PROYECTO DE LA ESCUELA DE VERANO DELPHOS 2021 – GRUPO 5

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ABSTRACT

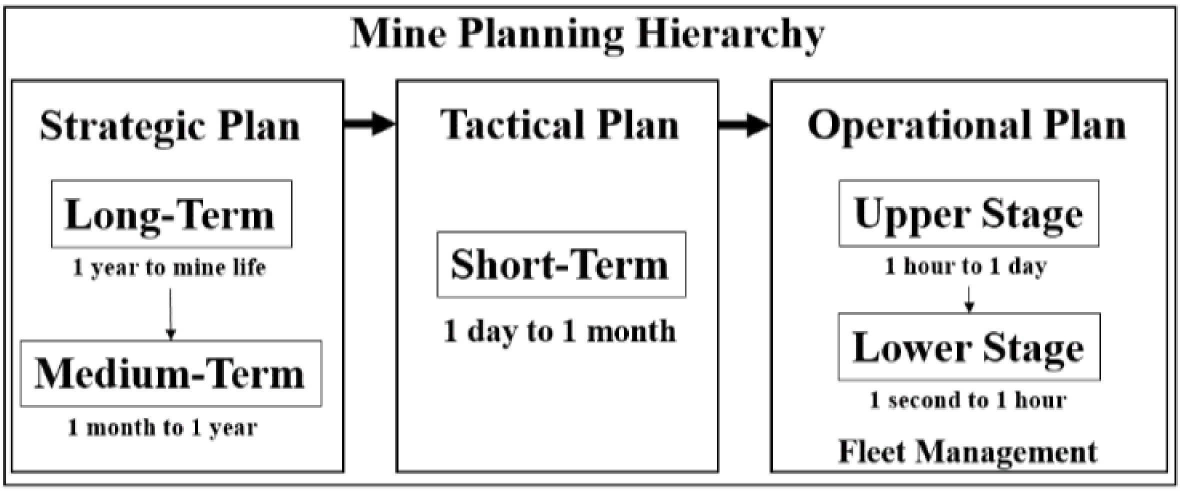
Fleets of trucks and shovels are responsible for more than 50% of the mine’s operating costs, which makes optimal utilization of truck and shovel fleet inevitable. An efficient way to assess the quality of the optimization system employed is the use of simulation, where stochastic processes governing the uncertainties underlying the material loading and haulage can be defined into a stochastic model. In this project, a pre-defined dispatch strategy is modeled and assessed in software Delphos Simulator Open Pit (DSimOP), where there are four shovels responsible for loading ore and waste, whose individual and simultaneous operation are analyzed, including the assessment of the necessary changes in fleets of each circuit aiming to attend the maximum productivity of the crusher. Operative and nominal productivity were evaluated for each scenario based on different premises, and an analysis is made comparing the performance of the circuits when considering or not failures, shift of teams and groupings of the fleet of shovels and trucks.

1 INTRODUCTION

Mining is a high risky activity, mainly due to the impossibility of having an definite geological knowledge and due to the impossibility of foresee the fluctuation prices of the commodities on stock markets, which affects widely the economic assessment and its adherence to reality. Mine planning is a fundamental stage in every mining project, whose impacts of unwise and inaccurate decisions can be dreadful to the enterprise, since the entire operation phase depends on this and on the geological modeling, activities that must be reevaluated every time new data arise. After the assumption that the long term geological model is reliable and the classification of the resources is approved, the long term mine planning team has the challenge of consider all the factors that can potentially restrict the economic extraction of the metals of interest, such as technical, social, legal, economic, environmental and financial constraints to classify the reserves [1, 2].

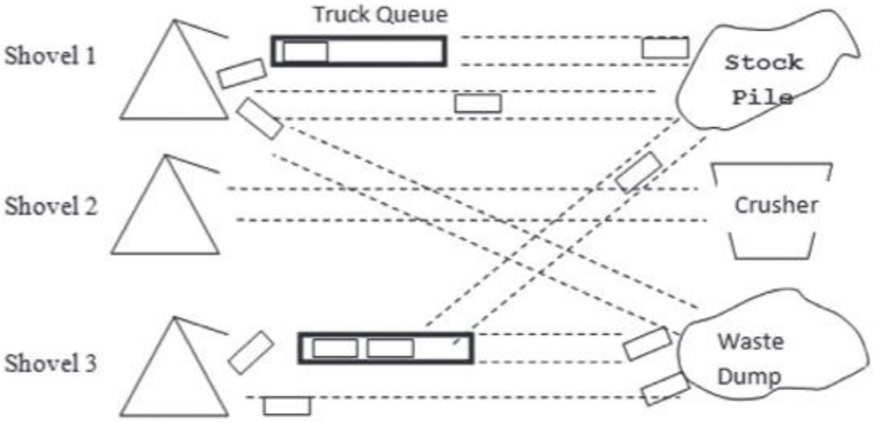
In a simplistic perspective, most practitioners would aim the maximization of the net present value (NPV) in long-term scenarios with different schedules, pushbacks, cut-off grades, ultimate pit shells and stockpiles attached to assumptions about orebody tones and grades, processing methods and costs, sales volume, commodity prices and discount rates. Tactical mine planning provides more detailed information that allows for an accurate design of extracting ore from a special area of the mine or information that would allow for equipment replacement. On the other hand, operational mine planners have a duty to maintain the mine's adherence to the long and medium-term plan, while aiming to meet production, processing and economic constraints in a daily time horizons. **Fig.1** presents a scheme of mine planning stages in surface mines [3-6].

