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IMPACTS OF DOWNTIMES MITIGATION RELATED TO FACE DRILLING RIGS IN MINING DEVELOPMENT CYCLES

Underground mining development is directly related to face drilling rig performance. Reducing operating costs and improving productivity are current and crucial topics for mining projects around the world within the development phase. Unlike past approaches, this article is based on variations of equipment availability and utilisation, and their impact on development plans success and costs decrease. To assess the influence of these parameters, daily field data were collected to identify major downtimes in normal cycles and apply adequate corrective measures to mitigate them. Additionally, this article presents the reader with a graphic illustration of the correlation between utilisation and development, including historical data. This paper was developed from October 2017 to March 2018. The result of this study seeks to identify when projects generate profits by comparing four situations with constant productivity, but variables such as the possession rate, maintenance fee, production and utilisation. Finally, it is demonstrated that success in mining projects, related to equipment, is proportional to the utilisation of the fleet, with the correct management of productivities.

Keywords: Availability, Utilisation, Downtimes, Jumbo, Productivity

1. Introduction

The decline in commodity prices in recent years has challenged mining companies and contractors to find new ways to reduce their operating costs and improve productivity, particularly during the mine development phase. Mine development is generally a pure cost as it rarely generates revenue. However, the phase is necessary for production to be realised (Valivaara, 2017).

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There are a great number of research projects aimed at major technological advances focused on improving the mining operations equipment. Parameters such as availability, utilisation, performance, and quality are analysed daily in operations around the world. It's necessary to measure, study and control them since the productivity of the mine depends, to a large extent, on them. One of the best theoretical instruments to measure the effectiveness of mining equipment is the Overall Equipment Effectiveness (OEE) Index. This index was created by the Japan Institute of Plant Maintenance (JIPM) to control effectiveness in the manufacturing industry, but it can be applied to any other industry (Samatamba & Zhang, 2019).

$$OEE = Availability \times Performance\ rate \times Quality\ rate$$

Fortunately, for the purpose of this paper, the OEE index is more suitable for drill rigs and not for any other type of mining equipment, due to the difficulties determining the quality rate. In the drilling process, this rate is easily measurable as it considers the deviations and depths of the perforations. Also, for a more appropriate use of the index in the mining industry, the performance rate is comparable to the utilisation rate and therefore replaceable to give a more precise usage. For an accurate monitoring process in drill rigs work, looking towards downtime mitigation, the average support hole drilling cycle time and the average time to drill one face hole should be measured. These different inputs can be considered when data is analysed with the Rstudio software to create an algorithm to evaluate the OEE for optimum mining equipment effectiveness. This process was developed by the Chibuluma South underground mine industry (Samatamba & Zhang, 2019).

The Colombian studies of equipment and mining process efficiencies differ from the downtime mitigations control proposed in this paper, as they are based on the workforce working delays. As a study case, the El Roble copper mine, located in Choco, Colombia, was used to develop a Kaizen methodology based on the Key Performance Indicator (KPI) in order to maximize the efficiency of the drilling process. Based on the collected field data and the creation of different cause-effect diagrams, it was determined that the best solution for optimum drilling was the training in different topics for all the workgroups of the mine (Henao, 2019). One way to solve the effectiveness problem is to find the reasons that minimise productivity. However, this paper proposes a novel point of view seeking to increase the drilling efficiency without taking into consideration productivity causes but instead quantifying the performance of the mining equipment itself.

This paper illustrates technical concepts in mining and equipment maintenance, sharing field experiences and practical examples in productivity increase and costs reduction of excavation in underground face drilling (Valivaara, 2017).

