State of the art

Underground and open pit mines are complex production systems with interacting processes such as drilling, blasting, ground control, ventilation, loading, hauling, hoisting, and logistics. As an increasing number of deposits in Sweden are mined at great depth, efficient mining processes will be of utmost importance. The unit operations (i.e. drilling, blasting, scaling, loading, hauling and rock support) as well as the full mining process also need to be improved and optimised.

Safe and stable underground constructions are crucial to achieve optimal utilisation of mineral resources and efficient mining at great depth. The ground control problems (large deformations and seismicity) in deep mines require rock support/reinforcement that can sustain these conditions as well as complementary measures, e.g., pre-conditioning, closing and re-opening criteria.

Fragmentation is a crucial part of the mining process. Examples of fragmentation processes are drilling and blasting, mechanical excavation and caving mining. The fragment size and the behavior of the fragmented material is important for the handling and has a major impact on loading and unloading of buckets and cars. Therefore, automation of loading and hauling will be strongly influenced by the ability to control the size distribution of the ore. The fragment size distribution is also very important in the filling and drawing of orepasses and bins. Many serious problems with hang-ups, jamming or other flow problems in orepasses are also related to the inability to control fragmentation and especially the occurrence of boulders.

The automation of mobile equipment is one way of minimising human exposure to high-risk areas and unfavourable climate, and of improving efficiency. Continuous excavation is a possible solution for some mining operations and this method can reduce human exposure at the face, reduce the environmental impact and increase the possibility for automation.

Mining equipment operates in extreme environments, and equipment design, maintenance and operation need to be optimised in order to facilitate successful mining operations. The availability and reliability but also the effective utilisation of the equipment is constrained by many factors which are mining system, machine and maintenance dependent. High equipment availability needs to be supported by effective maintenance programmes. Maintenance of ore passes, ventilation shafts and rock support also has to be considered.

A mine is a very large-scale, complex system that incorporates the need for real-time acquisition of thousands of signals, the analysis of the signals, the calculaton of optimal control strategies and, finally, the distribution of the planned control strategy in thousands of control loops. Such a control scheme, which can also be called dynamic real-time optimisation, has to be applied throughout the mine area in order to improve the entire process and fine-tuning it. The increased scale and complexity of control applications has brought about the demand for a focus on distributed and networked compositions of heterogeneous and semi-autonomous processes. These new types of systems are, in fact, collections of many sub-systems that need to be integrated to a common platform for achieving improved efficiency.

By improving the extraction methods and processes, mining operations will reduce their environmental footprint, greenhouse emissions, production costs and energy consumption, and the Swedish ore reserves will increase.

Summary

The mining industry is facing a number of important challenges in the future, such as increasing variation of the available mineral deposits, from spatial characteristics to mining depth (a large number of mines are moving towards greater depths). This may increase unforeseen mining challenges such as adaptive mining, ground control, and hot working conditions, which threaten the safety and the equipment as well as result in reduced production capacities. The demands on the mining industry in near and far future are high efficiency and productivity, minimum environmental impact, a safe working environment with a minimum of human injuries and zero fatalities. The societal pressure on the industry to reduce emissions of CO_2 and nitrogen, the amount of deposited waste rock, the mining-induced subsidence and the vibrations from blasts and seismic events will require research, development, demonstration and implementation of new technologies. The fragmentation processes have to be developed to obtain optimum fragmentation, a minimum of blast damage, undetonated explosives and dilution and a maximum of ore recovery. The CO_2 will be reduced by deploying equipment powered by non-fossil-fuel sources. The safety will be achieved by automation, improved ground control practices and reduced exposure of human beings at mining faces. This will require the development of new mining methods, and remote-controlled and/or autonomous mining equipment. Furthermore, mining in the near and far future will comprise conventional (manual) as well as remote-controlled and autonomous mining equipment, and have solutions for mixed traffic scenarios, i.e., interaction between autonomous machines and people. Since fewer humans will be in the mines, reliable and cost-effective methods for surface detection, positioning of equipment, rock mass investigation, rock support, fallout detection/observation and mining equipment monitoring have to be developed. To reduce the nitrogen emissions and to be able to use remote-controlled and/or autonomous equipment mining methods that can be selective and effective in different types mining environments, continuous excavation methods have to be developed. In the future mine fleets will be highly automated, which requires reliable communication networks with real-time capabilities that include localisation and navigation systems enabling automation and integrated process control.

