3.0 – Risk Assessment and Analysis Techniques and Tools

Risks are determined in terms of the likelihood that an uncontrolled event will occur and the consequences of that event occurring.

Risk = Likelihood of occurrence × consequence

The above relationship is used in both qualitative and quantitative risk analysis methods. A quantitative risk analysis method is a probabilistic estimation of risk where risk is calculated as a continuous series from high to low. A qualitative risk analysis method is a basic estimation where risks are typically ranked from high to low. Qualitative methods rely on a risk matrix similar to that demonstrated in *Table 2* where qualitative categories are defined, i.e. low-to-high, unlikely-to-likely, etc.

Table 2 - A generalized risk matrix used in many qualitative risk analysis techniques.

		Likelihood of Occurrence		
		High value	Medium value	Low value
Consequence	High value	High risk		
	Medium value		Moderate risk	
	Low value			Low risk

Risk assessment and analysis techniques and tools consist of a systematic, logical set of actions used to identify hazards, assess risk, and implement controls to mitigate high-risk conditions. These techniques and tools can be described by their levels of formality, the types of analysis performed, and the work processes they are attempting to address.

3.1 – Risk Assessment Techniques

The most fundamental risk assessment activity, called an informal risk assessment, occurs when workers are asked to think about the hazards in the workplace before work commences, determine what could go wrong, and report or fix the hazards. More formal risk management activities require structured procedures, often focusing on work processes that involve multiple levels of an organization. These activities are practiced at some mines and are typically organized by an operations safety official and developed with the help of individuals familiar with the work practice in question. Higher level risk management activities focus on major mining hazards or on major changes in the mining operations involving the entire organization, such as reopening a mine, moving to a new location within the mine, and utilizing a new mining technique or process.

3.1.1 – Informal Risk Assessment Techniques

Most informal risk assessment techniques consist of multiple steps where the worker is asked to look for hazards, determine the significance of the hazard, and take some action to mitigate the risk. Many systems have been proposed and are widely used in mining. Examples include, but are not limited to:

- Stop-Look-Analyze-Manage (SLAM) asks workers to stop and consider the work process before it is started, examine the work environment, analyze the work process, and manage the risk,
- Take-Two for Safety calls for persons to take 2 minutes to think through a job before it starts,
- Five-Point Safety System compels employees to take responsibility for the safety within workplace,
- Take Time, Take Charge requires miners to stop, think, assess and respond to hazards in their workplace.

3.1.2 – Basic-formal risk assessment techniques

Basic-formal risk assessment techniques are characterized by the requirement to follow a structured process that occurs prior to performing specific higher risk work activities. These techniques also require documentation that allows management to monitor and audit individual risk assessment activities. The most commonly used basic-formal risk assessment technique is the Job Safety Analysis (JSA). A JSA typically leads to development of Standard Operating Procedures (SOP) that define how to best approach a task considering the hazards identified in the JSA.

A JSA is a technique used to identify, analyze and record the specific steps involved in performing a work activity that could have hazards associated with it. JSAs are typically performed on work processes with the highest risk for a workplace injury or illness. It is essential that all actual or potential safety and health hazards associated with each task are identified and that actions or procedures for performing each step that will eliminate or reduce the hazard are documented and recorded. Other techniques similar to JSAs include Job Hazard Analysis (JHA), Critical Task Analysis (CTA), and Job Hazard Breakdown (JHB).

An SOP is a set of instructions that act as a directive, covering those features of operations that lend themselves to a standardized procedure. An SOP is typically a set of instructions or steps a worker follows to complete a job safely and in a way that maximizes operational and production requirements. SOPs can be written for work processes by the individual or group performing the activity, by someone with expertise in the work process, or by the person who supervises the work process.

3.1.3 – Advanced-formal risk assessment techniques

Advanced-formal risk assessment techniques require the use of a structured approach that incorporates one or more risk analysis tools (see Section 3.2) and produces a documented assessment of the risk associated with unwanted events. MHRA, the subject of this investigation, is an advanced-formal risk assessment technique. An MHRA can focus on a single major hazard, all the relevant major hazards, or an important change of mining method at a mining site. One study demonstrates the complexity that a change of mining method can bring to the risk assessment. In this case, a full week of effort from a large team was needed with multiple risk analysis tools. All other MHRAs studied are focused on a single hazard and were completed in 1 to 3 days.

