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Designing the Safe and Attractive Mine

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Division of Human Work Science
2016

LULEÅ UNIVERSITY OF TECHNOLOGY

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1. INTRODUCTION

Despite of major progress, deep mining is still a hazardous activity. The future holds the vision of the zero-entry, invisible mine; a mine in which no miner or operator has to work underground or at the mine face, and which is indistinguishable from an ordinary factory. Such a vision is both promising and within our grasp. But we can't sit and wait for this vision to become reality. The present situation requires our attentions and work; mining work must be safe even while the companies work hard to realise the vision. And we also have to prepare for this vision.

This handbook is about covers tools and gives guidance for making mining more attractive, safer and healthier. Making mining more attractive, safer and healthier requires as much work at current workplaces as it does future ones. It isn't enough, and sometimes not even possible, to work with these topics in the operating stages of a mine or development project. Often, we have to work in the early project stages; to hope to identify, reduce and reduce hazards in the workplace, we have to work through a continuous process of controlling risks. This starts in the planning stages and is carried on throughout the mining or project lifecycle.

By making mining attractive, safe and healthy, mining is also made more productive, efficient and profitable. While safe and healthy workplaces should be a goal in itself, there are there are several other advantages as well. This includes lower costs, higher productivity, improved quality, and so on. The picture of health and safety as solely an expense, required by law, has long since been erased. In fact, health and safety is most expensive when it is ignored.

Of course, health and safety isn't free; it costs money to create and maintain healthy and safe workplaces. But spending money on health and safety now, saves money in the future (Blumenstein et al., 2011); it is said that for every dollar spent on prevention, three to six dollars can be saved in loss avoidance (ASSE in Mine Safety and Health Program, 2011). From Figure 1, it is obvious why the planning stages are important. To be able to influence and to do so

The zero-entry mine

Based on Bäckblom et al. (2010).

The zero-entry mine is the inherently safe underground mine; it is the mine of the future. Many things characterises the zero-entry mine:

- *There is one control room*. The entire mine can be run from this control room. Information from personnel, machinery and equipment is gathered here.
- *There are no personnel in the production areas*. All machines are self-regulated or remote controlled from above ground. In the zero-entry mine it isn't necessary to care about work environmental conditions at the face, as everything is done by machines.
- *Continuous mechanical excavation*. The drill-and-blast method is abandoned. Instead mechanical excavators, such as roadheaders and long walls, are used. This is needed to automate the entire excavation process and for modern organisational concepts.
- *Zero-impact mining*. The zero-entry mine is also a zero-impact mine. By this it is meant that the mine should have no negative impact on the environment and surrounding community; there should be no subsidence, polluted water, and so on.

We need to remember the zero-entry mine is a vision – but an important vision. We know, for example, that we will never have a truly zero-impact mine; we will always affect the environment in some way. We will probably also require some personnel at some time in the mine; perhaps in the development phase, or perhaps when a machine breaks down. But we should still aim to achieve this vision.

Employee wellbeing and productivity

Based on Neumann and Dul (2010) and ILO (2006).

By now, a lot of research has shown that there is a clear connection between a safe and healthy workplace and a productive and efficient workplace. Neumann and Dul compared 45 scientific studies and found that 95% showed a connection between human and system effect: if system performance was poor, employee wellbeing was so too; and if system performance was good, so too was employee wellbeing.

Another study – this one conducted by the ILO – found that there is a correlation between competitiveness and accidents at work. These results are shown in Figure 2. And this is only a small selection of this kind of research.

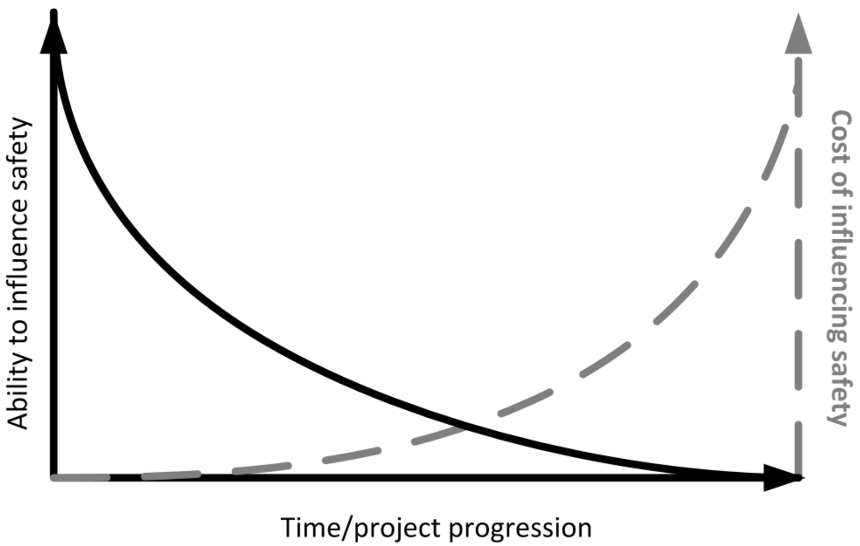

Figure 1: Graph of the ability to influence safety as a project progresses, and the cost of doing so. (Based on Szymberski, 1997, Karlsson et al., 2008.)

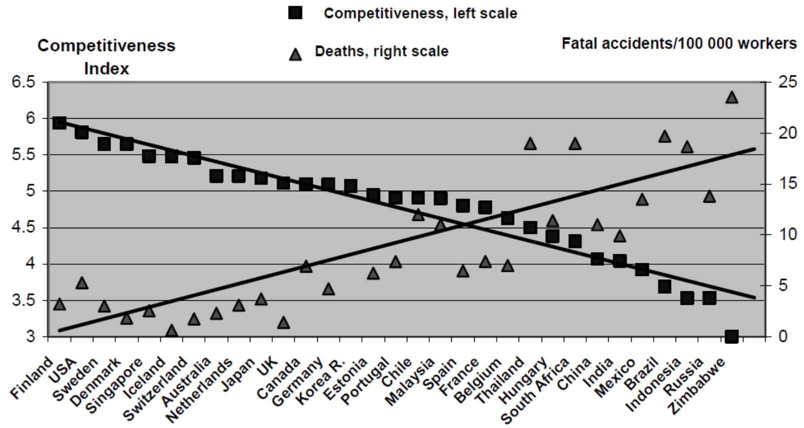

Figure 2: Correlation between competitiveness and the incidence of accidents at work. (Source: ILO, 2006.)

at low costs, health and safety have to be considered early (Szymberski, 1997, Karlsson et al., 2008). It is during planning that the most important decisions regarding work environment and safety are made when deciding on mining methods, technology, work organisation, and so on. We hope that this handbook will help, support and guide in this.

In Annex B, several checklists are included. The idea is that these can be used in parallel to this handbook. For large parts of the checklist (with the checklists for mining methods and rock mechanics related topics being the biggest exception), the handbook can complement each point with additional information.

2. ATTRACTIVE MINING

There are many reasons for making mining attractive. Put simply: attractive workplaces are good, safe and healthy workplaces, and good, safe and healthy workplaces are needed for effective and productive work. This of course still leaves us the question of what attractive workplaces are, and how mining can be attractive. This chapter will talk about that.

The easiest way to explain what we mean by attractive workplaces is to say: attractive workplaces are workplaces where people want work and enjoy working in. For mining, this is extra important because expert (for example Oldroy, 2015, Hebblewhite, 2008) say there is a lack of skilled miners and mining engineers, and also that the current workforce is growing older and mining companies find it difficult to recruit young, talented people – and future mining will depend of these very persons. The best way of solving this problem is by making future mining workplaces attractive for skilled and young people.

Figure 3 is a model on work attractiveness (from Hedlund, 2007). The axes of the model are the two ways in which we can look at attractiveness. The first way to look at attractiveness is the *internal view*. In the internal view it's the person who already has to job that decides if the job is attractive or not: if the person want keep his or her job, the job is attractive; if he or she doesn't want to keep the job, it is unattractive. The other way to look at attractiveness is the *external view*. Here it is a person who *doesn't* have the job that gets to decide: if this person wants the job, the job is attractive, if she or he doesn't want the job, it is unattractive. If we consider both views, we get the quadrants illustrated in Figure 3.

The problem is that the mining industry is in the left part of the model. Hopefully it's in the top left, which means mining is *hidden*. But it might also be in the bottom left, which would mean mining is *unattractive*. The goal is to move to the top right, to make mining *attractive*.

Åteg et al. (2004) argue that when we talk about attractive work

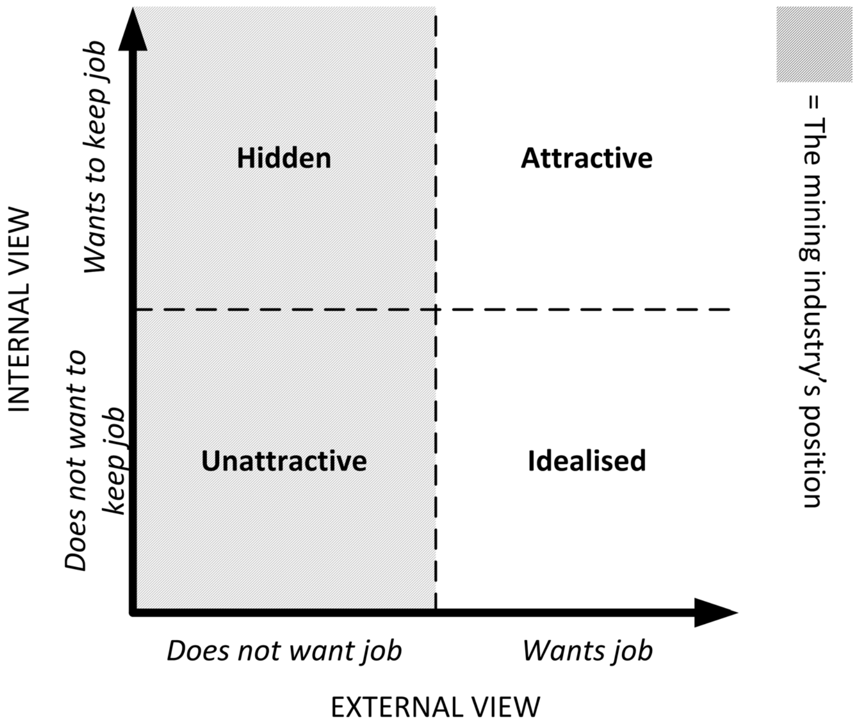

Figure 3: A two-dimensional model of the attractiveness of a given job. (Based on Hedlund, 2007.)

we talk about three parts of a job. These parts are working conditions, work content and work satisfaction. These parts can then be divided into 22 more parts, and these parts again divided into 80 parts. We have summarised the 22 first parts in the table below (Table 1). Obviously attractiveness is complicated and not easily solved.

But all this is for jobs in general. What can we concretely do to make *mining* more attractive? This is what we'll talk about next. Johansson et al. (2010a) developed 26 statements which, if fulfilled, will make mining more attractive (they also share much in common with the recommendations of Johansson and Abrahamsson, 2009). The statements are about *safety and health*, *physical work environment*, *psychosocial work environment*, and *social responsibility*.

Table 1: A model of the dimensions and categories that influence the attractiveness of a job. (Based on Åteg et al., 2004.)

Working conditions	Work content	Work satisfaction
Adequate equipment and tools	Work pace	Coveted
Working hours	Familiarity	Recognition
Physical work environment	Physical activity	Status
Leadership	Freedom to act	Stimulation
Loyalty	Practical work	Results
Location	Theoretical work	
Wage	Variation	
Organisation		
Relations		
Social contact		

We will begin with *safety and health*. Johansson et al. state that attractive mining has to be safe. Mining becomes safe through two strategies. The first is the *zero-entry mine*, which we mentioned earlier. This means that no human is allowed to enter development and production areas. Instead automation and remote-control technology is used. The other strategy is *systematic work environment management*. This means that risks are minimised through systematic and continuous work with risk assessment. These are two very important strategies and we talk about both these strategies later in the handbook.

The next set of statements is about the *physical work environment*. Here Johansson et al. state that the physical work environment will improve as the zero-entry mine is realised. This is because automated or remote-controlled machines will be doing the physically heavy jobs. But the physical work environment still can't be forgotten. There still has to be variation in the physical workload. Exposure to noise, vibration, chemicals and radiation has to be as low as possible. The climate has to be good as well; it can't be too warm or too cold. And even though many workplaces are underground, lighting has to be good. Finally it is important the locales, machines and vehicles fit the different needs and limits of humans.

The *psychosocial work environment* is also important. It will change in the future, but the statements by Johansson et al. apply as much today as they do tomorrow. To create a good psychosocial work environment management has to be supportive of the personnel and the personnel have to appreciate the management; management and personnel have to cooperate. Instead of planning top-down for individual personnel, the personnel work in autonomous production groups and there is a good balance between demands and self-control.

When employed in mining, there has to be continuous learning. This means both theoretical knowledge and understanding of mining and mining production in a holistic perspective. Mining work should offer new challenges and meetings with new professions.

The attractive mining workplace is also equal. There are many measures that will help create equal workplaces. Working in mining should mean good work security, grounded in efficient production. Also, the wages shouldn't make people take risks and work hours should be flexible so that social activities are possible.

The last part is *social responsibility*. This part is quite complex and we won't go into detail in this handbook. But it is still important to know about these responsibilities. Johansson et al. state that social responsibility comes down to that employees should feel proud to work for the company. This means that the mine site in some way has to be connected to a living society with cultural activities. Sometimes this will mean that fly-in/fly-out personnel and contractors are avoided. But fly-in/fly-out personnel and contractors of course have to have the same rights and obligations as ordinary employees. Finally mining companies have to be mindful of the environment and should do as much as possible to minimise the environmental impact.

Some of what we have talk about here might seem as common sense or obvious. But it is still important. Many mining companies want to increase efficiency and productivity. Lööw and Johansson (2015b) discussed the fact that sometimes these things can go hand-in-hand in mining, but the opposite is also possible. This is why it is so important to be aware of these issues.

3. THE DESIGN PROCESS

Mine planners and designers play an important role in the design of the work environment. The mine planners and designers will shape the work environment (either by directly designing the work environment or the equipment that is used in the work environment) for miners for many years to come. If the planners and designers design a poor solution and it is necessary to redesign it, it will be very expensive to fix, and be a bad working environment for the miners.

Sadly, it seems work environment and safety issues are often left unattended in the early stages of mine planning and design projects, when instead they should be systematically highlighted and developed in the very first steps. The best and most efficient ways to gain good safety is through proactive planning instead of reactive corrective actions. It is also the best way to reduce the costs of doing (see Figure 1). But the mine planner or designer isn't alone. He or she works in a company that has its own safety climate and culture, safety policy and safety management. All these things are important for the success or failure of the planner's work.

We have heard the slogan "*Safety First*" in the mining industry for a long time now. Yet in many cases it is still just a slogan. Safety doesn't always come first, especially if the business has financial problems. But it seems times are changing and many mining companies are now making great efforts to improve their safety climate and safety culture. We know from research (HSE, 2005) that a positive safety climate and a well-developed safety culture are important requisites for healthy and safe work environments. And we know mine planners and designers play an important part in achieving this. We know change and improvement is possible, even though mining has a strong conservative culture and tradition that is difficult to change.

But how do we change? And how do we work with health, safety and attractiveness when planning? There are many mining engineering handbooks, but health, safety and work environmental issues are mostly discussed in the production stages. These issues

Reactive and proactive

We use the works 'reactive' and 'proactive' often in this handbook. When we say "proactive work" we mean that, for example, work with a risk should be done before it becomes an accident. Working reactively means that dealing with the risk only starts once an accident has occurred. To work proactively systematic methods and many different tools are needed. We hope this handbook helps provide this.

should be dealt with in early mine design. An *iterative planning process* is needed to handle these issues.

Any planning or design process will always need much rework and many iterations. But today most of this rework and the many iterations are reactive and unsystematic; *ad hoc* solutions to problems are found whenever they show up during the design and planning work. But it doesn't have to be this way. It's possible to have a more deliberate, proactive, preventive and systematic approach. Below we describe a way of working in *iterative* way that was developed by Ranhagen (1995). It has already been used with good results in large projects, such as for base industry and city planning. We have modified the approach so that it better suites mining.

The *iterative* approach consists of four steps:

1. Planning the project
2. Making a diagnosis of the present status
3. Defining requirements
4. Creating and evaluating proposals

Each step is repeated several times – each step is *iterated* (see Figure 4). First, focus is on outline planning, then – step by step – focused is moved to a more detailed plan. By systematically moving back and forth several times, the final proposals are gradually improved.

An important part of iterative planning and design process is to create and judge several alternative solutions. By making many

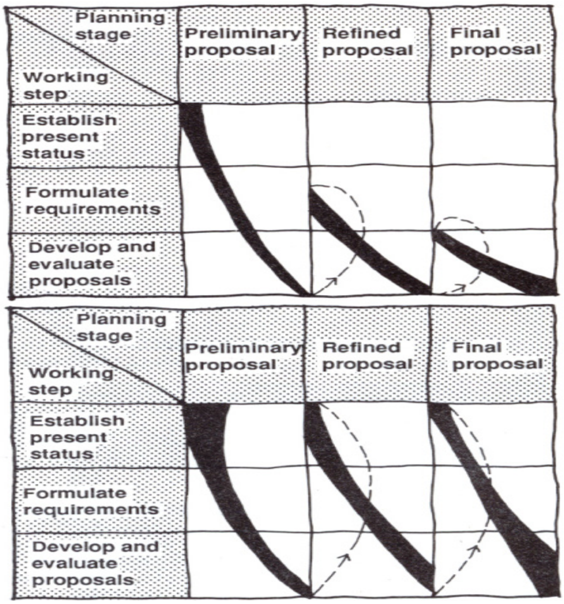

Figure 4: Examples of the iterative nature of the design process. (Source: Johansson and Johansson, 2014.)

conceptual solutions and eliminating the ones that aren't good enough, the number of solutions become fewer and fewer until a winning concept is found. The winning concept is then designed in detail.

By planning in this way the most important parts are designed early. Working out the details is usually very time-consuming. So, by focusing on the most important parts first and then on the details we can create solutions and designs that are cheaper and more flexible compared to using a traditional approach.

Earlier we talked about the importance of focusing on the early stages. This philosophy works well with the iterative process. Early in a project fewer resources are required and it is easy to change things. But as we get further and further into a project this changes; more resources are needed and changing things is harder. In the implementation stage it is very hard to change things about the project and needs very many resources.