Fig.1 - Stages of mine planning in surface mines [6]



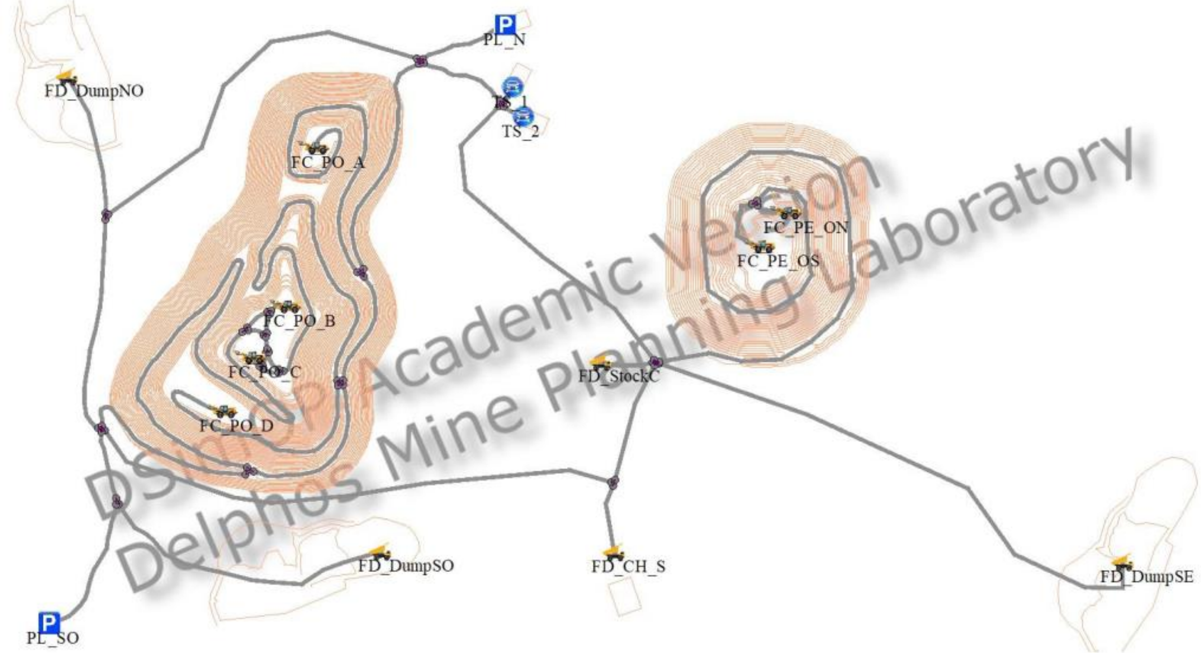
Fleets of trucks and shovels are the most widely used material handling systems in mining operations, accounting for more than 50% of the mine's operating costs. Truck fleets, in turn, consume about 30% of the energy required in a surface mine and are a primary source of greenhouse gas emission. The aforementioned issues are reasons enough to make optimal utilization of truck and shovel fleet inevitable. Based on long-term mine production schedule, the fleet management system's upper stage itself is the second stage in short-term schedule, whilst the first is the optimization of the material extraction sequence. The fleet management system evolved from manual to semi-automated systems in early 1970's, and to fully-automated computer-based systems in late 1970's, which have the ability to directly assign the trucks to task, handling a large amounts of information in a short time frame. The dispatch systems are based on different mathematical optimization concepts, incorporating heuristics, mixed integer linear programming, artificial neural networks, among other strategies, and common constrains are truck assignments (to a shovel or to a destination), minimizing truck and shovel waiting times, maximizing truck momentary productivity, minimizing shovel saturation and deviation from shovel production target. **Fig.2** presents a scheme of truck and shovel operation [6-12].

Fig.2 - Schematic of truck and shovel operation [13]



An efficient way to assess the quality of the system designed is the use of simulation, where stochastic processes governing the uncertainties underlying the material loading and haulage can be defined into a stochastic model, based on the random processes underlying the network-continuous-discrete event nature of the mining operation. In this project, for a given mine layout as shown in **Fig.3**, a pre-defined dispatch strategy is modeled and assessed in software Delphos Simulator Open Pit (DSimOP), developed and maintained by Delphos Mine Planning Laboratory, from *Universidad de Chile*. The loading fronts considered in the analysis are FC_PO_A, FC_PO_B, FC_PO_C and FC_PO_D; the dumping fronts are FD_DumpSO and FD_DumpNO; the parking lots are PL_N and PL_SO, while the truck shops are TS_1 and TS_2; finally, the crusher is located in FD_CH_S, while the stockpile is in FD_StockC [13].

Fig.3 - Mine layout with topography, with loading and dumping fronts, truck shops, parking lots, a crusher and a stockpile



2 METHODOLOGY

On the dumping front FD_CH_S there is a crusher with a capacity of 10,000 t/h, which is assumed to have no scheduled maintenance or failures. All simulations were run considering 24 hours of operation, and since the project does not aim the fuel consumption analysis, the default values of the software will be used. The loading capacity assumed for the trucks is 280 t, being necessary 174 s to accomplish the loading. The truck dumping time was estimated at 54 s, while the time required for maneuver (loaded or empty) was considered to be 40 s. Double queues were also considered at both loading and dumping points, and the availability of trucks and shovels (when required) is equivalent to 82% and 80%, respectively. We also considered (when required) two stops for changing teams and two other breaks for snacks, all lasting 65 min. **Tables 1** and **2** present, respectively, the assignments for each group of shovel and trucks and the speed layout for trucks.

