# Optimization and Sequencing a Semiautomated Ramp Design in Underground Mining: A Case Study

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**Abstract.** Access ramp design in underground mining is an important challenge to mining engineers, however, there are few optimizing methodologies that may guide the process. These methodologies consider only very simple costs when they made the economic evaluation of the project, because they design access first and then they complete the extraction schedule.

This work presents a methodology to generate ramp designs in underground mining, their development plan and the extraction of ore plan, and then apply it in a gold and silver mine extracted by Bench & Fill method. We consider two models to approach the problem, which are combined. A first model determines a ramp design that aims to minimizes both CAPEX and OPEX without considering time. The second model considers a given ramp and maximizes the net present value (NPV), i.e., it schedules the construction and production over time. Both approaches work on the block model and rely on mathematical programming for optimization. The methodology uses both models iteratively to find a design with high NPV.

We apply the methodology to a case study consisting of three zones of a Bench & Fill mine, for which different scenarios are compared, including an initial design developed using traditional design methods. The results show that the methodology improves the NPV in comparison with initial designs. Interestingly enough, the result also shows there is not necessarily a direct correlation between NPV and costs, that is, the designs with best NPV are not necessarily those with the lowest costs.

**Keywords:** Ramp design · Scheduling · Underground mining

## 1 Introduction

In the mining industry, there is constant research in methodologies which can improve processes and get the best feasible economic indicators. However, in underground mining, there is little research around access ramp design and tasks scheduling.

[1] and [5] identified the opportunity to develop algorithms for access design in an underground mine to maximize NPV, so a genetic form to solve this kind of problems is proposed. A workspace is created to develop a tool to obtain an optimum access ramp design to the mine. [5] proposed the discounted junction point algorithm (DJPA)


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which must find the location of junction which was formulated with using Steiner networks. The proposed model assumes that ramp links are straight lines, so the proposed theory and algorithm can only be applied directly to underground mines in which terminal points are in a near-horizontal plane to satisfy the gradient constraint, i.e., they cannot be used in mines with several production levels.

On the other hand, [4] determined that the lack of available software to assist the production scheduling in underground mines has implied that this task continues being a hand-made procedure, which it includes also an intensive and complex use of spreadsheets. Thus, there is no doubt that this is a highly tedious and time demanding process where a feasible solution can be found, but there is a minimum possibility to obtain the optimum solution, in some sense.

[3] proposed a heuristic with the optimization model capable of obtaining operative ramp designs in a little time, which uses some operational and economical inputs. The input parameters focused on development cost and operational cost of ramps because the objective is to minimize the total cost to obtain a design. This work does not consider temporal factor so the evolution of mine development and operation are not included, because of this the decision is set by the minimum cost.

In this paper, we propose a methodology from the work made in [3] to assist ramp design in underground mines while economic benefit of the project is maximized, and then we obtain a ramp design with development and production schedule.

## 2 Methodology

The proposed methodology in this paper utilizes two tools to work: a heuristic developed to obtain preliminary ramp design while it minimizes costs, and UDESS, a scheduling tool that maximizes NPV of the project.

The heuristic mentioned uses several design parameters to achieve a preliminary operational ramp and some cost values according to the case to minimize the total cost of configuration. This model returns a ramps and crosscuts configuration from inputs like connection points location to access to production levels, start point and endpoint and tonnage to extract.

[2] UDESS is a scheduling tool which needs three inputs: activities, precedences, and constraints. Activities are the tasks that we want to manage in a schedule; the precedences are the relations among activities that set the requirements that need each one to start to develop it; the constraints set limits in using of some resources that are necessary to carry out the activities.

First, we must determine the project in which we are going to work, so a block model is necessary to have a spatial reference of the mine and it allows to define the available zone to design ramp and crosscuts. Then, the inputs of heuristic are set according to each case: gradient, curvature radius, development cost, operational cost, ventilation cost, production levels (quantity, location, and tonnage to extract from them).

When those inputs are got into, the heuristic is executed to obtain a preliminary ramp and crosscuts configuration to refine. With this design, we set activities, precedences, and constraints. Activities are the segments of ramp, crosscuts and production sectors from where ore is extracted. Precedences set the sequence in which the tunnels must be developed and ore from levels must be extracted, and they define relationships among production levels like the direction of exploitation (for example, from bottom to top). Constraints restrict the resource consumption to carry out the tasks, like available hours of equipment, maximum extraction capacity per period, etc.

Later, we use UDESS to obtain a development plan of ramp and crosscuts, and ore extraction plan from production levels and NPV of the project. With those results, we adjust the development, haulage and ventilation costs value with the time value according to the plan, so the previous costs are changed. We run the heuristic again with the new values and changes in the obtained design are analyzed. If the configuration of ramp and crosscuts vary, we carry on the next steps, otherwise, we have a final design, because the possible changes that it can have will be very mild. This is an iterative process with using heuristic and scheduling tools to obtain the Gantt chart of the project with its NPV (Fig. 1).