An example of the iterative process

To give a more detail view on the iterative design process we have included two examples:

- Stages two to four are performed three times: first to create a preliminary proposal, then to refine proposals, and lastly to arrive at a final proposal. The first developed proposals results in new data input for the present status and requirements. The focus is shifted depending on how difficult and uncertain the planning conditions are. Complex situations (and most mine planning projects involve complex situations) or projects need more detailed iterations.
- A feasibility study could be completed three times with a focus that's gradually moved forward. This keeps the design work on track and gradually develops both detailed specifications of demands as well as detailed suggestions for well-functioning solutions from a holistic perspective. The specification of demands get sharper for each iteration and this is especially useful for the work with the following more detailed designs.

3.1. Planning the project

The planning of the project is the first step in the iterative planning process. It has three stages:

1. Define the project objectives
2. Form the project organisation/group
3. Split the work into stages

When *defining the project objectives*, the objectives should be expressed in general terms so that they don't have to be significantly changed during the project (but *some* change is almost always needed). Below

Mine stages and iterative planning stages

There are many oversimplified descriptions of the mine planning process. Perhaps the most common is the description of mine planning as a straight on linear process. But underground mining is a complex, difficult and high cost business where mistakes can be costly for companies, society and individuals. Therefore feasibility studies are used at all stages in order to maximise the different values of a mining project and reduce different risks.

Mine planning and design is also often described as a step by step process with gradually improved levels of detail, starting with a conceptual study followed by an engineering study and finalizing in a detailed engineering design stage. This fits in well with the iterative design process.

After each study is completed, the company's top management or board decides to proceed or not or to complement the actual study so that necessary results for each decision are well-founded enough. For each new step the financial accuracy is improved and more money is spent to get this improved accuracy.

In the conceptual study the level of financial accuracy is normally about ±50%. In the following preliminary feasibility study the accuracy has improved to about ±25%. In the final feasibility study the financial accuracy usually is about ±15%. This level of accuracy is often regarded as sufficient for deciding to go on or to stop further engineering work in the studied mining project.

we have added some suggestions for topics that the goals can concerns and some examples:

- Production and productivity: to increase production capacity by x tonne per year over a four year period.
- Product quality: to achieve quality improvements in the form

of higher percentage of recovered ore for each mined tonne.

- Health and safety: to halve the amount of workplace accidents and to decrease the days of sick-leave from x to y.
- Work environment: to decrease exposure silica and diesel fumes; to create flexible, silent, clean, beautiful and safe workplaces.
- Environmental issues: to lessen ground subsidence in x area.
- Economics: to decrease costs through rationalisations in the hoist.

In this handbook we are especially concerned with the health and safety and work environment goals. But these goals many times go hand in hand with production, productivity, quality and economic goals.

Setting goals for health, safety and the work environment needs involvement from both the top management and the company safety committee. If top management sets clear and challenging goal, it will likely to be a commitment to the goals. But if management doesn't set clear and challenging goals, the opposite can happen.

Forming a project organisation is different depending on if it is a small, simple project or a big, complex one (or anything in between). In a simple project, it is enough if the project has a decision making body or person, a health and safety reference group and a project group. The project *group* should have an experienced designer or planner and people from relevant functions. By relevant functions we mean the part of, for example, the company that is affected by the project. This could be a certain department, such as maintenance or geology. People who are affected by the project or can gain something for it are called the project's *stakeholders*.

With larger and more complex design projects, a larger and specialised project organisation is needed. The project should then involve personnel from both inside and outside the company. And a project leader is needed to ensure proposals are developed and submitted to top management and boards for decisions.

But it doesn't matter what type or size a project, subgroups or special project groups for health and safety matters should *always* be formed to analyse and eliminate problems as early as possible in the mine design process.

Complex projects need to be *split into stages* that step by step develop designs from preliminary concepts to final, detailed solutions. The stages are the same even as the stages repeat. But the focus will change. In the beginning the first stages can be more important, and in the end of the project the last stages can be more important.

3.2. Making a diagnosis of the present status

The second step is *diagnosing* (by this we mean establishing and analysing) *the present status*. This step is very important: it is the base for all health and safety improvements; to know what areas to improve, and how to improve them, good knowledge about the present status and situation is needed. In short, it is about getting a good picture of the positives and negatives of the area that the project is about. The best way to start a diagnosis is to consider what problems the project is supposed to solve and then go from there.

But some carefulness is required when making a diagnosis. It is important to remember that all involved in making the diagnosis have different backgrounds, with different experiences and different perceptions. This can affect the results of the diagnosis. If, for example, looking at risks in a diagnosis, one has to be aware that one person can think something seems dangerous and another think it's very safe. But there are tools to help (see Annex A).

3.3. Defining requirements

The third step is *defining requirements*. It is important to be extra mindful in this step so that the best solutions can be found. The goal is to create functional and measureable objectives that also make it possible to create different solutions. These demands are called *functional demands*. It is important to find the most important

A note on available tools

Based on Neumann (2006).

It is important to use the right tool for analysing the present status. But there is no "best" tool and no tool is perfect. The choice of tool depends on the purpose of the description, evaluation or design. How the tool is used is also critical and thus the user's competence. The tools and the user's competence must match each other.

Neumann has made a comprehensive inventory of tools for description, evaluation, and design of work environment/ergonomics. He found that there are many different tools available and that the tools can be categorized and also sequenced as follows:

- Tools for Strategic Decision Making
- Tools for Work System & Product Design
  - Complex Human Simulation Models
  - Simpler Computerized Human Biomechanical Models
  - Design Checklists and Other Design tools
  - Flow Simulation Tools
  - Tools for Product Design
- Instruments for Evaluating Work Environment
- Computer Based Evaluation Tools
- Checklists for Workplace Evaluation
- Questionnaires on Risk Factor Perceptions
  - Physical Risk Factors
  - Psychosocial & Psychophysical
- Questionnaires on Health & Wellbeing
  - Fatigue, Motivation, Satisfaction etc.
  - Pain, Disability & Symptom surveys
- Economic Models

The most common tool is the "Checklist" type tool, many in computerized versions. Tools for description, evaluation, and design of work environment/ergonomics were found in all categories except for strategic decision-making. This shows that there is a need to adapt old or develop new ergonomic tools for strategic decision making. Such tools would be very useful when using Ranhagen's planning method.

Neumann suggests that it may be suitable to use simulation approaches that are based on fundamental design specifications early in a design process. If a workplace is already in production, and a specific problem or question is to be addressed, then simpler tools may be more cost effective than actual simulations.

functional demands and that the demands are inspiring and reasonable. At the start of a development process, demands can be relatively few and more visionary. But as the project progresses they need to become more specific and detailed. If there are no demands or if they are too vague, it will be difficult to expect any worthwhile results

When formulating demands, they have to be stated in a way that opens up for several different solutions and proposals. Functional demands should say what and how much should be achieved. A functional demand should *not* specify *how* a certain requirement should be fulfilled; the demand should only state that it should be (or has to be) fulfilled. For example, the functional demands on air quality regarding purity (e.g. concentration of carbon monoxide). There are several ways to achieve such a requirement: reduction of emission, reduction of dispersal, reduction of exposure.

The demands have two purposes:

- *Guiding and directing the creative work to create concepts and solutions*. This work is usually guided by a few but highly important demands dealing with core problems. One has to be careful to not include too many demands here as it can strain the creative processes.

Demands specified by laws and provisions

Laws and provisions often specify demands. However, these demands often only specify minimum *acceptable* levels. When planning for projects these levels must be much lower. For example: if the hygienic threshold value for eight hours of exposure to airborne dust is 5 mg per cubic meter, then the planned level should be less than 0.5 mg per cubic meter, to be on the safe side. One should *always* strive to exceed demands set by laws and provisions.

- *Systematic evaluation of concepts, ideas and detailed suggestions.* The full list of demands is used so that a holistic, broad and detailed evaluation can be performed. Detailed demands have to be expressed in qualitative *and* quantitative terms when possible. For example: if the demand is for "very good air quality" (a qualitative requirement), this can be expressed with a quantitative demands on air purity, temperature, humidity, and so on.

3.4. Creating and evaluating proposals

The fourth step is *creating and evaluating proposals*. This is a step of both innovative and analytical work. Planning and designing proposals are based on a mix of practice, science and innovation. "Common sense", analytical skills and creativity are all used here to create design alternatives that can be evaluated against the specified demands (that is the demands defined in the previous step).

Of course, some demands are more important than others and the evaluation has to reflect this. One way to do this is to assign a number to each demand: the higher the number, the more important the demand. Sometimes this is called the demand's *weight*.

When *evaluating* proposals something called an *evaluation matrix* (see Figure 5) is created. In an evaluation matrix each row represents a demand. The rows are cross-sectioned by the different

		Design 1		Design 2	
Functional demand	*Weight*	Fulfilment	Points	Fulfilment	Points
High safety	4	3	12	3	12
Product quality	4	4	16	3	12
Environmental impact	3	1	3	3	9
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
Total points			**53**		**45**

Figure 5: An example of an evaluation of two designs using an evaluation matrix.

designs and proposals. For each demand it is assessed how well the design or proposal fulfil it. By multiplying the fulfilment number with the weight number, a score for that demand is obtained. By summing every score for one design, a get a total score for that design is obtained. This is then done for every design.

It is necessary to use an absolute scale for criteria fulfilment in evaluation matrices so that it is possible to judge if a proposal is good enough. This means that a proposal has to reach a certain score to be good enough. If a relative scale for criteria fulfilment is used, it is only possible to see which one of the proposals is the best; it isn't possible to see if a proposal is good enough.

The criteria fulfilment scale has to have clear definitions. It must be obvious what has to be fulfilled to reach a certain level; there can't be any question of the difference between "almost fulfilled" and "completely fulfilled".

But an evaluation should never be a simple arithmetic task; the solutions with the highest points shouldn't automatically be chosen. Planners and designers must always be sceptical. Before making a

final decision it has to be assessed if the results make, and if not: why. If there are two alternatives with similar scores, the most important criteria have to be investigated. The most important criteria are the ones with the highest weights. The similar alternatives have to fulfil these criteria and alternatives that fail this check are excluded.

An alternative way of using the evaluation matrix

The demands of the evaluation matrix can also be binary. This means it is only important whether or not a demand is fulfilled or not, not the extent to which it is fulfilled. Let's say there's a demand on ventilation: "sufficient ventilation for all active faces". In this case, the only concern would be if this is fulfilled or not. It is also possible to require these demands to be fulfilled for the proposal to be considered. If a solution doesn't have sufficient ventilation at all active fronts, it has to be improved or rejected; it can never be accepted as it is.

The result of an evaluation is dependent on the person who performed it. So to get a more objective evaluation different people, with different expertise, experiences and interests should also perform the evaluation. It is even better if some of these persons aren't (directly) involved in the project. It is also possible to validate the results of an evaluation and reduces potential biases if the evaluating group is separate from the project. This makes it easier to make an informed decision and to formulate the best recommendation for the following design phases.

In the end there are three types of decisions or recommendations that can be made for a proposal or design:

- The proposal is acceptable and can be further detailed
- The proposal needs improvements in a certain area (or demand) before it can be designed in detail
- The proposal should be rejected and isn't suitable for further detailed design

By using this systematic evaluation of design proposals, more rational, conscious and wise decisions can be made, so that the best solutions are promoted.

4. DESIGNING FOR SAFETY

There are many hazards in mining, and many pose a risk to the health, safety and wellbeing of the workers. The iterative planning method talked about above is systematic, but has no systematic way of working with health and safety issues; other tools and methods have to be used to identify risks. And there are many useful tools and method, each with its specific application area. Because there are some many different tools available we can't give a definite answer, in this handbook, on which tool or method to use. Instead we talk about the concept of risk analysis in general, briefly introduce it, and summarise some methods that are useful in mining.

To identify, eliminate and reduce hazards in the workplace, a continuous way of doing this – throughout the whole lifecycle – is needed. There are many ways to do this. And once again there is no best choice. We are going talk about a process which we have based on a combination of two approaches. Part of it is based on Harms-Ringdahl (2013). The other part is based on IEC (2009). The process is iterative and is similar to ISO standards. In Figure 6 a schematic picture of the procedure is illustrated. In this chapter we will go into more detail about each part.

But before we start we have to talk a bit about some terminology. Very many different but similar terms are used and this can cause confusion. For example, Harms-Ringdahl (2013) use the term 'safety analysis', while IEC (2009) use terms like 'risk management' and 'risk assessment'. It's important to know the ISO terms, thus we have indicated them in Figure 6. Yet we think Harms-Ringdahl's definition is better suited here, so we have based this chapter on his definition. The good thing about talking about 'safety analysis' is that it fits well with the ISO procedure and most safety analysis methods.

4.1. Establish the context

Establishing the context is about deciding what should and

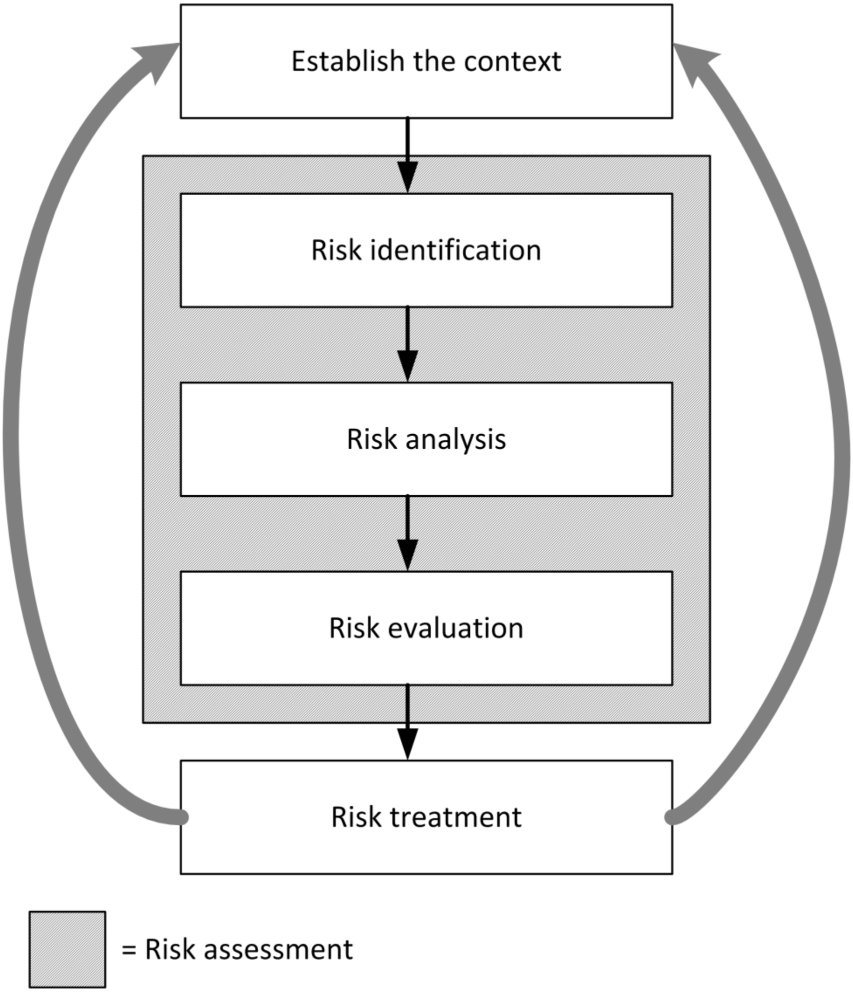

Figure 6: A model for managing risks in projects.

shouldn't be investigated. In this stage it is decided what is going to be looked at (the whole workplace, a mine face, a certain machine, for example), definitions are defined (for example what a risk and an accident is), responsibilities decided, and so on. We can compare this stage to diagnosis stage in the iterative planning process. In this the question to answer is: "Why is this analysis needed and how are its results going to be used?"

Risk management in the zero-entry mine

Based on Ventyx (2013).

An international global survey analysed mining companies' top challenges and priorities. Somewhat surprisingly, the alternative "Ensuring workforce safety" emerged as the respondents' top challenge. The result of this survey confirms that safety already is prioritised in modern mining. But ultimate safety in mining can only be reached through zero-entry. Still, there is a long way to go before the zero-entry mine can be realised. We must accept that there will still be a lot of underground workers in the nearest future and their jobs must be safer. This is a challenge that must be tackled in a systematic way. The road consists of a large number of development projects where risk analysis must be conducted in a systematic way, especially in early stages so that safety solutions can be optimized.

It is important to remember that at early stages of the work, a broad perspective is usually required. As more iterations or laps of the iterative process are completed, the perspective becomes more and more specific. In the first iteration or lap it might only be required to look at the biggest risks, risks that can't be accepted in the concept. In the last lap, looking at small risks that can happen on a task level can be motivated.

For mine planning projects, whether to use broader or narrower perspectives also depends on what mine phase the project is regards. In the operating or exploitation phase of a mine, hazards can be looked at a task level. But in the design phase it is usually not known how the tasks will be carried out, so a broader level perspective has to be used.

4.2. Risk identification

The next step is *risk identification*. Here the goal is to find and

What is risk?

Based on Harms-Ringdahl (2013).

There are many definitions of risk. It is not uncommon to hear "what is the risk of that happening?" or similar things. In such questions, risk refers to the chance of something negative happening. The 'that' in the questions is usually the consequence. Many times, in ISO standards for example, risk means something different. In these cases risk is usually the product of the likelihood and consequence of a (negative) event happening. We also use such a definition.

describe risks (and to find and describe risks, risks have to be recognised). All situations in the workplace that can cause accidents have to be identified. Damage or injury to a person, the environmental, property and equipment has to be included. This is one of the most important steps in safety analysis – because it's not possible to eliminate or control risks that are not known about. Safety analysis tools are used to systematically identify risks. A short summary of many such tools are included in Annex A.

4.3. Risk analysis

Risk analysis is about understanding the nature of risk and to determine the level of risk. This means that in the risk analysis-step the causes and sources of risk are found. The consequence and probability of the risks (remember that risk is both the *likelihood* of something happening and the *consequence* of this thing happening) are also determined. How this is done depends of the method chosen. There is much specialised literature about these kinds of methods so we are satisfied with including a summary in Annex A. The results from the analysis are used as input for the risk evaluation that follows.

