ABSTRACT

Mobile mining equipment presents only a small portion (ten per cent mining project costs but the selected technology will determine to a large extent the mining performance and mine profitability. The actual performance of the selected mobile equipment technology will rely on the support functions, infrastructure, user interface and user acceptance. Optimising the technology to match the circumstances is an increasingly important phase in a mine feasibility study. Smartly done feasibility studies include the possible future needs of changing or building-up of the selected technology.

In massive mining applications the machinery faces quite different challenges than in selective or small-scale mining applications. In massive mining applications the efficient and continuous move of large amounts of material has led to the use of increasing degree of automation. This higher degree of automation in a mining application, on the other hand, will be best applied to a smooth and streamlined mining process and operation. Mining methods like block caving support automated operation.

Automated mobile equipment needs supportive infrastructure, monitoring and information transfer systems as well as well established working procedures. Too often the user interface and human factor is disregarded during the consideration of automation.

Through the available supplier programming tools it is possible to see how much the selected technology provides flexibility in changing production or economical situations, when major rebuilds or replacements are necessary, and view the effects of all these on the mine economy. When adequate technology is available from various sources, the difference becomes from preparing for the future, managing costs and combining the best layout with the most suitable technological solutions.

INTRODUCTION

Different operation targets and mine layouts support different technology solutions. Massive mine layouts like block and sublevel caving set different demands for applied mobile mining technology than narrow mining operations. Existing mines are bound by their infrastructure during expansions and renovations, whereas the new projects can review the available technology much more openly. In a change the resistance to change increases exponentially with time, one more reason to overview carefully the technological alternatives at an early stage. Smartly done feasibility studies include the possible future needs of changing or building-up of the selected technology.

OPTIMISING TECHNOLOGY

In a typical mine several levels of technologies are applied at the same time. The importance of thorough technology analyse in a mine project at an early stage is better acknowledged today. The mobile machinery may only be a fraction of the total mine investment, but it will largely determine the effectiveness and economy of the operation. The higher the technology applied the more important it is also to plan for its support and long-term economy in advance. Mine layouts are determined by geology, rock mechanics, and market situation and production requirements. The mine layout, technology applied and production form the optimisation playground.

The following factors in the mine impact the selection of the underground mobile technology:

- physical (drift size, curves, inclinations);
- environmental (humidity, temperature, water quality, rock mechanics, geology);
- ergonomic (machine layout, noise, vibration);
- safety (fire protection, covers, breaks, system shutdowns);
- legal (international, regional or mine based legal notes in any subject);
- processes (main processes and sub-processes);
- operation targets (schedules, unit and fleet capacities, operation cost, investment);
- people (level of skills, compensation, training, hierarchy, decision making);
- way of working (monitoring, support systems and logistics, measuring, reporting);
- communication; and
- infrastructure.

These can be combined in a few main categories such as:

- meeting process requirements, meeting operational requirements and meeting unit and fleet functional requirements (Figure 1).

The approach is the same for all technology levels from manual to automated.

![Optimising technology to meet process requirements.](image)

Identifying processes

Process thinking has today reached also the underground development and production of a mine. There is a desire to integrate the underground production tighter with mineral processing. When this becomes a full chain, an underground rock factory has been created.

The identification of all underground mine processes (eg development), subprocesses (eg development loading) and support processes (eg ventilation or service material flow) is the basis for applying optimised technology and support functions for them. This provides information to critical path thinking and simulation models.

The identification of various mine processes will promote cross-functional thinking and lead to optimised technology solution and minimised technology risk. Most often there is a
direct performance improvement to be gained directly through existing process improvement. The traditional approach optimises the unit performance and physical size in relation to the given mine layout. The unit performance gives limited information for the fleet performance without understanding of how the total process works.

