PRODUÇÃO ONLINE
REVISTA CIENTÍFICA ELETRÔNICA DE ENGENHARIA DE PRODUÇÃO
ABEPRO
ISSN 1676-1901

INTEGRATED MANAGEMENT ANALYSIS OF PRODUCTION PERFORMANCE, MAINTENANCE, AND PDCA CYCLE: A CASE STUDY OF THE IPCC MINING PROCESS

ANÁLISE DE GESTÃO INTEGRADA DE DESEMPENHO DE PRODUÇÃO, MANUTENÇÃO E CICLO PDCA: UM ESTUDO DE CASO NUM PROCESSO DE MINERAÇÃO IPCC

Rafael da Silva Fernandes* E-mail: rafasfer2@ufra.edu.br
Jaci Clayton da Conceição* E-mail: Sousa jclaytoncs@icloud.com
Rosana Maria do Nascimento Luz* E-mail: rnascimentoluz@gmail.com
*Universidade Federal Rural da Amazônia (UFRA), Belém, Pará, Brasil.

Resumo: A medida de desempenho de uma produção pode ser determinada pela aplicação de ferramentas que possam avaliar a relação entre funções de produção, qualidade do processo e manutenção, e propor um modelo de gestão integrado. O objetivo deste estudo foi propor a aplicação do ciclo PDCA e utilizar sua análise para minimizar os impactos operacionais que levam ao descumprimento das metas estabelecidas no Plano Diretor de Produção em relação ao real. O problema motivacional no trabalho está relacionado à adoção do método inovador de mineração IPCC por uma mineradora brasileira, que em 2019 tinha um plano de produção de 18.051.425,8 toneladas; no entanto, produziu 13.526.587,5. Foi possível observar o bom desempenho do plano de ação quanto aos resultados dos indicadores e padronização dos processos. Em resumo, os indicadores apresentaram desempenho médio acima do esperado para 2020. Quanto à variabilidade, os indicadores apresentaram diminuição do desvio padrão entre desempenho e cronograma. Ressalta-se que os indicadores de PU, produtividade e produção média apresentaram tendência de alta.

Palavras-chave: Minério de ferro. KPIs. Processo de mineração. Gestão da qualidade. Perfil de perda de produção.

Abstract: The performance measure of a production can be determined by applying tools that can evaluate the relationship between production functions, process quality and maintenance, and propose an integrated management model. The objective of this study was to propose the application of the PDCA cycle and to use its analysis to minimize the operational impacts that lead to non-compliance with the goals established in the Production Master Plan compared to the actual one. The motivational problem at work is related to the adoption of the innovative IPCC mining method by a Brazilian mining company, which in 2019 had a production plan of 18,051,425.8 tons; however, it produced 13,526,587.5. It was possible to observe the good performance of the action plan regarding the results of the indicators and standardization of the processes. In summary, the indicators showed an average performance higher than expected for 2020. As for variability, the indicators showed a decrease in the standard deviation between performance and schedule. It is noteworthy that the PU, productivity and average production indicators showed an upward trend.

Keywords: Iron mining. KPIs. Mining process. Quality management. Loss profile.

1 INTRODUCTION

The mining industry is undergoing major changes, which have mainly been triggered by technology advancement and a growing effort to consider the problem of Integrated Production (IP), Quality Management (QM) and Maintenance Planning and Control (MPC) subject to reliability, quality and production losses. Correspondingly, this problem becomes considerably complex when factors, such as the following, are taken into consideration: (1) management of temporal instability and correspondence analysis of results, quality, productivity and maintenance (Campos et al., 2021); (2) optimization of stock limit, of production lot size, and sampling plan parameters and revision limit aiming at minimizing the total cost incurred (Campos et al., 2021); (3) The collective effects and importance of the relationship between MPC practices and individual QM practices in the dimensions of organizational performance (Xu et al., 2020); (4) relationships between Industry 4.0 and the high-tech strategic plan, as well as its vertical integration from the factory floor to the business level and horizontal integration throughout the supply chain (Chiarini, 2020); (5) consideration of the impacts of operations on the natural environment, requesting that a practical management of Corporate Social Responsibility (CSR) be adopted, in order to seek the best solutions that integrate social, environmental and economic aspects, and Green Corporate Performance (GCP) (Abbas, 2020a, 2020b).

In the context of Industry 4.0, technological development aims to enable the acquisition of measurable process parameters and the acquisition of information obtained directly from the equipment, and thus the process is capable of integrating several devices into an integrated system, which collects data from the infrastructure and of the environment, as well as better management and measurement of the mine's spatial and intertemporal compliance with the plan in open pit mines in a comprehensive and integrated manner (Gackowiec et al., 2020; Otto & Musingwini, 2020). In particular, when a company implements the concepts of Industry 4.0, it becomes more mature in monitoring and controlling processes and tends to improve the overall performance of the mineral market in a sustainable way.

Over the years, the ore extraction process has undergone many technological advances and competitiveness, which leads companies to invest in the development of the production process based on strategic elements linked to their objectives (Mohammadi et al., 2017; Nairn et al., 2020; Pereira & Nunes, 2018; Santos et al., 2020). In this way, the relationship between the sale price, the cost of mining the ore and the mine's useful life must be taken into account to obtain a profit perspective and consequently the feasibility of the project (Drummond et al., 2017; Reichl et al., 2014; Wårell, 2018).

The open pit mining method is the most used by Brazilian mining companies in the mining stage, being remarkable at the beginning of the macro-process of ore extraction, ensuring that the iron ore is delivered to the final customer with the specifications required by the legislation of the international market. The choice of this type of process was guided by the economic criterion, given by the lowest unit cost, considering all operational variables (Barratt & Ellem, 2019; Sane, 2018; Shen et al., 2018).

In the context of this study, as well as an alternative way of transport, the "off-road" trucks transport the ore from the mining front to the beginning of its processing. In this way, technological and sustainable innovation for mining operations (Clune & O’Dwyer, 2020; Drummond et al., 2017) called “In-Pit Crushing and Conveying” mining technology, referred to as IPCC mining, is highlighted carrying out the initial process of the crushing stage inside the mine itself, through a mobile system composed of an excavator, a crusher and interconnected conveyors.

The specific equipment used in the IPCC process has robust structures and need performance monitoring, and for this a measure known as Key Performance Indicators is used (Nunes et al., 2019; Osanloo & Paricheh, 2020). KPIs play an important role in the process as they need to provide quick project and current performance information to achieve objectives (Gackowiec et al., 2020; Parmenter, 2015). This comparison process is a measure of the quality of the indicators. In particular, it allows measuring physical impacts by process properties, such as: some differences in physical availability (PA), use (PU) and productivity. The problem that motivates the work is related to the use of the IPCC contracting method by a Brazilian mine, whose performance is measured by KPIs.

Thus, given presenting the problem and the importance of guaranteeing the quality of the process, this study aims to fill a research gap by analyzing the integrated management between production performance, maintenance management and quality in a multinational mining company located in southeastern Pará state. The company produces several iron ore products and, in 2019, it showed a record of results of its

KPIs’ diverging from what was established by the Master Production Plan (MPP). Specifically, this study has a dual objective:

The first objective in this study is methodological: the application of the PDCA cycle and quality tools is proposed here to investigate causes, develop action plans to improve KPIs, and minimize operational impacts that cause the goals set in the Master Production Plan not to be met to the detriment of what is performed.

The second objective in this study is practical: the application of an integrated management vision incorporates to performance analysis mechanisms that can provide additional information to identify the trade-off behavior between production, productivity and maintenance performance. Specifically, by analyzing integrated performance, it is possible to provide information to develop the action plan and evaluate the efficiency of the integrated model to a temporal variability in operational management.

In summary, given the concepts presented, the mining industry context and an operation management perspective, this study focuses on a case study that relates KPIs with equipment downtime analysis and corresponds to an integrated model in which the production, process quality and maintenance functions are evaluated. To date, different strategies have been adopted in this context, each with its own advantages and disadvantages, but without the help from quality tools, PDCA methodology, statistical data analysis and integrated analysis of dimensions and practices. Thus, the three functions addressed will be discussed separately: Quality Management and Evaluation, Key Performance Indicators and Maintenance Management.