Mining is a capital-intensive industry, so it is essential to reduce the total production cost and get an early return on the investments, hence why equipment utilisation and accurate estimations of this utilisation is vital (Elevli & Elevli, 2010). Likewise, drilling accounts for a significant part of mining budgets. Hence any time-saving measure directly relates to a reduction in costs. (Hegde & Gray, 2017). Similarly, at the San Ramón mine, a semi-mechanised gold underground project located in Antioquia, Colombia, face drilling rig data was collected daily, seeking to identify the downtimes, their causes and their influence on the equipment's availability and utilisation. Subsequently, with this data, corrective actions were suggested to increase the present utilisation in the equipment in order to analyse how this can influence the production of the mine and finally how this was reflected in the costs.

2. Materials and methods

Data collection was carried out on a daily operational timeline with all the activities performed by the Jumbo. The evaluation of these activities determined their importance and impact on the mining cycle, more specifically in the development labours of San Ramón. During data collection, breakdowns were identified and classified in order to create a database with historical and real information about the principal causes of downtimes. This paper was principally based on the performance of three face drilling rigs. These include one Atlas Copco Boomer 282 and two Atlas Copco Boomer 281. It is important to know the difference between the two types of equipment. The Boomer 282 is a Jumbo with two Hydraulic booms different from the one hydraulic boom of the Boomer 281. The San Ramón project categorised their equipment with the reference JB-0008 and JB-0009 for the Jumbos with one boom and JB-0010 for the two booms' Jumbo. During data collection, the database was fed with information taken by the professional and technician interns of the mine, including:

- Name of the operator,
- Type of jumbo,
- Activity performer,
- Name of the tunnel (with the geomechanical classification of the rock),
- Breakdowns,
- Area supervisor,
- Accurate times of every event during the cycle.

The period of the data collection, information analysis, application of correctives and measurement of impacts was observed from October 2017 to March 2018.

2.1. Availability and utilisation measurements

Parameters of availability and utilisation are measured in San Ramón by the maintenance department with equations (1) and (2):

$$UT = \frac{OT}{AT} \times 100\% \quad (1)$$

$$A = \frac{AT}{ST} \times 100\% \quad (2)$$

Where:

- **OT (Operational Time):** All the hours measured by the hour-meter, except those occurring during maintenance or moving equipment to the workshop or maintenance area for corrective maintenance, consist of operating hours and operating delay hours
- **AT (Available Time):** Hours that a piece of equipment is available to be used by operations
- **ST (Scheduled Time):** 24 hours per day, 365 days per year. No adjustments are to be made if the programmed time is different from the calendar hours (e.g. Projects or equipment that works only on day-shift, or only from Monday to Friday)

3. Results and discussions

Equations (1) and (2) calculate weekly, monthly, and yearly reports about equipment performances that contain important information for the maintenance and operations departments to take advantage of the fleet with a planned and organised distribution.

Fig. 1, 2 and 3 illustrate the behavior of the face drilling rigs utilisation for four months, from December 2017 to March 2018. In capital development where the critical path is one or two faces, utilisation of face drilling rigs will normally be low, about 20% to 30%. In the San Ramón project, jumbos are focused on development tunnels and other equipment are in charge of production tunnels. From Fig. 1 and 2, it is notable how the utilisation increased during the time of the study and the application of correctives, from percentages of 20% to 24% and 24% and 24% to 32%.

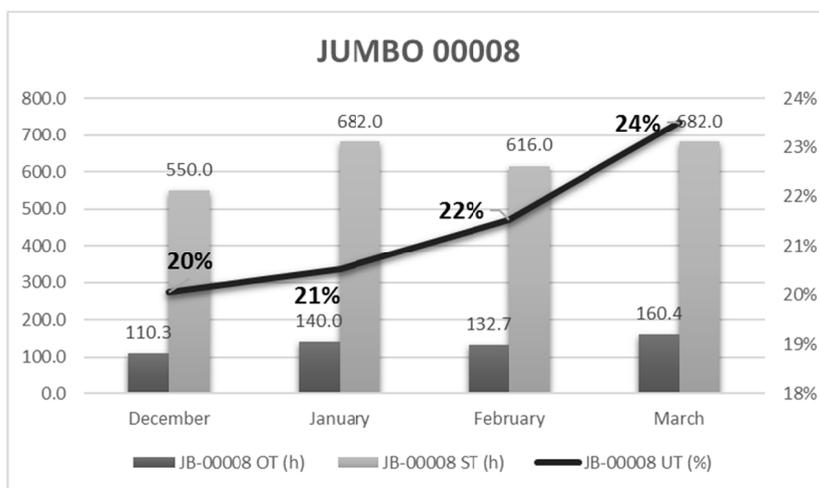


Fig. 1. Availability and utilisation values for JB-00008 (Boomer 281)