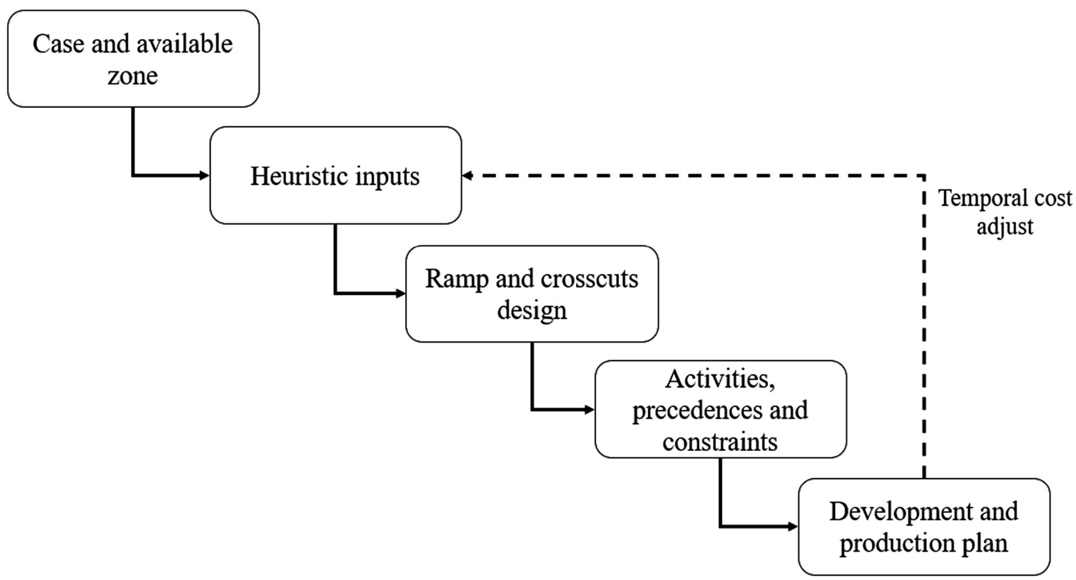



**Fig. 1.** Proposed methodology steps.

## 3 Case Study

We used a gold and silver mine which contemplated Bench & Fill method to extract the ore. The data was provided by an engineering mine company who made a pre-feasibility study, which included from geostatistical study until final economic analysis.

The mine has three exploitation zones: Y East mine, Y West lower mine, and Y West higher mine. The first zone had 26 production levels, but the design had to reach an access to 13 main drift because in these levels the drift system was implemented, which allows to access to two adjacent levels, so the number of developed tunnels can be reduced. The second zone there were 11 drifts to access; therefore, there were 22 production levels. Finally, the third zone did not have the drift system; there were 15 production levels to access directly.

The extraction method considers accessing to the mine by a shaft from surface to the bottom of each mine zone and starts to develop the ramp and crosscuts from there until the higher production level. Thus, as the development is advancing to higher production levels, the journeys are increasingly longer.

From the case study, we took two ramps and crosscuts designs base case to apply the proposed methodology. The first one is a simulation of real design and the second one is a design which seeks to minimize total cost associated without considering the time.

Tables 1 and 2 show the design parameters obtained when we used methodology with three zones of the case study. Each zone was considered independently from the others.

**Table 1.** Comparison of design parameter results in simulation case.

| | Scheduling of design obtained by simulation | Application of methodology in design obtained by simulation | Variation |
|---|---|---|---|
| Length developed [m] | 8,178 | 8,891 | +8.7% |
| Development cost [USD/ton] | 1.22 | 1.29 | +5.7% |
| Haulage cost [USD/ton] | 1.01 | 1.01 | −0.2% |
| NPV [MUSD] | 1,008 | 1,019 | +1.1% |

**Table 2.** Comparison of design parameter results in alternative case.

| | Scheduling of alternative design | Application of methodology in alternative design | Variation |
|---|---|---|---|
| Length developed [m] | 9,978 | 10,285 | +3.1% |
| Development cost [USD/ton] | 1.41 | 1.49 | +5.6% |
| Haulage cost [USD/ton] | 1.24 | 1.30 | +4.4% |
| NPV [MUSD] | 994 | 1,011 | +1.6% |

We can note that in both scenarios the use of methodology allows obtaining a better NPV of the project. In general, length developed, development cost and haulage cost increase, because the methodology makes a trade-off between length and NPV. It is a problematic situation because the increasing total cost sometimes is a difficult scenario when the investors are not willing to risk. But in other scenarios, the investors are willing to risk, and they prefer to pay more expenses in early periods and obtain better NPV of the project. This decision depends on the aim of the company and politics in the state where the project is.