2 LITERATURE REVIEW

2.1 Quality

Several specific theoretical contributions have allowed a better understanding of quality and, consequently, they have expanded the possibilities of applying this concept at the business level. Quality, which has come to be adopted by (ISO 9001, 2015), is conceptualized as customer satisfaction regarding adequacy for use.

This concept performs a dual function - it satisfies customers and allows the company to function as efficiently as possible. Quality is perhaps the only area in which there is great alignment between customers' goals and employees' goals and achieving such an alignment is a way in which a focus on quality fulfills its dual function (Fernandes et al., 2021; Rocha et al., 2021).

Furthermore, (Paladini, 2019) discusses the use of quality as a definition, which is complex and imperfect, as it refers to a dynamic and evolving marketing context, both in terms of content and, especially, its scope. Therefore, quality should always be used in a compound form, that is, it is necessary to always make explicit which noun it refers to or, in other words, it is necessary to conceptualize quality according to the specific context for which it is adopted.

Finally, from the operation perspective and from the perspective of this study, quality can be conceptualized as a company's ability to perform the scheduled annual production, that is, the company's ability to meet the KPIs that determine its performance and deals with Process Quality. In other words, it refers to operational efficiency that must be managed through studies, analysis and the treatment of process deviations.

2.2 Key Performance Indicators (KPIs)

Key performance indicators (KPIs) are properties that contribute to the management and assessment of quality in the ore production process. They bring consistent information that support decision-making in the company. In the context of this work, three KPIs were used, physical utilization rate (PU), physical availability (PA) and productivity. Even though these indicators vary greatly from company to company, (Xenos, 2014) states that the basic concept remains unchanged.

To obtain the best indicator results, we defined that the times were grouped in hours and the set of equipment that occurred in the system. These can be sub-divided into three classes: running; stopped and reallocating. From there, they are classified into hour categories, which are: effective hours (EFH); internal idle hours (IIH); external idle hours (EIH); corrective-maintenance hours (CMH); systematic preventive hours (SPH) and non-systematic preventive hours (NSPH).

The physical availability equation varies according to the productive sector and company under analysis, and in the mining sector, one of the formulas is:

$$PA = availability = \frac{operating\ time}{planned\ time} = \frac{planned\ time - downtime}{planned\ time} = \frac{CH - MH}{CH} = AH/CH \tag{1}$$

Where CH refers to calendar hours and MH to maintenance hours.

The physical utilization rate (PU) represents how the maintenance and production sectors are taking advantage of the productive capacity of their means of production. In the sector, the can be according to:

$$PU = \frac{effective\ hours}{available\ hours} = \frac{EFH}{AH} = \frac{EFH}{CH - MH} = \frac{EFH}{EFH + IH} \tag{2}$$

The productivity indicator (P) represents all the mass produced in the time available for operation, that is:

$$Productivity = \frac{total\ mass\ produced}{EFH} \tag{3}$$

Finally, for cases in which a production system does not reach targets, it is also possible to obtain the loss of production by performance by checking the relationship between the representativeness in tons of production for each indicator. As an example, given that the PA indicator represents the greatest impact on production loss, it is indicative that the system under analysis is little available to perform its functions, due to maintenance time. Thus, the equations to calculate the production loss for each indicator are described:

$$PL_{PA} = \left(AH_{scheduled} - AH_{performed}\right) \times Productivity_{performed} \tag{4}$$

$$PL_{PU} = \left(IH_{perfomed} - IH_{scheduled}\right) \times Productivity_{scheduled} \tag{5}$$

$$PL_{productivity} = \left(Productivity_{scheduled} - Productivity_{performed}\right) \times EFH_{scheduled} \tag{6}$$

2.3 Maintenance Management

Maintenance Management plays an important role in developing system and process quality and, consequently, in increasing a company's competitiveness. As a support to the operational process, maintenance is a strategic element, not evaluated in itself, but as a means of action in which its evaluation depends on the proper operation of the process, without equipment breakdown in a given period. However, when evaluating the integrated model, beyond its relationship with operation, maintenance in Industry 4.0 has adopted its own indicators and its own evaluation (Bokrantz et al., 2020; Darestani et al., 2020).

Typically, five repair strategies can be found in the literature, namely: Corrective Maintenance (CM); Preventive Maintenance (PM); Predictive Maintenance and Condition-Based Maintenance (CBM); Reliability-Centered Maintenance (RCM); and Total Productive Maintenance (TPM) (Ben-Daya et al., 2009; Darestani et al., 2020).

Thus, the assumptions regarding the way a system ages and how it is affected by failure and repair will guide the choice of model for a repairable system and, consequently, the maintenance policy. Generally speaking, interventions made on a repairable system in order to correct or prevent the occurrence of failures can be classified into two types: Corrective Maintenance - CM and Preventive Maintenance - PM.

An important issue related to the concept of Preventive Maintenance is the fact that it is a planned intervention. In general, a maintenance policy in this condition determines periodic times for inspection actions, namely the sensitive inspection (subjective), instrumental inspection (objective) or even programmed corrective inspection, in the case where a failure does not interrupt the equipment's functions.

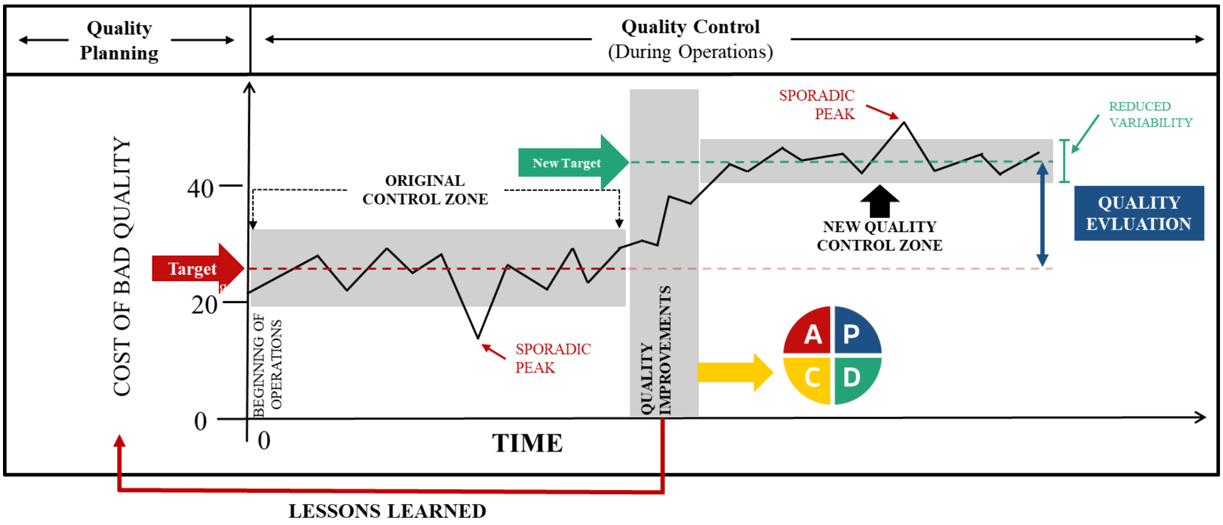
It is worth noting that any type of maintenance (corrective, preventive or predictive) imposes costs that are directly related to the maintenance activity or to indirect costs. Thus, increasing the frequency of preventive maintenance in a non-judicious fashion, for example, aiming to reduce the expected number of failures, is not necessarily a good strategy.

3 RESEARCH METHODOLOGY

Studies that aim to measure degrees of differences in production processes, particularly focusing on the difference between schedule and performance, fall under a more general scope known as Quality Management and Evaluation.