3.2 – Risk Analysis Techniques and Tools

When conducting an MHRA several risk analysis techniques and tools may be needed. A brief description of the most common tools follows.

3.2.1 – Workplace Risk Assessment and Control (WRAC)

The Workplace Risk Assessment and Control (WRAC) tool is a broad-brush risk ranking approach, allowing the user to focus on the highest risk. As applied to a MHRA, this structured preliminary analysis begins by breaking down the mining process associated with the potential major hazards at the mine in some logical manner. This is often accomplished using a flow chart or process mapping technique where the potential major hazards of each step in a work process are identified. The mining process could be a breakdown of a major project or a geographical breakdown of the underground mine. JSAs and SOPs can be used as a framework for the WRAC analysis.

After preliminary analysis, the team then considers each breakdown segment of the mining process and identifies the potential unwanted events associated with the identified hazards (*Figure 4*). The likelihood and consequence of each stage are determined using some variation of a risk matrix, followed by a risk rating calculation.

Part of mine, phase of mining, etc.	Potential unwanted event	Consequence	Likelihood	Risk rating
	↕			

Figure 4 - An example of a WRAC risk ranking form.

Prior to ranking the hazard, the team must come to an agreement on how to categorize the consequences for consistency purposes. Consequences should be considered as either the maximum likely or the maximum potential consequence. For example, while the maximum potential consequence of a slip/fall is a fatality, the maximum likely consequence is a severe injury. Variable scales are often used when determining the maximum reasonable consequence associated with different kinds of unwanted events. *Table 3* provides some examples of the maximum reasonable consequence for safety, equipment, production and environmental risks. This table also provides a scale for determining the maximum reasonable consequence of a specialized safety event, in this case a mine fire.

Table 3 - Examples of variable scales used to determine the maximum reasonable consequence associated with different kinds of unwanted events.

	Safety	Equipment	Production	Environment	Mine Fire
1	Multiple fatalities	> $ 5 M	1Week	> $ 5 M	Huge fire
2	1 Fatality	$ 1 M	1 Day	$ 1 M	Major fire
3	Major lost-time injury (LTI)	$200 K	1 Shift	$200 K	Moderate fire
4	Avg LTI (4-5 days)	$50 K	1 Hour	$50 K	Small fire
5	Minor injury (1 day or less)	< $ 10 K	<1 Minute	< $ 10 K	Smoldering

LTI = lost time injuries
M = million
K = thousand

The ranking of likelihood will be influenced by the choice of consequences. There is no correct choice, but there is a need to be consistent in the application of ranking across the exercise. Examples of variable scales used to determine the likelihood of different kinds of unwanted events is given in *Table 4*.

Table 4 - Examples of variable scales used to determine the likelihood of occurrence for different kinds of unwanted events.

	Based on Maximum Reasonable Consequence			Based on the Events / Year
1	Common	Highly likely	Expected	> 10
2	It has happened	Likely	High	1 to 10
3	Possible	Possible	Moderate	0.1 to 1
4	Unlikely	Unlikely	Low	0.01 to 0.1
5	Almost impossible	Very unlikely	Not Likely	< 0.01

3.2.2 – Preliminary Hazard Analysis

The Preliminary Hazard Analysis (PHA) is another broad-brush risk ranking approach. Like the WRAC, this tool identies all potential hazards and unwanted events that may lead to miner injuries and ranks the identified events according to their severity. Its main purpose is to identify those unwanted events that should be subjected to further, more detailed risk analysis. Once the potential unwanted events are risk ranked by the team, they can be prioritized so that the highest risk unwanted event is listed first and so on. The technique or form for the PHA method is shown in *Figure 5*.

#	Description of potential unwanted event	Total Exposure	Likelihood	Most Likely Consequence	Risk Rank
1					
2					
3					
4					
Etc.					

Figure 5 - The Preliminary Hazard Analysis (PHA) Form.

3.2.3 – Failure Modes, Effects and Analysis (FMEA), also FMECA

Generally, an FMEA is used to determine where failures can occur within hardware and process systems and to assess the impact of such failures. For each item, the failure modes of individual items are determined, effects on other items and systems are recognized, criticality is ranked, and the control is identified (*Figure 6*).

