Extended Abstract

Monitoring and Management of Mining Operations in an Underground Mine at Garpenberg Mine, Sweden

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Abstract

Currently, there is growing concern about the way in which a mineral mass or deposit is explored. Nowadays, a correct analysis of extractive capacity is increasingly important for the success of a mining enterprise. With the increase in production objectives and the competitiveness of the global market, there is also an increase in the need for control and production management through its monitoring and optimization.

The case study presented throughout this dissertation corresponds to the Garpenberg mine, located in the municipality of Hedemora in Sweden, which is part of a group of mines belonging to the company New Boliden AB.

The study that will be presented throughout this document addresses the area of Geological and Mining Engineering, more precisely, mine and strategic planning through the study and calculation of KPI's related to the management of mining equipment. Thus, the GanttScheduler software was used in order to analyze the daily production of the equipment and to calculate the respective rates, averages and work cycles.

This study proposes an analysis of the extractive capacity of the mine in order to support the planning department in a better management of mining equipment.

Through this study it is possible to show the importance of constant monitoring and follow-up of work in real time. The results of this study allow us to realize that the availability of the equipment is not equal to its use. There are performance losses associated with work and mechanical stops that condition the use and availability of the equipment. Understanding this dynamic results in a better job management and equipment usage policies. The calculation of work rates is essential in this analysis because they represent the effective rate that the jobs require.

In short, it was possible to conclude that the monitoring of equipment depends on a high set of variables, and its estimate is essential for a correct assessment of the quality of operations and the feasibility of associated management decisions.

Keywords: Optimization, Efficiency, Equipment Management, Mining Equipment, Mine Planning

1. Introduction

In the mining industry, the non-renewable nature of mineral resources, forces companies to continuously seek to optimize their operations. With technological advances and digital transformation, new opportunities for its optimization and cost reduction appear.

Although almost all mining companies perform optimization with varying degrees of precision, very few actually see the real benefit of optimizing best practices. By understanding the operation of the mine at a deep level, it will be possible to analyze where the problems are in the operation of the mine and how to unlock the ideal solution that consequently generates its optimization. Mine optimization is a comprehensive exercise. It allows to identify variations between 'optimal' or 'ideas' and 'real' measures, consistently testing the robustness of each component in the industry. (DekaDynamics, 2018)

Mining machinery and equipment is a fundamental part of the industry, both economically and productively. The reality of industrial competitiveness and equipment complexity, currently experienced by companies, raises the importance of their management and optimization, becoming an essential factor in improving the quality and productivity of organizations. To this end, by betting on its innovation and continuous improvement, it is possible to extract maximum performance from the equipment, resulting in an increase in the quality of the production process.

The main reasons that drive the optimization of mining equipment performance are:

1) Understand the movement of machinery in operation; 2) Develop metrics to monitor the accuracy of the data used in the reports; 3) Improve productivity; 4) Economic profitability; 5) Minimize downtime;

Within the scope of this study it is intended to improve the productivity of mining equipment through more efficient management. Improving productivity has become an important goal for the current mining industry in the race to increase competitiveness. The only way to achieve the desired improvement is to reduce production costs, improving equipment productivity, efficiency and effectiveness. This study aims to identify the various factors and problems that affect the productivity of mining equipment in an underground environment and propose appropriate measures to improve them. As such it is expected:

1) Determine work rates (efficiency, utilization rate and types and stop times)
2) Assess possible improvements in order to bring the actual indexes closer to the planned ones.