Meeting fleet requirements

The mobile equipment fleet and suitable technology, for example in a development stage, needs to match the production needs. Even if the rock support capacity or loading capacity is sufficient for one or two face attack, it may become the critical link in multiple face development like block cave development typically is. One individual unit utilisation may rise to critically high value (close 100 per cent) in a multiple face excavation case even if the fleet utilisation stays as a considerably lower figure (70 per cent). This can be an indication of missing resources, but also, bad machine-match, wrong development cycling or fleet distribution. The way of working, accesses between levels, daily shift and service arrangements for example affect the fleet utilisation.

All resources should be well utilised in an optimised process with built-in flexibility for unexpected disturbances. Looking at the full process makes it possible to see the size and seriousness of changing parameters in relation to development time. Noticing this only at the actual development stage leads typically to throwing in more resources without the necessary cause and effect thinking; what are the consequences in other parts of the fleet performance and support functions. Delays in development stage can seriously affect timing in production phase and the mine rate of return. Modern technology review shows the level of flexibility and how the fleet performance and cost will develop in time.

Meeting layout and infrastructure needs

In less than 30 years, underground loader development has evolved from the first simple LHD models to integrated, automated loading systems. Performance, reliability and safety have been the three main development focuses in the LHD-development. During the 1990s, the 25-ton carrying capacity electric LHD was developed for massive mining purposes. Each generation reflects the equal mining method and mine process development and operational requirements.

Applying a new technology to a mine process affects the design, infrastructure, production and way of working in many ways. Finding the best matching layout requires discussions between the mine designers and machine supplier. For example, in block caves the angles and lengths of the draw point depend on the caving layout, rock mechanical factors and draw configuration. Draw points also have the tendency to decrease and shorten in time due to draw point maintenance. For best material moving performance, the optimal herring bone angle and length needs to be reviewed also from the loading machinery’s point of view. Energy and underground ventilation requirements have re-boosted the use of electric loaders underground. When electric machinery is considered, the full loading process needs to be thought through for the largest

![Diagram](image)

**Fig 2 - Example of three-face development resource use with Sandvik Tamrock study program.**
possible machine coverage and to avoid for example the machine electric cables crossing. Plans need to be in place for maintenance and service bays.

Full benefits with the lowest operational costs and highest production can only be achieved by reviewing technological alternatives well already in the feasibility stage. The use of simulation models has made it possible to test the suitability of the various technological alternatives in given mining conditions. Simulation is also the only way in identifying possible congestion in complex development or production situations. The more detailed simulation models require more information on equipment operation and long-term cost behaviour.

Available study and simulation tools show how much the selected technology provides flexibility in changing production or economical situations, when the major rebuilds or replacements are necessary, and view the effects of all these on the mine economy. When adequate technology is available from various sources, the difference becomes from preparing for the future, managing costs and combining the best layout with the most suitable technological solution.

Benchmarking
Benchmarking of planned performance factors and layout to existing mines is a part of the feasibility stage. Both mines and suppliers have recorded information on machinery performance and costing in corresponding operations. They should never, though, be viewed without their operational environment information. Benchmarking best practises is a good way of determining the best use and utilisation of technology and people skills. Some of the values to compare are general machine performance, unit and fleet availability, utilisation, capacities, cost and reliability. Beyond lay the issues under cover like inventory volumes and costs, response times, turn-over, human competence, compensation, working arrangements.

Automation
Automation has become an attractive technological choice in massive mining applications. Mining methods like block caving, where large amount of material is moved during steady state production support well automated operation. The higher degree of automation in a mining application on the other hand will be
best applied to a smooth and streamlined mining process and operation. The challenge is then to master the effect of process disturbances or discontinuities like secondary breaking and build that into an automated model.

Fig 6 - Infra-free system used in position measurement in an automated LHD-system. View through an automated LHD front camera.

The obvious expected result of an automated system is the increase in utilisation and decrease in operative unit cost. To obtain this task, several optimisation steps must be followed. The operational alternatives both for manual and automated solutions must be visualised and analysed. This helps to identify the benefits, challenges and possible risks. The automated system must be functional in the given mining process and the mine layout must be adapted to automated operation. There has to be a clear understanding of what type and level of decisions and how frequently need to be made at any given stage of the process. Only when the full system with machinery, process control, communication and operator interface has been identified, the final economical justification can be made.