Process quality management, or management focused on process quality, is understood as the adoption of a set of activities that includes three processes known as the Juran trilogy (Juran, 1986). The Figure 1 exemplifies the Juran trilogy, in which **quality planning** is associated with the cost of poor quality and the establishment of a target and/or specification limits, where the original **quality control** zone shows deviations and sporadic peaks and, consequently, triggers the search for problem solving by PDCA-based tools and methods. Since the actions result in effective **quality improvements**, for example, reduced cost of poor quality, reduced process variability, and/or improved indicators, there is a standardization of the most impactful actions and a new turn of the PDCA cycle for new searches for improvements. Finally, **quality evaluation**, which aims to measure the alignment of indicators with the organization's goals.

Figure 1 - Juran Trilogy Diagram

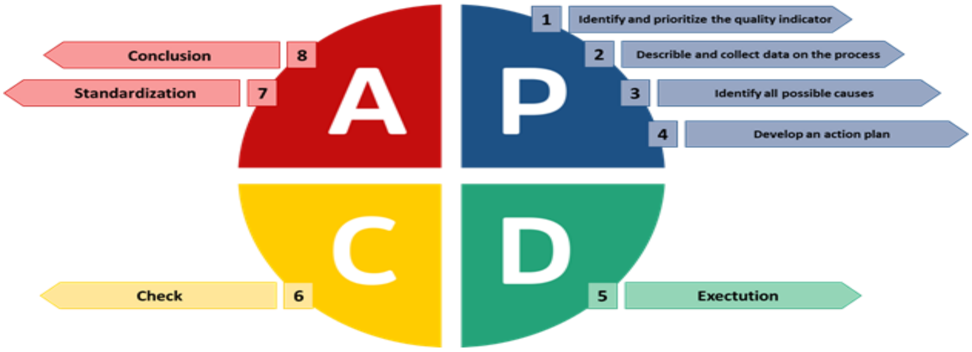


Source: (Juran, 1986).

That said, just as important as producing quality, quality evaluation determines whether the results obtained after implementing production actions confer viability to planning, as well as full achievement of the objectives that planners and schedulers set out to accomplish.

Finally, as a methodology for improvement, PDCA is a simple tool that induces gradual changes to the process, thus leading the company's development. As shown in Figure 2, the cycle is divided into the following steps: planning, doing, checking, and acting.

Figure 2 - PDCA cycle steps



Source: (Silva et al., 2017).

For the steps to be effectively executed, the sub-steps must be correctly defined. Importantly, the planning step tends to require greater execution care, since the identification and prioritization of the evaluation metrics will provide a better investigation of the causes of problems. Moreover, the use of quality tools to support the PDCA cycle is essential and indispensable for the efficiency and effectiveness of the action plans developed.

Thus, proposals for changes, process standardization and/or action plans are then based on structured methods and tools, and it is always recommended to establish a communication and training process and documentary formalization.

4 RESULTS AND DISCUSSIONS

4.1 Problem Identification

The storage of data from the production processes is carried out through software that has a database, used to control and monitor the production of ore. These data were made available for this study by the mining company.

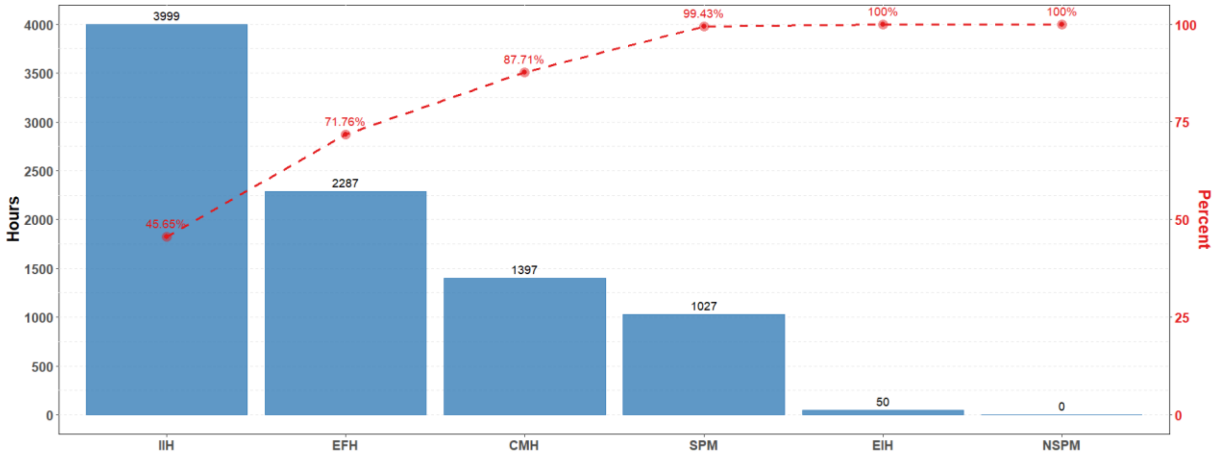
Through the methodology, monitoring schedule and improvement actions, the indicators are directed towards the goal. Thus, the monitoring of indicators occurred daily and was carried out by the process control team.

In 2019, a production schedule of 18,051,425.8 tons was planned for the production system; however, only 13,526,587.5 tons were carried out, and this represents a deficit of 4,524,838.3 tons, that is, the system performed 73.82% of what was expected, which represents a deficit of 26.18% as compared to the schedule.

A detailed study of all KPIs was carried out, before determining the possible causes that generated the low performance of the system in relation to production in 2019. It was verified how the calendar hours could be classified and their distribution by category, to enable comparison between those performed and those predicted, the analysis was performed using graphs generated from the information in the database.

Figure 3 shows the representation of the calendar hours in the production system classified by category. It can be seen that 45.65% of the 8,760 hours are related to IIH, 26.11% to EFH, and 27.67% to MH - Maintenance Hours.

Figure 3 - Calendar Hours Chart - CH



Source: The author(s) himself(themselves).

Table 1 shows, for the year 2019, the production schedule for the production system, the 8,760 calendar hours and the main performance indicators used. Note that, to produce 18,051,425.8 tons, a productivity of 6,165 ton/h was estimated, with PA of 78.5% and PU of 42.6%.

Table 1 - 2019 production system - production indicators

Production Indicators	Scheduled	Performed
Physical Availability - PA	78.51%	72.08% ↓
Physical Utilization - PU	42.59%	36.14% ↓
Productivity	6,179.72 t/h	5,828.11 t/h ↓
Production	18,051,425,82 t	13,526,587,47 t ↓

Source: The author(s) himself(themselves).

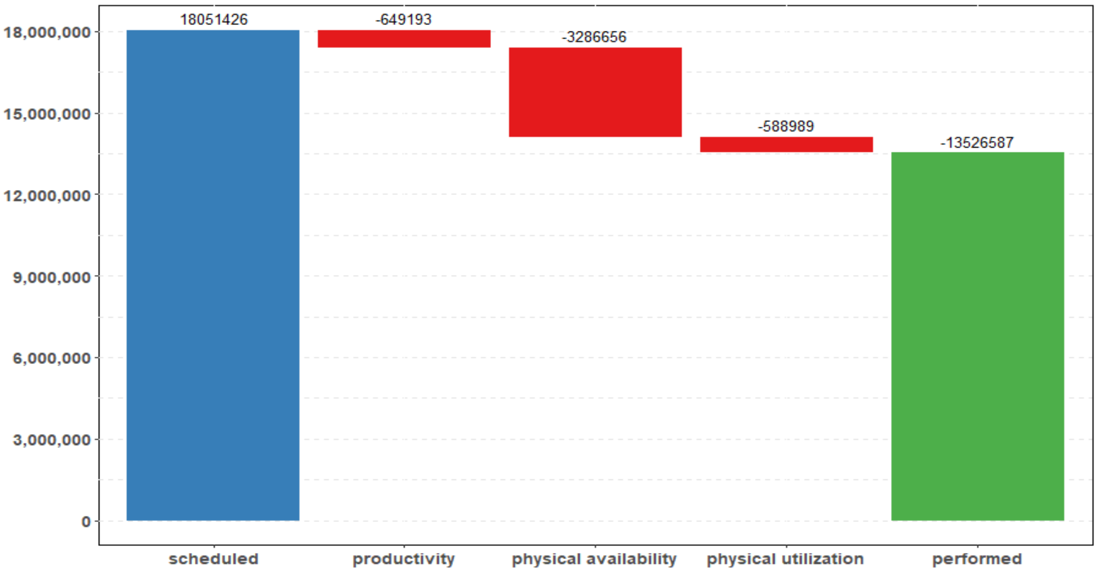
When the schedule data and the performed data are compared, it can be observed that productivity was 5,943 t/h, which represents 96.4% of the schedule. For PA, the performed was 72.2%, with an 8.02% loss and, finally, PU was 36%, which is 15.5% less than the 42.6% schedule.