2. Garpenberg Mine

In 1957 the company Boliden acquires the Garpenberg mine, located in the municipality of Hedemora. It is one of the oldest mining areas in the country. Thanks to the efforts made by the prospecting team, the main deposit at Lappberget was discovered in the late 1990s, which prevented its closure and in 2011 the financial decision was made to significantly expand the mine's capacity. In 2014 the new facilities are inaugurated and the Garpenberg mine is labeled as the company's second largest investment. Today Garpenberg is considered one of the most modern mines in the world, with an annual production of 2.6 million total tons, considering all the products and by-products explored, which are: zinc, copper, lead, gold and silver, and a leading technological investment worldwide. (Westling, 2018)

Garpenberg consists of eight deposits (Finnhyttan, Kyrkan-Tyskgården, Dammsjön, Kvarnberget, Lappberget, Kaspersbo, Huvudmalmen and Gransjön), of which only four are active and currently being explored (Dammsjön, Kvarnberget, Lappberget and Kaspersbo). The Dammsjön deposit is in the pre-exploration phase and is already being planned for 2021. (Figure 1)

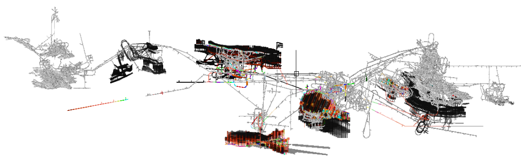

Figure 1 - Geographic layout of Garoenberg Mine deposits. (Source: PrintScreen of Deswik Software application)

The exploitation method initially used was the CUT and FILL, but since 2014, according to the geology present in the mine and its geotechnical characteristics, a transition has started, with the Sub-Level Stoping method with transversal stopes, which, today, is the predominant method. The main reasons for the change were: verticality of the deposit (~ 85 degrees), high economic profitability as the operational costs involved in this dismantling are relatively low when compared to the CUT-and-FILL (although it involves several stops that are associated with the process installation of screws/cables in the ceiling, in order to guarantee the stability of the access and the safety of the operators), high performance in terms of time and contractual terms, greater security and greater use of the deposit. The dismantling sequence is divided into primary and secondary stopes with the following dimensions: primary stopes (width: 10m, height: 25m) and secondary stopes (width: 15 / 20m, height: 25m). (Figure 2)

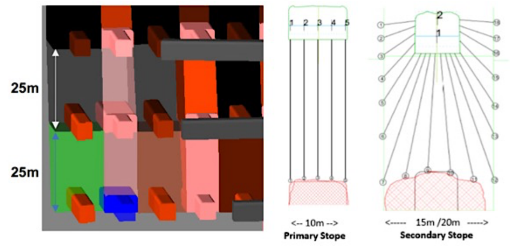

Figure 2 - Primary and Secondary stopes measures. (Source: Deswik software application printscreen)

Due to stability factors, the stopes are explored alternately and by levels from the bottom up, that is, for each three levels of primary stopes, a level of secondary stopes is removed, resulting in a V-shaped dismantling sequence redirecting the induced stresses in the rock to the outer sides of the deposit. (Figure 3)

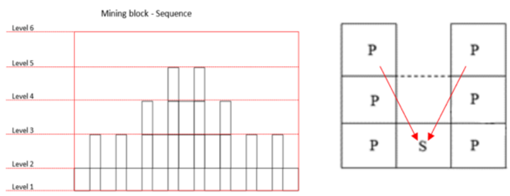

Figure 3 - 'V' shaped disassembly sequence. (Source: Printscreen of Computer Application)

The removal operation is performed by remote control of mining shovels. After the removal operation, the stopes are filled with Paste Fill.

The main characteristics of Paste Fill are (Ercikdi, 2017): a) Use of total rejects; b) Significant reduction in the deposition of tailings on the surface; c) Greater mechanical resistance; d) Better recovery of exploited mineral reserves; e) Reduction of the ore dilution and working cycles;

After filling the stopes, it is necessary to check the stability, as there may be a lack of contact between the walls of the chamber and the filling paste. Although this method allows exploration with good productivity rates, it may compromise the stability of the next stope, due to the absence of tightfill. This phenomenon is frequent in cases where the filling pipeline runs through large spans with significant heights. (Murch, 2018)

3. Methodology

The methodology applied in the present study is divided into five main parts. The first part is the classification of activities. In accordance with the purpose of this dissertation, the following categories were chosen: Effective Work, Mechanical Stops, Lunch, Meetings, Lack of Front Conditions, Lack of Services, Lack of Material, Priority Activities and Others. The second part is the calculation of 'times': Total Working Time, Planned Production Time, Production Time or Availability and Time of Use or Use. (Figure 4)

