Performance indicators and their importance for effective short-term and operational mine planning

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Vilson Carlesso dos Reis[1,2]
https://orcid.org/0000-0001-8720-9250
Beck Nader[1,3]
https://orcid.org/0000-0002-7215-7379

[1]Universidade Federal de Minas Gerais – UFMG, Escola de Engenharia, Departamento Engenharia de Minas, Belo Horizonte – Minas Gerais - Brasil.

E-mail: [2]carlessor@yahoo.com.br, [3]beckn@demin.ufmg.br

Abstract

Mining in Brazil is one of the pillars that support its GDP (gross domestic product). Its execution requires technique and expertise. In a mining venture, the value chain drives the business to achieve its goals. Mine planning has a great influence on its performance, as it is through it that the organization is based to offer its products to the market and, consequently, the low compliance with the established premises will bring undesirable inconveniences. Within the planning, the short term is dedicated to operationalize the plans made possible by the long and medium term teams, in addition to attending to market variations. The indicators that control this process are of great importance, as an incorrect identification inserted in the various criteria that compose it can guide managers towards inefficient decision making. The objective of this study was, through lean methodology, to identify the main performance indicators that impact on the non-exception of the mining plan measured by the adherence and compliance indicators. In this method, the main causes of non-adherence and compliance with the mining plan were identified, enabling short and medium-term actions that leveraged the indicators. This study leveraged the average adherence and compliance by 17% and 54.9%, respectively, exceeding the target set for 6.5% and 49.2% respectively.

keywords: performance indicators, mine planning, adherence and compliance, operational.

1. Introduction

Companies are composed of activities that are carried out in order to achieve well-defined objectives, namely, to plan, produce, and market, among other activities (Cao; Zhang ,2011). This division will permeate from the raw material to the customer, which allows mapping strategic and relevant tasks, as well as understanding its control variables, such as costs, productivity and others.

The value chain, defined as the mapping of the primary activities of companies in order to break the formed silos and generate a single final product with higher productivity and quality at lower cost, is a robust management method.

In mining, specifically, its raw material, which is the extraction of ore, a non-renewable input, generates a need for a prior study to determine this chain, unlike other economic activities, thus ensuring the optimal performance of the venture (Nader; Tomi; Passos, 2012). The iron ore value chain involves all processes necessary for the execution of mineral activities.

A key player in this value chain, mine planning plays a fundamental role, being responsible for the link between the various activities and guiding each of the processes. In general, the mining industry consolidates its mine planning process in three phases, long-, medium- and short-term (Campos, 2018).

This study sought a greater direction in short-term planning, highlighting its phases and particularities within the mining value chain. Short-term planning is necessarily restricted to the requirements predefined by long- and medium-term planning. Thus, one of the tasks is to translate the goals elaborated by them, as operational bases of short-term planning, besides being responsible for making the operational plan to the point of avoiding movement at all costs, that is, solely to meet targets and indicators.

In order to achieve its objectives, which go directly through the value chain objectives, short-term planning prepares its mining plan and from it determines the ROM (run of mine).

According to Curi (2014), there is a great dynamic in the mine planning, in which, during the execution phase, several processes are directly involved in the success of the plan. For the elaboration of a short-term mining plan, it is necessary to follow the premises: final pit, topography, geotechnical parameters, block model, maintenance and key performance operational indicators (KPIs), hydrogeological model, legislation, interferences, mass and quality premises, among others. In possession of all the premises, the planner makes the advances in proper software and determines the objectives for the mining plan.

If proper adherence and compliance has occurred, the proposed geometry must necessarily meet all demands of the value chain. In this scenario, the proper definition of the follow-up of all percussion activities of the pre-established premises is essential for the proper progress of the mining plan.

In this context, defining the main indicators for business management was necessary. Nader; Tomi; Passos,(2012) suggested control measures and defined them as key result indicators (KRI), result indicators (RI), performance indicators (PI) and key performance indicators (KPI), where KRI determines how activities should be performed, RI indicates what has been done, PI determines what needs to be done, and finally, the KPI that informs which parameters generate a significant increase in performance.