Examples of detail levels

In the design phase, it is difficult to know exactly how the tasks will be carried out and thus a high level of detail is complicated. Still, it is possible to know the job and its tasks in broader terms. For example: one can know that a certain machine has to be used for a certain job. It is also possible to know what tasks are needed to operate the machine. The smaller the boundaries and the more details and knowledge there is about the system, process or tasks, the more detailed the hazard identification will be.

4.4. Risk evaluation

After risks have been identified and analysed, they then have to be *evaluated*. In this step, it is decided if the risk is acceptable or not, and what should be done about it. Risk evaluation is about making decisions like:

- Should a risk be treated or not?
- In what order should risks be treated (the priority of the treatments)?
- Should a certain action be taken (e.g. purchase the evaluated item or not)?

There are many ways of evaluating risks but the two most common are *risk matrices* and *direct evaluation;* we are going to talk about these two in this section.

4.4.1. Risk matrix

The most popular way to evaluate risks is to use a risk matrix. What the methods does, is it classifies a risk based on its likelihood of happening on one axis and its consequence on the other. This creates a grid or *matrix* (see the example in Figure 7). From the *risk analysis* the risk's consequence and likelihood is known and can then be placed in the matrix based on these two attributes.

Probability	Consequence			
	Minor	Medium	Large	Catastrophic
Frequent	*Medium*	*Medium high*	*High risk*	*High risk*
Probable	*Medium*	*Medium*	*Medium high*	*High risk*
Remote	*Low risk*	*Medium*	*Medium*	*Medium high*
Very unlikely	*Low risk*	*Low risk*	*Medium*	*Medium*

Figure 7: An example of a risk matrix. (Source: Harms-Ringdahl, 2013.)

This combination of consequence and probability results in a classification of the risk. In our figure we have four classifications. Those risks classified as *low* (or similar) can be safely ignored, but those classified as *high* (or similar) have to be treated or solved immediately. Usually for the highest classifications, work or the project can't continue until these risks are solved. The risks in-between (for example, *medium* and *medium-high*) should be treated or investigated further but doesn't have the same priority. Many times it's a question of time-span, that is, how fast we have to deal with the risk (within the week, month and so on). It is important that all levels are clearly defined when *establishing the context*.

4.4.2. Direct evaluation

In a *direct evaluation* the decision of doing something about a risk, or not, is much more direct than with a risk matrix. First, a list with criteria that risks can't break is generated. Then each risk is check as to if they break one of the criteria. The criteria can, for example, be that a risk shouldn't break company policy or any authority directive, or has a high consequence or likelihood. Usually if a risk breaks one of the criteria, something has to be done about it. If a risk breaks more than one criterion this means it has a higher priority.

Harms-Ringdahl (2013) give the following criteria as examples of what risks can be evaluated against. The risk:

Different scales and definitions

It is usual for either scale of the risk matrix (likelihood and consequence) to vary in detail and definition. Likelihood can, for example, be graded as the risk occurring

- Once a week
- Once a month
- Once a year
- Once every ten years
- Once every 100 years
- And so on

The probability can also be based on factors such as occurrence in the whole sector or industry. The risk can be classified as

- Never being heard of in the industry/sector
- Being heard of in the industry
- Having happened in the organisation or more than once per year in the industry/sector
- Having happened at the location or more than once per year in the organisation
- Having happened more than once per year at the location

Of course, consequences vary in classification in a similar way. The consequence of the risk could, for example, cause

- Some discomfort but is otherwise harmless
- Injury but no sick leave
- Short sick leave
- Long sick leave
- Permanent serious injury or death

Other way of classifying consequences is determining if the risk can cause

- No injury or health effect
- Slight injury or health effect
- Minor injury or health effect

- Major injury or health effect
- Permanent total disability or up to three fatalities
- More than three fatalities

Consequences don't have to be limited to just people. Many times it is also good to consider consequences to assets, the environment and reputation.

- Is a breach of authority directives
- Deviates from the company's policies and/or rules
- Has big consequences and/or high probabilities
- Deviates from good praxis
- Involves many uncertainties (i.e. there is too little knowledge about the risk)
- Can be easily eliminated or reduced by an obvious solution
- Can affect a system with low tolerance for error and/or faults

But it is possible to also come up with more or other criteria that are relevant.

4.5. Risk treatment

Risk treatment is the next step; having decided that something has to be done about a risk, they have to be treated. In this step the goal is to find ways to reduce or eliminate the risk. Usually when we talk about reducing risks we mean either reducing its likelihood or its consequence (but sometimes both). And this can be done in several ways. The important thing is that it is done in a systematic way (as always). A strong recommendation is to use something called the *hierarchy of control*. The hierarchy of control is popular and have a few different looks; we use the one pictured below in Figure 8 (based on Safe Work Australia, 2011) and we will describe closer soon.

The way the hierarchy of control is used is that a risk is first

The problem with risk matrices

Based on Cox (2008).

In the article "What´s Wrong with Risk Matrices?", Cox discusses that, even though risk matrices are widely accepted and used, little research has gone into to validating their performance in improving risk management decision. Cox continues with pointing out the limitations of risk matrices (such as, at worst, they are worse than random when it comes to giving guidance in decisions) and concludes that they should be used with caution, and only with careful explanations of embedded judgments.

attempted to be treated at the top level, then at the next level if the current one isn't possible. Then the procedure is repeated: it is decided if the risk can be treated at the new level or if the next level has to be attempted. Before doing this, it's important to decide if risks should be treated *as low as reasonably practicable* (ALARP) or *as low as reasonably achievable* (ALARA).

Before we continue we also have to add that one type of treatment doesn't fall under the hierarchy of control. Sometimes enough simply isn't known about a risk to make a fair decision. In this case the risk "treatment" can be to gather more information.

4.5.1. Level 1

At the *first level* risks are completely eliminated. This is *always* the most effective solution but not always efficient. An example of this level would be eliminating the risk of falling by performing the work at ground level, or using automation and remote-control to eliminate manual or mechanised underground work.

4.5.2. Level 2

At the second level, risks are minimised and reduced. There are three different strategies for this. (And as we talked about earlier, most strategies are either about reducing the consequence of the risk

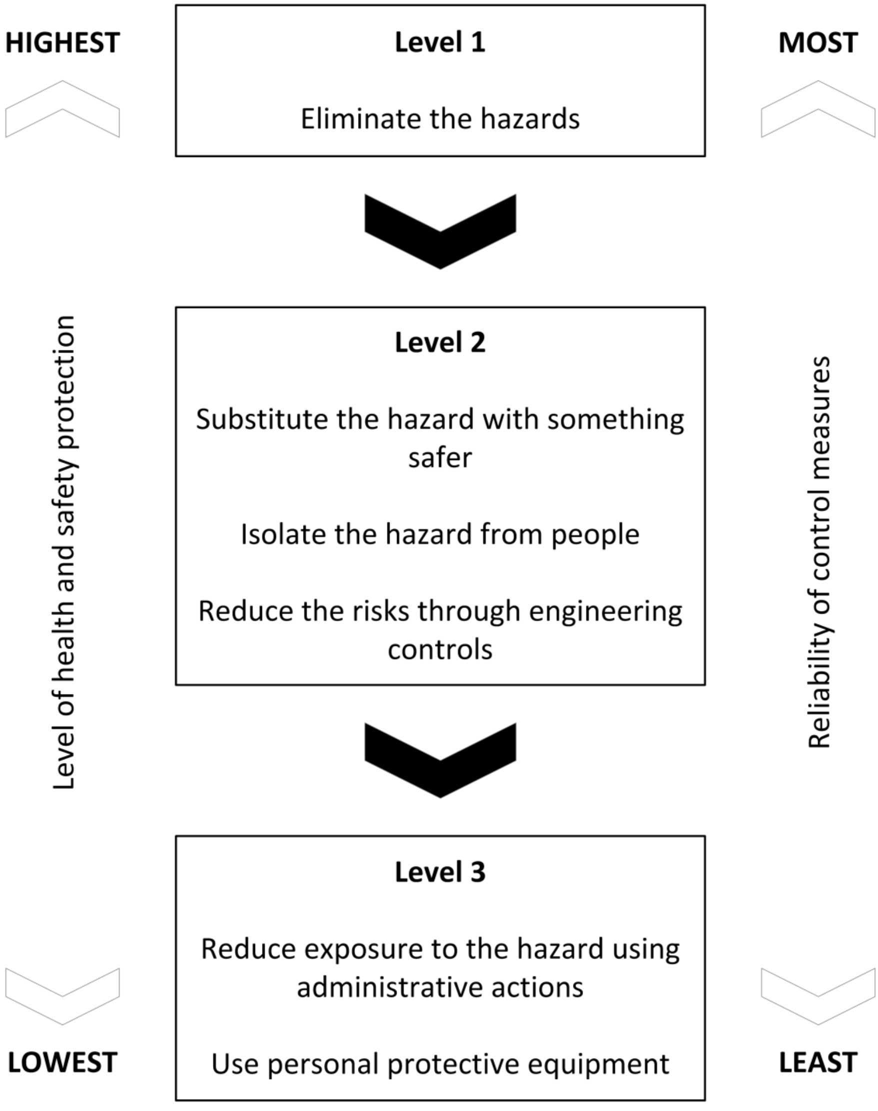

Figure 8: The model used for risk treatment. (Based on Safe Work Australia, 2011.)

or the likelihood of the risk.)

First, we try to minimise the risk by substitution, that is, we try to replace the (source of the) risk with something safer. For example,

How to choose risk evaluation method

Based on Harms-Ringdahl (2013).

There are many safety analysis tools that can be used in the different project stages. Different tools serve different purposes or are more applicable for a certain situation. The preferred tool depends on a number of variables. Some of these variables examples are:

- The objective of the study
- Availability of resources (people, time and budget)
- What the business is doing
- Regulatory and contractual requirements
- In what stage of the business life cycle the business is in
- What information is available

If conducting a thorough analysis, more than one tool can be used to cover more parts of the risk spectrum. Harms-Ringdahl shows how the three methods of Energy Analysis, Deviation Analysis and Function Analysis identified roughly the same number of hazards, but only 5% were generated by all three methods.

This highlights how the different safety analysis tools provide different outcomes and the need to use a number of different tools to cover all areas of safety. It also show that it is important to be familiar with a number of tools in order to choose and use the one that best fits the need of the organization at any particular time and situation.

replacing solvent-based paints with water-based ones, or using DTH-drilling with water hydraulics instead of pneumatics to reduce dust emissions.

The second strategy is to isolate the risk from people (or other vulnerable objects) or people from the risk (but it's preferable to use

The difference between ALARP and ALARA

Based on Harms-Ringdahl (2013).

Reducing a risk as low as reasonably possible or low as reasonably achievable might sound like almost the same thing. But this is not the case. If the ALARP principle is used, one has to do as much as possible given the current situation and context, to treat the risk. A solution to a risk has to be implemented as long as it is shown not to be reasonably practicable. ALARA is often seen as less strict. Here risks are reduced as far as reasonable instead of as far as possible. Here, for example, one weighs the cost of a measure against the gains.

the first case). This means physically separating (or isolating) risk and people by distance or barriers. Installing guard rails around holes in the floor is an example of this strategy; as is mining machines with safety cabs and good climate control.

With the third strategy, engineering controls are used. Risks are reduced by changing the workplace or work organisation. We *aren't* trying to change the behaviour of operator here, for example, and we *don't* put the responsibility on the operator either. So using trolleys to move heavy loads instead of carrying it manually is an example of engineering controls. And reducing work rates to reduce fatigue is also an engineering control.

4.5.3. Level 3

In the *third level* we have personal protective equipment (PPE) and administrative control. This should only be used as a last resort.

Administrative control means, for example, using work methods or procedure designed to minimise the exposure to a risk. This can

It is worth it

Based on European Commission (2011).

A study investigated the costs and benefits of prevention measures. The highest benefit cost ratio was found for measures aimed at substitution or avoidance. The lowest values were found for measures such as training and personal protective equipment. This study shows that the most effective measures, such as substitution and avoidance, are also more cost-effective (profitable). Furthermore, these measures are easier to implement in early project stages, before machines have been bought and layouts constructed.

mean using warning signs, worker training or guidelines for safe machine operations. A common example of administrative control is the procedure for safe handling of explosives.

The alternative is to use PPE. PPE includes hard hats, gloves and protective eyewear. PPE can be efficient, but it's important to remember that PPE only limits the harmful effects of a risk if they are used (correctly). Many times in mining PPE isn't used. This is why PPE should only be used as a last resort.

Example of risk assessment tools

Based on Johansson et al. (2010a).

Classical tools for identifying occupational risks in the production environments are *safety rounds*, and *incident and accident reporting*. But these tools are less suitable to identify and assess risks in future work environments. Here, proactive methods needed. These include *preventive deviation analysis* and *preventive energy analysis*.

In *preventive deviation analysis,* a deviation defined as an event or condition that deviates from the intended or normal. The purpose of a deviation analysis is to prevent, to predict abnormalities that can cause damage. It is also used to develop proposals to improve safety measures. Deviation analysis is a useful method since it takes into account the entire system: human, technology and organisation.

Energy analysis focuses on technology and is be useful when developing new productions systems. In an energy analysis, three main components are considered: energy that can damage, targets that may be harmed, and barriers to energy. The energies usually considered are: gravity, height (including static load); linear motion; rotary motion; stored pressure; electrical energy; heating and cooling; fire and explosion; chemical effects; radiation; miscellaneous (human movement, sharp edges, and points).

There are also other risk analysis methods that can be used during the development of new production systems. These include Preventive Work Safety Analysis (PWSA), Failure Mode Effect Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and Work Environment Screening Tool (WEST).

5. HEALTH AND SAFETY IN MINING

So far, we have talked about *how* to identify and eliminate different workplace risk, but we haven't talked about *what* workplace risks there are in mining. This is done in this section. Every workplace risk and its specifics aren't covered, but the most common risks are. This means we won't go into what machine causes what problem, or a specific solution for a specific problem; focus will be on common problems and how they *generally* can be solved.

When talking about *workplace* risk we often talk about risks to the employee's *health and safety*. But the term "health and safety" is not always clear; sometimes it can mean a single area but in reality they are two separate ones. We use a definition by Saleh and Cummings (2011), which is illustrated in Figure 9.

Safety risks are immediate or short-term, such as slipping, falling and being hit by falling rock. Many times *accidents* are the because of safety risks. Health risks on the other hand take a long to develop and become noticeable. Health risk can, for example, be hearing loss or respiratory disease. The picture also shows that there is overlap health and safety risks. But to make things easier we talk about these risks separately.

5.1. Health

When it comes to work-related health problems (health risks often cause work-related health problems) mining is overrepresented. A study (European Commission, 2010) showed that in 2007 it was the sector with most work-related health problems in the EU. The same study also showed that work-related health problems in mining had also increased in mining. (Health problems have increased in all sectors but they have increased more than most sectors in mining.) Of course the situation in mining varies – sometimes greatly – between countries and companies. But even when mining is healthier (compared to other countries or companies) mining is often worse than other sectors.

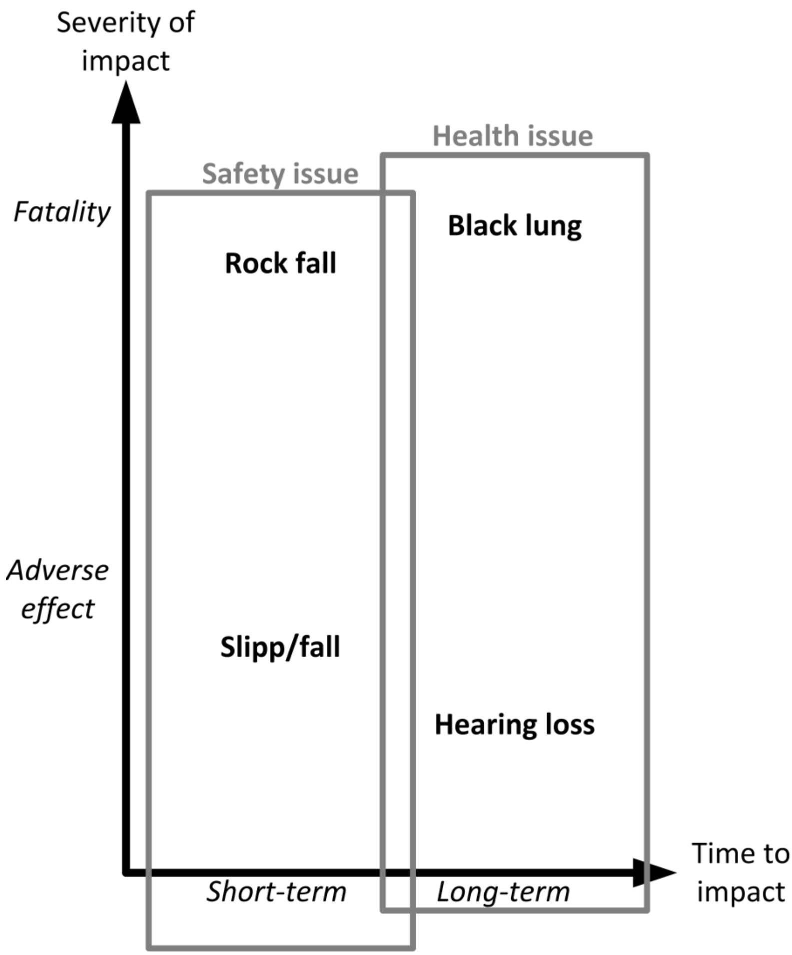

Figure 9: A graphical representation of the difference between safety and health issues. (Based on Saleh and Cummings, 2011.)

Common health problems in mining are respiratory diseases, noise-induced hearing loss and musculoskeletal disorders (Elgstrand and Vingård, 2013). These problems are *consequences* of physical, chemical and ergonomic risks. We will take a closer look at these problems and risks below.

5.1.1. Dust and respiratory diseases[1]

There're many different respiratory diseases. Elgstrand and Vingård (2013) and Donoghue (2004) list coal workers' pneumoconiosis, silicosis, asbestosis, emphysema and chronic bronchitis as common in mining, and that these diseases are caused by exposure to airborne dust found in mines (the dust in mines often includes silica, coal, radon and diesel, which is what actually causes the disease). They also argue that many of these particles also increase the risk of lung cancer.

Instead of focusing on the individual diseases, we are concerned with methods that control workers' exposure to the airborne particles. For many of the methods the specific particle isn't important – the methods work for particles in general – but there are a few exceptions and we will handle them separately.

