Loading Equipment Planning Considering Optimization and Simulation for the Fulfilment of a Production Plan in Open Pit Mining

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ABSTRACT

Open pit mining is a resource and equipment intensive process. The decision of which equipment to use, how many to buy and where they should be operating has a strong impact on the value of the business. In current operations this decision is made manually considering theoretical performance or historical operation data, which do not necessarily adjust to current mine conditions. Due to the complexity of the mining operation it is likely that the manual equipment allocation will not achieve the ideal configuration as the mine evolves and develops, which can result in sub-optimal configurations.

The work developed seeks to provide guidance in the assignment of equipment and in the generation of production plans. By incorporating a simulation model together with an equipment assignment methodology, it was possible to capture the uncertainty of the shovel-truck systems in an operation and achieve an adequate load equipment assignment, which would allow both minimizing operating costs and ensuring compliance with a production plan. Two different exercises were developed, one in which different loading equipment was available and the model could decide which of them to effectively use and another in which there was no freedom of equipment selection, only assignment.

Among the main results obtained is that, for the exercise of varied equipment, an improvement of 83 % to 99 % is achieved in the total extraction, which is achieved through the inclusion of new equipment that was not in the base case. For the exercise of fixed equipment, it is not possible to exceed 86 % extraction of the original plan. However, a new extraction plan is generated (with less material) in which the assignment of base case equipment achieves even 100 % extraction of planned material.

INTRODUCTION

The main objective of mine planning is to maximize the benefit of a mining project by defining a sustainable extraction sequence over time. The sequence to be determined will depend on the stage the project is at, which can refer to what portions (phases) of the mine should be extracted at what time period, i.e. the strategic scale; or later at the short-term level, where decisions need to be done in order to do the most efficient utilization of mechanical equipment used for extraction in order to fulfil the strategic plan. Indeed, the proper management of these assets will have a strong impact on costs as well as on the achievement of material extraction goals.

In mining, equipment operates in an environment that is varied and full of interactions. Due to the inherent conditions of open pit operations, a large amount of equipment is required, which is highly mechanized, of gigantic proportions, and must be present throughout the life of the mine. These conditions result in the largest percentage of operational costs in open pit mining being associated with loading and transportation.

The decisions that are made around the equipment in general are made manually and considering theoretical or historical productivities of the equipment. These are considered as a constant within the operation and are not usually updated according to the changes in the work environment.

The high costs involved and the improved planning strategy make the loading and transportation operation a point of high interest for the implementation of tools and improvements. The planner must have at his disposal the adequate tools that allow him to predict the behavior of the operation and be able to anticipate possible problems. In this way, equipment can be used efficiently, optimizing the use of assets as production plans are met.

The main objective of this work is to develop and propose a methodology to assign the loading equipment to the different benches, so that the long-term plan is achieved as best as possible. However, the methodology also aims at improving the robustness of mining plans by incorporating operational uncertainty. This is realized by combining two techniques that are commonly used independently in mine planning: linear optimization model that assigns the equipment, and a simulation that evaluates the assignment and provides feedback to the optimization model to generate a better assignment of loading and transport.

In order to achieve this interaction between models, the following will be carried out: (i) a production plan will be determined based on the assignment of equipment that minimizes the cost of operation; this first solution will consider an estimated productivity in a deterministic manner of the loading equipment; (ii) a simulation model will be constructed from this solution and it will be determined which are the tonnages extracted and the effective productivity reached by the equipment; (iii) this simulated productivity of the equipment will be re-entered in the optimization mode. This process is repeated iteratively until a convergence in the solution is obtained.

METHODOLOGY

General Scheme

The methodology developed in this work can be summarized in three stages:

- Optimization Model: generates a production plan by selecting loading equipment and assigning it to different benches.
- Simulation Model: t the production plan is simulated, considering a fleet of trucks, equipment failures and scheduled stops.
- Communication between models: the methodology involves an iteration between the two previous stages in which the production indexes of the equipment will be adjusted. The optimization model first considers an estimated performance of the equipment which is adjusted according to the results of the simulation. This process is outlined in Figure 1.