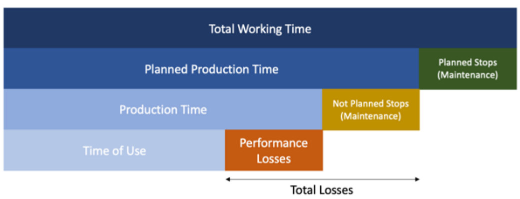

Figure 4 - Diagram of: Equipment's Use. (Source: Elaborated by the author)

The third part is the calculation of performance losses. The fourth part is the calculation of work rates and, finally, the fifth part consists of a statistical analysis of the data obtained in order to analyze interdependence relationships between the data obtained.

Classification of Activities

After conducting a survey of existing information related to previous years and data stored in the GanttScheduler software, the activities are classified and allocated to categories. Using an existing filter system in the program it is possible to make this allocation.

Calculation of 'Times'

To calculate the various types of times recorded in this study, the Excel software was used, namely the Pivot Table tool and the following mathematical functions provided by the program: sum, averages and elementary arithmetic operations.

Performance Losses

The calculation of Performance Losses consists of the difference between Production Time and Usage Time. The analysis of this parameter allows us to conclude about the origin of these 'losses', that is, if the equipment is effectively stopped 'in Standby' for lack of work fronts or if there is another dominant reason that leads to the destruction of the equipment. If there is another reason, for example, we can conjecture hypotheses about poor management of equipment and/or operators or poor work planning, among other reasons.

Work Rates

Productivity rates are used by planning as an estimate of the expected rate for the following year. The work rate corresponds to the division between production and the actual work time reported for each category of equipment.

Statistical analysis

In order to understand behavior patterns or trends in the use of the equipment considered, a brief statistical analysis will be carried out on the results obtained. The analyzes considered were the Univariate Descriptive Analysis and the Multivariate Descriptive Analysis, namely, the Principal Component Analysis.

Univariate Descriptive Analysis

The Univariate Descriptive Analysis is the simple form of inference and description of the statistical analysis, where there are no causes or relationships, consisting of the individual analysis of the data, in order to describe and synthesize the most important parameters, in order to understand which ones are the characteristics and trends of the data. For the description of the variables, the mean, the median, the minimum value, the maximum value, quartiles and percentiles were used as measures of central tendency. As dispersion measures, variance and standard deviation.

Principal Component Analysis

Principal Component Analysis allows finding the factors that best explain the similarities and oppositions between individuals and variables. These factors, ranked in decreasing order of their importance for the explanation of the starting table, constitute a system of orthogonal axes where it is possible to visualize, in graphical form, the projections of the constituents of the data matrix. The interpretation of the graphs is based on a set of simple and clear rules, showing the most significant relationships in the input tables. (CVRM - IST Geosystems Center, 1989-2002)

4. Results and Discussion

According to the methodology adopted, in determining the Total Working Time it is necessary to make the following considerations: 1) Shift Time: 10h; 2) Shifts per year: 730 shifts; 3) Ascent time: 30min (0.5h); 4) Descent time: 30min (0.5h); 5) Work pass: 15min (0.25h); 6) Lunch/Meal: 45min (0.75h); 7) Pauses: 15min (0.25h);

Based on the above, subtracting the respective considerations, a shift makes a Total Working Time of: 7: 45h

Total Working Time (per year) = 5657: 30h

Figure 5 shows the time distribution of the components that constitute a shift.

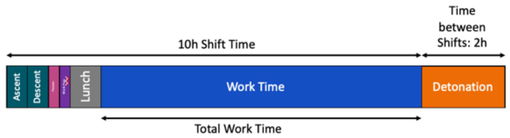

Figure 5 - Temporal distribution of components present in a 10h shift. (Source: Elaborated by the author)

The following figures (from figure 6 to figure 13), represent, in an intuitive and summarized way, the parameters calculated in percentage in order to be able to compare.