It is also important to note that increased automation, mechanisation and remote-control reduce dust problems. In a control room, dust is no problem at all. But, as mentioned, we aren't here yet and mining has to improve today, as well as tomorrow.

Respiratory diseases are best controlled by controlling the materials that cause the diseases. Dust in mining is generated when mining takes place; that is, when the rock is fragmented. Thus, it's seldom possible to *eliminate* the source of the risk, because this would mean not fragmenting the rock (but *in situ* leaching might be an exception). However, the risk can often be *reduced* or *isolated*.

Ventilation is often used to control dust. (We use the word 'dust' here but ventilation works for controlling all particles.) It *reduces* the risks by reducing the amount of dust that personnel are exposed to. There are two types of ventilations: dilution and displacement. Dilution ventilation works by diluting the dusty air by providing more clean air. This means the air contain less harmful particles percentagewise. But this method can be costly and have some technical barriers.

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[1] This section is largely based on Ross and Murray (2004) and Kissell (2003).

With displacement ventilation airflow is used to "trap" the dust source and keep it away from the worker; the idea is to keep the dust downwind form the worker. This is a way of *isolating* the source of risk from personnel. All ventilation that puts dust downwind from the worker is displacement ventilation in the end. It can be hard to implement this kind of ventilation but, if done right, it is amongst the most effective dust control. The problem is that it's sometimes difficult to keep the dust source downwind. Using remote-control can make it easier for the operator to be upwind from the dust. In fact, moving just a small distance can greatly reduce dust exposure (operator isn't in the middle of a dust cloud).

Displacement ventilation can be problematic because it can cause air turbulence (this is common when using displacement ventilation together with other dust control methods, such as water spraying). The air turbulence can cause the dust to affect a bigger area than it otherwise would.

Another and important method for controlling dust is *water spraying*. Water spraying can prevent dust from getting into the air after the dust is generated. This method can also capture dust that is already in the air, but the first use is more effective. The two methods are called *wetting* and *airborne capture*, and both ways *reduce* the amount of dust personnel are exposed to.

Wetting means spraying dusty material with water. And generally, the more water used, the more the dust is reduced. However, too much water can be a problem. It can be bad for operation due to quality issues and material handling problems, for example. It can also be bad for safety by, for example, making the ground slippery. (Of course, the further away from the front the operator is, the less of a problem this is.) Still, fragmented rock should always be wetted, as early as possible.

Airborne capture is harder to use. It builds on the idea that the water and dust particles stick together and fall to the ground. However, if not practiced with care, airborne capture can increase the air movement and spread the dust instead of containing it.

When using water spraying it is important that the water is as clean as possible; dirty water releases dust when drying. It is also important to keep in mind that ventilation can speed up the drying process and also spread the dust.

Dust collectors are another method that can be effective, but they tend to require much space and high power. Dust collectors function like vacuums cleaners. They can, for example, be used in cabins or at roadheader cutting heads. But they need frequent maintenance. Without frequent maintenance filters will clog often, they might start leaking dusty air and the effectiveness of the filters will drop if they are mishandled (and these are just a few of the problems).

Of course, the less dust that is generated in the first place, the have to be removed from the air. Thus, dust generation should always be reduced where possible. There are a few different ways to do this. For example, when it comes to mechanical extraction (that is, mining with continuous miners such as a long-wall or a roadheader), deeper cuts will result is less dust compared to shallower cuts.

When drilling, it is a good idea to inject water through the drill-steel. By using *water injection* almost all respirable dust can be removed, though this technique suffers a lot from poor maintenance as it can easily clog. Dust collectors can also be used when drilling, but they aren't as effective as water injection.

Dust is usually not a big problem when blasting. This is because personnel leave the production area when blasting takes place. Then dust is allowed to settle or be removed by the ventilation system before the personnel returns. But once the dust has settled it can get into the air again if it's stirred by vehicles or the personnel's movement. By wetting the blast area with water, dust can be further controlled.

Dust can also be generated by moving equipment. Poor roadways can kick up dust from trucks moving loads and the roadways themselves can generate dust. In both cases it is important to have well-maintained roadways of high quality. Chemical treatment on the roadways that reduce generated dust can also be used.

There are some risks that can be reduced through *substitution*. An example is using electric mining machines instead of diesel driven ones. Thus exposure to diesel fumes can be reduced. Diesel fuels and engines that have a high European emission standard (for example Euro VI) also reduce diesel fumes, as these fuels and engines have very low emissions. Many times, however, mines have enough ventilation to control diesel fumes (to below threshold values). It also interesting to note that if the threshold values for diesel fumes are met, mineral dust is also well-controlled.

It is very common that PPE is used. PPE in this case is different kinds of breathing masks that reduce the amount of dust reaching the lungs. But this should never be a preferred solution, as PPE is sometimes (or often, even) not used.

5.1.2. Noise and hearing loss[2]

Loud noises are very common in mining. Too much exposure to too loud noise has short-term and long-term effects. Short-term, noise can increase stress and the feeling of tiredness. In turn this can lead to increased risk of accidents. One long-term effect of noise is noise-induced hearing loss and this has been a problem in the mining industry for a long time. Even though it's been known about for a long time and despite that there are many regulations, it is still a big problem in mining. Continuous exposure to noise can cause short-term reactions (such as increased blood pressure and muscle tension) to become permanent. Noise can also make conversation harder or masks the sound of alarms. This can also have negative effects; warnings might not be heard, for example.

Most things in mining make noise; it can be from drilling, blasting, materials handling, ventilation, crushing, conveying and ore processing. With so many potential sources of noise, it is hard to control it all. Fragmenting rock, for example, will always be noisy.

Dealing with noise can, basically, be reduced to three things:

[2] This section is largely based on McBride (2004) and Reeves et al. (2009).

source, path and receiver. The idea is that the *source* of the noise can be eliminated, reduced or isolated; the *path* of the sound can be altered, thus reducing noise; and finally, the *receiver* (in this case, usually the personnel) can be protected and isolated (Horberry et al., 2011). Eliminating the noise completely is the most preferable option, but seldom possible as then the source of the noise has to be removed (which blasting, shearing, and so on). But *engineering controls* are often practical and effective. Usually in mining, barriers and sound-absorbing materials are used.

There are a few things to keep in mind when using barriers to control noise. They should be placed as close as possible to source of the noise, and be made as tall and wide as possible so it can better interrupt the *path* from the source and to the receiver. Barriers have to be both solid and airtight and they can be made more effective by making the barrier heavier or by adding many layers. When choosing the material of the barrier, porous material is a good option, as porous material is better at absorbing sound (energy) and stops the noise from reflecting.

Many times it's possible to use a combination of a barrier and sound-absorbing material. For example, an engine can be isolated with a barrier, and the barrier can have sound-absorbing material. (However, it's important to consider the risk of overheating.) Using enclosed cabs is a very good engineering control that also combines barriers and sound-absorbing materials.

Isolation and reduction controls are also available; for example, sound from an engine can be *reduced* by installing (better) mufflers, and noisy machines can be *isolated*. Remote control can reduce exposure to noise or completely isolate from it.

As shown, much noise comes from machines. This means efforts to procure well-designed machines can have significant effects on noise in the workplace. Retrofitting machines is common, but many times this is both more expensive and less effective.

PPE (in this case hearing protection) is also often used in mining. But should only be a last effort. Many times they are misused (or not used at all). It can also be hard to make sure they fit the personnel and not all are very efficient. When using PPE, it is also harder to communicate and warnings might not be heard. Still they are many times required by law if the noise reaches a certain level.

Administrative controls can also be used. This means reducing the personnel's exposure to noise by reducing the time they spend in noisy environments, or by controlling the source of noise (for example, a certain machine is not allowed to be used when there are much personnel around). But this is also a last resort solution.

5.1.3. Ergonomics and musculoskeletal disorders[3]

There are many ergonomics risks in mining. These include:

- Cumulative trauma disorders
- Shoulder disorders (caused by overhead work such as ground support or installing ventilation)
- Ankle injuries (caused by, for example, broken or uneven ground)
- Fatigue (from shift work)
- Sleep disruption (which can cause cognitive and motor impairment)

However, the most important ergonomic risks in mining come down to vibrations and manual tasks. The consequences of these risks make up a big part of the work-related health problems in mining.

Mining has become more and more mechanised and this has reduced the need for physical work. This means that manual tasks and hand-arm vibrations (hand-arm vibrations come almost exclusively from powered hand-tools) are uncommon. Now it is mostly relevant in maintenance. All this instead puts focus on correctly designing machines.

Whole-body vibrations (WBV), on the other hand, are still very much a problem in mining. This is because almost all machinery used in mining is a big source of WBV. It is a serious problem

[3] This section is largely based on McPhee (2004) and Horberry et al. (2011).

because many neck and back injuries can be traced back to WBV. Often, WBV is caused by "rough rides". A "rough ride" can be caused by, for example, aggressive and careless driving. It is the few severe jolts or the extended exposure to moderate jolts that are problematic. The type of vehicle, its speed and maintenance and the condition of roadways are all important factors in WBV. WBV can be reduced in a few different ways; for example by:

- Regularly monitoring vibration levels
- Training operator to drive carefully
- Setting speed limits
- Making sure road problems are quickly discovered and corrected
- Developing effective road maintenance programs
- Making sure vehicles have appropriate design
- Making sure vehicles are effectively maintained
- Making sure that operators that drive a lot have variations in their tasks
- Introducing regular breaks that are "out of seat"

When it comes to manual tasks the most important thing is to design work tasks and workplaces with the personnel's capabilities and abilities in mind; it is essential to keep in mind such things as age, height and strength. (Here, age can be especially important because of the aging workforce in mining.) Today most manual tasks take place in materials handling and maintenance. In this example, the weight of the object and the personnel's strength have to be kept in mind. There is much to consider when working with these issues; it would be too much to review them in this handbook, but there is much specialised literature on this (for example, Horberry et al., 2011).

A final thought on ergonomic risks relates to early mine planning: when buying new machines and equipment, ergonomics should be a deciding factor (a *demand* in the *evaluation matrix*); it isn't enough to only look at costs, capacity, and so on; the machines also have to be very ergonomic.

5.2. Safety

The effect of health risks can sometimes be hard to see and take a long time. The effects of safety risk are often obvious directly. Most times when we talk about safety, we talk about accidents; safety is about preventing accidents.

If we look at accident statistics for the European Union (European Commission, 2010), we can see a positive trend for mining between 1999 and 2007 (we can see this trend in all sectors). Mining is also one of the sectors which have had the largest decrease in accidents during this period. But mining accident rates are still above the average accident rate, telling us that there are still things to do. And even if there is better safety now, we can also see that accident rates are now levelling out instead of decreasing.

Many safety risks can be dealt with in the early stages of the mine planning process. In many cases, the most cost effective, appropriate and effective solutions are found in early project stages (see, for example, European Commission, 2011). And some solutions are only possible in the early stages. Here, the most common causes of accidents in underground mining are reviewed. We will also talk about how to best deal with these accidents and risks.

Many accidents are because of physical risks such as:

- Explosions
- Electrocution or electrical burns
- Fires
- Collapsing mine structures
- Rock falls and rock bursts
- Flooding
- Slips, trips and falls
- Workers becoming trapped
- Malfunctioning or misused mobile mining equipment.

Even though it is the consequences of these risk that cause injury, they say very little about what actually caused the accident. We are going to explore this deeper.

Simpson et al. (2009) argue that it is a common belief that most mining accidents are due to human error, but that this is a truth with some modification. Almost all accidents (around nine out of ten) are *triggered* by a human action (for example, an unsafe act by an operator), while the root cause is usually a combination of factors (Patterson and Shappell, 2010, Lenné et al., 2012). We have to be aware of these factors because without knowing the root cause, safety can't truly be improve; the root cause can't be found if is only at what the operator did wrong.

We can categories the root causes of mining accidents as in Table 2. There are also more factors than these, but they are rarer and it would be too much to talk about them here.

The general principle should be to design workplaces, work and its organisation so that these acts and error become less likely to occur. But there are probably as many potential errors as there are solutions (if not more) so it isn't possible give recommendation for each and every situation.

So how is this important to use when planning? A lot is gained just from knowing about these issues and how to deal with them. But it is also important that investigations about a previous workplace, equipment, and so on, are done when designing new workplaces, equipment and so on. If this aspect of design is ignored, old problems risk being repeated.

5.2.1. Human error

Simpson et al. (2009) describe *skill-based errors* as "auto-pilot errors". Walking into an elevator and pressing the wrong button because usually another is pressed is an example of this. Skill-based errors are common when using PPE, tools or equipment. For example, many times vehicles aren't properly parked – the parking brake might not be applied, the engine might still be running, and so on. To solve this, an alarm could be installed that sounds when the vehicle is

Table 2: Root causes of accidents in mining. (Based on Lenné et al., 2012, Patterson and Shappell, 2010.)

Unsafe acts of the operator	Skill-based errors	
	Decision error	
	Violations	
Preconditions for unsafe acts	Environmental conditions	Technical environment
		Physical environment
	Conditions of the operator	Adverse mental state
		Adverse physiological state
		Physical/mental limitations
	Personnel factors	Coordination and communication
Unsafe leadership	Inadequate leadership	
	Planned inappropriate operations	
Organisational influences	Organisational process	
	Organisational climate	
	Resource management	

exited with the engine still on or with no parking break, as recommended by Patterson and Shappell (2010). They also suggest that a similar alarm solution could be used to increase the use of PPE: PPE could be fitted with RFIDs and certain areas would then sound an alarm if operators enter the area without the PPE. (Note, however, that this doesn't guarantee that the PPE is used, only that it is available. But sometimes a simple reminder can be enough. Note also that many times *violations* are behind non-use of PPE.)

Simpson et al. (2009) also cover *decision errors*, which mean a procedure was done wrongly. This can be because of lack of training or instructions. Patterson and Shappell (2010) suggest making sure the workforce has the correct training, or improving the current training programme (for example, by using pedagogic methods), can decrease the chance of this happening. To make personnel remember procedures even after training, they recommend that tools like checklists be used.

But decision errors can also happen because a situation was assessed wrongly, which can also be improved with training, but here with a focus on identifying risks and how to act in certain scenarios (Patterson and Shappell, 2010). Administrative controls, such as signs to make risks more obvious, can also be used but this is less desirable.

Violations are often linked to adverse mental states, lack in and management of resources, and the physical environment. Here, we might have to re-evaluate and possibly redesign procedures and equipment that are prone to violations. It is also important that we increase the awareness of violation activities.

5.2.2. The physical and technical environment

Around half of all underground mining accidents involve the *physical* or *technical environment* (Lenné et al., 2012, Patterson and Shappell, 2010). Often ground or roadway conditions are important factors in the *physical environment*. Trips, slips and falls are the most common accident in mining. They often happen because ground or roadways condition are bad. But it is not as simple as making ground and roadway conditions better. Earlier, the importance of water sprays to control dust was mentioned; however, water spraying also makes surface and roadway conditions worse by making surfaces slippery and muddy.

Water sprays are very important for controlling dust and preventing health problems, so they can't be removed just to prevent another accident. Instead, mitigation techniques have to be considered. For example, boots with high traction and protection against strains can be, and hand rails in slippery and muddy areas can be installed to prevent trips, slips and falls.

Visibility can also be a problem. Many times accidents happen because the operator couldn't see something (Patterson and

Shappell, 2010, Lenné et al., 2012). Sometimes this is because that there isn't enough light. This can best be solved by having enough and appropriate lights on machines and personal equipment. In fact, some provisions specify the required amount of lighting.

The *technical environment* concerns the design and construction of equipment. Accidents that happen because of the technical environment can, for example, be because of confusing or contradicting control layouts; one machine may have one set of controls and a similar machine a different set of controls – if the machines are similar usually we expect the control to be similar (Lenné et al., 2012, Horberry et al., 2011, Patterson and Shappell, 2010). Equipment designers are of course first and foremost (practically) responsible for the technical environment (in this case). But it's important to be more active in choosing correct equipment; "standard controls" could, for example, be a *demand* in the *evaluation matrix*. Also, many times when equipment has a bad design, it is often modified on site. When modifying equipment, they can't affect the integrity of the equipment; the modifications should be done by certified personnel.

5.3. Depth-related problems

When mining deeper and deeper, there are a lot of different problems, but only a few are directly related to safety and health. At depths greater than 1,000 m below the surface, there are normally three major depth-related problems, which are both difficult and expensive to solve:

- Increased rock stress may, for example, result in mining-induced seismic events that can cause damage of drifts and stopes. It can also result in large deformations and squeezing conditions that lead to large convergence of underground openings. High stress magnitudes may also cause unstable or blocked blast holes, resulting in poor charging conditions. Poor charging conditions can increase the risk for undetonated blasting agents, which are dangerous to handle. The handling of boulders can also be more dangerous.

- Increased bedrock temperature cause heat stress on miners.
- Prolonged transportation distances reduce effective working time and makes evacuation of the mine more critical.

The most difficult of these problems is the increased rock stress. The increased *in situ* rock stress is caused by the increased gravitational weight of the overlaying rock as well as by tectonic stresses. This affects the rock mass hosting the mine excavations (for example, tunnels, shafts, and ramps). The increased stress magnitude can result in an increased risk for serious rock falls and rock bursts due to induced seismic activity. The consequences can vary from minor to devastating. Therefore much effort has to be spent on trying to reduce the present risks, both proactively and reactively.

The main cause of rock bursts is high *in situ* stress magnitudes. Rock bursts can, for example, be caused by locally high stress levels exceeding the strength in a violent manner (strain burst); pillar burst (violent collapse of pillar); and fault slip/shear rupture, which can induce seismic waves which (at arrival to the underground openings) can cause different kinds of damage to the surrounding rock mass. Strain bursts can occur also in shallow mines in geological environments characterised by high tectonic stresses.

In early design and planning, the occurrence and severity of rock burst can be affected in several ways. These factors include:

- Mining method
- Sequencing of ore extraction
- Pillar layout and geometry
- Blast damage
- Strong and brittle rock
- Rock and backfill used to stabilise mined out areas
- Rock support characteristics

The most important preventive measure is a carefully designed, safe mine layout. Yet this is a difficult task because other demands on production and product quality, metal recovery, and so on, have to be fulfilled. It is important to always consider the fact that rock bursts and structural collapses are complex high risk phenomena that are difficult to predict. Therefore, top qualified expertise on rock mechanics and rock reinforcement should always be engaged in early mine design and throughout the project, all the way into production phases, so that the risks can be minimised.