In order to provide details of the factors that resulted in not achieving the production goals in 2019, we will proceed to a stratification of the production system data, thus showing all the occurring events through tables and graphs, according to the classification of hours, and indicating their impacts on the established indicators.

It is known that the production system did not achieve its production goal for 2019, thus, its performance indicators will be analyzed. In Figure 4, it is possible to verify and calculate the loss of production by performance indicators, evaluating the representativeness in tons for each one of them. We can see that PA represents the biggest impact on production loss, accounting for a total loss of -3,286,656 ton/2019. In addition, it indicates that the system under analysis became inoperative due to maintenance time beyond the scheduled time.

The preventive maintenance hours were programmed and calculated for the production plan, so the excess of the scheduled corrective maintenance hours was considered in this work as failures and direct impacts on the PA indicator.

Figure 3 - 2019 production system – production indicators



Source: The author(s) himself(themselves).

4.2 Process Description

The mining macroprocess is commonly given by the following phases: mining, processing and shipment. The mining phase is characterized by the extraction of the ore in its raw form, the beneficiation phase is where the ore undergoes physical and chemical treatment steps to meet the customer's needs and the shipment phase is when the material is stored in piles in the storage yards, and then it is transported by rail to the sea port, where pelletizing takes place, to be sent to the final customer by ship (Lovón-Canchumani et al., 2015).

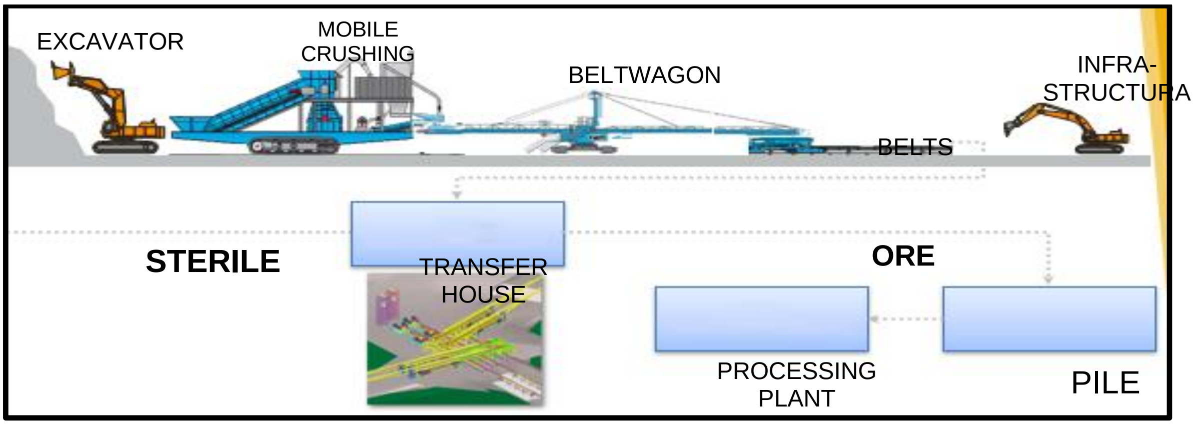
The problem investigated in this work corresponds to the extraction and mining stage, characterized by the adoption of a new method of mining iron ore, the so-called IPCC (In-Pit Crushing and Conveying) mining method. This method consists of integrating the mine and primary crushing inside the pit, that is, the entire primary processing system for the material taken from the mine is mobile.

The innovation in the ore extraction process brings a new format and arrangement to the mine layout, as shown in Figure 5, based on the production flow and with a new configuration of the equipments, consisting of an excavator, a mobile crusher and a track wagon. In some cases, portable belt conveyors (PMC-D - Portable Modular Conveyors Type), bench belt, bench connection belt, connection belt, transfer house and buffer pile are also used (Sousa et al., 2022)

The main objective of the IPCC mining method is to reduce operating costs and environmental impacts generated by ore exploration, incorporation of mobile crusher. Achieving these goals is possible only the possibility of production of transport equipment) in, since it represents the largest slice of the operational cost in conventional mines, given that its transportation process consumes a big amount of diesel oil and a large number of tires, which are considered to be the major pollutants responsible for the emission of polluting gases into the atmosphere by the mining industry.

The use of the IPCC method requires a detailed technical planning for the mine, including from the equipment used in mineral extraction, which must take into account the mining demands imposed by the system, especially that each installation well that must be available in a given mine location. The new technique needs to meet the quality of the product and the number of slopes to be mined.

Figure 4 - IPCC Mining Layout



Source: (Sousa et al., 2022).

The mine is made up of production systems and has a layout that includes specific equipment such as an electric excavator (ERC), a mobile roller crusher (MC), a transfer belt wagon (MBW), a bench conveyor (BC), a bench connection conveyor (BCC) and a connection conveyor (CC) and a fifth line where the material from the opening of the mining fronts (BoxCut) is taken back to the production systems.

4.3 Investigation of Causes and Development of an Action Plan

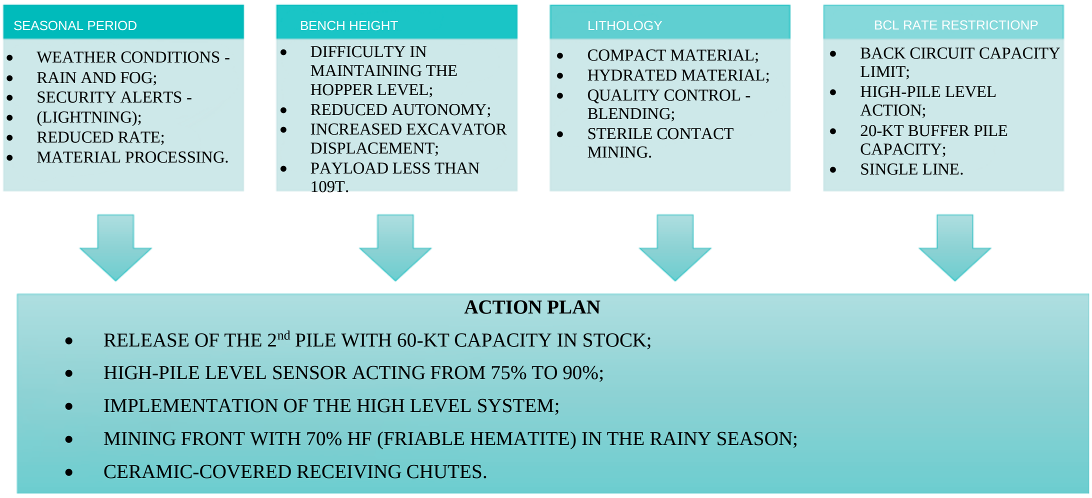
4.3.1 Productivity

Some production factors directly influence productivity. Among them, the seasonal period, bench height, lithology of the mined material, area with unstable material, hourly rate restriction of the return circuit, compact material (Jaspelite and Compact Hematite), quality control or mixing and operator training. The most relevant are:

- Seasonal period: It comprises the rainy season in the region, which can affect the hourly rate reduction due to the humidity of the material or even the total shutdown of the system as a result of operational risks.
- Bench height: The lower the height of the bench to be mined, the lower the filling factor of the excavator bucket, consequently requiring less autonomy between movements around the rosette and the system as a whole.
- Material lithology: The density of the material used for the mining itself is directly proportional to the lithology of the material mined, that is, the lower the density, the greater the volume, thus affecting the high filling factor and low productivity.
- Hourly rate restriction of the back circuit: The restriction of the back circuit should result in a rate reduction or downtime of a given system to adapt to its limit in transporting the material, thus preventing overloads and damage to the structures.