As it is possible to analyze, there was a better management of this type of equipment. Standby time periods decreased significantly, equipment utilization increased, and mechanical stops decreased. (Figure 6 and 7)

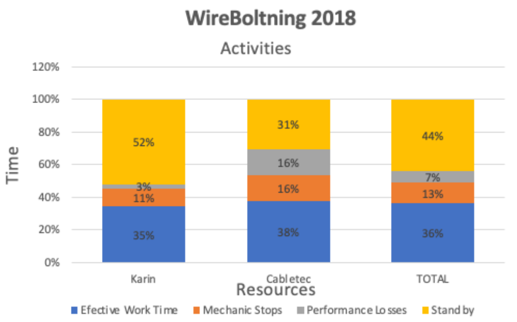

Figure 6 - Equipment Mapping: WireBoltning | Year: 2018

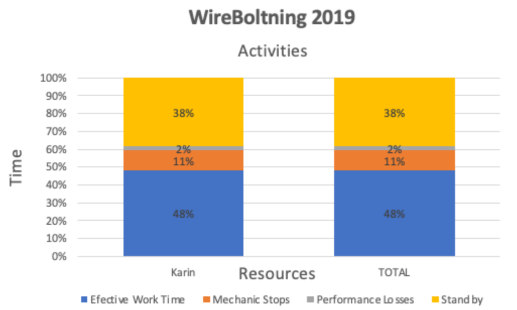

Figure 7 - Equipment Mapping: WireBoltning | Year: 2019

In this type of equipment, standby periods have increased, mechanical stops have decreased, but usage has also decreased. (Figure 8 and 9)

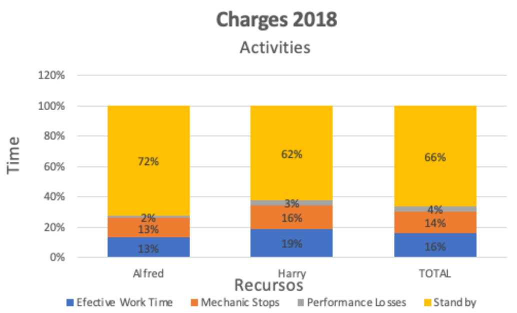

Figure 8 - Equipment Mapping: Charges | Year: 2018

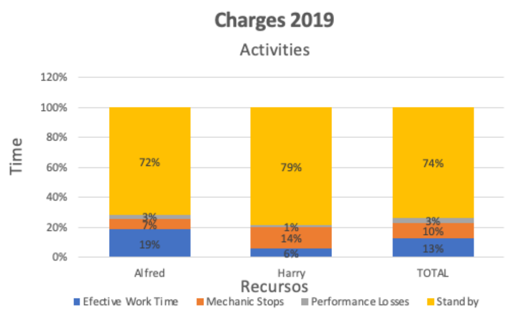

Figura 9 - Equipment Mapping: Charges | Year: 2019

Over the period of time considered, there is no major changes between the values. This type of equipment is the one with the highest percentage of time associated with mechanical stops and the one with the highest percentage due to performance losses. As this type of equipment can work remotely and autonomously, this factor can be one of the possible justifications for the values presented, software errors in the referencing of the path and/or the work front that led to the work stoppage. (Figure 10 and 11)