A second significant problem is the increased bedrock temperature at larger depth. In average, the temperature increases by about 25°C for every 1,000 m. The warm bedrock heats up the air; if cooling (usually ventilation) isn't available, this will cause heat stress for underground personnel. Cooling measures are expensive but necessary if miners working hours aren't to be drastically reduced. Therefore, the systems for managing hot environments have to be carefully considered in the conceptual study so that the basic ventilation principles and design are appropriate.

A third depth related problem is prolonged transportation distances and transport time. This reduces the effective working hours for the miners. The increased distances cause higher labour costs per tonne of mined ore and makes fast emergency and rescue transports more difficult. It also means more traffic with bigger loads, which can increase the likelihood of accidents and also the consequence of them.

The rest of the work environment conditions in the deep mines are quite similar to more conventional underground and shallower mines.

6. MECHANISATION AND AUTOMATION

History, practical experiences, and our intuition tell us that mechanisation and automation must improve health and safety. Today, safety even seems to be the strongest motivation behind automation of mining operations. If we look at Sweden, we can see that fatalities have decreased (Elgstrand and Vingård, 2013) during a period in which less people have worked in mining (SGU, 2012) but produced more than ever. That is, accidents have decreased as mechanisation and automation in mining has increased. This would mean that mechanisation and automation does, at least in part, increase safety (see also Blank et al., 1996).

Improved safety is one obvious and positive effect of mechanisation and automation, but there are also negative effects; experience shows, for example, that operators' tasks often change to a more passive role where they monitor the production process rather than being involved in it. This can be seen in industries where automation and teleremote operation have already been used on a large scale. Here, it is not unusual to see operator jobs and tasks that change to a more passive role of monitoring the process. The more positive outcome, where the operator becomes an active controller or driver of the process, is rarer. This problem of underused or misused human capacity must be solved in future mining.

Full automation will certainly be expensive due to a significant number of difficult technical prerequisites and, so far, unsolved problems. This raises a number of questions:

Full automation will be expensive. So far, we don't know the exact effects of full automation either. This means that we might not experience the productivity gains we hoped for, or that safety is improved in the way we expected. A number of questions have to be answered:

- How much of a better and safer working environment can be achieved through extended automation?
- What new risks will arise?

- What old risks will disappear?

A core question that needs to be answered is if money spent on developing automation is the best way to improve safety in mines. It might be better to invest in changing the attitudes and behaviours among the miners and management. The negative and positive effect for health and safety for different automation levels need to be identified and related to an economic analysis that will show how cost effective automation is when it comes to improving health and safety. Only then will we know if automation will be "worth it".

6.1. The road to automation

Only a few researchers have tried to give a detailed picture of possible working conditions of future, more (or fully) automated mines. Most of these attempts show a strong belief that technology development and automation automatically will result in a healthier and safer mining work environment; progress is assumed to occur in a revolutionary manner that will completely change the mining industry overnight. This in spite of the fact that automation has developed slowly since the first automated truck was commissioned in one of Boliden's underground mines in 1971.

Today, and even more so in the future, special attention needs to be paid to the many and different aspects of automation. Automation will impact the working environment; the question is if it will be negative or positive. For example, Widzyk-Capehart and Duff (2007) point out that automation in mining may lead to increased safety and productivity, but also that it can lead to the opposite, decreased safety and productivity. It seems the outcome is dependent on the mining industry's willingness and ability to learn from experiences in other business, such as aviation, nuclear power generation, transportation, base industries and manufacturing.

Although the mining business has managed to automate some of the operations, full automation is still a distant goal in most underground mines. Part of the reason for this is because Noort and McCarthy (2008) argue that technology has not been developed

Experiences from the project: the mining industry is learning

It seems the mining industry, or at least its suppliers, are already learning from other industries. For partly automated machines, some companies have looked toward the work situation of train drivers, especially in regards to the supervisory tasks, and designed their technology with regards to this.

with the aim of total automation in mind. Instead, focus has been on limited and local goals, such as improving safety or productivity (both for work and machines). But the mining industry needs to make realistic evaluations of the commercial value of full automation; the authors argue that a vision of full automation must contain a total reconsideration of the basics regarding mine layout, mining methods and sequence of development.

Increased automation both demands organisational change and makes such changes possible. A number of features characterise the future mining work: an ageing workforce and problems with recruiting new personnel means that the workforce is minimised at the actual mine, potentially made possible by the use of Fly-In/Fly-Out workers. Most of the miners would instead work at the remote operations centres (ROCs).

6.2. Remote operations centres

Noort and McCarthy (2008) argue that future mining will rely on remote control from ROCs. This will be (and is) possible through the use of advanced IT; mining companies will use (and to some extent already is using) automatic mobile mining equipment, automated process control, sensor technology, advanced analysis technology and service oriented IT architecture. Extensive cooperation will be possible due to computer-based systems for communication and information mining. This gives the mining companies better information so that they can make well-informed decisions along the whole value creating chain (planning, mining, maintenance, environmental surveillance, logistics and transports,

A model for the future, fully automatic mine

Based on Noort and McCarthy (2008).

Full automation can hardly be justified with economic reasons alone. Instead, the driving force behind further automation will have to be the need for improved work environment and safety, and the need to attract mining personnel. One model for an approach to automation is presented in Figure 10.

During the first phase – that of fully enclosed vehicles – operations like sampling, surveying and maintenance is gradually mechanised and controlled by operators working from vehicles equipped with manipulators and safety cabins. The cabins resist falling rock and the vehicles have systems protecting the vehicle from rolling over and collisions. All work will be performed from inside the safety cabin that holds a comfortable climate. Similar safety cabins are integrated with other mobile mining operation units and thus protecting all personnel from a hostile environment.

The second phase – remote operations – means that the miners are removed from the mining front to safe control rooms where they supervise and, if necessary, steer and control different operations. No one needs to enter mining areas in production.

In the final phase – full automation – an overarching automation system is introduced. This phase needs a total revision of the mining layouts and methods used in traditional mining. For example, drill and blast will probably have to be substituted by mechanical fragmentation (such as a continuous miner).

The goals of the first phase are most important. The need to move further with the second and third phase is highly dependent on the degree of success with the first one; if the first phase is successful the need for the second and third phase will decrease.

However, it is important that we approach this model critically; today, an alternative route to automated mining exists, which is not considered by the model. Experiences show that the first stage is largely ignored. Instead, mining machine are developed more in line with the second stage. Now we see semi-automatic mining machines (such as continuous hard-rock miners) that are remote controlled. But not remote controlled from a control room. Rather they are controlled from near, but not in, the machine.

The trade-off in health and safety can be discussed. For example, while operation from a secure cabin attached to the machine might offer better protection from rock fall (*when* they

coordinating of contractors, deliveries to customers, and so on). A common visualisation system that shows problems, limitations and possibilities makes optimisation of the whole value chain possible.

Many scenarios on future mining (for example, Bassan et al., 2008) present a similar picture, where there is a strong belief in automation, remote control and changed, more advanced tasks for the miners/operators. Whatever the scenario, work is always conducted from ROCs.

Work in ROCs show many similarities with conventional control room work. And this is quite a well-researched area. Among the most prominent researchers in this area is Bainbridge (1983), who challenged the classic approach of automation design. In the classical approach, humans are regarded as unreliable and inefficient. Therefore, human input should be minimised in the control system. Bainbridge's research, on the other hand, highlighted the need for a human-machine-interaction (HMI) approach in control system design. This has been recognised in many industries, such as nuclear power production, chemical industry, aviation and military defence. Yet, research on work in control rooms within the mineral and mining business has been sparse and fragmented.

Process control in the mining business has been focused on mineral processing and not on the remote control of underground mining activities. Since the 1970s, the industry has tried to

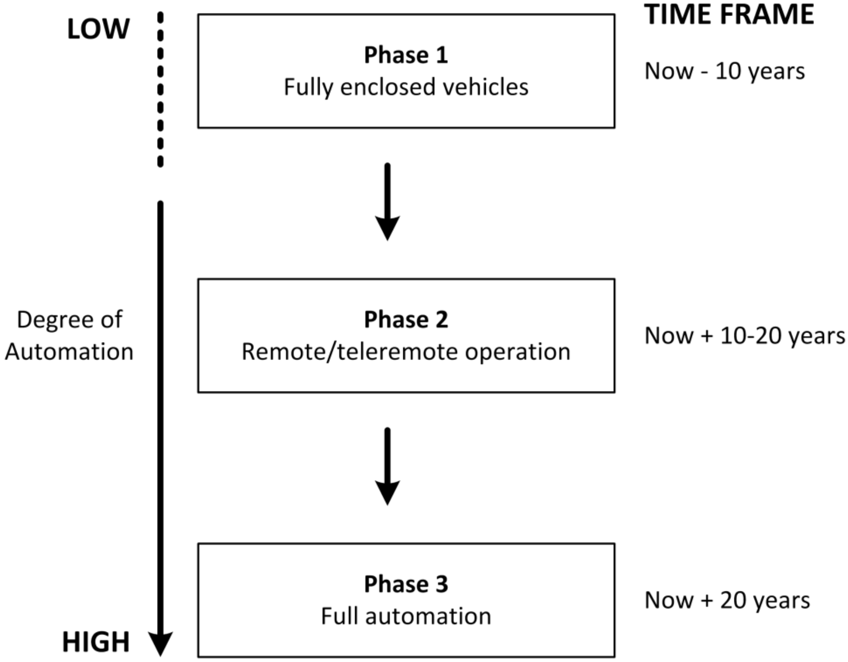

Figure 10: The model for the phases to fully automated mining. (Based on Noort and McCarthy, 2008.)

maximise the capacities of the mineral processing control systems but not managed very well. One of the major reasons for this has been lacking performance of control room operators. Control room operators often have a difficult situation with too little useful support from the technical system (Nachreiner et al., 2006).

The technical parts and aspects of control rooms are usually well managed by the mineral industry but the human factors, normally, aren't. The role of the process operators is often forgotten, even though the high significance of the operators is recognised among mining and mineral professionals. Instead, control rooms have become even more technically advanced, which requires *more* crucial contributions from the control room operators. The increased automation complexity has caused an increased and fluctuating mental work load as well as skills demanded from the operators.

A deeper look at *Ironies of Automation*

Based on Bainbridge (1983).

There are several pitfalls in automation and automating procedures, processes and work, which is the essence of what Bainbridge's paper is about:

> *The designer's view of the human operator may be that the operator is unreliable and inefficient, so should be eliminated from the system. … [But] the designer who tries to eliminate the operator still leaves the operator to do the tasks which the designer cannot think how to automate … [This] means that the operator can be left with an arbitrary collection of tasks, and little thought may have been given to providing support for them. (p. 775.)*

This means that humans are needed in highly automated systems for supervision, adjustment, maintenance, expansion and improvement and that automated systems, thus, still are man-machine systems. But, as the quote above illustrates, this is not always recognised, which can leave the operator with mundane tasks which have been given little thought in terms of design; the operator often becomes a passive observer.

Yet, being a passive observer, the operator is still expected to intervene when the system is not performing as it is supposed to or if something fails. This requires manual control skills and knowledge about the process. The problem with being a passive observer is that skills deteriorate and knowledge is forgotten. Thus, the operator might not possess the skills and knowledge required to successfully intervene in the system if and when it malfunctions.

Another problem is when a new process is automated: when a previous manual task is automated it is usually former manual operators that become the new operators of the automated system. These operators might perform well within the system because they have a fundamental understanding of the technology which they control, having previously worked with it. The next generation might not have this understanding. Thus, training for new operators has to include process knowledge; the new operators need to have the same fundamental understanding of the process as the previous operators who operated at the mine face.

It is also important that operators are skilful to the extent that they know they can take over if required. If this is not the case, Bainbridge argues that the job will turn into one of the worst kind: one that is "very boring but very responsible, yet there is no opportunity to acquire or maintain the qualities required to handle the responsibility" (p. 776). In the long run, this can even affect the workers' health.

Hollnagel (2007) specifies what the mineral industry needs to do when it comes to control system design:

> *The new mission of process control system design is to enhance human capacity rather than to enhance technology capacity alone.*

This is not to say system vendors, for example, don't focus on human factors; several do (for example, Lundmark, 2008). But there is still much to improve: the mining industry has to develop HMI-based control systems, improve the training of operators, and investigate and improve work load and work organisation for operators (Li et al., 2011).

The miners (operators) at the ROCs in future mining, then, need to be supported by intelligent systems for decision making. The systems have to integrate complex information from many functions and present the miners with information and analyses in real time. Only the most important information (deviations or problems in production) should be visible at a quick glance, but the operators need to have full information access all the time to access when required. Decisions must to a high degree be automated. The miners will have a mostly supervising role where they can concentrate on more advanced and complex problem solving. They will also cooperate with different groups within the mine and with external specialist teams. This can include mining engineers, logistics experts or maintenance experts. Specialist teams will be called on whenever needed and they can quickly simulate, analyse and

An example of ROCs in processing plants

Based on Li et al. (2011).

In this study, two Australian processing plants and the work performed by the control room operators was analysed. The plants were broadly representative of typical Australian mineral processing plants. It was found that the control room environment was noisy and disturbing due to noise (from machines and people) and sounding alarms. At the same time, the operators' workload was very high, especially during periods when the mineral processing was unstable. The study also found that operators' control was mostly passive and focused at equipment. Operators tended to respond only when the process or machinery failed – proactive planning activities were few. Equipment failure was the dominant failure of interest and little thought was spent on optimisation and stabilisation of the process. Furthermore, operators were often overloaded and confused by a large amount of useless data; alert signals and failure messages often came too late and the operators didn't have time enough to think through what actions were most needed. Operators also rejected or distrusted alarms as they basically were too complicated, but also because they didn't improve and ease the operators understanding of the different processes.

The study indicated that there were significant differences in performance and knowledge between different operators, and that these differences impacted on the important stability of the production process. Most of the operators had learned by successive hands on training with a more experienced operator. Systematic training was lacking and the mineral industry has a lot to learn from other business when it comes to operators training.

When mining work is moved to a control room

Based on Abrahamsson and Johansson (2006).

What happens when manual underground work is replaced by remote control from above ground? One study explores this.

Deep knowledge about the rock is essential for the underground miners and their skills are related the ability to read the rock. For the miners above ground, it is a question of abstract knowledge, an ability to read and understand pictures and symbols and relate them to different measurement test results.

Another aspect is social belonging and identity. The workers have their roots in a changing context where they have to leave their old blue-collar pals and move into a white-collar environment. The old type of macho behaviour is challenged and the workers have to find new ways of forming their identity. But how will their new identity be?

thereafter adjust production.

As we have seen, the mine of the future will require intensive and extensive interaction between humans and computerised

The operator's cognitive ability and demands must be considered during all stages of automated system design. Thus, future automated production systems in mining must

- Support a high situation awareness, especially in complex high demand emergency situations
- Support a high situation awareness that stimulates to good performance
- Support a high situation awareness and at the same time establish a reasonable perceived subjective workload

Automation in the manufacturing industry

Based on Dencker et al. (2007).

The mining industry can learn a lot from manufacturing industry which has a long experience of automation. Automation is a common way to improve productivity and efficiency in manufacturing industry, but automation also often tend to create inflexible, rigid, expensive and complex solutions. The choice of automation level is a delicate and difficult task – more automation isn't always the right answer; manual labour is the most flexible resource and will likely remain so. The balance between automation/technical resources and human work/operators is therefore a crucial task, especially if the production is characterised by many and rapid changes.

In a production context where flexibility is a leading demand, Dencker et al. suggest that proactive production is a feasible solution. This means that instead of simply reacting to demands, problems, and so on, the system will be well ahead and prevent problems from occurring. Such production systems integrate complex technical solutions with highly competent human operators. Dencker et al. suggest that three parameters strongly influence proactivity:

- Level of automation. Flexible and quickly adjustable levels of automation, applying both to mechanical/physical and information/cognitive levels of automation.
- Level of information. Efficient and dynamic flow of predictable and unpredictable information through the whole value chain.
- Level of competence (among operators). Quick, precise, and efficient competence development for the operators.

- Not over- or under-stimulate the operators so that they rely too much on decisions made by computers
- Not create automation bias, an over-reliance on decision support from the computer system
- Provide reliable operator feedback, as without appropriate feedback operators will make mistakes
- Have been usability tested at all stages of the design process of automated systems

In the end it is about creating proactive production systems. In the manufacturing industries, this has been on the agenda for some time, but it is time that mining too strive for this. A proactive production system is constituted by a combination of "knowledge workers", information, and automation. Operators receive correct information, at the right time, in sufficient amount, and in the right form. A well-designed and well-functioning information system will be a necessity. Operators will have to work with planning, programming, monitoring, intervening and learning. Operators' competence will be most necessary during deviations from normal production, disturbances and breakdowns.

7. WORK ORGANISATION

Good workplaces, employee wellbeing, safety, high performance and productivity all depends on good work organisation. Work is always organised is some way, even if much thought hasn't been put into the question. The problem is, if no effort is spent on work organisation, there will be several negative outcomes. It would also seem that the mining industry doesn't have any longstanding tradition of working work organisation issues, looking many times instead to technology to solve problems.

In this chapter we will talk about what good work organisation can look. Our recommendations are partly based on the concept *Lean Production*. Lean Production is chosen because it's a popular *rationalisation strategy* that can improve performance and productivity and employee wellbeing at the same time – if done right. It's also a concept that mining companies seem interested in. This chapter has two parts: one where we talk about the Lean Mining concept and one where we talk about other issues that are related to work organisation (such as psychosocial work environment).

7.1. Lean Mining[4]

An important term in *Lean Mining* is value. Many times, value means value for the customer. A common example of value is that a product is delivered on time, in right quantity and of the right quality; value is everything a customer is willing to pay for.

In Lean Mining, value is looked at differently: it isn't just what the customer think is valuable but what *all* stakeholders think is valuable. This means values and opinions of, for example, land owner, local business owners, employees and citizens of the community are considered. Below are some examples of what this can mean:

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[4] This section is based on a report and papers by Lööw (2015) and Lööw and Johansson (2015a, b).

Lean Production

Based on Womack and Jones (2003), Liker (2004) and Lyons et al. (2013).