Table 1 - Assignments for each group of shovel and trucks

Load equipment	Loading front	Dumping front	Type of material
Shovel 1	FC_PO_A	FD_DumpNO	Waste
Shovel 2	FC_PO_B	FD_CH_S	Ore
Shovel 3	FC_PO_C	FD_CH_S	Ore
Shovel 4	FC_PO_D	FD_DumpSO	Waste

Table 2 - Speed layout for haulage trucks

Truck state	Descend (Km/h)	Horizontal (Km/h)	Climb (Km/h)
Full	24	16	12
Empty	39	30	25

Finally, there are four options for managing the dispatch system, all aimed at meeting the primary objective of shovels with allocation by neighborhood, although some have additional criteria. Option 1 directs all reserve trucks at random to the available shovels after the primary objective has been met; option 2 defines a secondary objective aimed at stopping the shipment of trucks after the shovel is saturated; option 3 directs all reserve trucks at random to the available shovels even after the saturation criterion is met. Considering that the designation of reserve trucks is unnecessary when the primary and/or secondary criteria have already been met, option 2 was used to manage the dispatch system.

The first assessment aims at the maximum productivity of each individual circuit consisting of a shovel, assigned to dumping and loading fronts, and the assigned number of haulage trucks. Maintenance, failures or intervals were not considered in this assessment, whilst the number of trucks that saturate each circuit was verified, along with the productivity of each circuit, the average waiting times for loading and dumping, and the utilization factors of shovels and fleets. The second assessment aims at defining the configuration that maximizes the productivity of all circuits operating together for the same premises, which includes a comparison between the productivity of the individual circuits and the simultaneous scenario, which was reevaluated after defining the optimum number of haulage trucks to increase the global ore productivity. The third and final assessment aims to include operational factors such as failures, shift of teams and groupings of the fleet of shovels and trucks to the simultaneous scenario, with a comparison between the productivity of this scenario and the previous one, in addition to obtaining factors such as availability, utilization, etc.

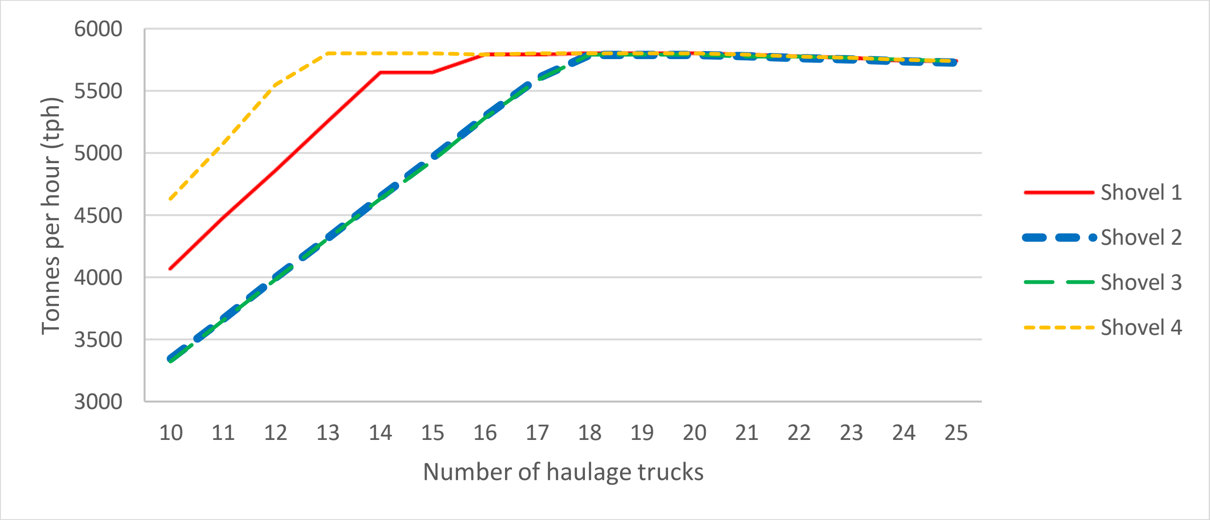
3 RESULTS

When analyzing the productivity of each production circuit (**Table 1**) independently according to the number of haulage trucks used, it was possible to verify that the ideal quantities of trucks for shovels 1 to 4 (saturation number) are 16, 18, 18 and 13 units, respectively, as shown in **Fig.4**, which presents circuit productivity according to the number of haulage trucks. **Table 3** presents, in turn, for the number of haulage trucks considered as optimal for each circuit, the maximum productivity per day (t), the average productivity (t/h), the average waiting time at the loading (min) and the utilization factor of the truck fleet (%). All average waiting times at dumping fronts are zero, and the utilization factors of the shovels are 100% on all circuits. The average productivity evaluated disregarded the first and last hours, which would introduce bias to the assessment.

Table 3 - Indicators of the individual simulated production circuits

Individual circuits indicators	Shovel 1	Shovel 2	Shovel 3	Shovel 4
Average productivity (t/h)	5,790.91	5,790.91	5,790.91	5,803.64
Average waiting time at the loading front (min)	4.60	1.26	0.99	1.15
Utilization factor of the truck fleets (%)	90.87	97.76	98.24	97.24

Fig.4 - Circuit productivity according to the number of haulage trucks



On the other hand, the second analysis consider the effect of a simultaneous operation of all circuits, which affect the productivity as presented in **Fig.5**, where it is highlighted that the circuits whose destination is the crusher are affected by approximately 13%, whilst circuits whose destination is dumping fronts have undergone few or no changes when all circuits operate simultaneously. **Table 4**, in turn, shows simultaneous simulated production circuits indicators, where the maximum productivity per day, the average productivity, the average waiting time at the dumping front and the utilization factors of shovels and truck fleets changed when comparing to **Table 3**, mainly in circuits 2 and 3, whose destination is the crusher. Average waiting time at the loading front reduced in this new configuration.

