational values. The numerical sensitivity of the probability of failure, however, detracts from the clarity of its meaning. The probabilities of various kinds of losses of life, canopyerty, etc. vary exponentially over many orders of magnitude between very large and very small values. The meaning of such a measure is often difficult to understand.

The difficulties that designers have in selecting acceptable thresholds for probability of failure can be resolved by using the norms and guidelines for selecting acceptable probabilities of failure for design, presented in a paper entitled: “Review of norms for probability of failure and risk in engineering design”, (Kirsten, 1994). Acceptable probabilities of failure are discussed further in Section 6.

The acceptable lifetime probabilities of total loss of life described in this paper by Kirsten are summarised in Table 1 below. Also included in the table are the corresponding probabilities assigned to hazards associated with the installation of rockbolts.

Table 2 Acceptable lifetime probabilities of total loss of life and corresponding probabilities assigned to hazards.

Degree of risk / Probability of occurrence	Acceptable lifetime probabilities (after Cole, 1993)
Very Risky / Certain (C)	7×10^0
Risky / Very high (VH)	7×10^{-01}
Some risk / High (H)	7×10^{-02}
Slight chance / Medium (M)	7×10^{-03}
Unlikely / Low (L)	7×10^{-04}
Very unlikely / Very low (VL)	7×10^{-05}
Practically impossible / Extremely low (EL)	7×10^{-06}
Practically zero (PZ)	7×10^{-07}

In certain cases, probabilities of occurrence could also be determined more accurately by assigning probability density functions to primary faults. This is particularly important in geotechnical engineering designs where input parameters, especially those that are affected by geology, are often not known accurately and the influence of their variability should be accounted for. However, probabilistic analyses of multiple variables require sophisticated numerical techniques that are beyond the scope of this project.

A simplified approach is to assign probabilities based on engineering judgement and past experience with this type of work. Probabilities assigned to certain levels of risk as described in Table 1 could be used as a guideline. The final result will then show if a more accurate assessment of the probability of occurrence would be necessary. It is likely that the detailed assessment will only be required for key sensitive areas which will be revealed by sensitivity analysis.

It is important to note that probabilities of occurrence may not have unique or discrete values. It is possible for a probability of a particular fault (or event) to change in sympathy with another probability that it is coupled with. This is best illustrated by means of an example:

Take the example of a “wrong support installation procedure” being used in an underground excavation. The probability of a wrong support installation procedure being used depends upon the probability that:

- *the knowledge about the correct support installation procedure is lacking, or;*
- *the equipment being used for support installations is out of order, or;*
- *the discipline and supervision are poor.*

The probability that the knowledge about the correct support installation procedure is lacking in turn depends on the probability that:

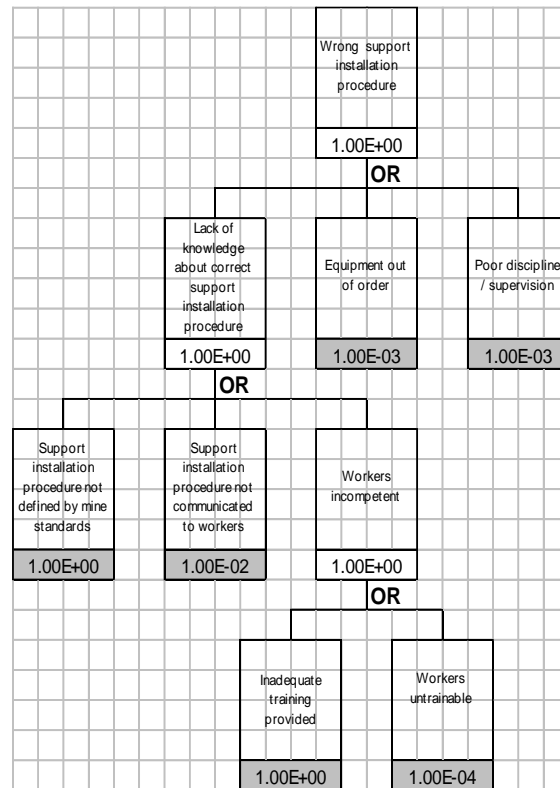
- *the support installation procedure is not defined by the mine’s standards, or;*
- *the support installation procedure is not communicated to the workers, or;*
- *the workers are incompetent.*

The probability that the workers are incompetent depends on the probability that:

- *inadequate training is provided, or;*
- *the workers are untrainable.*

The probability of a wrong support installation procedure being used could be different for different parts or sections of the mine. For example, the equipment being used for support installation in one section could be more reliable than the equipment being used in another section.

The probability of a wrong support installation procedure being used can be represented as follows:



6 ACCEPTABLE PROBABILITY OF FAILURE

The use of probability of failure is a means of incorporating acceptable and tolerable levels of risk into engineering designs. As mentioned before, risk is the product of the probability of failure and the consequence of an unwanted event, in this case, falls of ground.

The acceptability of probabilities of failure for particular design applications can be evaluated in terms of the magnitudes and distributions of actual frequencies of total losses of life, canopyerty and money. For example, the lifetime frequencies of fatalities due to unstable ground in gold and coal mines in South Africa in 1993 amounted to approximately 7,9% and 2,8% respectively (Kirsten, 1994). (These correspond with fatality rates/1000 at work of 0,76 and 0,37 respectively.)