Lean Production is known by several different names (for example, Toyota Production System, lean thinking and world-class manufacturing). Although these concepts may have the same core, their application differs; practices considered the essence of the concept by one party may not even be a part of the other party's interpretation of the concept. Different industries will also require adaptations or modification of the concept to 'fit' their specific needs. These facts and others make it hard to arrive at one widely accepted definition.

One model, used in this handbook, describes Lean Production as consisting of four principles. In turn, these principles consist of a number of practices. The principles are:

- Demand-based production
- Waste elimination
- Supplier integration
- Workforce involvement

Demand-based production is the principle that products should be manufactured on demand instead of being 'pushed' through the production. This means that production is 'pulled' based on the demand of downstream customers. Customers can be internal (for example, other workstations) or external (for example, people or companies buying the product). Another way to express the idea is that production should be 'make-to-order' as opposed to 'make-to-stock'.

Waste elimination is probably the most recognisable Lean Production principle. There are eight different kinds of waste:

1. Overproduction
2. Waiting times
3. Unnecessary transportation
4. Unnecessary processing or reworking

5. Inventories
6. Useless motions
7. Scrap, repairs and inspections
8. Unused employee creativity

To effectively and efficiently eliminate waste, standard operations are required for instruction and evaluation. Visual control and 5S is used to support standardisation and ensure quality. Quality is further ensured by *poka-yoke* (meaning 'mistake proofing'), in which technology and tools are designed so that it's almost impossible to make mistakes in positioning, number of operations, operations sequence and so on. Total productive maintenance (TPM) is also used. TPM involves ensuring that everyone knows how to clean, inspect and maintain equipment so that they can continuously make small improvements and conduct preventative maintenance.

Supplier integration means actively supporting suppliers to adopt Lean Production and assisting in solving problems and improving performance. The aim should be to develop long-term contracts and relationships between the supplying and ordering companies. Through these long-term contracts, both parties can develop.

Workforce involvement deals, partly, with developing and training the workforce as well as improving the working environment. Work should be organised in multifunctional teams with no one worker assigned to a single task. Instead, each member of the team should be capable of doing the tasks of the other team members, making the teams less sensitive to disruptions and allows workers to rotate between different tasks and develop their competencies. Continuous improvements, which is the idea that organisations should continuously strive to improve on every last detail (for example, to develop existing, stable and standardised processes in small steps), is also part of this principle.

- Many stakeholders (for example, the surrounding society) value low environmental impact. Value for a mining company should thus strive for low environmental impact. This would also mean that activities that have negative environmental impact are wasteful.
- A sustainable working life is valued by all stakeholders. This means that mining needs to have safe employment conditions and that it shouldn't be harmful to employee health and wellbeing. Mining company values have to acknowledge this. This could mean that activities that are not safe are wasteful.

We will now talk about Lean Mining in four distinct (but overlapping themes): waste elimination, supplier integration, demand-based production and workforce involvement.

7.1.1. Waste elimination

Waste, like value, is also an important concept in Lean Mining. The concepts are very closely related, being, essentially, different sides of the same coin: everything that is not value or valuable is waste. This means that everything that is not valuable for one or more stakeholders is wasteful. But there are two types of waste: "pure" waste and necessary waste. "Pure" waste (or just waste) is just that, it has nothing of value. But necessary waste is needed, often to create value. A common waste is transportation. For example, transportation distances can be shortened but never removed completely (the ore needs to get out of the ground somehow). This is necessary waste.

We are talking here about waste elimination. This category includes different practices that can help remove waste. Here we have included *standards, 5s and visual control, total productive maintenance* (TPM), *quality*, and *"poka-yoke"*.

Standards are important because they define what has to be done to create value. They are used so that one never has to wonder what to do and to avoid unnecessary, wasteful activities. But these standards have to be flexible than they would be in traditional manufacturing, because of the more variable environment in

Balancing interests

Sometimes values and opinions of different stakeholders will be opposite each other. Or sometimes certain values can't be fulfilled. For example: to not mine at is of course the best way to not do environmental damage, but other stakeholder need the metals.

mining. But most important is that the *standards* are developed with the involvement of the operators they affect. Without their involvement the standards can be rejected and valuable information lost.

Yet, because the production process, and related functions, in mining tends to involve many variations, standards can be especially important here, as this could decrease variations. An example of standard operations in the production process can be found in rock-bolting: with the help of the operators, a technique (how many bolts, in what order, and so on) that guarantees safety, a good working environment, and efficiency can be developed.

As mining become more mechanised and automated, however, the flexibility of the standards become less important. It can also be argued that standardised work procedures assist in automating the process in the future.

TPM should be fully adopted in mining. This practice has the ability to improve machine availability and decrease the variations of the production process. Similar practices are already established in the mining industry. This is mostly in the form of preventive maintenance or simple non-routine maintenance. Thus, it could be argued that the practice is need in mining and that it would relatively easy to adopt. However, it is important that the operators, who are performing the maintenance, receive proper training for this. Otherwise, faulty maintenance can result in additional variation. The practice of TPM mainly applies to the activities related to the production processes, but could also relevant for supporting functions such as transportation.

5S and visual control are common starting places for Lean Production, so too for mining. Some mining companies have already implemented the practice and have seen positive results.

The view on quality is different in Lean Mining. Operators can seldom control product quality in the same extent as in manufacturing, for example. For example, it's possible to increase the waste rock to ore ratio when loading through technology and training, but this will still mostly be dependent on factors that are beyond the operator's control. The big opportunity for Lean Mining is in "internal" quality. Mining continuously "produce" new workplaces which need a high quality. Thus, a focus on high quality in mining will mean, for example, that ramps, pillars, and roadways are produced with quality.

Mistake proofing (poka-yoke) is practiced mostly through equipment design. It's realised through designing machines, for example, to not allow too big loads to be loaded and preventing them from going over the speed limit.

7.1.2. Supplier integration

The principle of supplier integration is beneficial to the mining industry. Though, apart from "traditional" suppliers, contractors should also be included. For the "traditional" suppliers, this principle doesn't differ from any other industrial sector and should be implemented in the same way as done there. (This is because the practices of this principle happen at higher levels of the organisation, where the mining environment isn't relevant.) It should be a priority to introduce this principle to contractors, because mining companies are increasingly dependent on contractors and contractors' working environment and accident rate is worse than those of regular employees.

Applying the principle of supplier integration means that contractor companies are challenged and assisted in their own efforts to become Lean and in providing a good working environment for their employees. Those who are successful in this should be rewarded with long-term contracts. Furthermore, when establishing supplier relationships, it is also important to look beyond monetary factors. Areas such as safety records should also carry heavy weight when choosing the most appropriate contractor.

However, there is an alternative to this: the use of contractors could be discouraged. This would be more in line with a traditional Lean Production philosophy. Here, mining companies maintain and possess necessary knowledge and a sufficient workforce. This workforce is developed and offered permanent work security.

As a part of this principle, equipment manufacturers should be involved. When procuring new equipment, on-going communication with the manufacturer is required, as is covered earlier. But this involvement should also include the previously mentioned "mistake proofing".

7.1.3. Demand-based production

The principle of aligning production with customer demand is complicated in mining. The biggest potential for the principle today is in supporting functions. Here, tools such as *kanban* can be applied to make sure supplies and material are delivered when needed, reducing inventories and creating a flow. Furthermore, the arrivals of transports to the mine site should be uniform, helping in keeping production levels balanced.

Some researchers argue that demand-based production (and Lean Mining as a whole) will be possible once continuous production techniques are available for metal mining. This means substituting the fragmentation technique of drill and blast for mechanical fragmentation. Machines capable of this would have to break the rock at the face and transport the ore to a transportation system (e.g. truck or conveyor). This type of machine should be able to install rock support as well.

7.1.4. Workforce involvement

The involvement of the workforce is a principle that isn't hindered by the mining industry's characteristics. For the most part, this principle can be adopted as it is described in the management literature. But there are some exceptions that require some further clarification.

Work under a Lean Mining philosophy is organised into teams. This can be complicated because the machines used in mining tend to be designed for one person. Furthermore, an operator is usually assigned to only one machine (at least for each shift). The practice of team-based work organisation is more common in mining with lower mechanisation levels, however, and in some tunnelling and development projects. These activities can be organised in small teams with a supporting team leader.

But teamwork in mines can also be a question of towards what level control is exercised (e.g. group or individual level). Team-based organisation in LM would mean that control is exercised at a group level rather than at an individual one. For example, a group might be assigned a face to work and requested to deliver a certain amount of ore, but which workers are assigned to which machines and for how long is left entirely up to the group. In the future, as remote control will come to be more dominant, and work being performed with several operators in one control room, teamwork might once again be possible.

Multiskilled operators are essential to Lean Mining. Mining still involves a lot of work with machines designed for one person. Therefore, even if work is not organised in teams, multiskilling is still important because Lean Mining requires a flexible workforce capable of operating several different machines (as opposed to only one or two as is often the case today). To some extent, this appears to already be the case. Operators in some mines are already multiskilled (including having knowledge about maintenance). Because of this skill set, operators can rotate to get variation in their work and reduce stress. There are times when operators don't know what task they will perform during their shift before the shift starts. This combines well with a team-based approach to work.

The competence and training of operators is also important. At the very least, this is something that is required for operators to become multiskilled. Operators have to be offered training and continuously have their competences developed. A solution also has to be reached regarding contractors and their training and competence. The goal of having multiskilled operators could be hindered by this practice. If the reliance on contractors remains, developing their skills should be an integral part of the supplier integration principle.

7.2. Psychosocial and organisational issues in mining[5]

Psychosocial and organisational issues are usually complex. This handbook won't be able to cover it all, or even a considerable part. Instead we focus on the most important and prominent issues that a present in mining.

7.2.1. Contractors

Contractors have become more a common in mining (Elgstrand and Vingård, 2013). Contractors in mining are overrepresented in accident statistics. Generally, contractors have more frequent and severe accidents, and they also perform other tasks, under other conditions, compared to regular the mining employees (Blank et al., 1995, Muzaffar et al., 2013).

Whether or not to use contractors isn't a question with an easy answer. In the discussion on a (mining) society that is sustainable over time, mining contractors may be preferred instead of in-house personnel; when mining operations cease, a number of contractors remains who hopefully have broadened their activities to other industrial sectors so that they are able to survive a mine close down. Another aspect that speaks in favour of the use of contractors is the development and ownership of competence. Contractors with a certain variety in their activities have the opportunity to gain experience in several different contexts – experience they can transfer and use productively in mining. A problem is that if knowledge isn't owned in the company, it may be more difficult to integrate in an efficient production development process.

The most important factor that speaks for in-house competence (i.e. to not use contractors) is the possibility of a systematic health

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[5] Much of this section is based on Johansson et al. (2010).

and safety work. It is difficult for the mining companies to maintain equal and good safety practices when many different contractors are engaged (Johansson and Johansson, 2008).

7.2.2. Wage systems - effects on health and safety

A well-motivated workforce is a prerequisite for high productivity. The use of different types of piece rate wages to increase and maintain a good work motivation is wide spread in many sectors of industry. The effects of such systems are however disputed. Research by Johansson et al. (2010b) tells us that piece rates in many situations have a negative effect on health and safety. Their review found that many studies have found negative effects of piece rates on different aspects of health and safety and give strong support for the hypothesis that, in most situations, piece rates have negative effects on health and safety.

Strong correlations are also reported from the mining sector. After a mine strike at LKAB in the winter of 1969/70, the wage system at the company was changed from a piece rate system to fixed monthly wages. The monthly wages varied depending on what type of work that was performed. Kronlund (1973) describes the effect on accidents, two years after the change. Severe accidents decreased with 95%, normal accidents decreased with 70% and minor accidents increased with 45%. There were several reasons for this development but the change from piece rates is considered to be the most important since risk taking among the miners was reduced and sick leave due to minor injuries did no longer reduce the earnings in a significant way. During work with piece rate pay, many miners ignored injuries from minor accidents so that they wouldn't lose any income.

7.2.3. Working hours and accidents

The use of extended workdays (regular shift lengths of 10 or 12 hours per day, while still maintaining 40 hours' work per week or less) has become more common during the last decades. It seems extended workdays is a popular solution among workers due to the increased number of days off, compared to traditional schedules.

However, management, workers, unions and experts on occupational health and safety fear that working long shifts will increase the risk of occupational accidents and health problems. Some research confirms this fear (Harrington, 2001, Dembe et al., 2005), while other research rejects it (Cliff and Horberry, 2008).

For future mining work, then, it is important to be aware of the described and obvious risks and, if possible, avoid overtime and extended working hours. Employers and trade unions have a shared responsibility to regard the risks when closing agreements about shift forms and working hours.

A VISION OF THE FUTURE[6]

The new mine was a true planning and co-operation success and a huge leap in mining history. A number of leading European mining companies had been inspired by a group of Australian researchers that had provided a conceptual system for automated and flexible mining, based on drill and blast technology for fragmentation of the ore. Continuous mining with road headers was still only used in development works where conventional drilling and blasting was abandoned. The large European manufacturers of advanced mining equipment had contributed largely to the technological success, which had opened a new global market for them.

The new automated mining method made it possible to almost continuously produce desired ore qualities and quantities on customers demand. This was a big comparative advantage compared to the old traditional bulk production mines that still existed and struggled for their survival. The new mining system dramatically reduced the prevailing and traditional use of expensive storing and stacking of mined ore. With the new way to mine an important first step towards true Lean-mining was taken and gradually one bottle neck after another was discovered and eliminated. It seemed as traditional mining had been a real waste of resources.

Advanced investment analyses had clearly shown that there were great financial benefits with the new automated mining technology. The heavy costs for underground development works were reduced with about 50% compared with traditional mining methods and high labour costs were reduced with more than that. This made it possible for the companies to make large investments in new technology and personnel competence and still be highly profitable. If profits for society and individuals also were included in the analysis the total expected financial benefits were overwhelming. Follow up of actual economical results showed even bigger savings than expected.

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[6] From Johansson and Johansson (2014).

An unusual feature of the new mine was that open pit mining was avoided although the upper parts of the ore body were close to the surface. A green mining philosophy, "in situ mining", was applied and most of the mining activities were invisible for people passing the mine site. Most of the waste material was directly used for backfill after recovering the metal content.

The mining companies had from the start of the project made use of a systematic iterative planning methodology that reduced common initial design errors when they designed the new mine. Basic guidelines provided very useful demands for the mine designers. During the development works there had for example never been any real ventilation problems, stability problems or water drainage problems. No severe accidents or incidents had occurred so far and all mining activities were systematically risk assessed. The new mine had set a new world standard for results regarding health and safety. Safety first was not only a simple a slogan, it was a complex and applied reality. In fact, no major physical work or main activities were performed unless they had been computer simulated and evaluated. This proactive way to handle production and safety risks had proven its value time after time. The old description of mining work as "Dark, dirty and dangerous" had definitively become out of date and irrelevant. Instead of being almost unpredictable and uncertain mining had become highly predictable. Some of the old miners meant that the original charm of mining was somewhat lost when all worked according to plans, but no one really wanted the old risky ways and days back.

One key to the success was the fact that the mine was already from the start designed for automation and sociotechnical principles with a work organisation based on production teams and broad professional skills among management and miners. One of the mines most impressive features was the information and decision systems based on sensor technology and production analysis in real time. This made it possible for the personnel to actively steer and control the production instead of just passively react on deviations and alarms from an automated production process. This was a major difference and advantage compared with traditional control room work, in for example regular processing plants. Impressive results regarding product quality and production availability and stability had been achieved thanks to this proactive philosophy. The philosophy also made the miners work interesting and challenging.

The new remote operations control centres (so called ROCs) were designed to promote co-operation and creative problem solving in multi skilled teams. The working teams were mixed regarding age, experience, gender, competence, etc. Diversity had replaced conformity and this had proved to be a good base for creating "production scouts", that is miners that were always ready and interested in improving the mining processes. Most of the team members were recruited from national and regional education programs that were specially developed with regards to the new demands that the mining sector had, basically that modern mining was an intellectual analytical work for wise and reliable persons. New education programs on all levels had been started and were recruiting well. Mining work had turned to be attractive, not only because the wages, but also because it was a very interesting work with good possibilities for personal and professional development in a safe and sound working environment.

The total progress had been astonishing although they only had started to utilise parts of the potential that the new technology and organisation offered. Investments in research and development work had paid off quickly and management were convinced that innovative R&D combined with a challenging vision had been and would continue to be the key factor for success.

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ANNEX A

Safety analysis tools in different life cycle stages.

Project Lifecycle Stages	Safety Analysis Technique	Purpose
Conceptual	Preliminary Hazard Analysis (PHA) - Initial	Identify hazardous situations and events within concept design. Prioritise hazards for further analysis. Identify potential significant project HSEC risks. Develop recommended actions.
	Checklist	Determine compliance to standards and legal framework. Check that everything has been covered.
Prefeasibility	PHA - Review	Review for design changes from concept design or develop new PHA.
	What If?	Identify and risk-rank how major unit operation will be affected by deviations from normal operations and behaviour. Provides a basis for a risk register.

Project Lifecycle Stages	Safety Analysis Technique	Purpose
Prefeasibility	Checklist	As above.
Feasibility	Hazard and Operability Study (HAZOP)	Assess process controls design hazard/risks at progressive percentage complete in conjunction with FMEA and FTA analysis. Define possible deviations from the expected or intended performance. Generates consequences, controls and control actions. Identify hazards introduced through human actions.
	Failure Mode and Effect Analysis (FMEA)	Identify potential failure of various parts of a system. Estimate the effect of the failure and how to avoid, and /or mitigate the effects of the failures on the system. Assist in selecting design alternatives with high dependability. Identify human error modes and effects.

Project Lifecycle Stages	Safety Analysis Technique	Purpose
Feasibility	Fault Tree Analysis (FTA)	Identify and analyse factors that can contribute to a specified undesired event. Illustrates factors and their logical relationship to the undesired event.
Execution and Construction	HAZOP	Review feasibility HAZOP.
	Construction Risk Assessment Workshop (CRAW)	CRAW per work package/area/construction type. Identify risks and controls during execution of project (including contractor).
	Job Safety and Environmental Analysis (JSEA)	Identify hazards and controls for tasks. Assess the risks of tasks. Can be used in the development of work procedures
	Stop, Look, Analyse, Manage (SLAM) or Take 5	Identify hazard and control methods for tasks. Used by individuals.
	Authority to Work (ATW) Process	Ensure all hazards and risks have been assessed and taken into account prior to starting a specific activity.