Fig.5 - Comparison of productivity between circuits operating individually (purple) or simultaneously (blue)

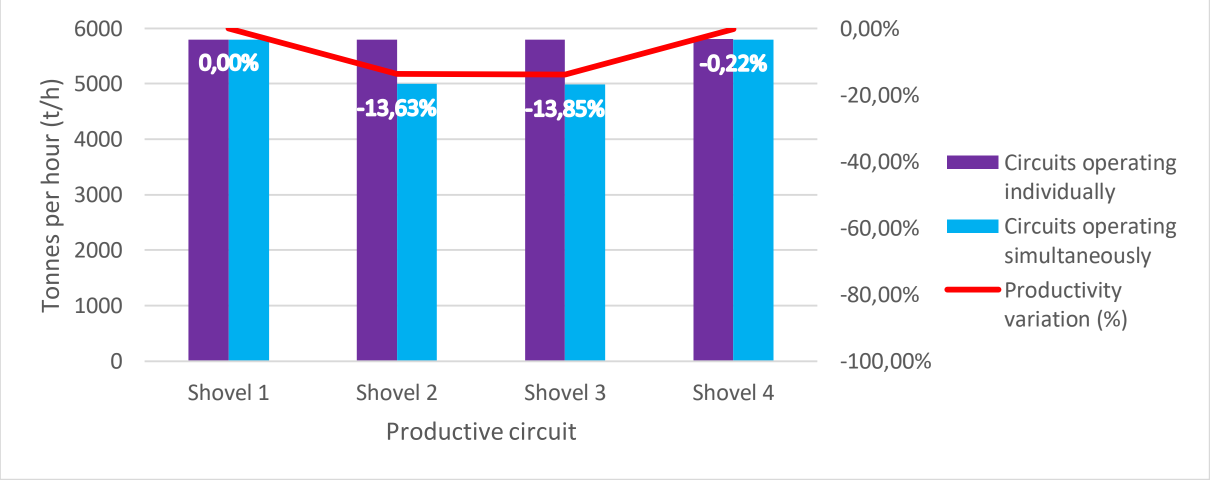


Table 4 - Indicators of the simultaneous simulated production circuits

Simultaneous circuit indicators	Shovel 1	Shovel 2	Shovel 3	Shovel 4
Average productivity (t/h)	5,790.91	5,001.82	4,989.09	5,790.91
Average waiting time at the loading front (min)	4.60	0.00	0.00	1.16
Average waiting time at the dumping front (min)	0.00	9.38	9.13	0.00
Utilization factor of the shovels (%)	99.97	86.85	86.74	99.79
Utilization factor of the truck fleets (%)	90.87	85.43	85.83	97.21

Whereas the optimum individual circuit configurations do not represent the optimum global operation, new simulations were run to identify by perturbation the optimum number of haulage trucks in each circuit, in order to maximize the crusher's productivity. The systems whose destination where the dumping fronts (shovels 1 and 4) were maintained, while those whose destination was the crusher (shovels 2 and 3) had their number of trucks combined from 16 to 18 units. It was observed that the global optimum configuration of the system is the obtained in Simulation 4, consisting in 16, 17, 17 and 13 units for each circuit respectively, whose total is 63 haulage trucks, which provided 21,598.18 t/h of productivity, as shown in **Table 5**.

Table 5 - Productivity provided by each set of trucks iterated by disturbance, aiming at maximizing crusher productivity.

Iteration	Shovel 1	Shovel 2	Shovel 3	Shovel 4	Total number of trucks	Productivity (t/h)
Simulation 1	16	18	18	13	65	21,572.73
Simulation 2	16	17	18	13	64	21,585.45
Simulation 3	16	18	17	13	64	21,585.45
Simulation 4	**16**	**17**	**17**	**13**	**63**	**21,598.18**
Simulation 5	16	16	17	13	62	21,585.45
Simulation 6	16	17	16	13	62	21,585.45
Simulation 7	16	16	16	13	61	21,572.73

From the definition of the optimum number of haulage trucks in each circuit it was possible to compose **Table 6**, which shows a reduction in the average waiting time at the dumping front and an increase in the utilization factor of the shovels for circuits 2 and 3 when comparing to **Table 5**, which explains the increase in the ore delivered to the crusher. With this configuration, there is a maximum productivity per day of 246,680 t/h of ore and 618,520 t/h of waste.

Table 6 - Simulated corrected production circuit indicators simultaneously

Corrected simultaneous circuit indicators	Shovel 1	Shovel 2	Shovel 3	Shovel 4
Average productivity (t/h)	5790.91	5154.55	4874.55	5790.91
Average waiting time at the loading front (min)	4.59	0.00	0.00	1.16
Average waiting time at the dumping front (min)	0.00	6.21	6.00	0.00
Utilization factor of the shovels (%)	100.00	86.68	86.54	99.77
Utilization factor of the truck fleets (%)	90.87	89.85	90.20	97.21

The third analysis consists of reevaluating the corrected simultaneous circuit including failures, changing teams and fleet groups, by including 82% and 80% availability for trucks and shovels, respectively, and stops for changing teams and other intervals, each lasting 65 min.. **Fig.6** presents the comparison of productivity between corrected simultaneous circuits considering maintenance, failures and breaks (blue) or not (purple), where is possible to realize that there are losses of productivity in order of 23.30%, 28.81% and 10.70% in dumping fronts FD_DumpNO, FD_CH_S (crusher) and FD_DumpSO, respectively. **Table 7**, in turn, shows simultaneous simulated production circuits indicators when considering stops and failures, where the average waiting time at loading fronts tends to increase due to shovel failures, and the average waiting time at dumping fronts may decrease if many trucks failure too. The utilization factor of shovels decreased, but the utilization factors of truck fleets increased, which is a result unexpected. With this configuration, there is a maximum productivity per day of 157,360 t/h of ore and 196,840 t/h of waste. **Fig.7**, finally, presents operational indexes of simultaneous circuits considering stops, as availability, operational utilization, effective utilizations, and utilization on nominal and available basis.