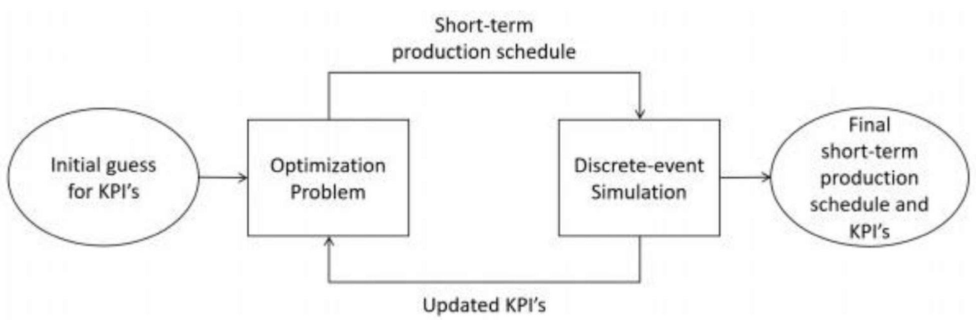

Figure 1 Simulation Optimization iterative framework diagram

Determination of Productive Indicator

The feedback mechanics between the models is directly associated with determining productive indices of the loading equipment in the simulation and then entering them into the optimization model. This stage is of utmost importance, since it is the way in which operational uncertainty will be incorporated into the optimization model. In this way, a solution that is sustainable in the operation will be obtained.

Equation 1 shows in a simplified way the calculation of the adjustment factor "Utilization". The simulated productivity of the loading equipment is obtained from the results of the optimization model, while the expected productivity is the first guess of the productivities, which is calculated based on the catalogues of current equipment and operational factors, with which the optimization model works.

$$Utilization_{shovel} = \frac{TPH_{shovel}^{simulated}}{TPH_{shovel}^{expected}} \quad (1)$$

The Utilization is entered into the optimization model of the next iteration, which uses it to calculate the expected productivity with which it going to build the schedule production. In this way, each production plan that is calculated incorporates the results of the simulation of the previous plan.

Optimization Model

The optimization model used is described in detail in "Optimal Selection and Assignment of Loading Equipment for the Compliance of an Open Pit Production Plan". Figure 2 presents an overview of the functioning of the optimization model.

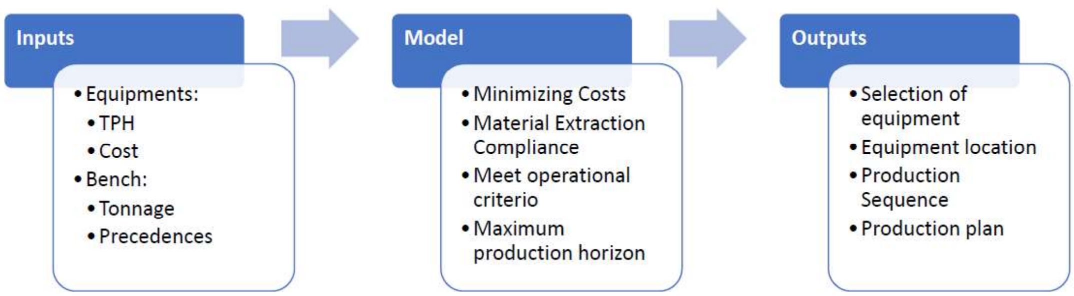

Figure 2 Functioning of the optimization model

The model allows the option of working with defined loading equipment or with varied equipment. In the first, the fleet of equipment to be used is already defined, while in the second, the model can choose which equipment to use from a larger catalogue.

Simulation Model

The simulation software used corresponds to DSIM Open Pit, a tool developed by the Delphos Mining Planning laboratory.

The simulation model is loaded in each iteration with the chosen equipment and with the production plan resulting from the optimization model. Figure 3 shows how the model works.