With the obligation to guarantee the values of mass and quality of ROM previously presented, two key performance indicators were initially established through bibliographic reviews and in-company documents to measure the effectiveness of the elaborated mining plan:

- The mine plan adherence index (AI), which determines how assertive the pre-established assumptions were, the operational maturity to follow the predetermined geometry, and hence the effectiveness of the planning in performing the geometry of the plan.
- The compliance index (CI), which measures the assertiveness in defining the parameters for the execution of the plan, how disciplined the operation is for the execution of the proposed geometry, the assertiveness of the block model and the original topography for the elaboration of the plan.

In turn, the AI and CI indicators are determined by the difference between geometries. These differences between geometries generate three indicators:

- Mined in plan (PR), which determines the volume that was mined and was within the mining plan.
- Mined out of plan (RNP), which measures the mined volume that was outside the proposed geometry.
- Planned not mined (PNR) which measures the volume that was within the mining plan and was not mined.

The identification of PNR and RNP occurs by the comparison between the planned and mined topographies, whereas for the determination of RP, the initial and mined topographies are required (Costa, 2015). The following formulas are suggested for the calculation of AI, CI and mining effectiveness (Costa, 2015):

$$AI = \frac{PR}{(PR + RNP)} \quad (1)$$

$$CI = \frac{PR}{(PR + PNR)} \quad (2)$$

$$\text{Mining effectiveness} = (IA+IC)/2 \quad (3)$$

Within the literature, processes that could support this survey were sought, concluding that the value stream map (VSM) for this specific need would be the most appropriate. The decision to use VSM was due to the need to mitigate the anxiety generated by the everyday life, which always makes us want to solve the problems that appear, but not always assertively and properly (Vinodh; Somanaathan; Arvind, 2013).

The need for continuous improvement in mining processes in which short-term planning, through adherence and compliance indicators, is very sensitive to operational, economic and environmental licensing variables, which justifies this study.

This study aims, through lean thinking techniques, to increase adherence and compliance with the mining plan, identifying the main causes by taking effective actions to leverage these indicators.

The need to increase the assertiveness of short-term mining plans and consequently to ensure that the ROM previously provided for the entire value chain of the company, supporting the various decision making and product sales, sparked interest in this article.

2. Materials and methods

Flowchart (Figure 1) illustrates the methodology applied to this study

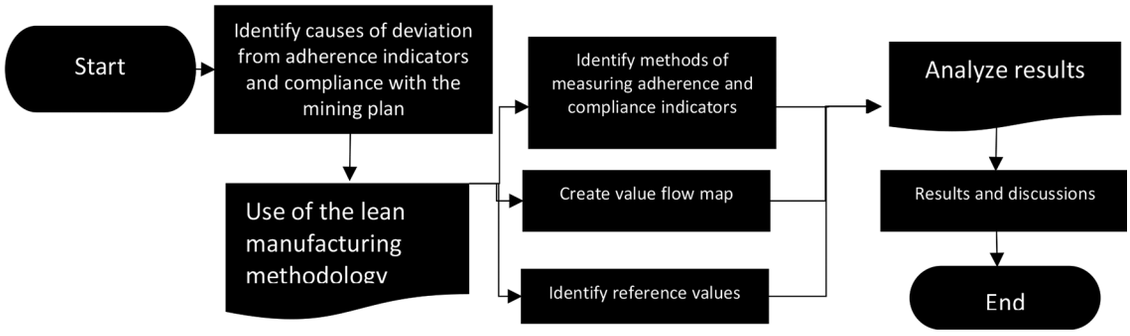

Figure 1 - Work methodology.

To identify the problem, data on adherence and compliance with the mining plan for the year 2018 were used, where the objective of the project was defined through the box plot graph, with the third quartile of both being determined as the goal to be achieved.