Item	Failure Mode	Effects on		Likelihood (L)	Consequence (C)	Criticality (LxC)	Control
		Other items	System				
			↕				

Figure 6 – Item-by-item risk assessment worksheet for FMEA.

Robertson and Shaw (2003) provide an example of the application of the FMEA approach where the risks to the environment, workers and the public associated with the closure of a mine were identified. This was accomplished by developing a FMEA worksheet for potential unwanted events post-closure of the mine.

3.2.4 – Fault / Logic Tree Analysis (FTA/LTA) and Event / Decision Tree Analysis (ETA/DTA)

The Fault and Logic Tree Analysis are systematic, logical developments of many contributing factors to one unwanted event. The FTA evaluates the one unwanted event while the LTA evaluates a wanted outcome. With both tools it is necessary to first clearly define the top event, followed by an analysis of the major potential contributing factors. Each contributing factor is broken down into discrete parts. A logic tree can be used to test the analysis with the use of "and/or" gates. Factors can be ranked from major to lesser. The product of the analysis is a deductive list of potential hazards. This tool is well-suited to quantitative risk analysis techniques when probabilities for each factor can be assigned.

Systems engineering and operations research approaches use a decision tree (or tree diagram) to help examine the decision. Event and decision tree analysis (ETA or DTA) uses graphical models to examine the consequence of decisions. A decision tree is used to identify the strategy most likely to produce a desired outcome. In the tree structures, leaves represent classifications and branches represent conjunctions of features that lead to those classifications. These tools are appropriate for establishing lines of assurance and determining their success and failure in preventing accidents.

3.2.5 – Hazard and Operability Studies (HAZOP)

Hazard and Operability Studies or HAZOPs have been used extensively in the chemical industries to examine what impact deviations can have on a process. The basic assumption when performing a HAZOP is that normal and standard conditions are safe and hazards occur only when there is a deviation from normal conditions. A HAZOP can be conducted during any stage of a project although it is most beneficial during the later stages of design. Typically a process or instrumentation diagram is used to trace the properties of materials or products through a plant by breaking down the process node by node (*Figure 7*). The properties can be flow, level, pressure, concentration or temperature. What-if guidewords are used to identify possible deviations. A HAZOP typically lacks a risk calculation.

Process Unit:____
Node: ________________ Process Parameter: ______________________________

Guide	Deviation	Consequence	Causes	Suggested Action
		↕		

Figure 7 - Process analysis form for a HAZOP.

3.2.6 – Bow Tie Analysis

The Bow Tie Analysis (BTA) was developed by Shell Oil in the 1980s as part of its Tripod package of concepts and tools for managing occupational health and safety in its business. The "Top Event" in the BTA is a statement about the initiating event that might lead to the major consequence (*Figure 8*). Threats (also referred to as potential causes) are discussed and controls examined that could mitigate the hazard (left side of the bow tie). Next, the consequences (also referred to as the potential outcomes) of the initiating unwanted event are identified and recovery control measures examined to reduce or minimize the loss (right side of the bow tie).

