

Selected references

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A deviation-minimization approach to short-term underground mine schedule optimization

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Production forecasts derived from the medium-term schedule represent the best path forward for underground mining operations to achieve corporate and operational goals. Unforeseen circumstances, such as equipment breakdown, can cause significant deviations from established production forecasts in the short term. Such situations require timely mitigation of the effects of the deviations in order to stay as close as possible to the medium-term plan. This paper presents a deterministic mathematical formulation for short-term scheduling that addresses this challenge. The formulation is able to make up for deficits resulting from operational disruptions by minimizing deviations from medium-term production goals and medium-term activity start dates. We demonstrate this in a case study by simulating disruptions involving reduction in ore extraction capacity and development advance rate. Aside from the rescheduling capability, this formulation can help mine planners conduct analysis on the impact of various disruptions on the schedule. The formulation can help identify those conditions or disruptions that are more detrimental to the achievement of forecast targets, or otherwise. The formulation also affords mine planners the flexibility to prioritize one production goal over the other, depending on operational conditions at the mine. In the future, we seek to incorporate in the formulation respirable dust, diesel particulate matter and ventilation constraints in order to create more realistic schedules, and enhance miners' health and safety.

Background

Underground mining methods are employed when the orebody is deep seated or significantly vertical such that surface mining methods are uneconomic and/or unsafe. In both surface and underground mining, a good mine plan is required for the safe and profitable extraction of minerals. In underground mine planning, production scheduling is the sequencing of mining activities — that is, development, production and remediation — needed to achieve clearly defined goals in order to generate revenue, while adhering to precedence and resource constraints. Scheduling results in

the determination of activity start dates for the operation with a scheduling fidelity corresponding to the desired planning horizon: long-, medium- or short-term planning.

Considering that the production forecast from the medium-term schedule represents the best path forward for the operation to achieve the corporate or operational goals — for example, contract requirements, market demand and corporate objectives — mine planners strive to develop short-term schedules that closely match the forecast. Notwithstanding, unforeseen circumstances, such as equipment breakdown and the downstream impact of geological and commodity price uncertainty, can cause significant deviations from established production forecasts in the short term. Situations such as these require timely mitigation of the effects of the deviations in an attempt to stay as close as possible to the medium-term plan.

Methodology

To this end, we develop a deterministic mathematical formulation for short-term scheduling that could be incorporated into existing workflows at operations to help assess different options as deviations arise. We achieve this by introducing penalties for the ensuing deviations. Aside from incorporating scaling factors by which mine planning engineers can assign priorities to the deviations, this formulation makes it possible to prioritize one production goal over the other, depending on operational conditions and considerations at the mine. This is to contribute to a more flexible and realistic short-term scheduling process for underground mining operations. We also simulate realistic operational scenarios by modifying production goals in the short-term plan and assessing solutions to determine impact and viable options while minimizing deviations from the medium-term plan.

Short-term planning engineers require flexibility because of dynamic and unique operational conditions of underground mines. We formulate this new approach to (1) rapidly schedule activities amid altered operational