Fig.6 - Comparison of productivity between corrected simultaneous circuits considering maintenance, failures and stops (purple) or not (blue)

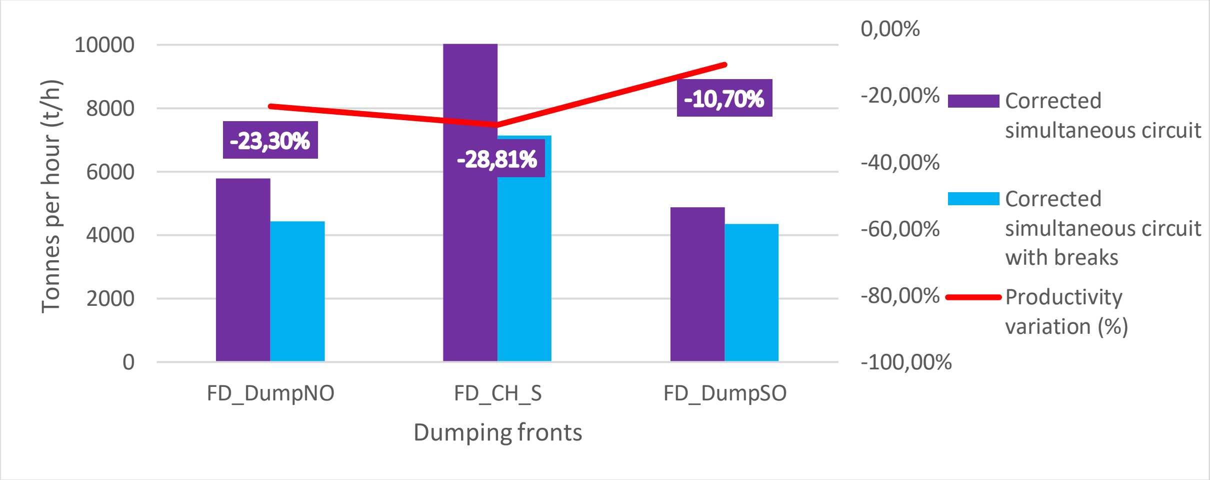
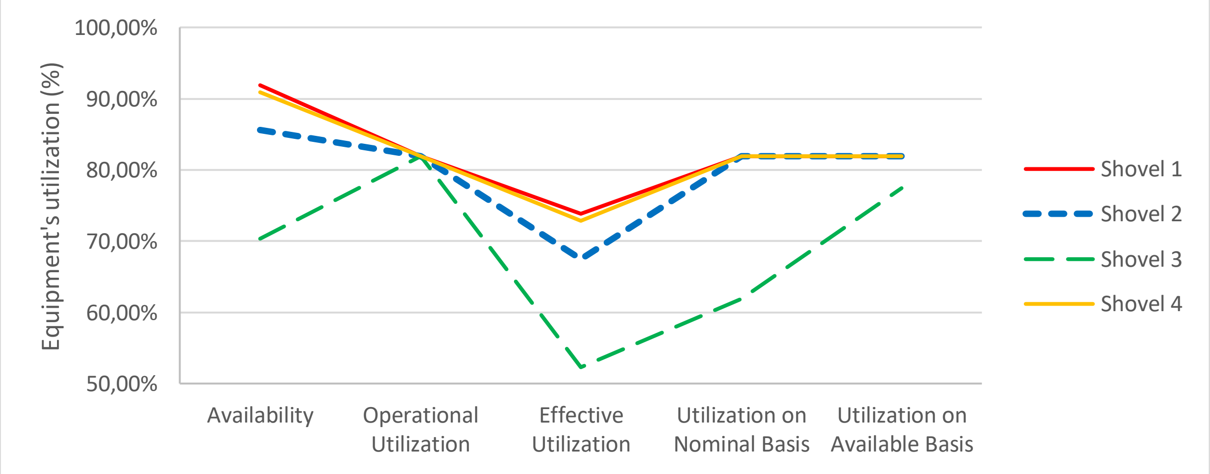


Table 7 - Indicators of the simultaneous simulated production circuits with stops

Productivity indicators for circuits with stops	Shovel 1	Shovel 2	Shovel 3	Shovel 4
Average productivity (t/h)	4441.82	4047.27	3092.73	4352.73
Average waiting time at the loading front (min)	3.85	2.68	3.34	1.29
Average waiting time at the dumping front (min)	0.00	2.24	2.63	0.00
Utilization factor of the shovels (%)	90.15	82.39	84.46	88.9
Utilization factor of the truck fleets (%)	92.24	91.78	90.24	96.91

Fig.7 - Operational indexes of simultaneous circuits considering stops



4 CONCLUSION

Due to the importance of the correct dimensioning of the loading and transport equipment fleets, which correspond to more than 50% of an open pit mine's operating costs, the possibility of carrying out this project represents a differential in the career of the participants of *Escuela de Verano Delphos*. Through the use of software Delphos Simulator Open Pit (DSimOP). In first evaluation, four production circuits composed of shovels and trucks were independently evaluated in discrete simulations regarding productivity, utilization and waiting times. In second evaluation, as the circuits operated together, the number of trucks was readjusted and all indexes were obtained again. Finally, in third evaluation, the stops and failures were considered, and new indexes were introduced in the assessment. It was the group's intention to still execute part D of the project, however due to the restricted time and the failures that the DSimOP software presented (even not showing reliable results on some computers), we had to be content with parts A, B and C.

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APPENDIX 1 - COMPLEMENTARY TABLES AND GRAPHICS, REFERRING TO PART A OF THE PROJECT.

