**Optimal Scheduling in Underground Mining**
Max Åstrand, Mikael Johansson, Kateryna Mishchenko
max.åstrand@se.abb.com, mikaelj@kth.se, kateryna.mishchenko@se.abb.com

**DESCRIPTION**
Underground mining comprises a range of activities, from rock excavation tasks (such as drilling, charging and blasting) to support functions (including managing the inflow of water, ventilating blast fumes, and building the necessary infrastructure). Automation in underground mining has previously focused on fixed equipment such as mine hoists, crushers, and conveyor belts. For underground mines to reach high productivity automatic scheduling of the mobile production system must be considered.

**BACKGROUND & MOTIVATION**
The margins in underground mining are constantly under pressure as costs increase with depth of production. A survey of more than 200 high level executives in mining companies around the world revealed that the top challenge modern mines are facing is maximizing production effectiveness [1]. The same study reports that increasing production effectiveness is more urgent than improving reliability of individual equipment.

Even in modern mines the part of the working time spent on directly value adding activities can be as low as 50%. Preliminary studies show that the amount of time spent on value adding activities can be increased by 20% using automatic scheduling compared to current manual practice. The scheduling of mobile machinery typically has a horizon of one week corresponding to a few hundred activities, and a solution need to obey constraints coming from both upstream and downstream processes, see Figure 1.

Underground mining automation has previously focused on fixed equipment, an area where ABB has a strong industrial record of successful deployments all over the world. However, it is essential for mines to utilize the mobile production system to its maximal efficiency in order to remain profitable when going deeper.

**METHODS & PRELIMINARY RESULTS**
Drift excavation follows the five-stage blasting cycle shown in Figure 4. This can be regarded a $k$-stage hybrid flow shop with $k=5$. The scheduling problem corresponds to a combinatorial optimization problem, which for non-trivial instances is NP-hard. Methods for solving the $k$-stage hybrid flow shop scheduling problem include

- Exact methods such as graph search with Branch and Bound, Mixed Integer Programming and Constraint Programming for solving the problem to optimality.
- Heuristic algorithms for quickly producing feasible solutions.
- Metaheuristic optimization methods such as Simulated Annealing, Genetic Algorithms, and Tabu Search.

Although the research on scheduling applied to other process industries can be found extensively in literature, work on scheduling in underground mining is scarce.

**BIBLIOGRAPHY**

**RESEARCH GOAL & QUESTION**
For underground mines to stay competitive several topics needs to be investigated.

- What are the suitable methods for automatic scheduling in underground mining? How can a robust schedule with real-time feedback be constructed which is not sensitive to minor disturbances?
- Common objectives in scheduling of underground mine operation is to minimize makespan, minimize deviation from targeted production, or minimize energy consumption. How are schedules constructed to consider this multi-objective nature?
- Underground mining comprises a range of activities. Should all mine activities be collated in one scheduling solution? If not, which parts are essential to integrate due to e.g., shared resources?
- In the end, a mine planner should use and rely on generated schedules. How can solutions be designed to be flexible and intuitive to interact with?

**ROADMAP & MILESTONES**
1yr Previous work, end-user-perspective, baseline solution
3yr Increase complexity of scheduling problem, proof-of-concept by simulation
5yr Verify methods and models in a real underground mine environment.