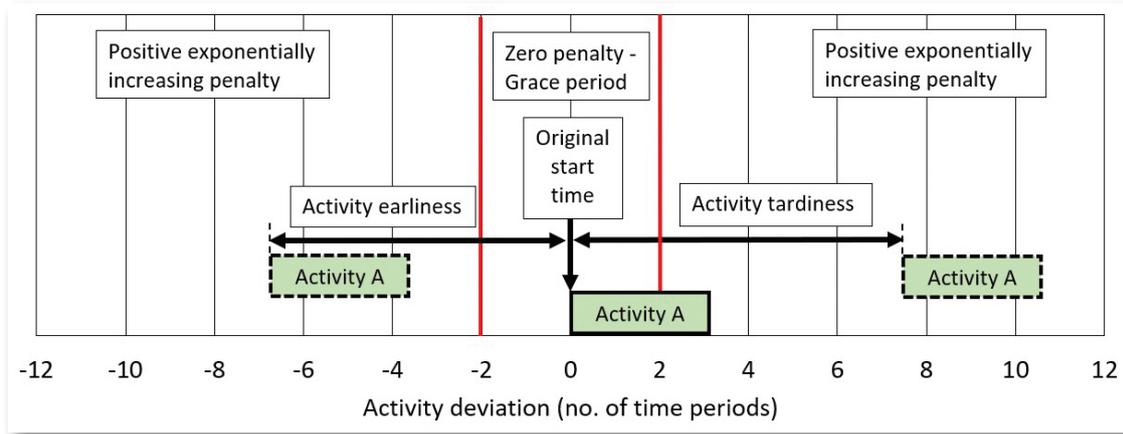


Fig. 1 Activity earliness, tardiness and grace period. No penalty is imposed if an activity is scheduled within the grace period: that is, earliness or tardiness within two time periods of an activity’s original start time. Scheduling activities beyond the grace period carries an increasing exponential penalty. It is also possible to impose a skewed penalty scheme: for example, earliness is less heavily penalized than tardiness.

conditions, (2) minimize activity start time deviations and (3) achieve production targets. We further make improvements by incorporating more realistic penalty functions for minimizing activity and production goal deviations. Activity earliness and tardiness are penalized with exponentially increasing values as deviations increase, while goal penalties are only imposed if certain predetermined production target levels are not met (see Fig. 1).

The case-study mine forms part of an underground mining operation that is located in South America. The operation is a multimine complex with three high-grade underground operating mines. As part of an expansion project, two additional underground deposits are being developed into mines, one of which is the focus of this study. Based on the medium-term plan, mine management would like to produce flexible short-term schedules that can accommodate unforeseen operational disruptions.

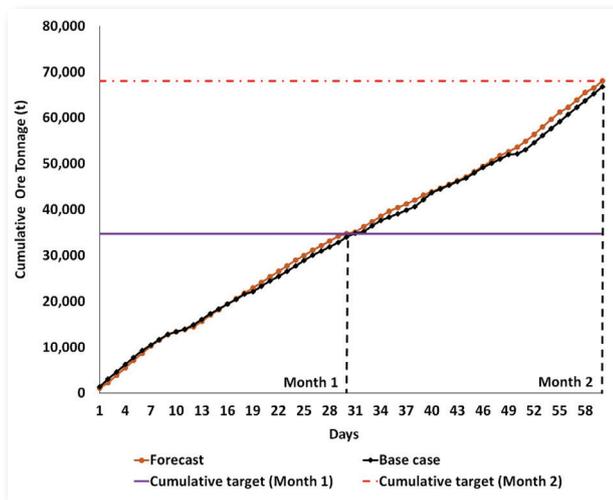


Fig. 2 Cumulative ore tonnage for base-case scenario. The base case closely follows the medium-term plan with minimal deviation from ore tonnage target.

Results

Using various problem instances, we solve for all scenarios at a 12-hour shift fidelity. We utilize a grace period of two shifts and an allowable goal deviation margin of 2 percent. The results show that each instance of the base case satisfactorily achieves the targets for the respective goals. The base case closely follows the medium-term plan with minimal deviation from both ore tonnage and lateral development targets (see Fig. 2). Thus, under normal operating conditions, this formulation is able to schedule at a finer fidelity while not significantly deviating from the medium-term plan.

We simulate equipment breakdowns, and other operational challenges, and the schedule results accommodate for these challenges by moving activities to meet production targets, while minimizing deviations from the medium-term schedule. This allows engineers to rapidly produce new schedules that adjust for these operational challenges to meet the desired production targets, or to provide sensitivity analysis as to how much production will be lost.

Conclusion

The strength of the proposed short-term model lies in its ability to make up for deficits resulting from operational disruptions. We demonstrate this by simulating disruptions involving reduction in ore extraction capacity and development advance rate.

Aside from its rescheduling capability, this tool can help mine planners conduct further analysis on the impact various disruptions have on the schedule. It can help identify those conditions or disruptions that are more detrimental to the achievement of forecast targets, or otherwise. In the future, we seek to incorporate in the formulation respirable dust, diesel particulate matter, heat and other ventilation-related constraints in order to create more realistic schedules that address current environmental challenges, and to enhance miners’ health and safety. ■

References

A list of all references is available in the full paper.