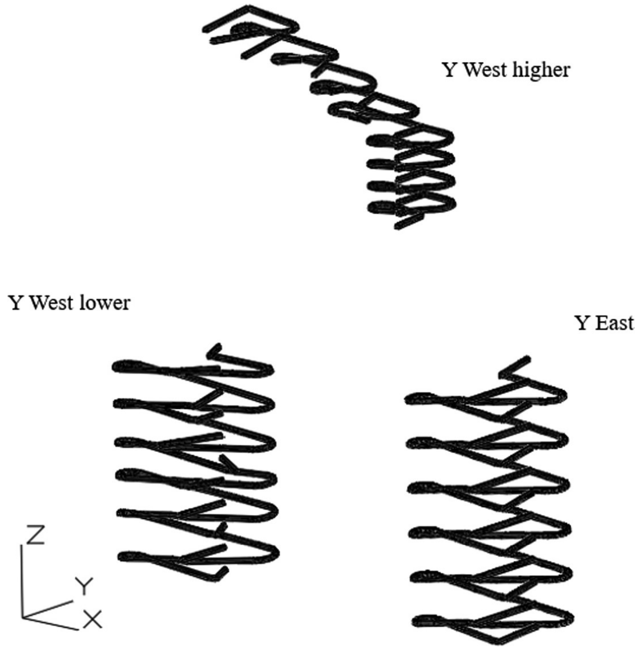
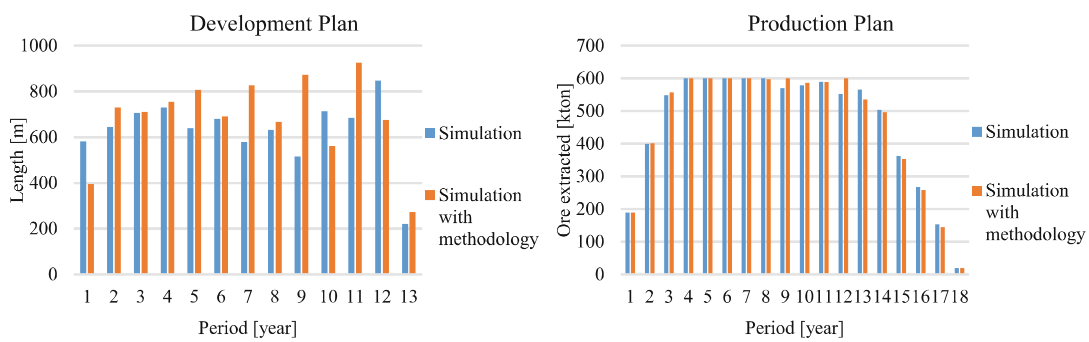
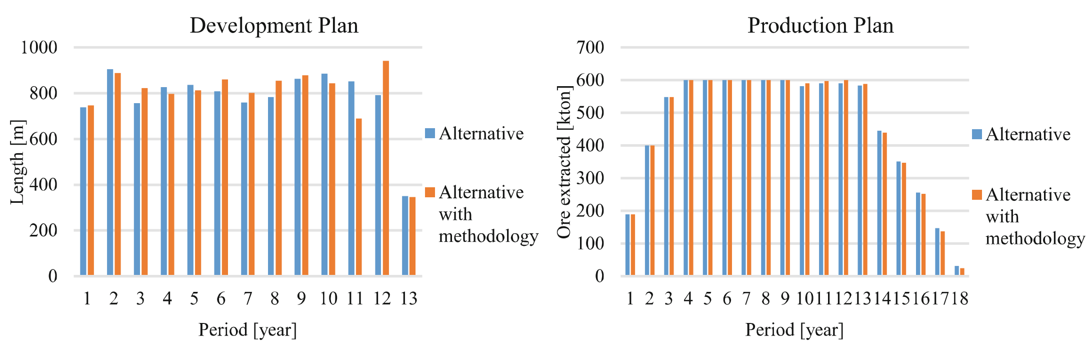



**Fig. 2.** Ramp and crosscuts configuration.




**a.** Simulation case.




**b.** Alternative case.

**Fig. 3.** Development and production plans.

An interesting observation is the second case because in the static methodology it was a good solution to minimize OPEX and CAPEX, but when we consider temporality in this analysis, the sequencing shows a different behavior because of the trade-off to obtain a better benefit.

In Fig. 2 we can note that when the design is developing upper levels, distance is increasing, and crosscuts are longer. This explains the different development plan in both cases.

Figure 3 shows the evolution in the development of ramp and crosscuts period by period. When we applied the methodology, the ramp and crosscuts configuration was different, so it allowed the change production plan because it was possible to extract more ore in previous periods. This tendency is noticed in both case and it can explain the better NPV of them.

## 4 Conclusions

The designs obtained with the proposed methodology in both cases are operative because they accomplish all operational constraints to allow equipment work and generate a possible plan to perform.

This methodology is capable to assist in designing and scheduling of the access development for the mine and shows its impact on production performance to maximize NPV. On the other hand, this tool allows to obtain results in reasonable time execution, so it is possible a comparison of alternative scenarios and makes an analysis of the advantages and disadvantages of each one.

The incorporation of the time value in this analysis to obtain a schedule of development and operation allows achieving a solution that gives a time reference to be carried out, which allows us to have more information to make decisions.

In both cases, results show that the methodology prefers to obtain better NPV despite increasing meters developed. It is an interesting analysis because while the benefit is higher, sometimes companies are not willing to pay more costs. It would be a good analysis to make in future, changing the objective function to minimize cost while a minimum NPV is required as a constraint to improve the base case.

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