Fig.A1 - Circuit productivity according to the number of haulage trucks (bars graph)

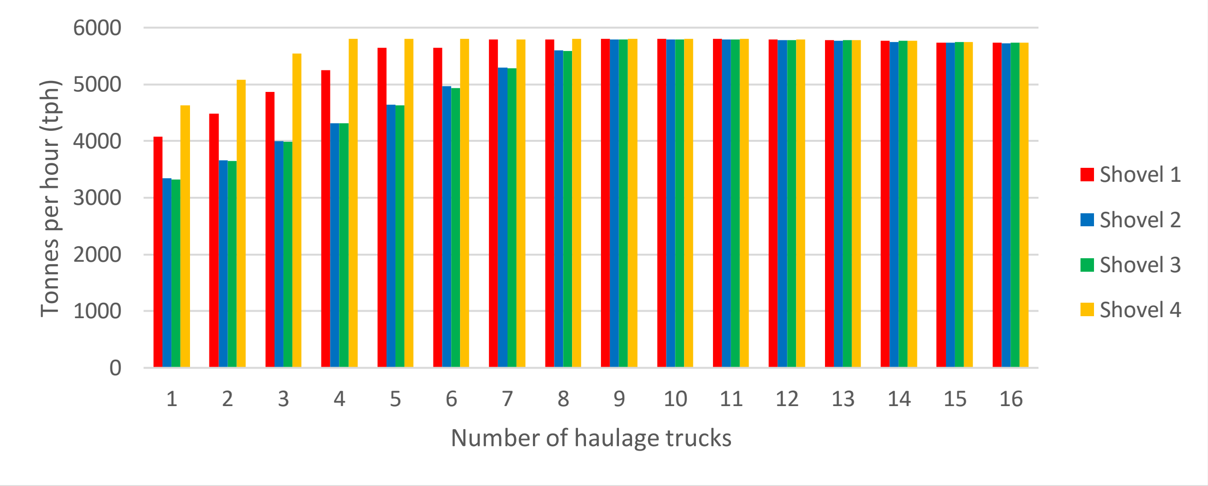


Fig.A2 - Average waiting time at the loading front (min)

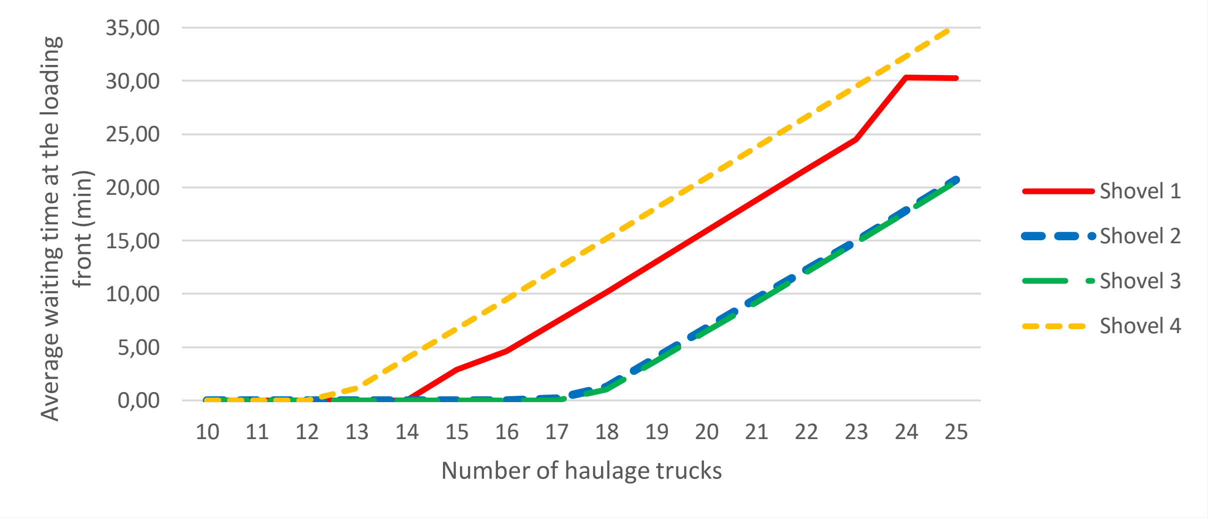


Fig.A3 - Average waiting time at the dumping front (min)

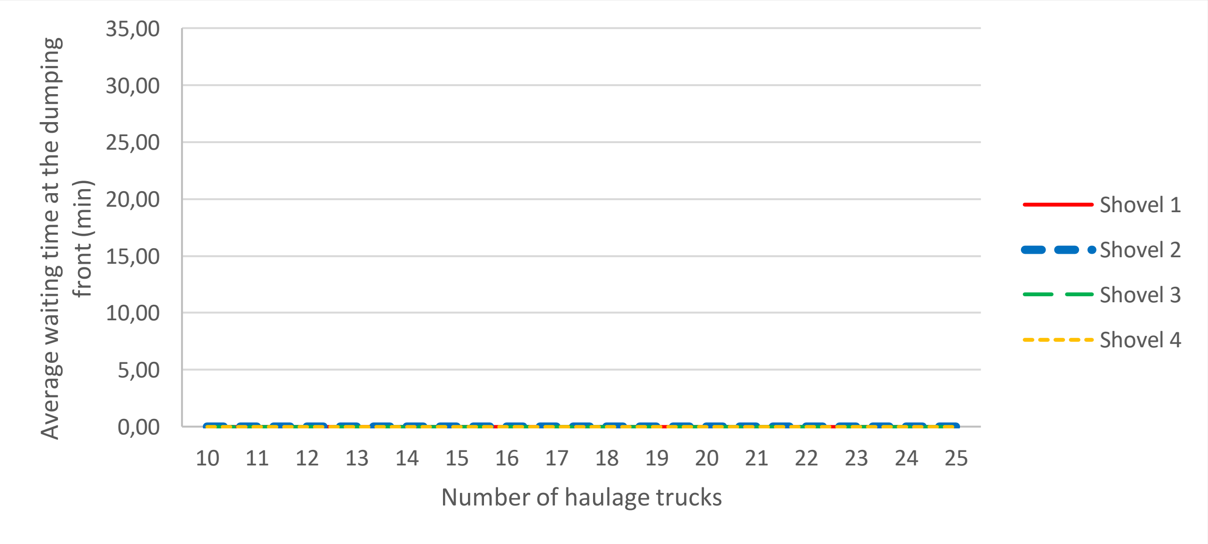


Fig.A4 - Shovel's utilization factor (%)