After determining the goal to be achieved by the quartile method, the months of March, April and May were used as a laboratory for the identification of the main losses and to trace the loss profile using the Pareto graph.

After this, using lean manufacturing techniques to address problems and propose solutions, techniques, such as value stream maps (VSM), brainstorms were used to map the entire process and implement effective control tools.

Brainstorming meetings were held with experts from the various disciplines that make up short-term planning, as well as those around them focused on identifying which performance indicators are the pillars for increasing the assertiveness of AI and CI indicators.

After all this process with the control tools in place, using the methodology, the experiment started in June, surpassing the goal and ending the project after the third month of meeting the established target.

3. Results

Through VSM and brainstorming, the KRI and RI indicators were determined and signaled. The KRI being initially based on the compliance and compliance indicators, generating six pillars, being (Figure 2):

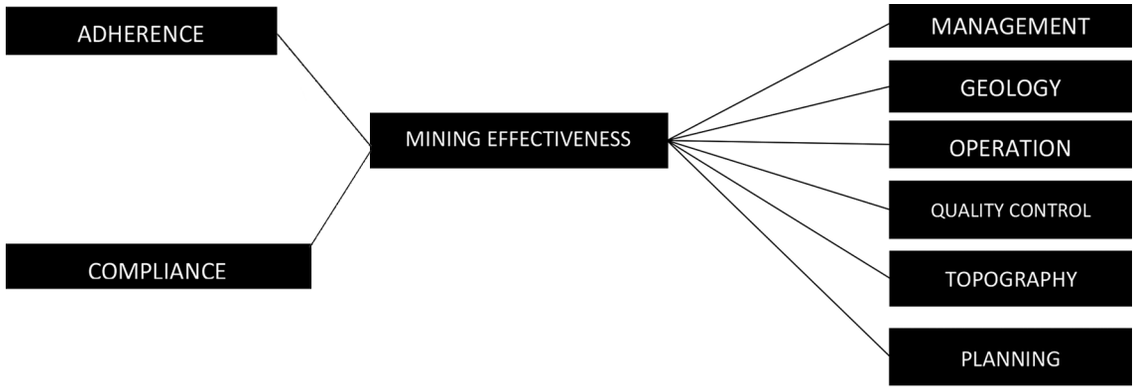

Figure 2 - KRI parameters.

During the sampling period (Jan / 18 to Dec / 18), it could be observed that the values of adherence and compliance of the mining plan varied between 47.62 and 79.83 and 23.81 and 41.75 respectively.

From this, each pillar generated its support indicators for each activity. A total of 76 indicators were listed. Showing what needs to be measured and how to measure it, totaling 62 performance indicators. Then, identifying what to measure (KRI) and how to measure it (IR), all indicators were strategically distributed according to the lean manufacturing methodology, in which the visualization of rapid identification of the indicators is based on normal and abnormal conditions, favoring a quick decision making, reducing waste in a daily monitoring panel.

Table 1 and the Box Plot graph in Figure 3 show that in adherence to the mining plan, the third quartile that will be the result to be pursued in this study is 79.93% and 39.96%.

Table 1 - Descreptive statistcs

Variable	Number of date	Average	Standard deviation	Minimum	1° Quartle	Median	3° Quartle	Maximum	Amplitude
IA	12	70.90	10.81	47.62	63.05	72.75	79.93	83.50	35.88
CI	12	35.45	5.41	23.81	31.52	36.38	39.96	41.75	17.94