After identifying the main factors that can influence the Productivity indicator, the Action Plan was established according to Figure 6.

Figure 6 - Productivity - Identification of Failures and Action Plan

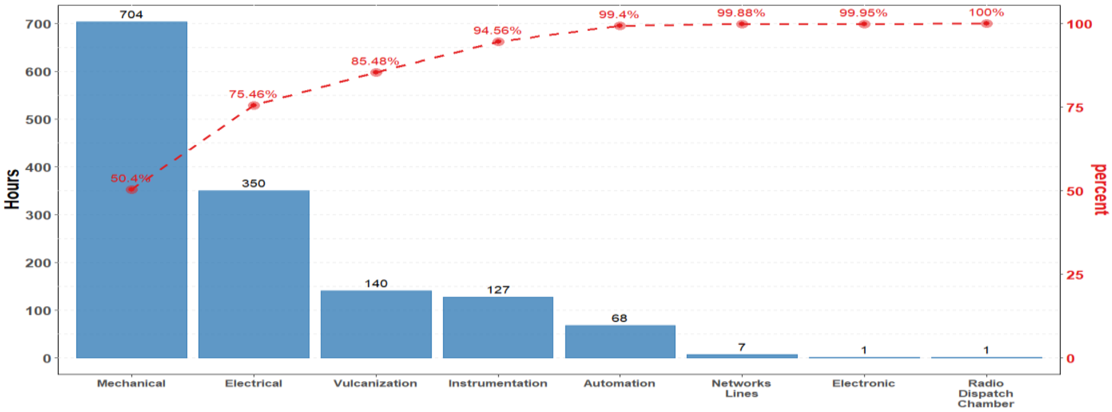


Source: The author(s) himself(themselves).

4.3.2 *Physical Availability (PA)*

The hours of preventive maintenance were programmed and thus accounted for in the production plan, whereas the hours of corrective maintenance that were scheduled will be considered in this work as failures and direct impacts on the PA indicator. By classifying them by sectors, such as: mechanics, electrical, vulcanization, instrumentation, automation, networks and lines, radio and dispatch. Figure 7 shows the hours accumulated in 2019 relative to corrective maintenance for each sector, and it is possible to identify that the mechanical, electrical, vulcanization and instrumentation sectors were those with the greatest need for repair. It is possible to highlight the mechanical sector as the most impactful on the PA indicator, with twice as many hours as compared to the second sector in corrective-maintenance hours.

Figure 7 - Corrective-maintenance hours by sector

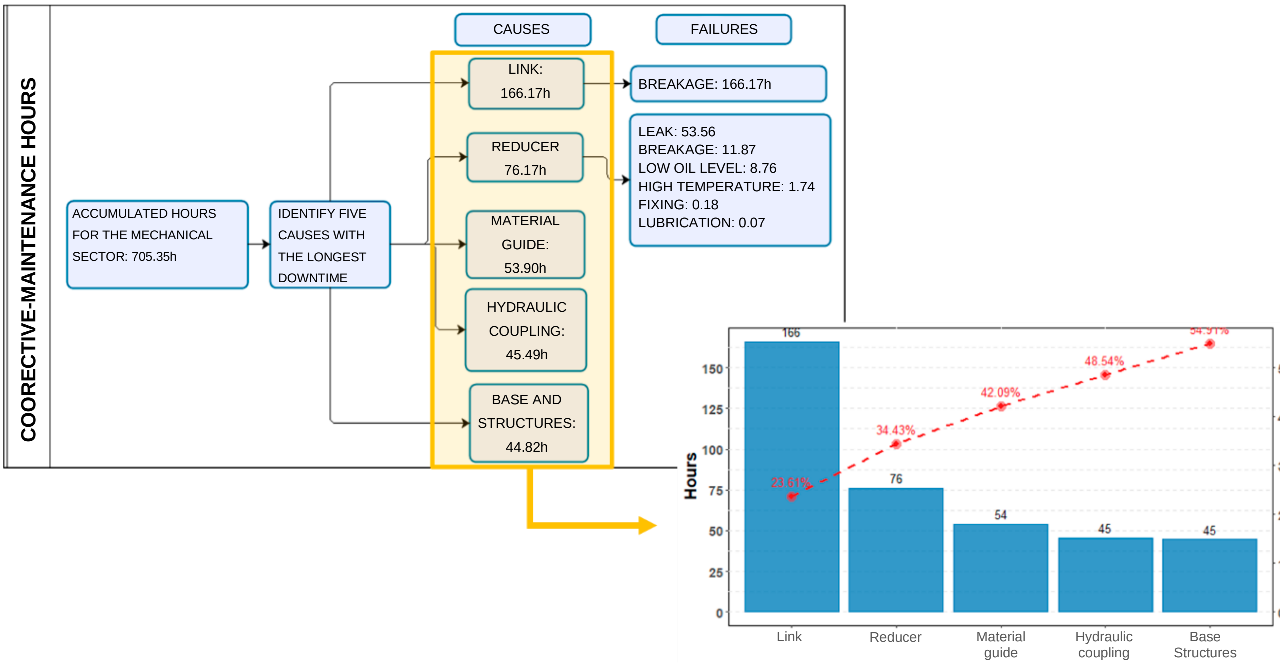


Source: The author(s) himself(themselves).

Knowing that the mechanical and electrical sectors together correspond to 75% of the hours that had an impact on the PA, and that only the mechanical sector accounts for 50% of the downtime for corrective maintenance, as a continuation of the investigative analysis, a breakdown of the failures and causes by sector was carried out, thus, it was possible to identify them for treatment, and reduce the downtime.

Next, Figure 8 shows the five main causes of downtime for the mechanical sector that had the most impact on the PA indicator for the period. It is noteworthy that link breakage was the major cause for downtime for corrective maintenance, corresponding to 23.61% of that time.

Figure 8 - Graph for the five main sector downtime causes

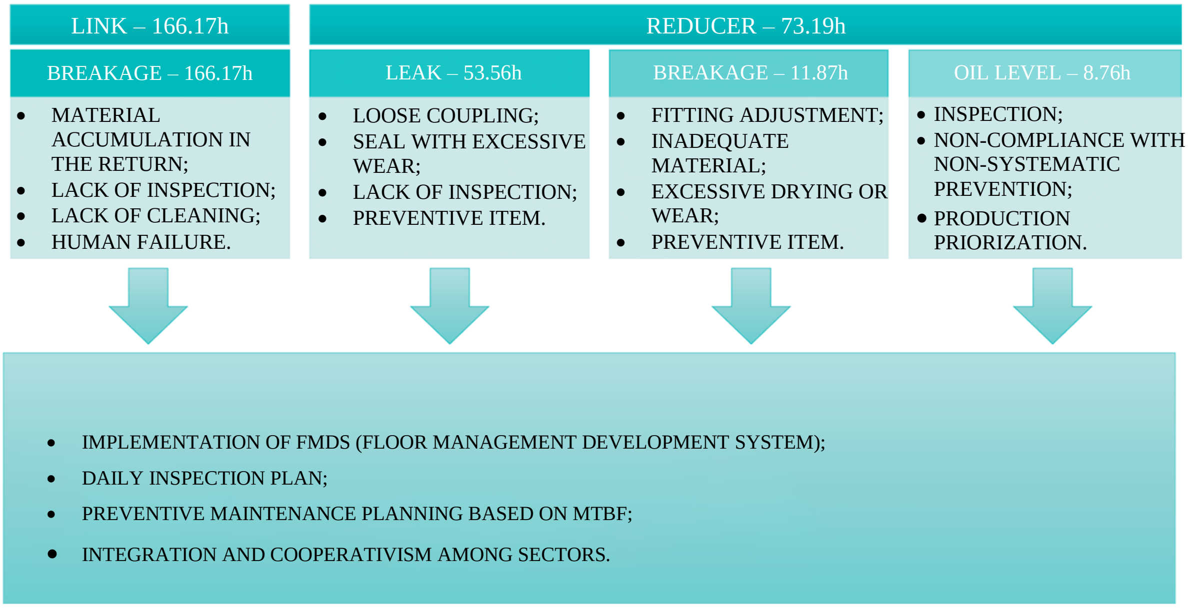


Source: The author(s) himself(themselves).