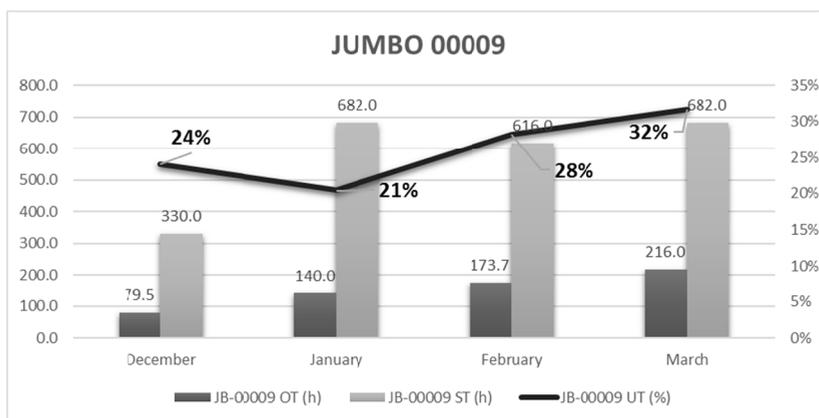


Fig. 2. Availability and utilisation values for JB-00009 (Boomer 281)

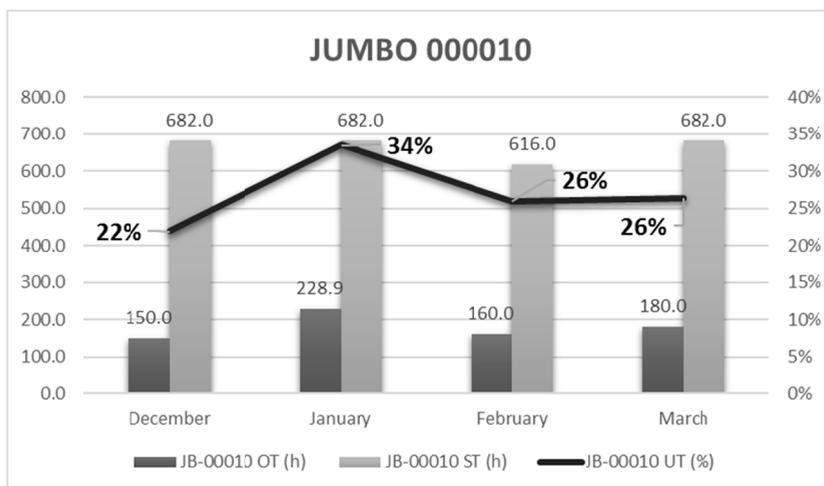


Fig. 3. Availability and utilisation values for JB-000010 (Boomer 282)

to 32%, respectively. Fig. 3 shows that the utilisation of the two boom jumbos has a behaviour that is also positive, from percentages of 22% to 26%.

3.1. Impacts

Data collection, analysis, and correctives were crucial in the entire jumbo performances in San Ramón. The process solved many causes of nonproductivity. Additionally, important aspects such as over-break and advanced efficiency were also improved, generating changes in planning achievements and finally in costs.

3.1.1. Development plan achievements

Mine development plans refer to the total meter calculated by the planning department. This achieves the project's objectives by advancing in waste zones to arrive in the ore areas and mine them. This development plan is given yearly, monthly, weekly and daily to the operations department, to be used by them in their mine activities.