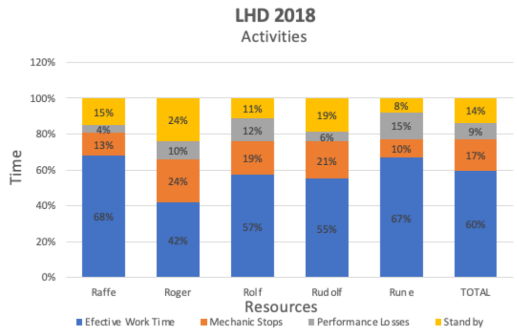

Figure 10 - Equipment Mapping: LHD | Year: 2018

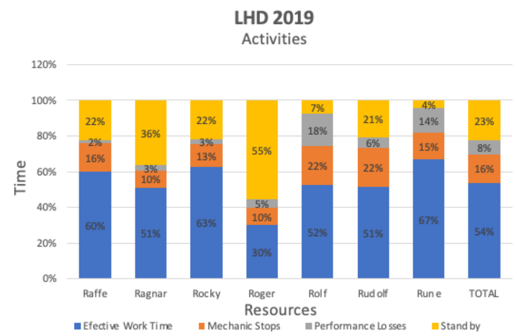

Figure 11 - Equipment Mapping: LHD | Year: 2019

In this type of mining equipment, there is an increase in its use, a decrease in standby time and a decrease in mechanical stops, suggesting a better management of existing works and resources. (Figure 12 and 13)

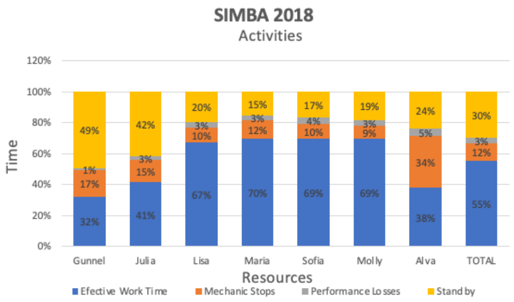

Figure 12 - Equipment Mapping: SIMBA | Year: 2018

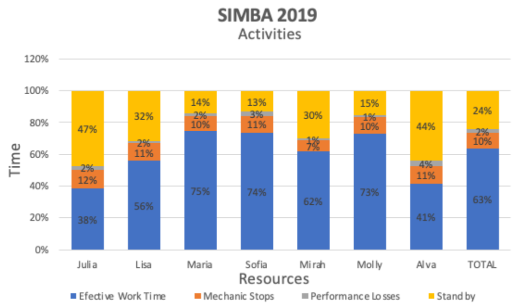

Figure 13 - Equipment Mapping: SIMBA | Year: 2019

The time series referring to the use of the mining equipment analyzed for the years 2018 and 2019 identifies some patterns, namely, the month of July, in both years, is a month where the use of the equipment decreases. This decrease is explained by the fact that it is a month associated with holiday periods and although production does not stop there is a significant decrease in available operators. On the other hand, the month of September is characterized by a month with a high percentage of machinery use, this increase in production is justified by the fact that it is the month of updating the general planning and production objectives. (Figure 14 and 15)