Project Lifecycle Stages	Safety Analysis Technique	Purpose
Commissioning & Ramp-Up	Checklist	As above.
	Failure Mode and Effect Analysis (FMEA)	As above.
	CRAW	As above.
	WRAC Based Risk Assessment	As above.
	JSEA	As above.
	SLAM or Take 5	As above.
Operation	HAZOP	As above.
	SLAM or Take 5	As above.
	JSA	As above.
	Checklist	As above.
	FTA	As above.
	JSEA	As above.

Based on Shooks et al. (2014).

ANNEX B

Checklists for safety and health in mine design – For use in conceptual studies, pre-studies and pre-projecting

BASIC SAFETY CHECKLIST[7] FOR CONCEPTUAL MINE DESIGN IN MINING FEASIBILITY STUDIES, EARLY MINE DESIGN AND PLANNING

General checkpoints

- Has safety and health been an integral part of the mine planning and design activities?
- Has a proper risk assessment been performed with the primary aim to eliminate hazards through good design?
- Has potential operating personnel been consulted regarding safety aspects?
- Has appropriate safety standards and other standards been used?
- Has a risk management approach been used during design?
- Has design modifications been controlled regarding changes in safety?
- Has a systematic recording procedure for designs and plans been used?
- Has appropriate stages of review, verification and validation been applied on design solutions?

Identification of core risks

- Have core risks been identified when new mining operations or methods have been considered?

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[7] This basic checklist is derived from chapter 4.1 Feasibility, design and planning in Minerals Industry Safety Handbook, NSW Department of Mineral Resources, Australia, 2002.

- Have core risks been identified at the beginning of the first feasibility study?
- Have strategies against core risks been planned and integrated in the proposed mine design?
- Have different mining methods or options been reviewed to assist in removing or controlling core risks?

Review of core risks

- Has the project been be reviewed by an independent and competent audit team, which is external to the project design team, during the feasibility or design phases.
- Has the audit process looked at the safety, financial and technical parts of the project and assessed whether the core risks have been identified and are being controlled?
- Will a review of core risks be repeated at regular stages of the project – during the planning through to the operational stages?
- Will the review consider any changes that have been made during planning and design? In other words, are all critical safety-related decisions and strategies still appropriate? (These reviews do not need to be done by external teams)
- Have the person(s) responsible for carrying out the reviews, and for any actions arising from them, been clearly defined and managed according to a suitably Mine Safety Management System?

BASIC DEMANDS FOR DESIGN AND EVALUATION OF MINE CONCEPTS

- Is the mine designed so that it meets the health and safety demands of "the working place of the future"?

- Is the design of the mine in accordance with the present company health and safety philosophy?

What are the five most important company specific demands regarding safety and health that have influenced this conceptual mine design?

1..
2..
3..
4..
5..

- Is "Safety First" the most important design criteria?

- Has the proposed conceptual mine design been evaluated regarding these demands?

- What was the result of the evaluation?

What are the five most important regulative demands (from laws, provisions and standards) regarding safety and health that have influenced this conceptual mine design?

1...
2...
3...
4...
5...

- Has the proposed conceptual mine design been evaluated regarding these demands?
- What was the result of the evaluation?
- Has the work with this conceptual mine design resulted in a comprehensive written specification of health and safety demands that are useful for further design and evaluation work in pre-studies and pre-projecting studies?

GENERAL SAFETY AND WORK ENVIRONMENT

Stability of openings

- Are major faults, crush zones or cracks identified and regarded in the layout design?
- Is the overall structural stability of the mine design good?
- Are the workplaces designed to withstand the anticipated environmental forces?
- Does a rock geological risk assessment show that such risks are acceptable?
- Does a rock mechanical risk assessment show that such risks are acceptable?
- Is the risk for massive air blasts from collapsing structures regarded?
- Are galleries and tunnels oriented and dimensioned with regard to rock stresses and structures?
- Are mine openings designed and dimensioned with regard to expected rock tensions?
- Are cross sections distanced enough (generally more than 3 x size of opening)?
- Are cross sections close to quadratic in shape?
- Are high wall openings avoided?
- Is the cross section shape uniform along the opening?
- Are breakaways placed to avoid large roof spans?

- Are sharp corners avoided?
- Are shafts distanced enough from each other (generally more than 3 x size of opening)?
- Is the need for rock support and reinforcement estimated or calculated?
- Is the layout stability numerically modelled and evaluated with acceptable results?

Fires

General

- Is a systematic and professional fire risk assessment done by an expert?
- Are all underground workplaces designed with the least possible fire load?
- Does the design of the mine apply to at least good practice to avoid fires?
- Is the mine designed to avoid, detect and combat the starting and spreading of fires?
- Is the mine designed to promote and ease fire extension?
- Is the mine layout, the ventilation system, doors, sealings etc. so designed that they together efficiently prevent and control the spreading of harmful smoke and gases from fires?

Water posts and spray system

- Are water posts for fire fighting properly placed and available for fire fighting vehicles?
- Are vehicle parking spaces, gas centres and cable tunnels designed so that they can be equipped with water spray systems?

Escape routes

- Are the escape routes located and dimensioned according to the number of workplaces and people working there?

- Are escape routes, including separate evacuation shafts, designed as fire areas?

Ventilation

- Are the location and the design of particularly sensitive installations such as workshops, fuel tanks, parking lots, storage facilities, magazines, etc. considered in relation to inlet of fresh air and discharge air currents?

- Are escape routes protected with fire gates and/or separate supplies of fresh air?

- Is the ventilation designed so that the major air flow and the force of this air can be directed to already evacuated parts of the mine?

- Are there horizontal drifts/tunnels dedicated for rapid evacuation of fire smoke and gasses?

- Can the air flow be controlled manually or automatically, both locally and by remote-control?

- Is the mine divided into partitions (fire areas) with fire gates?

- Is a ventilation partition made for at least every 200 m of sinking?

- Are fan stations, fire gates etc. provided with electric current and control wires from at least two separate directions so that they are redundant?

- Are ventilation pipes close to flammable stores, transformers, parking lots etc. made of non-flammable material?

- Are ventilation pipes in shafts made of non-flammable material?

Belt conveyors

- Are planned conveyor belts made of non-flammable material?
- Are planned conveyor belts made self-extinguishing?
- Is there a ventilation shaft designed for evacuation of smoke and fire gases in case of a fire in the belt conveyor system?
- Are planned conveyor belts compartmentalised with a length less than 100 m?
- Does every fire compartment lead to an escape route?
- Is every conveyor provided with smoke ventilation?

Electric installations

- Is the location of electrical installations and equipment made with greatest concern regarding fire safety?
- Is there a free distance of at least 1.5 m around all electric machinery (distribution boxes, engines, transformers, etc.) in order to ease maintenance and fire fighting?
- Are electric cables installed in separate shafts for cables?
- Will electric cables be installed in non-conductive environments?
- Will electric cables be installed far from flammable material and fuel hoses?

Fuel tanks

- Are tanks and oil reservoirs located to be protected against moisture and waste water, mechanical effects, shock waves due to blasting, rocks falling from the roof or the walls, traffic as well as collisions?

- Are tanks and oil reservoirs located at least 50 m away from workshops, magazines, parking lots, crushers, winders, changing rooms and the like, unless there is solid rock between?

- Is the distance between two tanks at least 100 m, unless there is solid rock between the tanks?

- Are diesel and gas pumps arranged and placed so that a fire or an explosion doesn't hinder an evacuation of personnel?

- Are diesel fuel stations designed with collecting basins so that a leakage doesn't spread?

Remote controlled and automatic machinery

- Are comprehensive fire risk assessments made for remote-controlled and automatic machinery and equipment?

Workshops and magazines

- Are workshops and magazines located at separate places?

Crushers

- Are crushers designed with regard to fire escape facilities, compartments, casings etc.?

Parking

- Is the parking lot designed with regard to the opinions from the supervisory authority and fire experts?

- Are parking lots excluded in escape routes and drifts for fresh air?

- Are lift shafts for passenger transport partitioned off from parking lots by fire- and smoke-separating walls?

- Is the distance between parking lots and workshops, canteen, transformer cabinets, fuel stations, magazines and areas where combustible goods are stored at least 50 m?

- Will all vehicles be parked in garages?
- Will vehicles for charging of explosives be parked in separated and remote placed garages?
- Are parking lots for small vehicles parked front-rear designed with a minimum distance of at least 2 m between the vehicles?
- Are parking lots for small vehicles parked side by side designed with a minimum distance of at least 1.5 m between the vehicles?
- Are separate parking lots for large vehicles designed with enough space for each vehicle?

Uncontrolled explosions

- Are all necessary design measures taken to prevent the occurrence and accumulation of explosive atmospheres?
- Are special storages designed for flammable and explosive products in order to minimise the risk of fire or explosion?
- Are all necessary design measures taken to prevent the ignition of explosive atmospheres?
- Are chambers for explosives placed and designed according to all valid safety regulations?
- Is there a risk for sulphide dust explosions?
- Are the mining method and its procedures adapted to this risk for sulphide dust explosions?
- Are specially designed rescue chambers designed to withstand sulphide dust explosions?

Escape and rescue

- Is every underground working site designed with at least two separate emergency exits?

- If at least two separate emergency exits cannot be designed, are other necessary measures designed for safe rescue and evacuation?

- Is the mine designed with escape man ways according to safety regulations?

- Is the mine equipped with efficient fireproof rescue chambers?

- Are mobile or stationary rescue chambers designed where necessary?

Air quality, thermal climate and ventilation

- Are major gas, dust and heat sources and other types of air pollutants identified and quantified?

- Are the engineering principles of mine air quality control regarding gases and dust applied in the proper order, as below?

    1. Prevention or avoidance
    2. Removal or elimination
    3. Suppression or absorption
    4. Containment or isolation
    5. Dilution or reduction
    6. Personal protective equipment

- Is the ventilation designed and dimensioned so that the air quality is good where people will work, reside and breathe?

- Will concentrations for the following pollutants be well below less than 10% of the hygienic threshold limits (HLT allowed for continuous work for 8 hours)?

Diesel engine exhausts
Blasting fumes
Quartzite dust and dust
Asbestos
Radon and radon daughter

- Will air quality demands be fulfilled regarding:

  Temperature, between 14-20 degrees C which is the comfort zone for physical work,
  Free air velocity, well below 2 m/s. For comfort it must be less than 0.2 m/s,
  Noise, causing only marginal increase of existing general sound level?

- Is the ventilation system fire proof and supports fire fighting?

- Is at least good practice in mine ventilation applied?

- Is the needed inlet ventilation air flow (m3/s) calculated for the whole mine?

- Is the total inlet air flow more than 0.08 m3/s per installed diesel engine based kW?

- Is the ventilation need calculated for the different individual work places?

- Are fixed underground work places ventilated so that comfortable conditions are achieved?

- Is exhaust ventilation used for welding, battery charging, repair and maintenance shops, toilets, showers and dining rooms?

- Is the ventilation system designed so that it easily can be adapted to different conditions and needs?

- Is the ventilation system designed to cope with large temperature differences between summer and winter?

- Is the design of the ventilation system well documented?
- Will the risks for ventilation breakdown be minimised?
- Is the ventilation system designed for safe and easy maintenance?
- Do main ventilation fans drive a push-pull system for intake air and return air?
- Are main inlet and exhaust shafts located in stable rock in the foot wall?
- Are air ways capacities dimensioned well above planned maximum air flows?
- Do main air flows run in blast proof shafts, ramps or tunnels?
- Are tunnels, drifts and ramps large enough to take necessary ventilation tubes?
- Is the use of air blast shock wave sensitive channels or ducts minimised?
- Is ascending (thermal induced bottom up flow) ventilation used?
- Is through flow ventilation used and series flow ventilation avoided?
- Do the air flows run from less polluted areas to more polluted areas?
- Has every level or sublevel its own flow through of air between shafts, ramps or raises?
- Is the mine ventilation system redundant?

- Does the mine layout confine/stop spreading of gases and dust from blasting?
- Are blasting gases from fragmented ore released during loading efficiently ventilated?
- Does every major work place have a separate balanced inlet and outlet airflow?
- Is work with the construction of inclining ramps ventilated with local exhaust ventilation?
- Is work with the construction of declining ramps ventilated with diluting local ventilation?
- Are major pollutants, e.g. crusher stations, ore shaft dumps, belt conveyors etc., equipped with air exhausts preventing spreading of pollutants to surroundings?

CHOICE OF MINING METHOD

- Is the knowledge about the ore-body and surrounding waste rock sufficient to make a first preliminary choice of mining method?
- Has the mining method been chosen with respect to the workers' safety and health as a top priority?
- Can expected risks be significantly reduced with another choice of mining method?
- Does the mining method permit good conditions for further mechanisation, automation and remote control?
- Can the chosen mining method be redesigned to significantly improve safety?
- Are different mining sequences evaluated regarding safety and ventilation?
- Have best practices been bench marked before the mining method was chosen?
- Does the mine design minimise the risks for disturbances in production?
- Is the choice of mining method validated regarding health and safety risks?
- What needs to be improved regarding safety in the next planning/design stage?
- Have relevant safety risk assessment been done (Risk = probability * consequence)?
- Are performed risk assessments documented in writing?

- Are risk data, for example LDIFR (Lost Day Injury Frequency) for different mining methods regarded when the mining method is chosen?

- What is the expected accident frequency (LDIFR, Lost Day Injury Frequency)?

  …………accidents/million working hours

- What is the expected fatality frequency?

  …………fatalities/million working hours

- What is the expected productivity?

  ……………… ton ore/working hour

- What is the expected occupational disease frequency?

  …………cases /million working hours

- What is the calculated risk expressed as number of fatalities per million mined ton ore?

  (fatality frequency/productivity) = …… / …… = ……

- Are expected fatality, accident and disease frequencies acceptable?

Cut and fill mining - specific demands

- Is the type of cut and fill mining chosen with highest regard to safety? In what way/how?

- Are open stopes dimensioned and distributed for maximum safety during primary ore extraction?

- Are sill pillars dimensioned and distributed for maximum safety during primary ore extraction?

- Is the mine layout and mining sequence adapted to safe sill pillar recovery?
- Will systematic rock bolting and shotcreting be applied in areas where workers will be present?
- Is mechanised safe mining of narrow veins possible (down to 2 m width)?
- Are handheld drilling (Jack-leg) and other manual operations avoided?
- Is highly mechanised or automated backfilling applied?
- Will at least good practice back fill technique be applied?
- Is the mine designed for the most appropriate and safe types of fill?
- Will the ore stopes be ventilated with blowing diluting local ventilation?
- Are there enough mining faces to handle disturbances and delays without losing production?
- Is there space enough for storing waste rock before backfilling of mined out stopes?
- Are the excavation and filling operations balanced to minimise variations in production rate?
- Will backfilling be performed directly after ore excavation is finished?
- Is backfill capacity high? Is rapid backfilling possible?

- Is the drainage system designed and dimensioned for rapid dewatering of hydraulic backfill?

Room and pillar mining – specific demands

- Is the type of room and pillar mining chosen with highest regard to safety? In what way/how?
- Is the general mining sequence safe (advance, retreat, recovery)?
- Is preliminary planned final extraction ratio less than 60 %?
- Is the mine layout and mining sequence adapted to safe pillar recovery?
- Are barrier pillars designed to avoid cascading pillar failure (domino effect failure)?
- Is the room width/roof span width based on safety reasons?
- Is safety regarded when deciding the height of mined out slices/benches?
- Will drifting/tunnelling be performed as much as possible as up-pitch > 1:50-100?
- Will systematic rock bolting be applied?
- Will systematic shotcreting be applied?
- Will systematic netting be applied?
- Will primary and secondary roof support and control be easy and safe to perform?
- Will pillar support and control be easy and safe to perform?
- Will mechanised and remote controlled primary and

maintenance scaling be easy and safe to perform?

- Are all haulage roads well ventilated?
- Is dilution ventilation applied at the mining front faces?
- Are there enough mining faces to handle disturbances and delays without losing production?
- Is stabilising backfill used?
- Are ventilation air flow stoppings and ventilation doors avoided?
- Is vertical stratification of polluted air considered?
- Is the ventilation system designed to withstand massive air blasts from structural collapses?
- Is a peripheral test site/area for room and pillar dimension optimisation planned?

Sublevel caving mining – specific demands

- Is the type of sublevel caving mining chosen with highest regard to safety? In what way/how?
- Does the mining geometry and fractioning technology produce a controlled, steady and safe flow of ore through the draw points?
- Does the mining geometry promote a synchronised advancement downwards of the mining front?
- Is the effect of seismicity well regarded in the mine design?
- Is systematic rock bolting and shotcreting applied in areas were personnel will be present?

- Does the mine design proactively reduce the risks for hang ups?
- Is the development layout designed for remote control or automation of production activities?
- Is the development layout adapted for electric powered production equipment?
- Can the automated production areas be closed so that no person can enter during production?
- Can production openings rest for at least one week before production is recommenced?
- Are there enough mining faces to handle disturbances and delays without production losses?
- Are opening slot drifts or slot raises designed for safe drilling, blasting and loading?
- Does the mine design reduce the risks with hang ups that still occur?
- Is the mine designed for safe and effective secondary fragmentation?
- Is the layout adapted for clearance of large amounts of waste and water from drilled fan holes?
- Are the crosscuts designed so that proper ventilation of longer (>30 m) crosscuts is possible?

DEVELOPMENT WORK AND SUPPORTING FUNCTIONS

- Are development work designed to physically fit the assumed type and fleet of equipment?

- Are minimum tunnel widths for mechanised equipment applied (equipment width + 0.6 m)?

- Are development works large enough to be reinforced with concrete steel armoured vaults?

Ramps, tunnels and horizontal developments

- Are ramps, tunnels and horizontal developments designed so that they allow and promote future automation and remote control of operations?

- Is the mine layout designed and are the transport routes designed so that they promote existing traffic rules and traffic safety?

- Is it possible to reach planned workplaces without danger and leave them quickly and safely in case of an emergency?

- Are ramps, tunnels and horizontal developments designed so that the risk for collisions is minimised?

- Are planned traffic and access routes clearly identified for the protection of workers?

- Are drifts, ramps and tunnels designed so that roadways of adequate standard can be maintained?

- Is road clearance of spill rock and ore possible with the use of wheel loaders?

- Are tunnels inclined or declined to direct water flow?