This paper and the operations department supported one another as it gave precise causes of breakdowns, and the operations department provided required solutions. The solutions implemented by the operations department were reflected in the productivity increase of jumbos and also in higher accomplishments of the plans proposed by the planning department. Fig. 4 illustrates the behavior between the planned versus actual development in San Ramon between October of 2017 and March of 2018.

From December 2017 to March 2018, Fig. 5 shows a correlation that an increase in the utilisation of the Jumbos will improve mine development. By using Fig. 5 it is possible to start identifying the benefits in the reductions of breakdowns. According to Kansake & Suglo (2015), the utilisation, also known as operational availability, is the percentage of available time that the machine is in operation. Therefore, Fig. 5 shows a proportional relationship between how much

time the machine is operated with the monthly achievements in development labors. Also, Fig. 5 illustrates the following:

- X:** Utilisation in percentages,
- Y:** Monthly Development in meters

$$Y = 7401.8x - 1257.8 \tag{3}$$

$$R_2 = 0.9656 \tag{4}$$

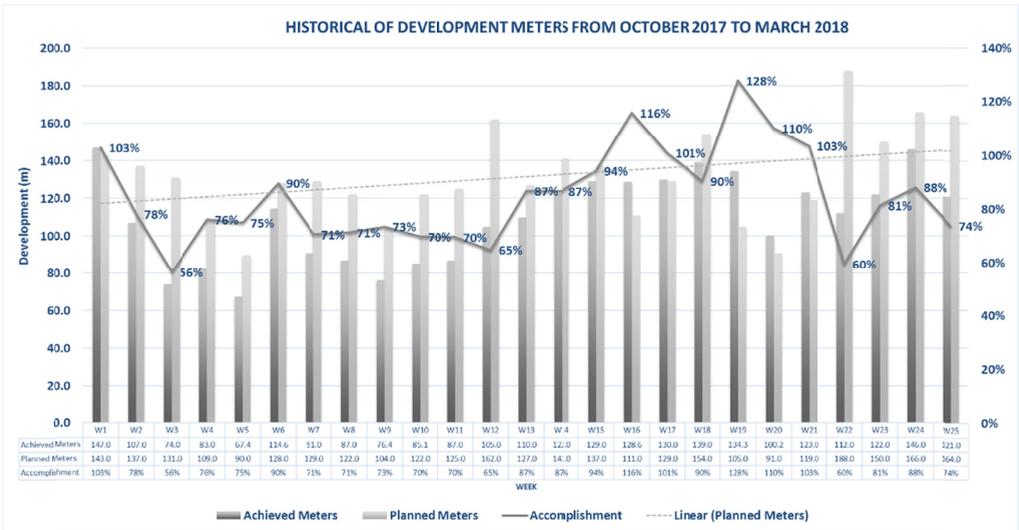


Fig. 4. Historical development meters during the period of the research.
 Weekly data for planned and achieved meters

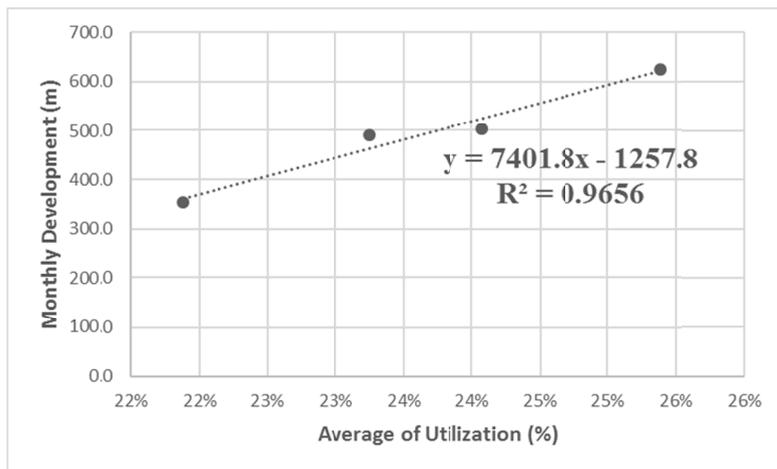


Fig. 5. Correlation between the average of utilisation (%) and monthly development (m)

Equation (3) represents the correlation model and equation (4) shows the relation between X and Y. With this correlation, it can be partially concluded that increasing utilization in face drilling rigs, is highly proportional to the development achievements.