This deployment can and should be applied to other sectors that had an impact on corrective-maintenance hours, thus leading to a longer downtime than scheduled.

After identifying the main factors that can influence the Physical Availability indicator, the Action Plan was established according to Figure 9.

Figure 9 - Physical availability – Failure Identification and the Action Plan



Source: The author(s) himself(themselves).

4.3.3 Physical Utilization (PU)

When analyzing the data related to the system's PU, nine causes and 76 failures that directly interfere in the system's effectiveness were identified, and the operation sector is responsible for the impact on the utilization of 88.69% of the causes. Table 2 shows the description of the causes, hours and their representation in percentages for the operation sector.

Table 2 - Downtime by operation classified by causes

Cause	Time (h)	%
Operational downtime	2,878.01	81.15%
Material accumulation	289.09	8.15%
Micro-stops	127.18	3.59%
Tripped protection	71.08	2.00%
Obstruction	70.46	1.99%
Waiting for labor	60.11	1.69%
Trackshift	36.14	1.02%
Power failure	12.43	0.35%
Equipment adjustment	2.00	0.06%
Total	3,546.50	100.00%

Source: The author(s) himself(themselves).

Note that the cause "operational downtime" accounts for 81.15% of the failures that have an impact on PU. By grouping failures into indicator categories, the accumulated hours and percentage of each category is identified. This division also allows for a closer look at the data, identifying the failures that can be corrected immediately.

Table 3 below shows the operational failures classified into seven indicator groups, enabling the development of an action plan and the flow of action to leverage physical utilization to its scheduled goal. Within the operational downtime, there is the indicator Production flow/system idleness and displacement as the activities that have the most impact on PU, together corresponding to 74% of the production system's downtime. The deployment of such indicators allows the identification of the root cause and determining if they are feasible to solve in the short term.

Table 3 - Operating Indicators

Operating indicators	Time (h)	%
Production flow/System idleness	1,210	42%
Displacement	918	32%
Excavator station adjustments	260	9%
Others	176	6%
Parallel trackshift	154	5%
Trackshift belt lengthening/shortening	105	4%
Presence of crushed stones in the crusher	55	2%
Total	2,878	100%

Source: The author(s) himself(themselves).

The production-flow and system-idleness indicator groups the high-production-level, back-circuit-capacity-limit, and stand-by equipment failures. These failures are generally imposed on the system by flow limitations in the circuits that carry the production to the processing plant. Such a separation allows the identification of downtimes, the percentage of each in relation to the sum of hours and mainly the investigation of the root cause for treatment and signaling of points for improvement.

- High-pile level: It corresponds to the tripping of the high-level pile sensor, that is, there is a height limit for the formation of the buffer pile, which feeds the back circuit to the mine. Thus, when this pile reaches the so-called high level, that device trips, causing the mobile bridge along with the belt and, consequently all previous circuits, to stop until the pile’s capacity level is stabilized to resume the receipt of material from the production circuit. Such a measure prevents overflow and overloading of the pile, ensuring the safety of assets, which, in this case, are the bridge and the discharge shut of the TR1085KS01 line (circuit that supplies the buffer pile).

- Back-Circuit Capacity Limit: The back-circuit capacity limit is understood as the limit imposed on a previous circuit by the maximum flow capacity of the next circuit, that is, when a belt circuit that is ahead of another has a lower receiving limit than the delivery capacity of the previous one, thus limiting the system’s hourly production.
- The receiving capacity of the 1085KS01 circuit is 25 kt/h, and it is responsible for feeding the buffer pile with a capacity of 20 kt. The buffer pile feeds the long-distance belt conveyor (LDBC), which transports the production from the mine to the processing plant. The entire LDBC belt circuit prefixed by the designation TR1085KSXX has a production capacity limitation of 18.2 kt/h. The outflow limit of LDBC at a certain time of the day will imply a limitation of the TR1085KS01 circuit, that is, the more restrictions LDBC shows, the more production restrictions it will imply to the previous circuits.
- Stand-by equipment: Stand-by equipment is understood as that which is waiting to start operating, that is, the equipment is stopped, available for operation. However, due to production strategy, prioritization of the mining front, quality control, and even by limitation of the back circuit, it is waiting for a request from the responsible area to start operating.

Operating downtime due to displacement is the second indicator with the greatest impact on the productive system’s physical utilization - PU, and it can be classified as mining-front advancement, inter-level displacement, lane change, repositioning, displacement for disassembly, connection and disconnection with PMC, connection and disconnection with BC/BCC (Bench conveyor Bench Connecting conveyor), and connection and disconnection with MBW.

Table 4 shows the representation of the times for each type of displacement in accumulated hours and percentage based on the total hours used for this indicator. The description of the types of displacement and the impacts that they can bring to the physical utilization indicator favor an assertive improvement plan, which helps to direct the goal to that originally planned.

Table 4 - Displacement

Displacement	Time (H)	%
Mining-front advancement	313.32	34%
Inter-level displacement	256.00	62%
Lane change	110.49	74%
Repositioning	106.09	86%
Displacement for perforation and disassembly	69.10	93%
Connection and disconnection with PMC	26.61	96%
Connection and disconnection with BC/BCC	20.52	98%
Connection and disconnection with MBW	12.65	100%
Advancement between lithologies	3.66	100%
Total	918.44	100%

Source: The author(s) himself(themselves).

Next, there is a detailed description of the displacement activities, considering those that have the most impact on the system's downtimes when performing these activities.

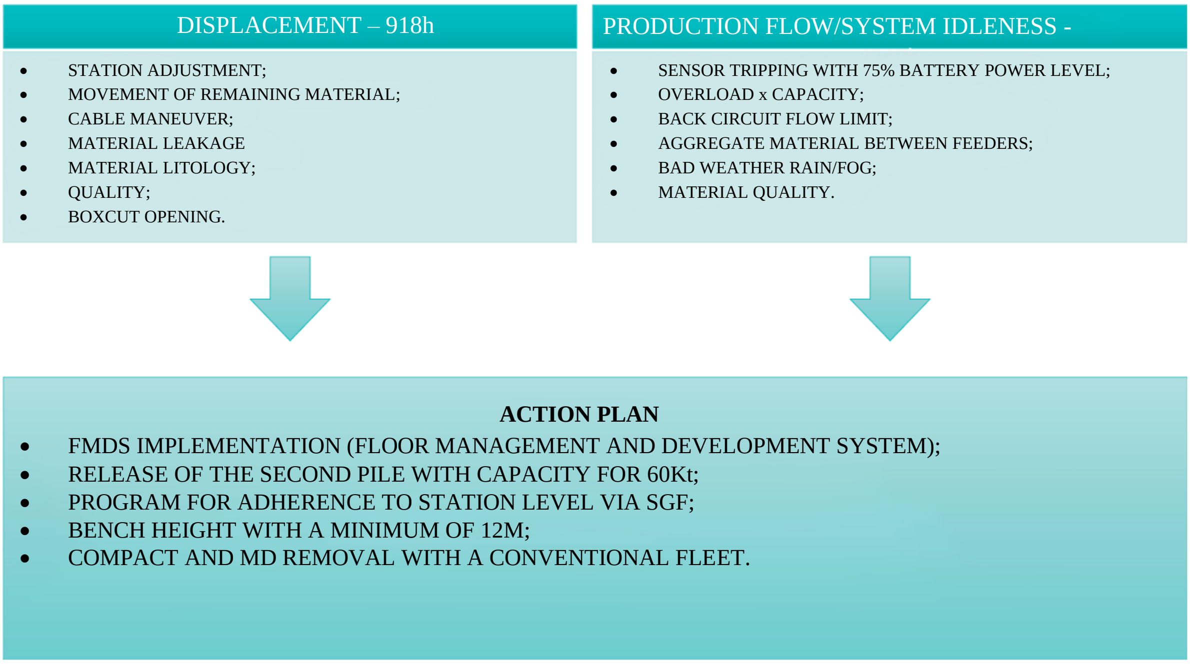
- Mining-front advancement: These are short-distance, forward-moving displacements that do not require crawlers to change lanes. They are necessary to keep the crusher hopper close to the material, allowing the excavator to feed the crusher.
- Inter-level displacement: These are long-distance displacements to ascend or descend a level. They are usually performed when the mining of a level is finished, where it is necessary to move the bench belt (trackshift). They can also occur due to the quality (blending) required in production and difficulties encountered in the mining of a given mining front, whether due to lithology (compact or sterile materials), or operating conditions, such as risk of equipment jamming during seasonal periods.
- Lane change: These are displacements that require the crawler to be steered so that the crusher is positioned closer to the material to be mined. This type of displacement requires maximum attention, as it demands more complexity with cable maneuvering and station adjustment. Lane change usually occurs due to the opening of a boxcut, the need to improve the hopper's positioning

in relation to the mining front, and mainly due to completion of a mining area, which requires new positioning.