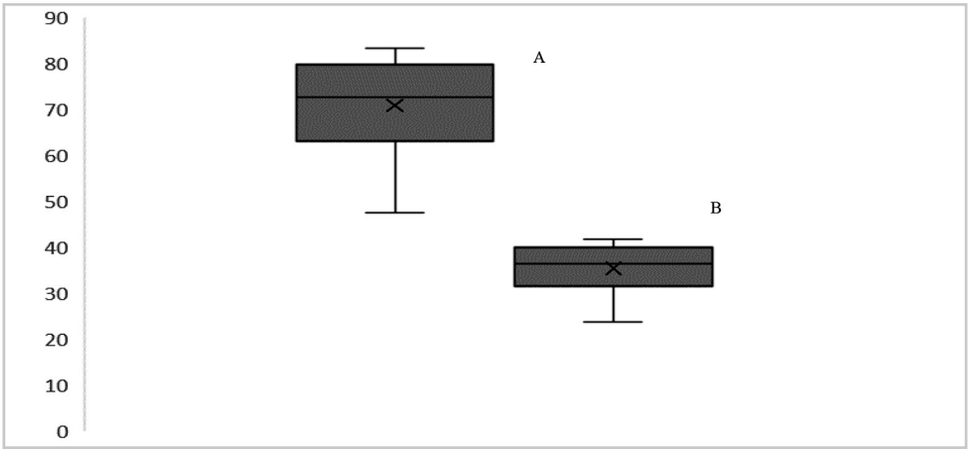

Figure 3 - Boxplot 2018 year IA (A) and CI (B).

With the start of the study and control of the main losses identification of the main causes, it was possible to verify the increase in compliance numbers, as can be seen in Figure 4.

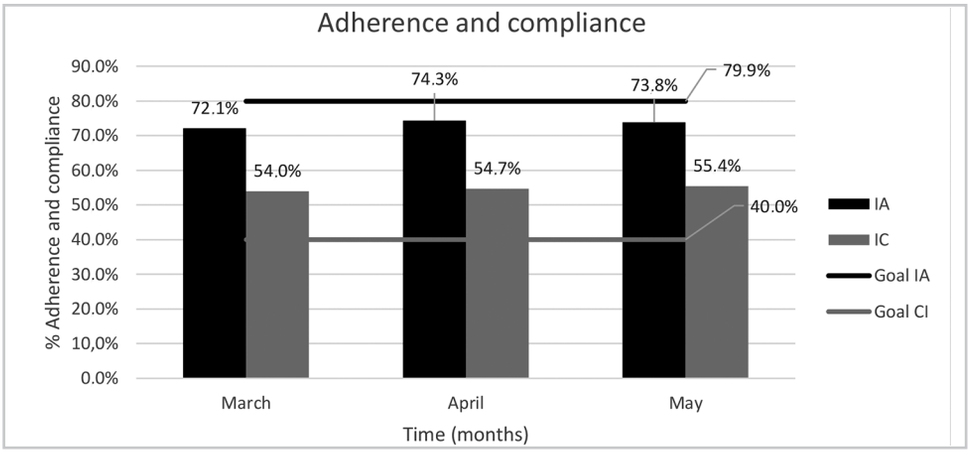

Figure 4 - Result generated from adherence and compliance rates.

As a result of PR, RNP and PNR, Figure 5 was generated, a Pareto chart that shows the main losses in the test months.

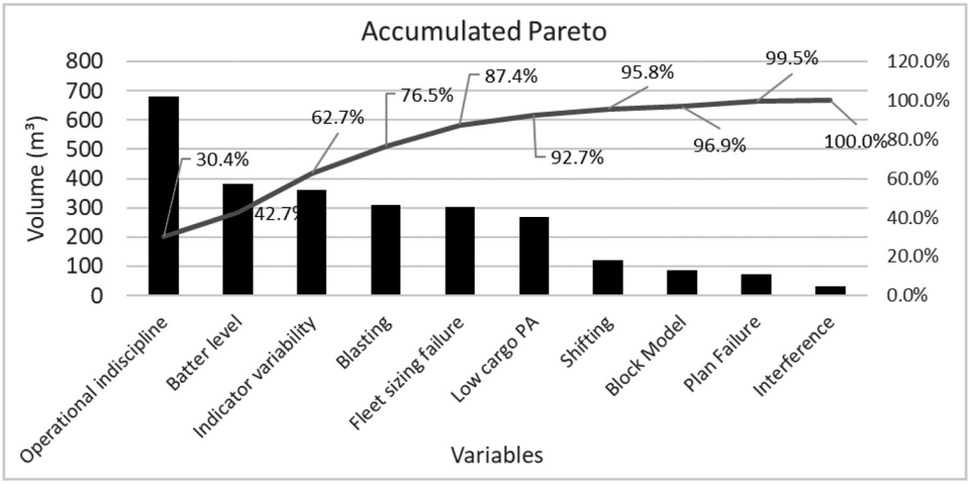

Figure 5 - Variables that impacted the project (accumulated time period).