According to Cole (1993), an acceptable lifetime probability of loss of life in respect of voluntary employment in underground mines would be 0,7%. This would bring about a 10 fold reduction in

the number of fatalities in metalliferous mines and a 4 fold reduction in the number of fatalities in coal mines.

The lifetime frequency of a detrimental event represents the probable unit number of times to which any person would be exposed to it during his/her whole life. It is directly related to the fatality accident rate, FAR, defined by Hambly and Hambly (1994) as the risk of death per 100 million hours of exposure to a dangerous activity. This is approximately the same as the probable number of fatalities from 1000 people involved in the activity for the whole of their working lives, each about 100 000 hours (50 years x 250 days/year x 8 hours/day). Expressed as a percentage, the lifetime probability of occurrence of an event is therefore equal to $FAR \times 100/1000 = 0,1 \times FAR$. This measure enables losses from different occupations to be compared on a common basis. It also enables exposures to losses for part of a day to be compared to full time exposures.

When the consequences of failure are serious, a reduced probability of failure needs to be adopted in order to achieve an acceptable level of risk, e.g., when mining a panel of pillars, the normal acceptable level of risk in terms of probability of failure is 3 in 1000 (Galvin et al, 1998). However, this probability of failure would be unacceptable for a more serious consequence of failure, such as flooding of the workings. In this case, a probability of failure of at least 1 in 100 000 may be chosen as representative of the tolerable level of risk, considering the seriousness of the consequences.

Other recommendations for acceptable probabilities of failure found in the literature can be summarised as follows:

- According to Galvin et al (1998), a probability of coal pillar failure of 3 in 1000 relates to a FOS of 1,59, and a probability of failure of 1 in 100 relates to a FOS of 1,48. This correlation is based on data from the Australian coalfields.
- According to the back-analysis carried out by Salamon and Wagner (1984), the rate of coal pillar failure in South Africa had been 0,003, which compared with the predicted probability of pillar failure of 0,003 for a FOS of 1,6.
- D'Andrea and Sangrey (1982) have shown that probabilities of slope failure of 0,1; 0,01 and 0,001 correspond with factors of safety ranging from 1,25 to 1,93; 1,43 to 3,13 and 1,58 to 4,49 respectively.
- According to Cole (1993), an acceptable life-time probability of loss of life in respect of voluntary employment in underground mines would be 0,7% or 0,007.

Kirsten (1994) suggests that acceptable levels for probabilities of failure for which designs may be prepared should be significantly smaller than the actual probabilities of failure observed for similar situations. This is required to account for the following aspects.

1) Natural aversion to involuntary total loss

Slovic (1987) found that the acceptability of risk is related to the benefits of the activity and the voluntary or involuntary nature thereof. Public aversion to risk is also related to the number of people involved. The design engineer should take note of these aspects when selecting a value for the probability of failure for a particular case.

2) Variations in perceptions

Slovic (1987) found that risk means different things to different people, depending on their background. Selecting a value for probability of failure should take cognisance of the variations in the perceptions of risk, but need not cater unduly for misconceptions on the part of the public.

3) Non-representativeness of actual comparative probabilities of failure

The design engineer should take note of the scatter of various acceptable probabilities of failure.

4) Variations in parameter values and biases in calculation procedures

Design engineers should be aware of the effects of variations in parameter values on the reliability of the probability of failure that may be determined.

5) Deficiencies in design data

Ground conditions are known to carry potentially high risks and uncertainty. According to Sowers (1993) a study of 500 geotechnical failures revealed that 88% of the failures were produced by human shortcomings and that 75% of the failures originated in the design process. Whyte and Tonks (1993) submit that these problems are directly and largely attributable to deficiencies in the site investigations undertaken for design purposes.

Acceptable probabilities of failure cannot be prescribed. Each mine should therefore decide on a value for probability of rockfall accidents that would be acceptable to the mine. In the mean time, SRK suggests that a value of 0,003 or 0,3% be used as an acceptable probability of a rock fall incident occurring. The lifetime probability of total loss of life should therefore be a few orders of magnitude smaller than the acceptable levels suggested by Cole (1993). This corresponds with Kirsten's (1994) suggestion that acceptable levels for probabilities of failure for which designs may be prepared should be significantly smaller than the actual probabilities of failure observed for similar situations.

7 REFERENCES

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Appendix B

Detailed Risk Assessment

1. Procurement Procedure

2. Receiving by Mine

3. Surface Storage

4. Dispatching to the Shaft

5. Shaft Transport

6. Horizontal Transport

7. Transport to the Workplace

8. Installation

9. Installed Canopy

10. Canopy Removal

11. Underground Storage

12. Daily Underground Canopy Assessment

ACKNOWLEDGEMENT OF RECEIPT
CAMLOK CANOPY RISK ASSESSMENT

This document was provided as a copy of the review of the risk assessment developed by **M Props** and I declare that no changes or alterations have been made to this document.

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