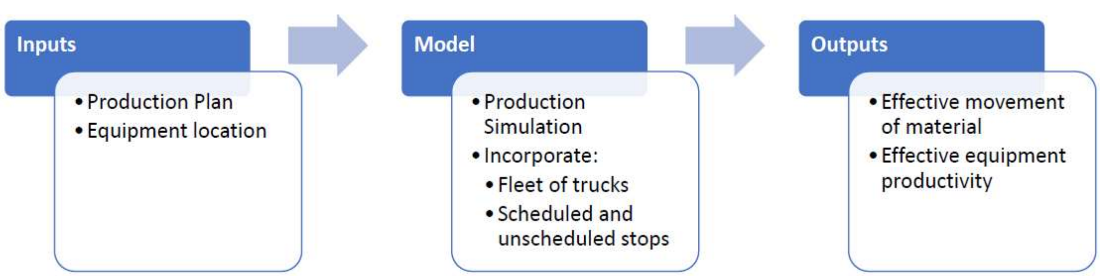

Figure 3 Functioning of the simulation model

The monthly tonnages of the plan are adjusted to daily production scale in order to make simulation possible. 12 representative days are simulated, each of one month.

The effective productivity obtained from each team is summarized according to the phase in which they worked. In this way, the utilization factor is obtained, which is used to adjust the productivity of the equipment of the next iteration in the optimization model.

Case Study

The case consists of the sequencing of one year of production. The basic elements of this plan are the benches, of which the tonnage and destination of each material present is known. The optimization model solves the assignment of the loading equipment to the different banks of this production year. With each iteration, it is possible to vary both the assignment of the equipment and the extraction sequence of the benches, always considering the precedences between them.

Simulation Layout

In order to carry out the simulation, we considered the information of the routes provided in the data together with the topography of the project. They will be considered

- Three dumps, each with its associated pushbacks.
- Two workshops, in which the teams carry out maintenance according to the failure.
- Two casinos, in which the teams perform shift changes and snacks.

Figure 4 present the layout considered for the simulation, which has four production phases with different loading fronts and multiple destinations for the material.

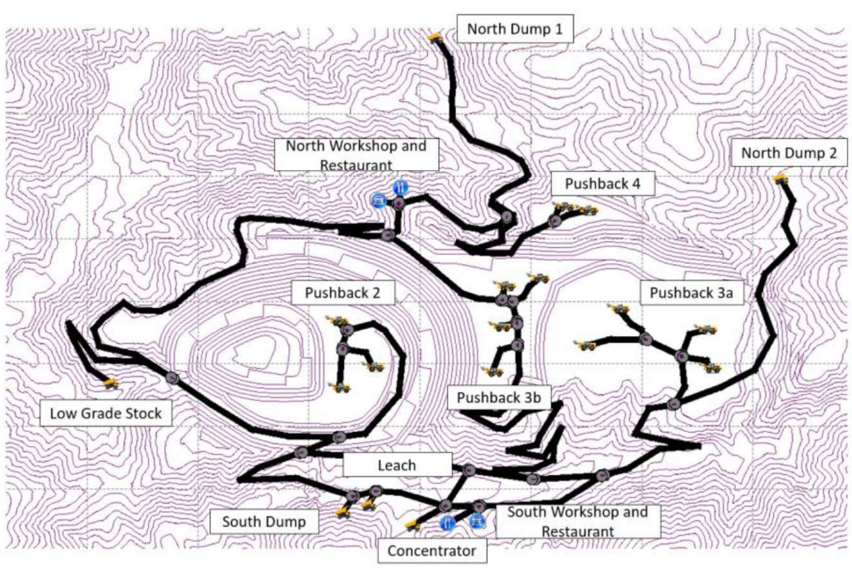

Figure 4 Production Layout for Simulation

RESULTS AND DISCUSSION

The exercises carried out were two: one in which the teams selected could vary between an iteration and another in which the fleet was defined for all of them.

In order to present the evolution in each iteration, two types of results will be presented: the comparison between expected and actual productivity and the mineral depletion graph.

The difference between expected and effective productivity will be shown along with the number of teams selected, the total cost of the case (including cost of operation and purchase of equipment), and compliance with the plan.

The ore depletion graph is presented with the remaining material from each phase for the planned and simulated case.

Comparative Parameters

Table 1 presents the comparative differences obtained between the base case and the best iteration. The total cost represents the sum between the acquisition cost of the shovels and the production cost (the equipment has different costs per ton extracted). Compliance with the plan compares the tonnages scheduled by the optimization model with the tonnages extracted in the simulation. TPH Difference represents the difference between the expected productivity and the effective productivity, if it is negative it means that the effective productivity is less than the expected one and therefore it was overestimated.