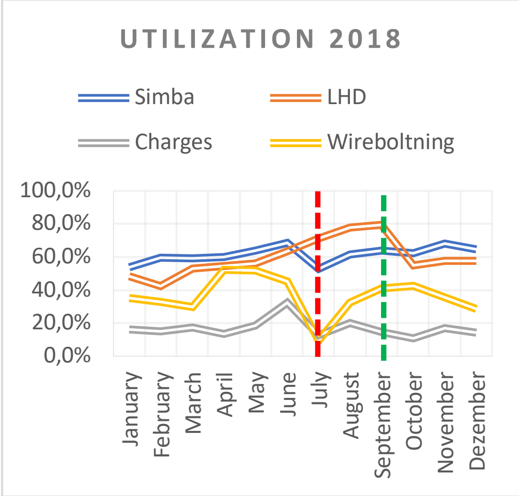

Figure 14 - Time Serie: Utilization | Ano: 2018

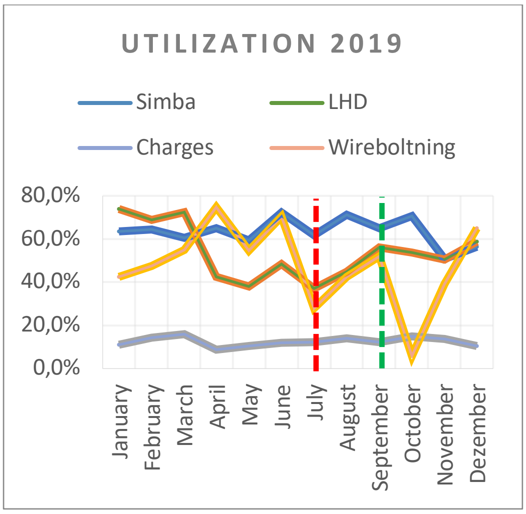

Figure 15 - Time Serie: Utilization | Ano: 2019

The calculation of work rates was performed according to the methodology described and based on data reported to the control room. Table 1 reflects the rhythms for the years 2017, 2018 and 2019 related to the types of mining equipment analyzed. The values for 2017 and 2018, referred to as '2017PE' and '2018PE', were provided by the strategic planning of the mine in question. The year 2018 was recalculated according to the methodology adopted in this study for the control and validation of the values obtained, this being called '2018C'.

Table 1 - Equipment Work Rates | Years: 2017 to 2019

		Ritmos de Trabalho			
		2017 (PE)	2018 (PE)	2018 (C)	2019
Equipamentos	Jumbo de Cabos (WireBoltning)	-	10,1 m/h	7,6 m/h	9 m/h
	Plataforma Explosiva (Charge)	276 Kg/h	-	464 Kg/h	623,1 Kg/h
	Pá Mineira (LHD)	125 ton/h	116 ton/h	115 ton/h	125 ton/h
	Jumbo de Bancada (Simba)	13.8 m/h	13 m/h	12,8 m/h	12,7 m/h

Considering the data in the table, we can see that the work rates of mining equipment do not vary significantly from year to year. Considering only the year 2018 (PE) and 2018 (C) we see a slight difference in values. This difference can be explained by the method used to calculate the presented work rates. All the considerations made generate differences in the final values, which shows the versatility and complexity that is their calculation and optimization. Comparing the years 2018 (C) and 2019 we see an increase. This increase is justified, essentially, by two factors: management decisions (sale and acquisition of more efficient and modern mining equipment); and strategic decisions (increasing the annual productivity target to 3 million tons by 2020).

In order to understand the interdependencies existing in the analysis of performance losses, the Principal Components Analysis was carried out. Principal Component Analysis is applicable to circumstances with numerical values referring to different domains that handle a large amount of information. Principal Component Analysis allows extracting essential information from the data, explaining the interdependence system between the variables and minimizing both redundancy and noise.

The results obtained show that the category Lack of Front Conditions (CAT2) has a direct correlation with the type of equipment LHD's because, in the axes considered, these are close. (Figure 16 and 17)

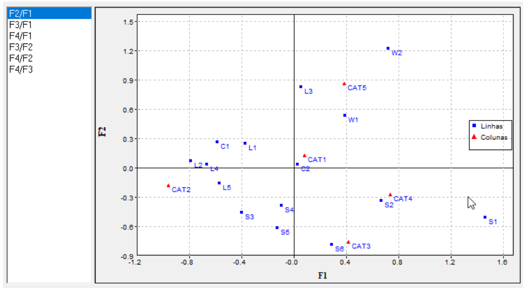

Figura 16 - Resultados ACP | Plano Fatorial (Linhas + Colunas) | Ano: 2018

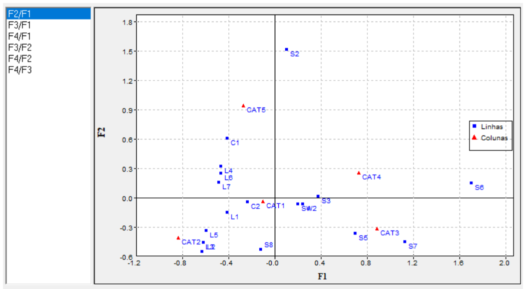

Figura 17 - Resultados ACP | Plano Fatorial (Linhas + Colunas) | Ano: 2019

It is also possible to observe that the category Lack of Front Conditions (CAT2) has an inverse correlation with the categories Lack of Services (CAT3) and Lack of Material (CAT4), meaning that, when one increases the other decreases, which was expected. The category Lack of Services (CAT3) and Lack of Material (CAT4) has a direct correlation because they are close on both axes analyzed. As for the remaining categories (CAT1 and CAT5), it is not possible to characterize the behavior of the variables. (Figure 18 and 19)