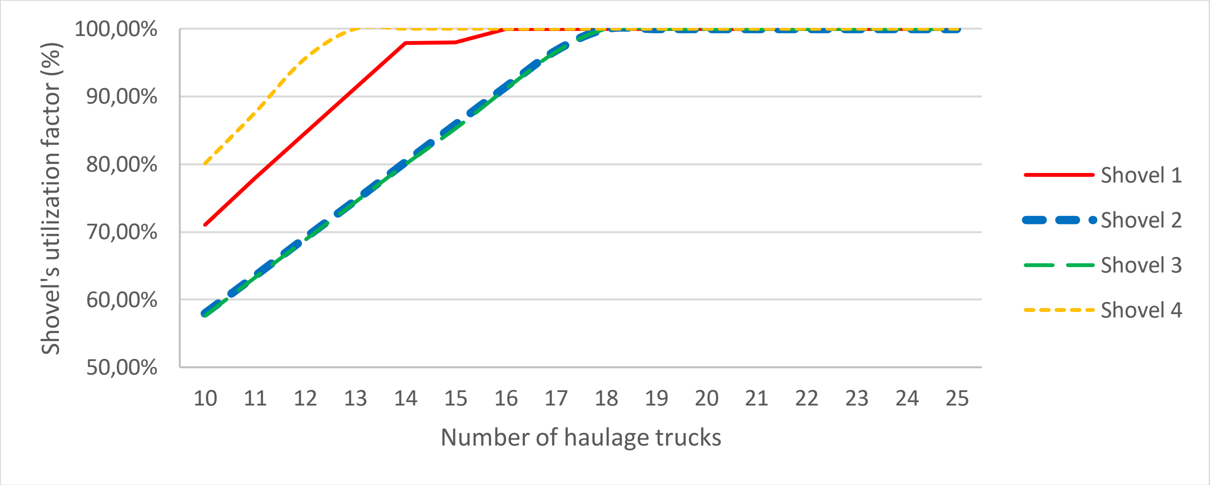
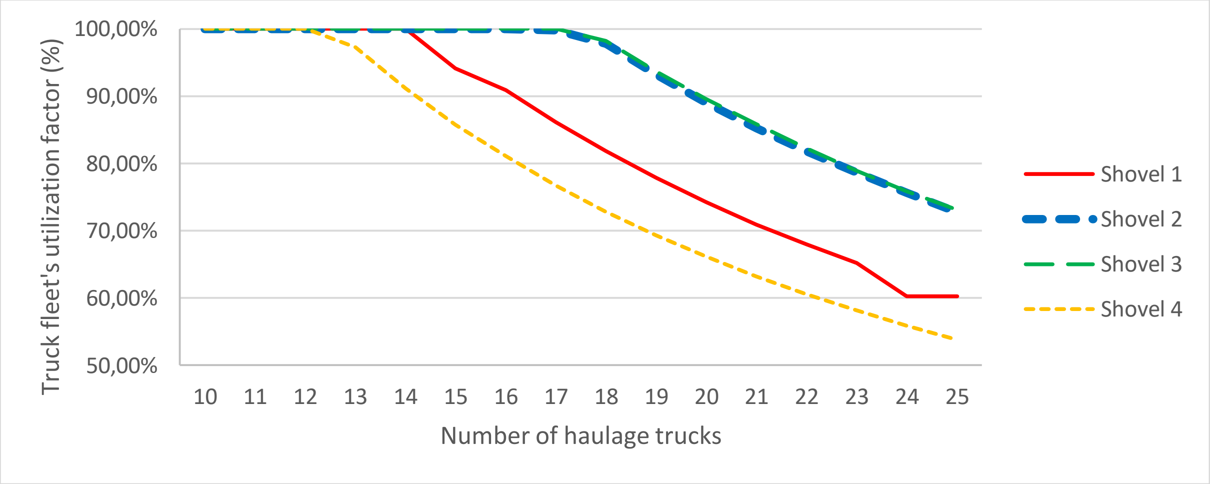


Fig.A5 - Truck fleet's utilization factor (%)



APPENDIX 2 - COMPLEMENTARY TABLES AND GRAPHICS, REFERRING TO PART B OF THE PROJECT.