Figure 6 displays the result of adherence, compliance and participation of behavioral indicators.

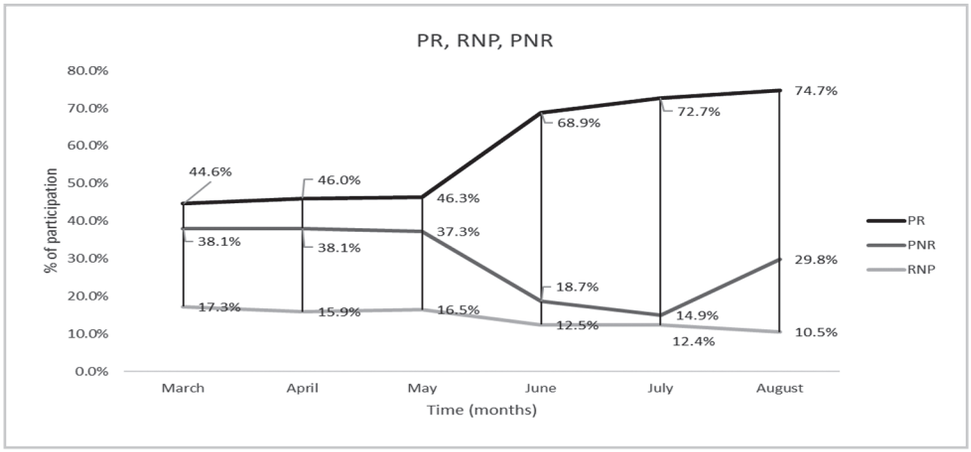

Figure 6 - RNP, RP and PNR result generated by the software.

As a result of the variables that impact the adherence and compliance process, accumulating the measuring months, Figure 7 was generated.

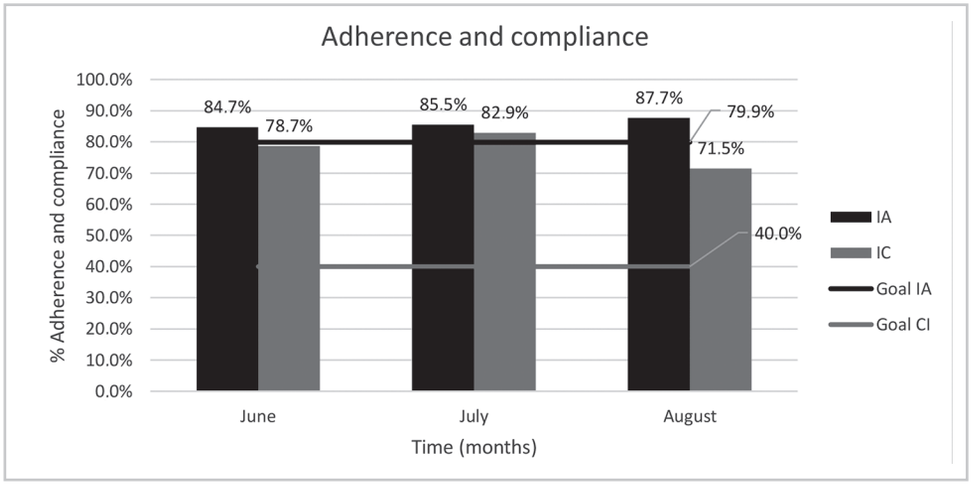

Figure 7 - Result generated from adherence and compliance rates.

