Assessing the impact of geology, ore grades and recovery uncertainties into production scheduling

Mohammad Maleki[1]
Enrique Jélvez[2]
Xavier Emery[3]
Nelson Morales[2]

1. Department of Metallurgical and Mining Engineering, Universidad Católica del Norte, Chile
2. Advanced Mining Technology Center, Universidad de Chile
3. Department of Mining Engineering, Universidad de Chile

Introduction: this work presents an integrated case study in geological uncertainty modeling and its application to strategic open pit mine planning. The main objective is to show that a stochastic production schedule that use a set of simulated ore body models as an input is able to manage geological risk and to increase the economics of a mining project with respect to a traditional deterministic schedule based on a single ore body model. The application deals with an iron ore deposit recognized by a set of exploration diamond drill holes.

Methodology: a two-stage approach is adopted for the construction of block models to be used in mine planning: in a first instance, three rock type domains (andesite host rock, skarn and mineralized breccias),

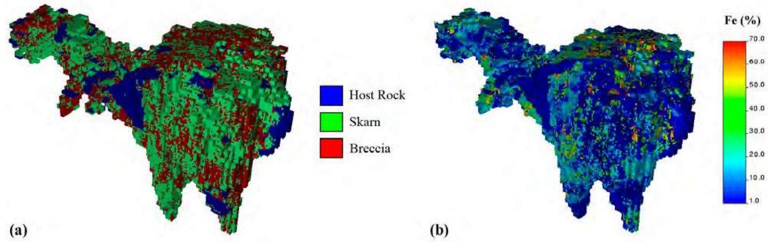

Figure 1 Three-dimensional representation of the ore deposit corresponding to the first scenario: (a) simulated rock type, (b) simulated iron grade. The simulation is shown at a quasi-point support, before upscaling to the support of the selective mining units.

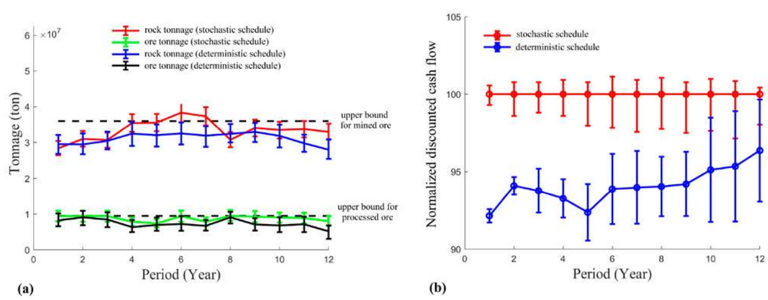

Figure 2 Production plans obtained from the deterministic and stochastic schedules over 12 periods: solid lines represent the averages over 100 scenarios, while error bars indicate the quantiles at 5 % and 95 % over these scenarios. (a) Rock and ore tonnes; (b) discounted cash flows, normalized to that of the stochastic schedule so that the latter has, on average, a cash flow of 100 % in each period.

identified as controlling the mineralization, are simulated by using a plurigaussian model, then seven quantitative variables related to the ore quality and its processing (iron grade, silica grade, sulphur grade, phosphorus grade, potassium grade, rock specific gravity and magnetic ratio, which quantifies the recovery of iron ore) are jointly simulated within each of the rock type domains by using a multivariate Gaussian model (Figure 1). Leave-one-out cross-validation is performed to check that the simulated quantitative variables are globally and conditionally unbiased and that they accurately reflect the geological variability.
The resulting simulations, consisting of 100 equiprobable scenarios of the ore deposit, are upscaled to the support of selective mining units and used as an input to determine the optimal pit limits and to schedule the production with a horizon of 12 annual periods, considering mining and processing capacities, as well as restrictions on the ore (Fe) and the impurity (SiO_2, S, P and K) grades. A deterministic schedule based on mixed integer programming and on the average of the 100 scenarios is compared to a stochastic schedule, based on stochastic integer programming, that accounts for each individual scenario and aims at controlling the risk of non-compliance with production targets associated with geological uncertainty.

Results and Conclusions: the stochastic schedule controls the cost of accepting iron ore tonnes with higher impurity contents, maximizing the expected profit and minimizing the risk of deviations from production objectives. It outperforms the deterministic schedule, with an increase, on average over the 100 scenarios, of the ore tonnes by 16% and of the cumulative discounted cash flow by 6% (Figure 2). An additional benefit of working with simulated block models is the possibility to provide a range (not only an average) for the production output and the economic profit.