The automation solution must have an organisation acceptance and management commitment behind it. Only too often the new aspects of way of working and performance measuring are forgotten. The operator’s role changes to a decision-maker demanding training and different motivational targets. Elements like amount of light, colour and changing images in a monitor have in experiments been found important for concentration. Communication in the control room or at the operator’s desk does not become less but more important.

Fig 7 - LHD-operator in a control room.

Automation is a higher form of technology, but it too needs supportive functions, service organisation, parts, diagnostics, logistics and a good supportive infrastructure. Automated systems build from ‘directed products’ that are integrated into one functional entity. From the owner’s point of view the operational reliability of this system becomes a different challenge since the boundaries between various suppliers are not straight lines. The system integrator, whether the mine or supplier, becomes the system supporter responsible for the functionality and system operation.

Eventually also the automated systems will grow old and need upgrading; new software and hardware. If the mine lifetime is 20 years, several upgrades will be made to the machinery and automation system, some of which will also need infrastructure changes.

LIFETIME OPTIMISATION

The initial investment cost is about one-quarter of the drilling machine lifetime cost. Drilling consumables and parts and service combined both are about one quarter each of the unit lifetime cost. The actual numbers depend on machine manufacturer, operational conditions and machine type and technology level. The rest of the costs are energy, water and operator. In loading the cost distribution is similar so that the initial investment presents some 30 per cent and operating costs some 70 per cent of the total costs. Out of the operating costs the fuel, tyres and bucket form most of the operating cost.

Interestingly enough, if the operation on an LHD is reviewed, the bucket filling time describes a large amount of the operating costs (affecting bucket, tyres, fuel, operator cost service and maintenance). How the unit performs is a combination of design and manufacturing, optimised mine layout and operator know-how. Those machines having long bucket filling time will also have increased operating costs.

In optimisation configuration a high-capacity unit typically has higher initial investment cost, but better reliability expectancy and thus longer lifetime and lower operational cost. The unit cost per hour is only interesting in relation to its performance and thus the over all high capacity unit cost per loaded ton will be lower than that of the low investment and low capacity unit.

To maintain lifetime profitability, the mine needs to view its technological competitiveness. These can be built in also in early stages through various service contracts, performance contracts and technological enhancement programs. They commit to a regular continuous improvement procedure where the best practises, performance, technology and operator knowledge are reviewed and brought up-to-date.

Mines are moving towards real time process control and resource monitoring systems. They combine the use of simulation tools for production forecasting and evaluating changing situations. This in turn means that processes are well defined and the resources carefully thought of. The resources will be increasingly more dedicated in autonomous system where moving a unit from one area to the other may not be possible at all. Using optimised number of resources and advanced working practices a building up a ‘transparent’ mine is possible. The information provided through individual unit monitoring will then be combined to process information in a larger scale.

The chain effect of optimised technology reaches from mining project profitability evaluation to operation and from initial investment to mine logistics. Optimised machinery provides flexibility and increases competitiveness in changing market situations and has a high user acceptance.

FUTURE

Massive mining methods like block caving and sublevel caving provide an excellent base for long-time optimisation where the technology optimisation is a part of the equation. It may be
difficult to optimise a full mine for its lifetime due to changing internal and external conditions. When the number of variables in the lifetime optimisation becomes so massive that the forecasting reliability decreases below acceptable, the real-time resource and operation control becomes the key in maintaining the desired profitability. Here the individual decisions (related to machines or people) have an increasing effect.

Increasing desire for lower cost and more massive operations moving to deeper deposits and decreasing human involvement will eventually lead to developing mining methods and processes more suitable for automation. Need of rock support may decrease and the importance of time and dimensions in development and excavation will increase. The future layout can be better fitted to suit the automated mining needs. The new mining machinery can look quite different with no cabin and no drivers seat, but will be more reliable and transmit more information than ever. The mining layouts and mobile mining technology will evolve tightly together for better over all mine rate or return.