As a result of the correlation between the PR, PNR and RNP variables and the Fe grade of the mined product, there are Figures 8, 9 and 10

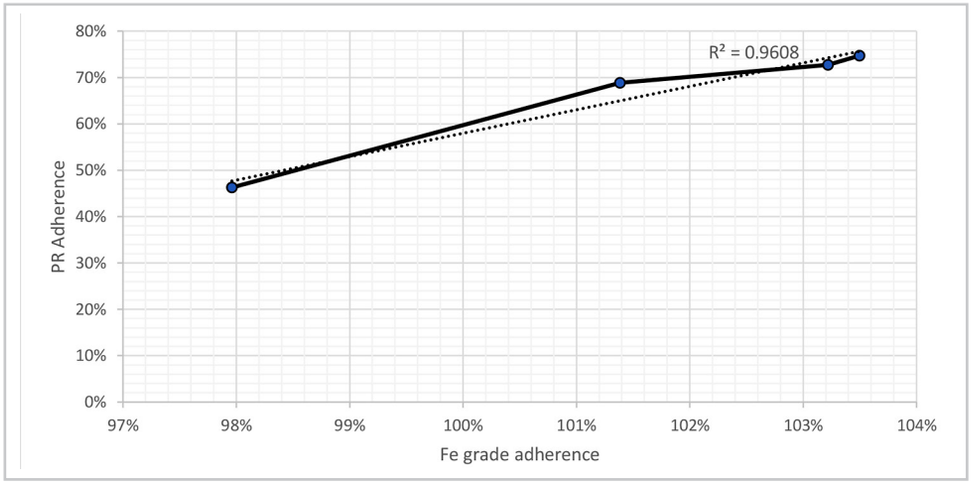

Figure 8 - Correlation between PNR and Fe grade of the product.

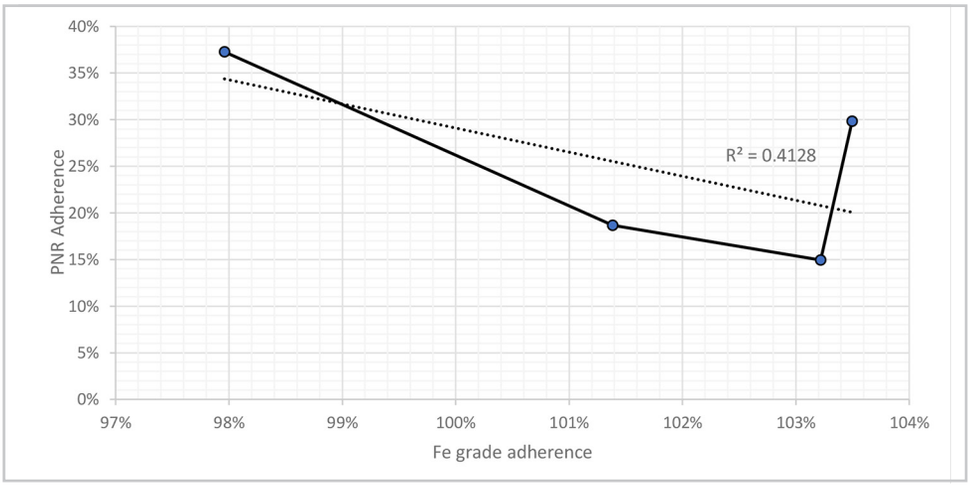

Figure 9 - Correlation between PNR and Fe grade of the product.