- Is the minimum curve radius more than 80 m in main tunnels where truck transports with full load are performed?
- Is the minimum curve radius more than 60 m in main tunnels where truck transports with no load are performed?
- Is the haulage tunnel for trucks clearly declined where trucks accelerate?
- Is the haulage tunnel for trucks clearly inclined where trucks decelerate?
- Is the mine layout designed so that areas with remote controlled vehicles and equipment easily can be closed for unauthorised personnel?
- Is a sufficient safety clearance provided for pedestrians if planned means of transport are used on traffic routes?
- Is sufficient clearance allowed between planned vehicle traffic routes and doors, gates, passages for pedestrians, corridors and staircases?
- Do areas which are regularly used by pedestrians contain an exclusive area for these?
- Is this pedestrian area at least 1 m wide and 2.1 m high? If this cannot be arranged, are special measures taken for the protection of those walking?
- Are effective safety precautions designed where there is a risk of vehicles or machines plunging off or overturning on the roadway?
- Is a barrier designed at the tipping area which prevents vehicles from driving off the tip?
- Will the following places properly indicated and illuminated:

- Permanent work places
- Places where vehicles might collide
- Shaft openings which workers might fall into
- Places where workers might fall to a lower level
- Places where there are other types of severe accidental risks
- Are main ramps designed so that they allow a significant change of mining method?
- Do the ramps hold a specified safety standoff distance to the ore body?
- Do the ramps hold a specified safety standoff distance to fault zones and other critical no-go regions?
- Do the ramps hold the allowed maximum gradient? (Normally 1:9 – 1:6.5. Trackless max 8 degrees, conveyor belt and trackless max 15 degrees, conveyor belt 15– 25 degrees. Clean up equipment for spill rock limits the angle for declines.)
- Will drifting/tunnelling be performed as much as possible as up-pitch > 1:50 – 100?
- Are work places for machine equipment designed so that the risk of sliding while working or transportation of the machine unit is minimised?
- Are there enough dewatering facilities in the ramps, tunnels and drifts?
- Are tunnels graded towards main water passes, water collection arrangements?
- Do the ramps hold the minimum allowed turning radius for

curved ramps? Typically between 15 – 40 m.

- Are changes in curves turning direction minimised?
- Are ramps designed as straight as possible to provide better safety and transport speed?
- Is there a straight tunnel length of at least 10 m before turning direction is changed?
- Are crosscuts oriented at 90 degrees towards the ramp?
- Is the excavation of declining ramps minimised and inclining ramps maximised?
- Is traffic in two directions in the same ramp minimised?
- Are there enough passing bays for the largest vehicles?
- Are parking/meeting places located at the down direction side?
- Are there enough ventilation shafts along the ramps?
- Has the ramp design been checked for structural failure and rock fall and rock bursts?
- Are ramps for belt conveyors designed for maximum fire safety?
- Are ramps for belt conveyors large enough to permit mechanised cleaning, repair and maintenance?
- Has the ramp design been checked for fire hazards and fire protection?
- Are there enough rescue chambers along the ramp?

Construction of ramps

- Can ramps be excavated with continuous full face technology?
- Can ramps be excavated with mechanised drill-blast-load-haul technology?
- Can remote control of ramp construction operations be applied?

Hoist/skip shafts

- Are hoist/skip shafts designed so that the shaft bottom can be cleaned from mud and spill rock with mechanised equipment?

Personnel transport and evacuation shafts

- Does the design of personnel transport and evacuation shafts apply to demands in provisions from authorities and to company specific demands?

Ventilation shafts

- Are central inlet and outlet air shafts designed so that sufficient airflow is brought to every workplace?
- Are ventilation shafts located and dimensioned for safe removal of blasting fumes?
- Are ventilation shafts located and dimensioned so that diesel exhausts can be properly removed?
- Are ventilation shafts located and dimensioned so that mineral dust can be properly removed?
- Are ventilation shafts located and dimensioned so that waste heat can be properly removed?
- Is the number of shafts enough to cope with a final loss of 25%

of the shafts due to structural instability?

- Are ventilation blind shafts bored or constructed in advance of ramps and drifts?
- Are shafts designed to ease maintenance work with the shafts?

Construction of shafts

- Will shaft sinking be performed with full face technology?
- Will sink shafts be excavated with mechanised drill-blast-load technology?
- Will raise shaft roaming be performed with full face technology?
- Will mechanised raise shaft climbing technology be used? E.g. Alimak raise climber.
- Will mechanised shaft concrete lining technology be used?
- Will mechanised shaft rock bolting technology be used?
- Will shaft construction areas be sealed off to prevent spreading of dust from cuttings?
- Can cuttings from full face boring be removed and deposited in a safe way regarding dust exposure?

Ore and waste shafts, drawing points and chutes

- Are shafts, drawing points and chutes designed to prevent hang ups and water locks?
- Are ore shafts dimensioned so that the production will not be halted?
- Are all ore and waste rock passes equipped with grizzlies that

sort out boulders?

- Are all ore and waste rock passes equipped with equipment that sort out rock bolts and other types of steel waste?
- Are loading chutes and pockets designed so that they can be reinforced in a safe way?
- Does the design of shafts, drawing points and chutes minimise the risk for hang ups due to boulder arches?
- Does the design of shafts, drawing points and chutes minimise the risk for hang ups due to cohesive arches of fine particles?
- Does the design of shafts, drawing points and chutes minimise the risk for uncontrolled muck flows due to insufficient drainage?
- Are the chutes remote operated from a safe place?
- Are passes and chutes designed to ease normal methods for hang-up removal?
- Are ore and waste rock passes connected with other passes or openings to avoid dust spreading due to pressure build up (a pump effect)?

Train tunnels and railways

- Is the transportation system based on highest security for personnel working with or close to the trains?
- Is the minimum curve radius more than 150 m in main tunnels where rail bound transports are performed?
- Is the haulage railway declined 0.3 percent or somewhat more where trains accelerate?

- Is the haulage railway inclined 0.3 percent or somewhat more where trains decelerate?

Ore storage pockets

- Are the ore storage pockets designed to avoid material hang ups?
- Are the ore storages big enough to avoid unnecessary stops in production?
- Are the ore storages small enough to show bottlenecks and balance problems in production?

Crusher stations

- Are crusher stations designed to minimise problems with boulders?
- Are rock crusher stations designed so that the occurrence and spreading of dust will be prevented?
- Do crusher stations have separate ventilation?
- Are crusher stations rooms big enough to ease repair and maintenance work?

Underground repair and maintenance shop

- Is the shop strategically and long term located, is access easy?
- Are there enough parking spaces close to the shop?
- Is the shop close to main underground supply rooms?
- Is there more than enough space for the planned work activities?
- Can the shop easily be expanded?

- Is the shop dimensioned for future sizes of mining equipment?
- Is there height and space for one or more high capacity overhead crane?
- Are acute repair and preventive maintenance areas separated?
- Is the mine equipped with the necessary number of automatic washing equipment for vehicles?
- Is there a space for high pressure washing and steam cleaning?
- Is it easy to ventilate the shop?
- Is there a separate welding area?
- Is there a separate area for tire and chains works?
- Is there a confined area/room for battery charging?
- Are there work benches and places for other necessary repair equipment?
- Is fire safety regarded and good?
- Is there an office for administrative work?

Drainage, sump area and pump station

- Are the ore bodies well drained?
- Are all major haulage and transport routes well drained?
- Is a general drainage system designed where water can run in designated central drains, tunnels, boreholes, pipes, ditches and storage areas?
- Is water drainage based mostly on gravity flow?

- Is there a special tunnel system for handling rock and spill ore, ground water inflow, communication and service of central crushers and chutes?
- Is waste and spill water collected and treated at an underlying level so that foul smell is avoided where personnel work?
- Is the sump area, pump station and water treatment located and designed for a high redundancy?
- Is the sump area and pump station dimensioned for the maximum expected water and mud inflow?
- Are there water basins large enough for sedimentation before water is pumped to the surface?
- Is the sump area and pump station designed to ease removal of mud and cleaning?
- Can mud be dewatered before removal?
- Can mud be removed with a conventional front end loader?
- Can water be mechanically filtered and cleaned?
- Can water be reused/recirculated for suitable industrial purposes?

Transports of personnel

- Is the mine designed so that all major personnel transports can be made by safe elevators, cars or buses?
- Is the mine designed to handle big transport disturbances or break downs? Are there alternative escapes and entrance routes?
- Is time for personnel transports to and from work places minimised for safety reasons?

Vehicle parking

- Is there enough with safe parking lots for all vehicles, also contractors vehicles?
- Is there a separate and safe space for parking the vehicles used for charging of explosives?

Power (electricity and compressed air) supply and distribution

- Is the mine designed with appropriate spaces for safe power supply equipment and distribution?
- Is the media system redundant enough?

Storages, material supply and disposal

- Is the mine designed with appropriate material storages?
- Is the mine designed for an effective disposal of waste material?
- Are waste and trash handling and recycling of material arranged in an effective way?
- Can the storage store material safely – without damage to personnel, equipment or materials?

Sewage system

- Is the mine designed with an effective and hygienic sewage system?
- Is access to toilets and running fresh water easy and close to every workstation?

Construction work

- Is the mine designed with appropriate spaces for safe construction work?

Other services

- Are there management offices close to production?
- Are there lunch services close to production?
- Are dressing and resting rooms close to production?
- Are appropriate first aid rooms with relevant equipment planned close to production?
- Are enough work spaces and offices reserved for contractors working in the mine?

Escape and rescue

- Is the mine designed for prompt and safe escape and rescue?
- Are emergency routes and exits designed so that they can remain clear and lead by the most direct means to the open air or to a safe area, a safe assembly point or a safe evacuation point?
- Are the design, numbers, distribution and dimensions of the emergency routes and exits depending on the use, equipment and dimensions of the workplaces and the maximum number of persons that may be present?
- Do accommodation and rest rooms have at least two separate escape routes situated as far apart as possible and leading to a safe area, a safe assembly point or a safe evacuation point?
- Are all emergency doors designed so that they are easily and immediately opened by any person who may require them in an

emergency?

- Do emergency doors open outwards or slide open?

- Are emergency routes and exits requiring illumination designed with emergency lighting of adequate intensity in case the lighting fails?

Maintenance of mine infrastructure

- Is the mine infrastructure (see examples below) designed so that it can be maintained and repaired in a safe way?

  Telephone and computer communication systems
  Ventilation systems
  Underground roadways (permanent, service, temporary)
  Crushing and hoisting systems
  Electrical power and compressed air distribution systems
  Mine dewatering systems
  Maintenance and repair workshop facilities
  Fresh and waste water systems and sewage systems

MAJOR UNIT OPERATIONS

General demands on equipment

- Is selection and design of mechanical and electrical equipment done with due regard for the safety and health of workers?
- Is well known and practically verified technology used to create a robust and safe production system?
- Is planned mechanical and electrical equipment suitable regarding risks of fire or explosion from ignition of gas, vapour or volatile liquid?
- Is mechanisation maximised?
- Is remote control maximised?
- Is automation maximised?
- Are all stationary processes (hoisting, conveying, ventilation etc.) designed for automation and remote control?
- Has the use of diesel engines been minimised?
- Are machines electric powered?
- Are basic safety and ergonomics requirements for all major unit operations fulfilled?
- Does a risk assessment of the planned mining equipment show that associated risks are acceptable?
- Is planned equipment fitted with suitable protective devices and fail-safe systems?
- Is planned electrical equipment and plant of sufficient size and

power for the purpose for which it is intended?

- Does equipment prevent accidents and illness due to?

  Falling rock
  Insufficient lighting
  Poor ergonomics
  Air pollutants
  Lack of oxygen
  Noise
  Vibrations
  Radiation

- Will personnel in tending vehicles or machines be protected from falling rock by safety cabins?

Surveying and geological mapping

- Will surveying and geological mapping be performed from vehicles with safety cabins?
- Will surveying be automated or remote controlled?

Continuous mechanical excavation

- Will automated/remote controlled continuous mechanical excavation (e.g. road headers) be used?
- Will operator's exposure for dust, noise and vibrations be well below, that is 10% or less, existing hygienic threshold limits?

Drilling

- Will automated/remote controlled drilling be used?
- Are drilling operations designed so that the occurrence and spreading of dust in connection with rock drilling is prevented?

- Is drilling with water flushing planned?
- Is planned dry drilling combined with high flow vacuum exhaust and filter technology?
- Are measures designed against secondary dusting from drill cuttings?

Charging and blasting

- Is the choice of explosives and detonator system based on highest safety demands?
- Will automated/remote controlled charging be used?
- Will blasting be remote controlled?
- Will blasting result in a well-controlled fragmentation with a minimum of boulders?

Loading and transport

- Will mixed (autonomous and human operated) loading and transport fleets be avoided?
- Will loading be automated/remote controlled?
- Will Load Haul Dump operations be automated/remote controlled?
- Will truck/lorry transports be automated/remote controlled?
- Will automated/remote controlled belt conveyors be used?
- Will train transports be automated/remote controlled?
- Will slurry transports be automated/remote controlled?

Secondary fragmentation

- Will secondary fragmentation be mechanised?
- Will secondary fragmentation be remote controlled?

Scaling

- Will scaling be mechanised and remote controlled?

Rock enforcement

- Will rock bolting be mechanised and remote controlled?
- Will shotcrete lining be mechanised and remote controlled?
- Will netting be mechanised and remote controlled?

WORK ORGANISATION, COMMUNICATION AND PLANNING

- Can normal mining activities be planned and time scheduled so that they can be performed in a careful and safe way?
- Can the mining activities be planned so that risks of severe disturbances are minimised?
- Is a Remote Operation Control Centre (ROC) at ground surface used to reduce risk exposure time underground?
- Is work organisation adapted for remote control and automation of mining operations?
- Is the work organisation, work content and work environment attractive for both males and females, and young potential workers?
- Is the work organisation matched with the physical layout of the mine (and vice versa)? How concentrated or dispersed will the workplaces be?
- Does the chosen technology match with the planned work organisation (and vice versa)?
- Does new technology cause new risks that are difficult to assess?
- Is the mine production system matched with the available workforce?
- Is the mental and physical work load for the personnel reasonable? Are planned working schedules designed so that workers fatigue and rest is acceptable?
- Is the number of employees and machines/equipment calculated/based on typical and reasonable productivity

measures?

- Is the mine design adapted to the planned use of and cooperation with contractors (outside firms)? How many percent of the workforce will be contractors during normal production?

- Is the mine layout and transportation system designed so that direct physical contact and direct communication between the personnel is facilitated?

- Is the mine layout designed so that wireless communication is facilitated?

- Is the mine designed to promote safe radio, telephone, and video and computer communication?

- Is the mine design suitable for broad band communication?

- Is the mine designed to promote an effective on-line personnel positioning system?

- Is the mine designed with the necessary warning systems and other communication systems to enable assistance, escape and rescue operations to be launched immediately if the need arises?

- Are facilities for starting an evacuation alarm planned at suitable locations?

- Is the mine designed with evacuation alarms which provide warning in the event of a:

  Fire
  Roof collapse
  Other seismic events
  Outburst of harmful gases

- Is it possible to train and practically educate personnel on safe sites in the mine?

WORK AND WORKPLACE DESIGN

Risk assessment

- Have the risks for accidents and occupational diseases at the different workplaces and areas been determined, assessed and properly dealt with prior to or during design work?

Workplace design

- Are the workplaces designed so that they will be easy to keep safe, clean and tidy?
- Are workplaces designed in such a way that workers can perform their work without endangering their safety and/or health and/or those of other workers?
- Do planned workrooms have sufficient floor area, height and air space to allow workers to perform their work without risk to their safety, health or well-being?
- Do work methods prevent accidents and illness due to?

  Falling rock
  Vehicles and other heavy machines
  Insufficient lighting
  Poor ergonomics
  Air pollutants
  Noise
  Vibrations
  Radiation
  High temperatures

Danger areas

- Has human work in high risk zones been eliminated?

- Is the personnel's exposure time for underground work conditions minimised?
- Are the different zones/areas where personnel will work risk classified?
- Are areas with special hazards delineated?
- Are planned danger areas clearly indicated?
- Are planned danger areas designed with measures preventing unauthorised personnel from entering?
- Are appropriate design measures taken to protect workers that are authorised to enter danger areas?

Ore-handling system

- Is the ore-handling system as a whole a safe system?
- Is remote controlled and automated loading applied at loading points?
- Are load and haulage vehicles separated from pedestrians?
- Are light vehicles separated from heavy load and haulage vehicles?
- Are ore passes designed to avoid mud rushes and air blasts?
- Is work around open holes/shafts minimised?
- Is material moved safely – without damage to people, materials or equipment?
- Is material moved easily – without rehandling or extra motions?
- Is material moved conveniently – without undue physical effort?

- Is material moved smoothly and quickly – without confusion or delays, unnecessary handling?

Doors and gates

- Are doors along escape routes appropriately distributed
- Is it possible to open planned doors from the inside at any time without special assistance?
- Is it possible to open the planned doors when the workplaces are occupied?
- Do planned mechanical doors and gates function without risk of accident to workers?

Safe working methods

- Are safe working methods designed and standardised at each workplace or in respect of each activity?
- Is the mine designed so that maintenance and other supportive work can be performed safely?

Ergonomics

- Are the workstations designed according to ergonomic principles? Most important is variation in physical workload.
- Do the dimensions of the workstations allow workers sufficient freedom of movement and enable them to perform their work safely?
- Are the workstations designed for easy adjustments for divergent ergonomics (for example short stature men/women) and personal preferences?

Slips and trips

- Are the floors of workplaces designed so that they can be kept free of dangerous bumps, holes or slippery slopes?
- Can floors be kept clean and tidy with mechanised equipment so that slips and trips are avoided?

Lighting

- Is every workplace designed with lighting capable of supplying illumination to ensure the health and safety of the personnel?
- Are lighting installations in rooms containing workplaces and in passageways designed in such a way that the type of lighting does not present a risk of accident to workers?
- Does the light direction ease work and minimise glare?
- Does the light distribution focus on important work objects?
- Does the light resemble daylight regarding colour rendering?
- Is the intensity of illumination suitable?
- Are workplaces in which workers are especially exposed to risks in the event of failure or artificial lighting designed with emergency lighting of adequate intensity?
- Are lighting installations designed to ensure that operational control areas, escape routes, embarkation areas and hazardous areas remain illuminated?