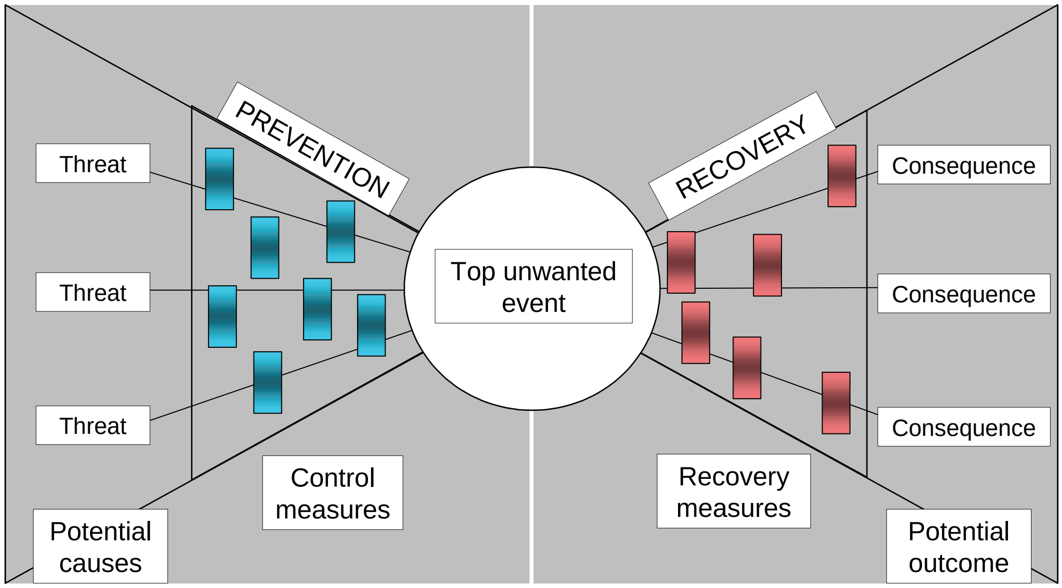

Figure 8 - Bow Tie Analysis (BTA) method.

Together, the prevention controls and recovery measures identified represent a comprehensive list of actions required to adequately control the hazard. Often these actions are assigned to individuals and controlled by the management planning and monitoring tool known as a risk register. A risk register provides for continuity in the way an organization deals with risks even as changes occur in management.

3.2.7 – Work Process Flow Chart

All mining processes have supplies, inputs, processes and outputs. Mining processes are sets of activities that produce a desired outcome. Many of these activities can be thought of as loops. If the outputs are wrong then adjustments are made to the inputs or the process. Defining these work processes in a step-by-step manner produces a flow chart that can be used in risk management. Flow charts are meant to describe a large, sometimes complex, process as small elements. Hazards are easier to identify and characterize with this type of systemic approach.

3.2.8 – Exposure and Risk

When miners are exposed to variable contact with hazards, it is often useful to determine the influence of exposure associated with different work processes or at particular work sites. An example of the variable scales used to define the effects of exposure on risk is given in *Table 5*.

Table 5 - Examples of variable scales used to define the effects of exposure on risk.

	Exposure (% of workforce)	Frequency of exposure
1	Most > 50%	Continuous
2	Many – 30%	Several times/day
3	Several – 10%	Once a day
4	A few – 5%	Weekly
5	Very few < 1%	Monthly

There are many ways to account for exposure when performing a risk analysis. One example is provided in *Table 6*. Here, the total exposure is estimated by combining the effects of the frequency of individual miner exposure versus the exposure to the total workforce.

Table 6 - A method to determine the total exposure using a 5 x 5 matrix.

TOTAL EXPOSURE			Frequency of exposure (*Table 5*)				
			1	2	3	4	5
			Continuous	Several x/day	1/day	1/week	1/month
Exposure (*Table 5*)	1	Most > 50%	A	A	B	C	D
	2	Many – 30%	A	B	C	D	E
	3	Several – 10%	A	C	D	E	E
	4	A few – 5%	B	D	E	E	E
	5	Very few < 1%	C	D	E	E	E

Once the total exposure level has been estimated, this value can be used to determine the overall likelihood (*Table 7*) and consequence (*Table 8*) of potential unwanted events occurring.

Table 7 - Estimation of overall likelihood by combining the estimates of likelihood and total exposure.

LIKELIHOOD OF AN EVENT		Total exposure (*Table 6*)				
		A	**B**	**C**	**D**	**E**
Likelihood (*Table 5*)	Common	A	A	A	B	C
	Has happened	A	B	B	C	D
	Possible	B	C	C	D	E
	Unlikely	C	D	D	E	E
	Very unlikely	D	E	E	E	E

Table 8 - The combinations of maximum reasonable consequence and the likelihood of the maximum reasonable consequence to establish the most likely consequence level.

MOST LIKELY CONSEQUENCE		Likelihood of the Consequence (*Table 4*)				
		Highly likely	Likely	Possible	Unlikely	Very unlikely
Maximum Reasonable Conse-quence (*Table 3*)	Multi-fatality	A	A	B	C	D
	1 fatality	A	A	B	C	D
	Serious LTI	B	B	C	D	E
	Avg LTI	C	C	D	E	E
	Minor LTI	D	D	E	E	E

The total probability and consequence of the potential unwanted event are then determined using a 5 x 5 risk ranking matrix (*Table 9*).

Table 9 - 5 x 5 risk ranking matrix.

RISK RANK		Overall Likelihood (*Table 7*)				
		A	B	C	D	E
Overall Consequence (*Table 8*)	A	1	2	3	7	11
	B	3	5	8	12	16
	C	6	9	13	17	20
	D	10	14	18	21	23
	E	15	19	22	24	25