3.1.2. Costs

The big question to answer in this paper is how increasing the utilisation of the jumbos can impact the costs of the project? Items below show that it is possible to partially assume that higher utilisation is translated in more meters achieved by the jumbos and consequently in more accomplishments related to the development plan. Table 1 presents four different cases with principal factors to determine how the utilisation can finally affect costs in the project.

TABLE 1

Example of final cost analysis with constant productivity

Case	Min hours	U (hours)	Meters	Productivity (m/h)	USD Tp	USD Tm	Total USD	USD/m
Case 01	8.00	3.00	10.00	3.33	3.00	2.50	31.50	3.20
Case 02	8.00	4.00	13.33	3.33	3.00	2.50	34.00	2.60
Case 03	8.00	6.00	20.00	3.33	3.00	2.50	39.00	2.00
Case 04	8.00	7.00	23.33	3.33	3.00	2.50	41.50	1.80

It is important to note that productivity (3.33 m/h) used in this example is constant in every case. Using more of the equipment but reducing this parameter (productivity) wouldn't be worthwhile.

- **Case 01:** The minimum hours to use the equipment are eight per shift, and in this case, the machine was used for only 3 hours. Costs of possession and maintenance are indicated in the table. The final or total cost was calculated with equation (1). The value obtained was 3.2 USD/m, which was also the reference in this example.
- **Case 02:** The machine was used for an extra hour, productivity was constant but the increase in the utilization was reflected in development meters (3.3 more than case 01). The only cost that increased was the maintenance cost but in low proportions. The important fact was that the unit price for one-meter (USD/m) decreased from 3.2 to 2.6.
- **Case 03:** The utilisation of the machine increased and the total cost decreased directly.
- **Case 04:** The utilisation hours are almost the minimum required, and it shows how the unitary costs decreased more.

Equipment costs are estimated in accordance with a minimum of hours (possession fee) and worked hours (maintenance fee). Generally, the budget is based on these minimum hours, but a possession fee must be paid if the equipment is used below these hours. When the equipment is used more, the production increases and the possession fee remains constant since it is a fixed cost. This is why the equipment usage increases the unit cost due to an increment in the meters achieved.

On the other hand, it is also important to mention that if an increase in the utilisation does not reflect higher development achievements, it is possible that productivity in the cycle is low and, in that case, there are no earnings. Above all, increasing the utilisation of the equipment must be supported by adequate management of productivities.

4. Conclusions

- i) Improving the utilisation of face drill rigs, such as jumbos, must be supported by adequate management of productivities in order to impact important parameters such as development plan achievements and unitary costs. Other parameters such as over-break and advanced efficiency are directly related to those improvements.
- ii) The average Utilisation hours of jumbos are proportional to the average availability. Mine development depends on the joint work performed by operations and maintenance departments.
- iii) Downtime causes in jumbos are generally related to spare parts of shanks, drill steels, drill bits and hoses near the equipment. Other external aspects such as overheating, voltage drops and non-adequate use by operators are crucial and controllable by the different departments of the mine.
- iv) Measuring the availability and utilisation of the three jumbos during the investigation, determined how the mitigation actions were taken in the project. This increased the number of meters developed in the operation, achieving higher percentages of accomplishments with plans whilst reducing the operational costs.

5. Recommendations

As a recommendation, to control and mitigate issues related to the availability and utilisation of jumbos, it is highly important to identify the daily causes of downtimes of the equipment. Only then can these causes be solved and prevented.

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