Table 1 Comparative Parameter for Variable Equipment

Parameter	Base Case	Best Iteration
Total Cost [$]	10,719,519	21,176,577
N° of Shovel [#]	5	9
Plan fulfilment [%]	83	99
TPH Difference [%]	-44	-0.3

From Table 1 it can be seen that in the best iteration, the equipment extraction and assignment plan created by the optimization model allows the loading equipment to reach the expected productivity. In this way, an almost total extraction of the planned material is achieved.

When considering the theoretically determined TPH in the base case the estimated cost is 10,719,519 USD. However, productivity is overestimated so that only 83% compliance is achieved. On the other hand, if the methodology is used, the adjustment in the iterations allows to obtain the real productivity of the equipment determining that it is necessary to increase the fleet (and therefore the costs amount to 21,176,577 USD) to achieve 99% compliance with the plan.

The problem to be solved with the methodology considering the fixed equipment fleet is a little different from the original one. As seen in Table 1, the original fleet does not provide enough for total extraction, therefore, what is sought is a new production plan that is achievable with the original fleet. The results are shown in Table 2.

Table 2 Fixed equipment results

Parameter	Base Case	Best Iteration
Total Cost [$]	10,719,519	9,997,097
Planned Tonnage [daily adjustment]	1,799,835	1,219,547
Plan fulfilment [%]	83	99

In table 2 it can be seen that the original plan cannot be reached and only 83% of the plan is extracted. However, the methodology allows to determine a new production plan with which 99% of extraction is reached in the case shown. Other iterations reached 100% extraction, but the planned tonnage was lower.

With the two exercises carried out, it can be understood that the base case plan is unfeasible to extract with the initial equipment. In the exercise with variable equipment the methodology leads to incorporate new equipment to achieve total extraction while in the exercise of defined equipment the tonnage to be extracted is reduced to achieve total extraction.

Depletion Graph

The depletion graphs represent how much remaining tonnage is in each phase as time passes. In this case, for each phase, the planned production (continuous line) is compared with the actual production (line and point).

These curves are directly related to the equipment operating in each sector, in the sense that the slope of the curves represents the productivity of the equipment in that sector at that specific moment.

In this case, the curve above the other is extracted slower, ie the productivity of that specific phase is lower.