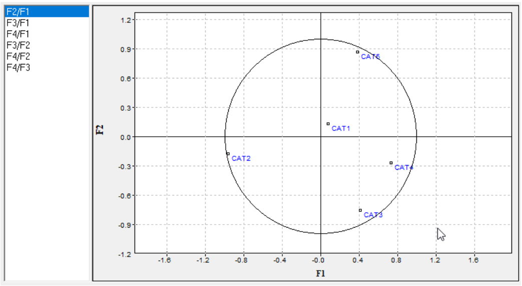

Figura 18 - PCA Result | Factorial Plan (Columns) | Year: 2018

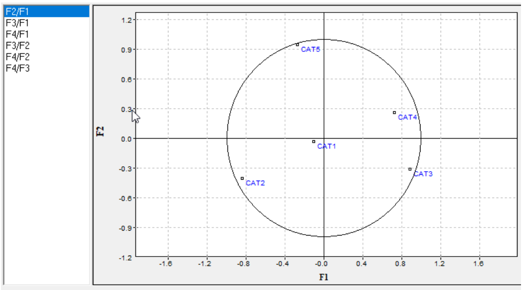

Figura 19 - PCA Result | Factorial Plan (Columns) | Year: 2019

5. Conclusions

The mapping and observation of the processes consists of monitoring the execution of all processes/activities. Collection of information regarding shifts carried out, times of entry and exit of machines, work location, stops, faults and data in the systems. With the information obtained it is possible to group it and build a logical and sequenced system, capable of demonstrating all the stages associated with the respective function.

By analyzing the mapping carried out, it is possible to identify what is hindering the progress of all processes/activities, investigating the weak and vulnerable points as well as measures to overcome and resolve them.

Process optimization aims to increase productivity and improve service level. This approach included analysis and diagnosis of possible necessary changes. Many of the considerations presented in this document have been implemented in accordance with the observed reality and in such a way that the values obtained reflect the truth of mining operations.

Throughout this document it was possible to verify some gaps/flaws in the reporting of the works, namely in their registration, either by the equipment operators or by the operators in the control room. The category analyzed throughout this study, which was most influenced by this lack, was the Maintenance category, especially in relation to subcontracted work, which made it impossible to fully analyze this equipment type.

This study also demonstrates the improvement in productivity and the management of the equipment in the mine under study over the years. Regarding the use of equipment, there was a better use of it, which is indicated by the increase in usage rates. Similarly, in relation to the stops, it was noticed that the majority occurs due to breakdowns associated with the work or due to the maintenance of the equipment itself.

The difference between calculated Availability and Utilization can and should be studied in greater detail in order to better understand its cause. From an economic and/or management point of view, the difference between Availability and Utilization of equipment is an indication of how much the production pace can increase while maintaining the same number of existing equipment, that is, without the acquisition of new machines. The calculated percentage difference can be an indication of how much production can increase without it meaning/representing a cost in equipment investment for the management of the mine.

The statistical analysis performed on them showed that there is no standard behavior in the use of the studied equipment. The reported low utilization of equipment is not associated with external causes such as vacation or low production times, but with less efficient resource management.

Regarding the calculated performance losses, it was possible to notice that among the categories considered there is a low correlation. In percentage terms, the Performance Losses presented, except for the specific cases addressed in the discussion of the results, in general, are acceptable and do not show crucial errors in the management of the works.

In the case of work rates, the results obtained do not vary considerably. With the exception of the equipment Charges, which saw a considerable increase in the pace of work, the pace of the other equipment improved slightly, always staying within what is considered 'normal' for an exploration of this type.

6. References

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