- Repositioning: This type of stop refers to the need to improve the fit of the equipment's lances when, after the system's displacement, it is observed, in a test, that there is material leakage with risks of obstruction, projection, and damage to the equipment's structure.

After identifying the main factors that can influence the Physical Utilization indicator, the Action Plan was established according to Figure 10.

Figure 10- Physical Utilization - Identification of Failures and Action Plan



DISPLACEMENT – 918h

- STATION ADJUSTMENT;
- MOVEMENT OF REMAINING MATERIAL;
- CABLE MANEUVER;
- MATERIAL LEAKAGE
- MATERIAL LITOLOGY;
- QUALITY;
- BOXCUT OPENING.

PRODUCTION FLOW/SYSTEM IDLENESS -

- SENSOR TRIPPING WITH 75% BATTERY POWER LEVEL;
- OVERLOAD x CAPACITY;
- BACK CIRCUIT FLOW LIMIT;
- AGGREGATE MATERIAL BETWEEN FEEDERS;
- BAD WEATHER RAIN/FOG;
- MATERIAL QUALITY.

ACTION PLAN

- FMDS IMPLEMENTATION (FLOOR MANAGEMENT AND DEVELOPMENT SYSTEM);
- RELEASE OF THE SECOND PILE WITH CAPACITY FOR 60Kt;
- PROGRAM FOR ADHERENCE TO STATION LEVEL VIA SGF;
- BENCH HEIGHT WITH A MINIMUM OF 12M;
- COMPACT AND MD REMOVAL WITH A CONVENTIONAL FLEET.

Source: The author(s) himself(themselves).

4.4 Action Performance Planning

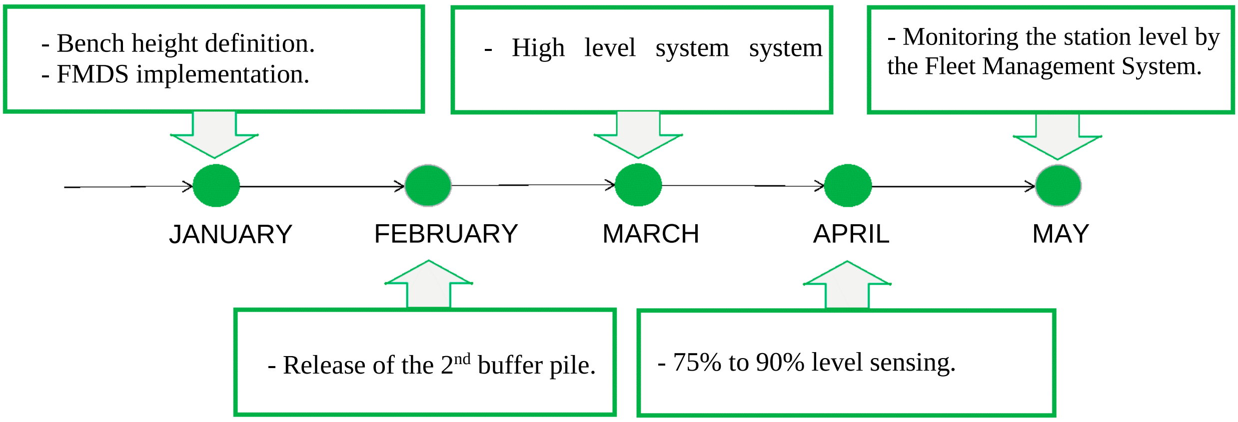
Anticipating failures means acting preventively against problems, with the goal of reducing the impact of system downtime, which directly influences cost increases and production losses. The need to maintain control of the indicators, as seen in this case study, needs to be effective and present positive results.

Throughout the study, data regarding the scheduled and performed production of a Brazilian mining company for 2019 were presented. They were extracted from a database used by the company which can filter details concerning downtime periods, causes, failures, and mainly the classification of hour categories for which an indicator is relevant in a given period.

Physical availability (PA), physical utilization (PU), and productivity are classified as the main production indicators. These, in turn, have a direct impact on the production schedules, and if not controlled, they can produce negative results, such as the non-fulfillment of the ore purchase contract pre-established by the company with its customers.

Thus, the Performance Phase (D) can be executed. Particularly for this study, the Action Plan was executed during the first semester of 2020, where the monitoring of KPIs was carried out based on the data from the production monitoring system. Performance planning is described in Figure 11.

