Long-Term Production Scheduling in an Open-Pit to Panel Caving Transition Context

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ABSTRACT

Today, many open-pit mines are starting to deplete their resources and could be forced to leave the ore in the deepest parts of the pit, which could lead to a loss of possible economical revenue. Therefore, open-pit mines are developing new strategies to extract the mineral via underground mining systems. For massive orebodies, the most profitable extraction methods are those that consider the caving of the rock, in particular, the block/panel caving methods, due to their low operational costs. Methodologies applied to define the optimum decision for transitioning from open pit to underground mines are often limited or biased because they tend to give priority to the open pit operation, which does not necessarily result in an optimum NPV.

In this paper, a new methodology is proposed to maximize the NPV based on the scheduling sequence. Open-pit and panel caving envelopes are calculated, considering a potential crown pillar between them for stability purposes. Subsequently, the block scheduling and NPV maximization of both systems is made, considering operational and geomechanical constraints to analyse their influence on the scheduling.

This methodology has been applied in both synthetic block models and mining scale cases. The production plans, NPV variations and block scheduling are analysed based on the different groups of parameters. Results indicate that the NPV and production plans, where both mining systems extract mineral together and the remaining periods where panel caving is the only system extracting ore, are heavily influenced by the caving sequence and the constraints related to the underground mine.

Using this procedure, the economic benefit of the panel caving mine and the feasibility of the different sequences that can be applied to the model can be studied. This model will allow mine planners to define the best strategy for the production capacity, sequencing and geomechanical decisions, while maximizing NPV and ensuring the safety of the workers.

INTRODUCTION

Transition is defined as the process of passing from one method of exploitation to another. This process can be triggered by the economic unfeasibility of extracting ore through the first method and thus perceive positive economic benefits of exploitation by another method. The most common example is the transition from an open pit (where grades decrease and mining costs increase as the mine becomes deeper) to an underground mine (allowing the extraction of mineral at a lower cost).

A common case corresponds to the transition to self-supported underground mines. This case is relatively simpler than caving operations because geomechanical constraints allow partially decoupling of the open pit and underground operations. However, operational constraints for scheduling in this case are more complex due to precedence between pillars and stopes for different activities (King et al, 2016). Therefore, some authors have studied the problem of optimizing economic envelopes. Bakhtavar et al (2009) and Bakhtavar et al (2012) propose an algorithm that is applied in non-massive underground methods. The algorithm works by sequentially evaluating different floors for economic envelopes and, thus, obtain the sequence combination with the greatest economic benefit.

For massive caving methods, such as panel caving, a similar approach to the one described was proposed in Julio (2015), which included the incorporation of crown pillars and dilution using the Laubscher's method. For this caving methods also, optimization of the simultaneous production scheduling was modelled by Epstein et al (2012), who considered different expansions and sectors for the open pit and the underground method, which have already been sequenced in a compatible way. Optimization models for scheduling have also been proposed for panel caving, for example, Smoljanovic et al, (2011) showed, through the application of precedence and capacity constraints, the importance of selecting the optimum starting point for the underground mine, which would affect the value of the project. Due to the large number of variables and constraints, simplification can be achieved by using material strata (Newman et al, 2013), where each strata is susceptible to be extracted by open-pit or underground. Through the use of vertical extraction constraints, a strata is fixed from which only the upper strata can be extracted by open-pit and the lower strata by underground. Another approach is to group extraction points into clusters (Yashar et al, 2013), based on column tonnage, mean grade, and physical location. This reduces the number of decision variables and the constraints associated with the model and, thus, reducing the computation time.

Palabora undertook a joint production (joint production includes the ramp-up of the underground mine) by extracting its main ramp, achieving a production of 16,000 [tpd] (Moss et al, 2006). However, this involved a constant study of the open-pit geomechanical conditions and, therefore, it is recommended not to exceed the joint extraction for more than 6 months (Visser, 2006).

The objective of this work is to establish a methodology for the optimization of joint production plans of an open pit and an underground panel caving operation, at the block model level. The model aims to generate the highest NPV and schedule for each mine. A mathematical program modelling both operations and their potential interactions is proposed and applied to case studies.