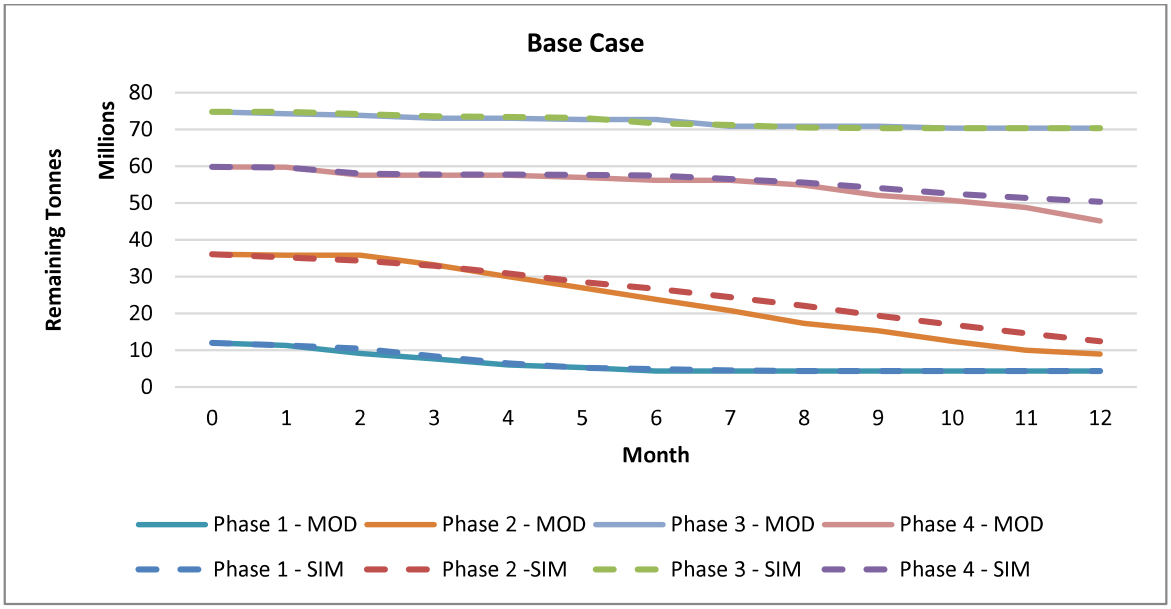

Figure 5 Depletion graph – Base Case

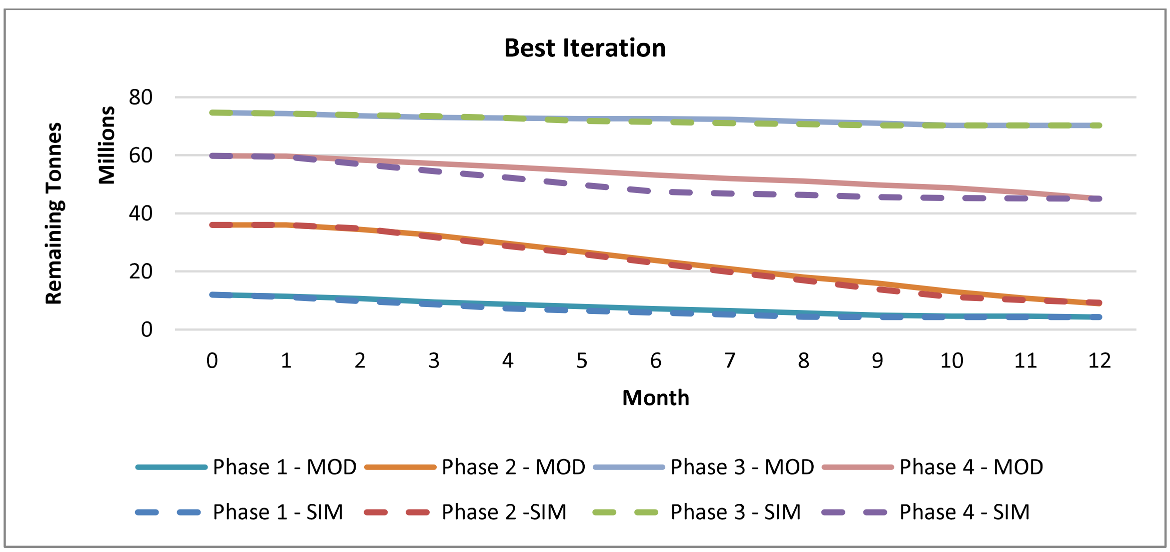

Figure 6 Depletion graph – Best Iteration

In Figure 5 it can be seen that for Phases 2 and 4 the simulation curve is above that of the optimization model. This means that the rate at which the material is actually being extracted is lower than expected according to the planning. This means that at the end of all periods there is still material remaining in the phases, which can prejudice the planning for subsequent periods.

Even more serious is the fact that the plan generated in the base case involves a smaller amount of extracted material which can negatively affect the feed to the plant.

On the other hand, in Figure 6 you can see that the simulation curves are now lower than that of the optimization model. This implies that the resulting extraction rate is higher than the planned one. In this way the almost total extraction of the planned material is achieved. This is a direct consequence of the better estimation of the productivity of the equipment and the assignment of suitable work locations. The implemented methodology allowed to pass from a situation of delay of material sent to the plant and with remaining material at the end of periods to a better situation where all the material is extracted in the stipulated time and the plant is fed as planned.

CONCLUSION

The proposed methodology permits the correct feedback between the optimization model and the simulation, allowing the planned material movements to be reached in the simulation.

When not considering the methodology, the error in the estimation of the productivities was 44% on average, while when considering it, it drops to 10%.

This decrease in error implies an increase in compliance with the plan, going from 83% in the base case to 99%.The final allocation manages to improve the estimated extraction rate and get closer to full compliance.

The methodology also allows the construction of production plans whose compliance is achievable for a given fleet.

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