Objectives and KPI

The long-term vision for 2030 and beyond is to improve the competitiveness of the Swedish mining industry with more efficient and highly competitive and environmentally sustainable mining processes, equipment and methods for underground as well as open pit extraction, more energy-efficient extraction and improved safety. In order for this to be achieved the following objectives are stated:

- No fatalities
- Minimized Loss Tinme Injuries (LTI)
- Minimize waste and/or all waste into "products"
- No CO_2-emission from mining equipment
- Air quality and temperature in accordance with Swedish regulations
- Energy-effective mining processes.
- Mine process systems in cooperation with mining machines (of varying brands) that can handle mixed traffic scenarios i.e, interaction between automatic/autonomous machines and/or interaction between automatic/autonomous machines and manually driven machines and/or people.
- Improved mining methods/layouts that ensure safe mining conditions
- Continuous excavation methods that can be used in most mines
- Fragmentation processes that gives an optimum fragmentation and a minimum of undetonated explosives and no spillage
- Improved ore recovery and a minimum of dilution
- Ground control measures that can ensure safe conditions with no unforeseen fallouts
- Reliable communication networks with real-time capabilities - 100% coverage 24/7
- 100% continuous/on-line process control and dispatch in 100% of the mine.
- Reliable monitoring systems for production and rock mechanics purposes (e.g., positioning, surface detection, rock fall detection, deformation)

Research and innovation needs, strategies and actions
In order to mine Swedish deposits both at increasing depths and near the surface with minimised environmental impact and increased productivity and safety, the research should be focused on optimising the mining processes and methods. The research activities should aim at improving and optimising all separate parts of the production process, as well as finding solutions that enable an optimisation of the complete process. The research should focus on the following areas:

Short – medium term (2021 – 2030)

- Infrastructure that support equipment driven by alternative power sources e.g., electric, battery, fuel cells
- Remote-controlled charging and connection to the firing station
- Digital twins of unit operations that enable optimization of the complete mining process
- Methods to handle big data collected from various instruments

Short – long term (2021 – 2045)

- Develop
  - Fossil free mining equipment to reduce the environmental impact
  - Transport systems of ore, air water etc. to reduce the overall energy consumption.
  - Reliable remote-controlled and autonomous systems which enable continuous mining, which is a key issue to increase the efficiency, and/or reduce exposure of human beings at mining faces
  - Autonomous mining machines which can handle mixed traffic
  - Mining methods, for deep mining conditions (down to at least 2 km depth)
  - Operator training and procedures
  - The drilling and blasting process to optimise the use of explosives and minimize the emission of nitrogen from undetonated explosives
  - Reliable communication networks with real-time capabilities that include localisation and navigation systems enabling automation and integrated process control in real time
  - Production prediction systems, calculation and prediction of KPIs in real time.
  - Operator training and support systems based on augmented reality to increase the work understanding an job satisfaction for operators.
  - Condition-based and predictive maintenance of mining equipment and systems, ore passes, ventilation shafts and rock support
  - Mining methods or mining sequences in present methods to mitigate seismic hazards and to achieve stable and safe conditions
  - Rock support, pre-conditioning, close and reentry systems, that improves ground stability and safety
  - Systems for cybersecurity-
  - The next generation of continuous extraction methods for Swedish conditions

Kommenterad [U1]: One comment which I have not been able to solve myself:
Shouldn’t this be written together with ”överordnade system”?!?!?

- Implement available cutting-edge technology and lead the development of future technology for surface detection, positioning of equipment, mining equipment monitoring, rock mass data collection, rock mass - rock support monitoring, rock fallout detection/observation
- Reduce waste by selective mining methods and develop products based on waste rock
- Improve and develop ventilation and air conditioning by employing battery powered machineries, controlled partial recirculation, ventilation on demand, and natural-assisted cooling techniques

Long term (2021 – 2045)

- Develop
    - Infrastructure that support equipment driven by alternative power sources e.g., electric, battery, fuel cells
    - Remote-controlled charging and connection to the firing station
    - New continuous selective excavation methods for all types of orebodies (even large-scale), resulting in a minimum of human exposure and waste rock production
    - Small mine machines using swarm technology enabling to control hundreds of small inexpensive units instead of a few big ones
    - Monitoring instruments for data collection in a mine without human exposure by developing and using cutting-edge technology, i.e., replace the human senses, using the mine fleet, infrastructure, drones, drilling and scaling machines as well as remote controlled installed instruments (e.g., seismic system, stress monitoring)
    - Digital twins of unit operations that enable optimization of the complete mining process
    - Surface support with high stiffness and ductile behaviour for deep mining conditions that replaces the combination shotcrete and weld mesh
- Reduce the environmental impact by zero CO_2 and minimized nitrogen emissions

Expected impact

- Technical
    - Optimised mining processes
    - Reduction of ore losses and dilution
    - Integrated process control and one control room.
    - Minimised human exposure at the production face and safer mining with fewer accidents
    - More cost-effective mining process overall.
- Economical
    - Reduction of cost per tonne.
    - More cost-effective rock support.
- Environmental
    - Reduced energy consumption.
    - Reduced CO_2 and nitrogen emission
    - Reduced waste rock
    - Reduced mining induced vibrations
- Social
    - Increased social acceptance
    - Increased job satisfaction
    - Increased holistic work understanding (from planning to performance) for all employees.
    - Acts as a responsible and active partner in society
- Health:
    - Improved air quality
    - Increased safety