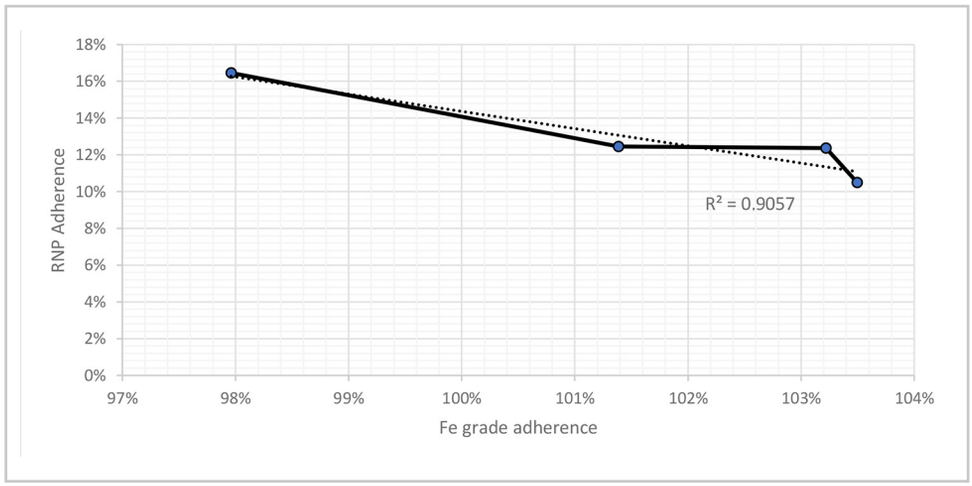

Figure 10 - Result generated from the correlation between RNP and Fe grade of the product.

4. Discussion

This experiment demonstrates the importance of creating performance indicators for monitoring and controlling key performance indicators.Not following indicators that support key performance indicators can bring us unpleasant surprises at the end of each cycle.

Figure 7 clearly demonstrates, within the methodology applied, the implementation of controls, signaling already in the first month after its implementation a significant increase in the planned indicator realized (PR) and an also significant reduction in the indicators planned unrealized (PNR) and accomplished unplanned (RNP) being that the last and the first maintained the trend in the last month and the second due to the implemented control showed an increase by management decision.

Once the PR, RNP and PNR values have been determined, the adhesion values and compliance with the mining plan are determined instantly. Figure 6 demonstrates that with the implementation of the methodology and the treatment of the deviations indicated in Figure 7, there is a considerable increase in these indicators, reaching the goal of adherence and compliance for this study.

Finally, it was necessary to validate whether the results were sustainable for customers, that is, if what was established for the quality of the products' feed correlated with the results achieved.

Figures 8, 9 and 10 show a high correlation between the PR values and the Fe content fed in the crusher, a low correlation between the RNP indicators and Fe content in the crusher and a high correlation between the Fe content and the PNR respectively. These low correlation results between RNP and Fe content in the crusher were expected, as the low PNR was due to the waste and not to the ore of the mining plant, that is, it was guaranteed that the ore planned at the plant was fed to the crusher.

5. Conclusions

Approximately 18% of the problem presented in the general objective of this study is related to variables, such as operational indiscipline, variability of physical availability (PA) and physical utilization (PU) indicators and inadequate batter level and face angle, which proved to be resistant to the problem solving tools that were applied because they depend largely on behavioral attitudes. Even with the reduction of losses associated with them, they still have an impact on AI and CI indicators and, consequently, on mining effectiveness.

On the other hand, in the remaining approximately 82% of the problem, the use of this methodology proved to be robust for the identification and control

of AI and CI indicators, a method that increased the credibility of the mining plan, and consequently, greater adherence and compliance with geometry.

The identification of the most impacting factors in the AI and CI processes, defined as operational indiscipline, variability of BP and PU indicators and inadequate mass level and face angle, started to be considered as key indicators of the process performance, receiving special monitoring from management, and consequently, control of those directly involved in the elaboration and execution of the mining plan.

Finally, it can be said that the complex problem presented in herein can be conveniently addressed through the proposed methodology, coupled with the behavioral improvement initiatives of employees involved in the mining value chain, observing the importance of behavioral factors represented by them; in the case study, 18% deviation to reach 100% adherence and compliance with the mining plan.

But it is worth mentioning that the goal proposed by this experiment was achieved, raising the indicators of compliance and compliance by 17% in relation to the average of adherence in 2018 and in 54.9% in relation to the average of compliance in 2018 and in 6.5% in relation to adherence and 49.2% in relation to compliance according to the target set for this experiment.

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