Fig.B1 - Average waiting time (min) at loading and dumping fronts of the corrected simultaneous circuit

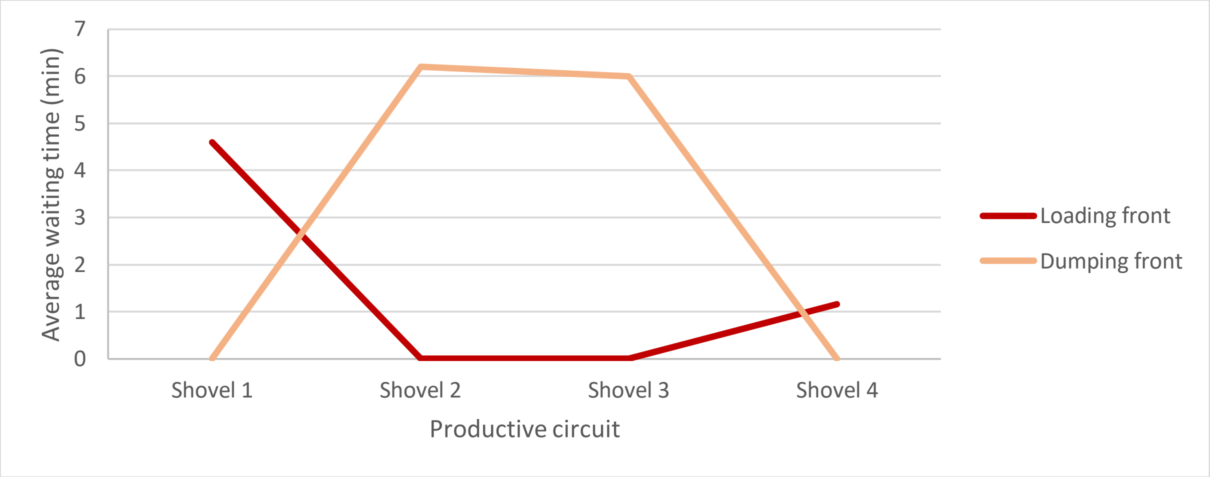
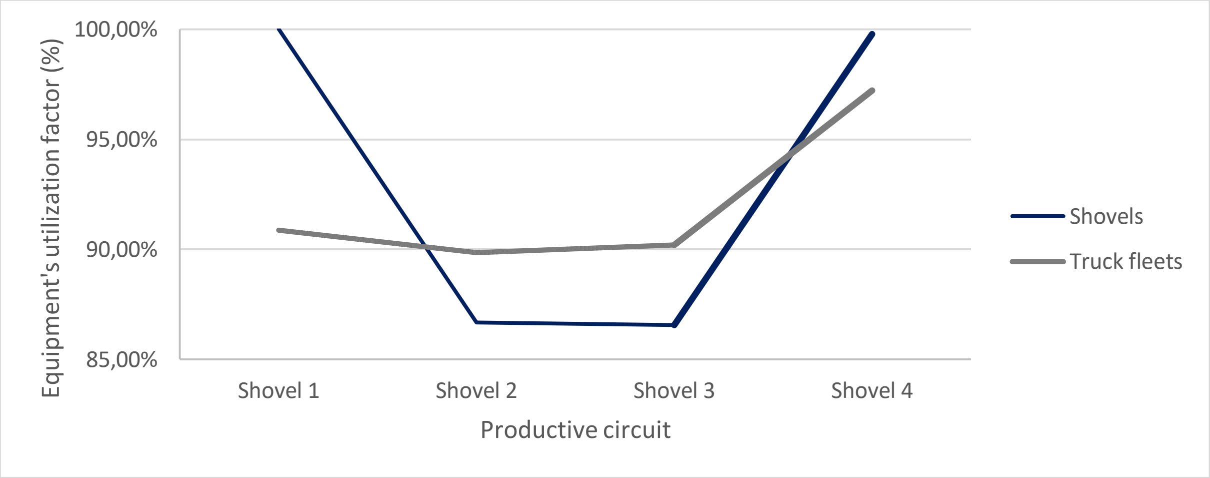


Fig.B2 - Equipment's utilization factor (%) of the corrected simultaneous circuit



APPENDIX 3 - COMPLEMENTARY TABLES AND GRAPHICS, REFERRING TO PART C OF THE PROJECT.

Fig.C1 - Average waiting time (min) at loading and dumping fronts of the corrected simultaneous circuit with breaks

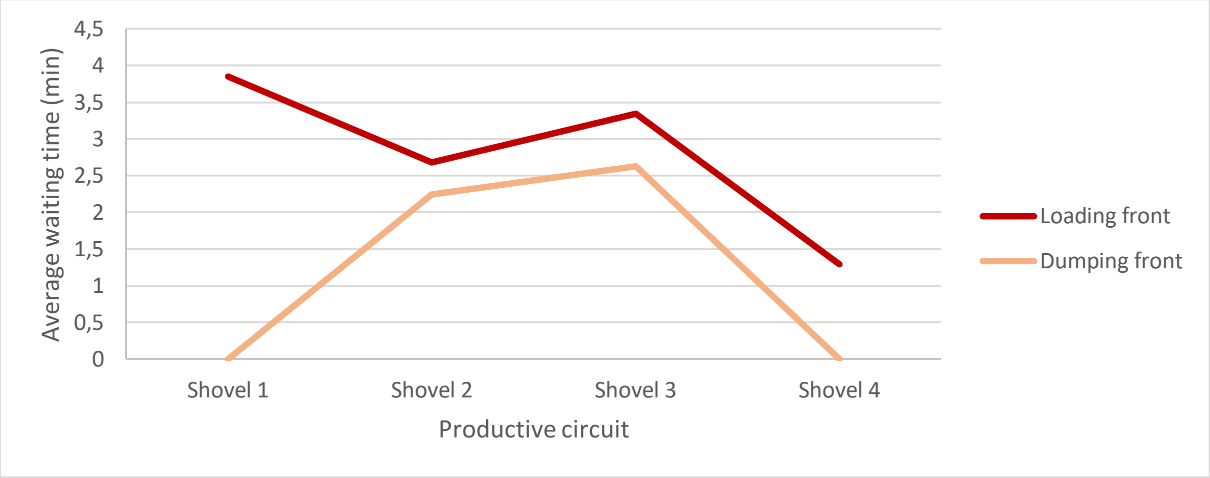


Fig.C2 B2 - Equipment's utilization factor (%) of the corrected simultaneous circuit with breaks