Figure 11 - Performance Planning for Established Action Plans

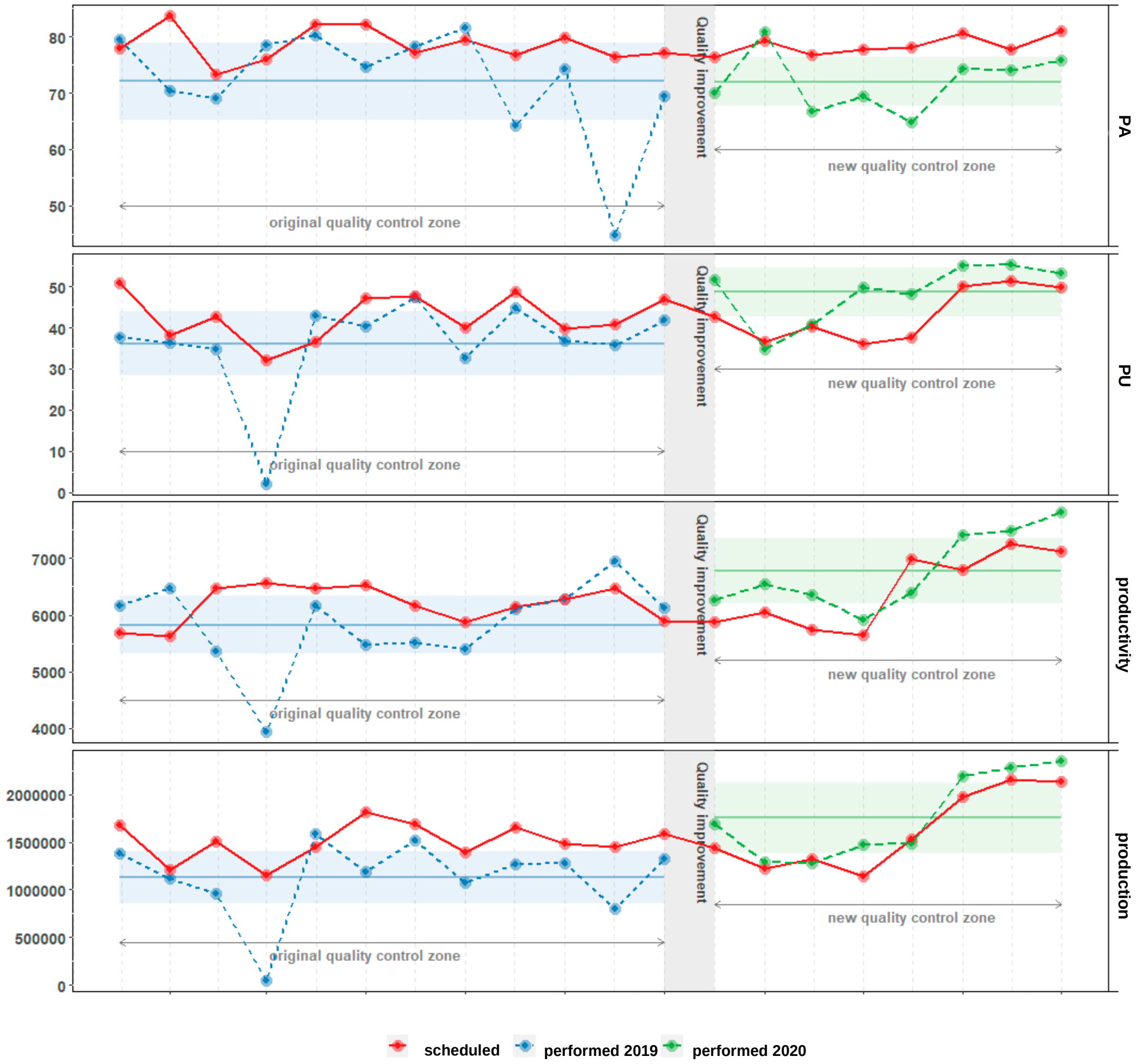


Source: The author(s) himself(themselves).

4.5 Checking the Action Plan

At first, it is possible to observe the good performance of the action plan based on the indicator results, which indicate the possibility of standardizing the established processes, of action improvement and a focus on even better results (Figure 12). As a quality improvement goal, we are interested in a lower variability, average increase, and greater proximity of the performed to the scheduled.

Figure 125 - Control chart for key performance indicators



Source: The author(s) himself(themselves).

In summary, and as presented in Table 5, the PU, productivity, and mean production indicators showed, on average, that the performed was higher (↑) than the scheduled for 2020. When comparing the performed in 2020 against that in 2019, those indicators also showed (+) increase, thus indicating improvement. However, the PA indicator maintained the performed below (↓) the scheduled with its dropping from 78.49→71.99, and an average equivalence (≈) of the performed in 2019 and 2020.

Regarding variability, all indicators showed an increase (↑) in the standard deviation between the performed and the scheduled; however, it is noteworthy that the PU, productivity, and mean production showed a tendency to increase. Moreover, when comparing the performed in 2020 with that in 2019, the PA, PU, and productivity indicators showed (-) decrease in variability and indicated improvement.

Table 5 - Descriptive statistics of each KPI.

		Scheduled			Performed		
Indicators	**Year**	**Mean**	**Standard Deviation**	**Confidence interval**	**Mean**	**Standard Deviation**	**Confidence interval**
PA	2019	78.51	3.03	(76.80; 80.22)	72.08 ↓	10.15 ↑	(66.34; 77.82)
	2020	78.49(≈)	1.69(−)	(77.32; 79.66)	71.99 ↓ (≈)	5.29 ↑ (−)	(38.32; 75.65)
PU	2019	45.59	5.69	(39.37; 45.81)	36.14 ↓	11.58 ↑	(29.59; 42; 69)
	2020	43.07(≈)	6.49(+)	(38.57; 47.56)	48.64 ↑ (+)	7.30 ↑ (−)	(43.59; 53.70)
Productivity	2019	6179.72	336.14	(5989; 6370)	5828.11 ↓	767.22 ↑	(5394; 6262)
	2020	6435.20 (+)	671.28(+)	(5970; 6900)	6773.39 ↑ (+)	693.29 ↑ (−)	(6293; 7254)
Mean production	2019	1504285	196644	(1393023; 1615548)	1127215 ↓	406239 ↑	(897364; 1357067)
	2020	1614137 (+)	416480(+)	(1325531; 1902743)	1754083 ↑ (+)	450257 ↑ (+)	(1442072; 2066095)

↑↓ - the performed increased/decreased as scheduled.
(±) **-** the performed in 2020 increased/decreased as compared to that in 2019.
Source: The author(s) himself(themselves).

4.6 Conclusion and Standardization

4.6.1 PA analysis

After a planning (P), performance (D) and checking (C) analysis, it was possible to identify the failures with the highest downtime rate for corrective maintenance, which enabled the indication of standardization of measures or the possibility of new PDCA rounds. Thus, the following conclusions can be listed for the PA indicator:

- FMDS (Floor Management and Development System) maintenance for identification and analysis of the failures occurring on the previous day and a focus on the current day.
- MTBF (Mean Time Between Failures) follow-up by failure and cause.
- Intensification of the inspection plan.
- PCM - perform preventive maintenance planning based on MTBF.
- Plan for integration and cooperation between maintenance and operation.

The increase in maintenance hours can be seen as a result of the Physical Utilization leveraging process, discontinuing the practice of opportunity maintenance without its proper indication in the system. Thus, during the system's unproductive stops, if there is the need for maintenance in any operational equipment, this can be done as an opportunity, but the downtime will be classified as maintenance and observed as an opportunity because it is understood that, in this case, the equipment is not available for operation.

4.6.2 PU Analysis

The Physical Utilization indicator became better assisted, based on the continuous improvement program adopted by the company. The operation sector adopted a disciplined attitude in its inspections, as well as the opening of work orders when necessary, the improvement of the interface with the mine planning and mutual collaboration between the sectors in removing compacts from the mine front, as can be seen in the action plan indicated:

- FMDS (Floor Management and Development System) implementation with the identification and analysis of the failures occurring on the previous day and a focusing on the current day.
- Building and releasing the second pile with a capacity for 60kt and a new single conveyor circuit.
- Sorting out dead material between feeders using mobile equipment.
- Changing the high-level sensor's tripping logic c from 75% to 90% of the pile's capacity.
- Monitoring the supply via the HLS system and prioritizing mining by lithology (blending).
- Covering the bench connection belts.
- Alternating the operation between the piles, thus providing greater maneuver flexibility and preventing high-level system downtime.
- Mining scheduling with a higher percentage of friable hematite during the rainy season - 70%.
- Planning displacements by following the mining priority.

For the displacement indicator, a second action plan was proposed with the descriptions below.

- Monitoring burning at the station level through the MineStar on-board fleet management system.
- Anticipating the removal of remaining material using crawlers or wheel loaders when the need is identified.
- Training and agility in cable maneuvers using an adapted agricultural tractor.
- Inspecting conveyors and correcting leaks in advance when necessary.

- Designing a mining plan with a single bench, thus reducing the need to move the system frequently.
- Designing a mining plan with appropriate blending, thus reducing the need to move the system when mining hydrated material.
- Removing compacted material in advance using a conventional fleet and replacing the area with friable material, thus avoiding moving the system.
- Keeping the boxcut opening for lower benches with conventional mining.
- Keeping the cleaning routine of equipment rotation (BM and MBW) in advance of displacements.
- Designing a mining plan that allows the continuity of systems on continuous lanes, thus avoiding displacements by changing lanes.

Besides the continuous improvement program adopted by the company, important factors, such as actions aimed at decreasing station adjustment periods that directly affect displacement activities, bench-height standardization at a minimum of 12m and a maximum of 17m, have helped to keep the system in use for a longer period, resulting in higher production.

4.6.3 Productivity Analysis

As for the productivity indicator, it showed the best results, going from a mean level of 5.6 kt/h in the first semester of 2019 to a mean of 6.5 kt/h for the first semester of 2020, which is the result of the action plan outlined below:

- Keeping the mining-front system with 70% HF during the rainy season.
- Keeping the BCC conveyor coverage plan.
- Replacing the transfer chutes’ lining with ceramics.
- Defining the minimum bench height of 12m for building the mining plan.
- Installing a GPS in crushers, thus enabling excavator operators to visualize the virtual rosette.
- Intensifying operators’ training.
- Geological mapping with drill holes which are updated weekly.
- Removing compact sterile with conventional material.
- Increasing ore flow capacity using the 2nd pile with a capacity for 60kt in stockpile, thus avoiding system shutdowns.
- Changing pile high-level sensor tripping from 75% to 90%.

- Routinely inspecting the single line, thus increasing reliability.

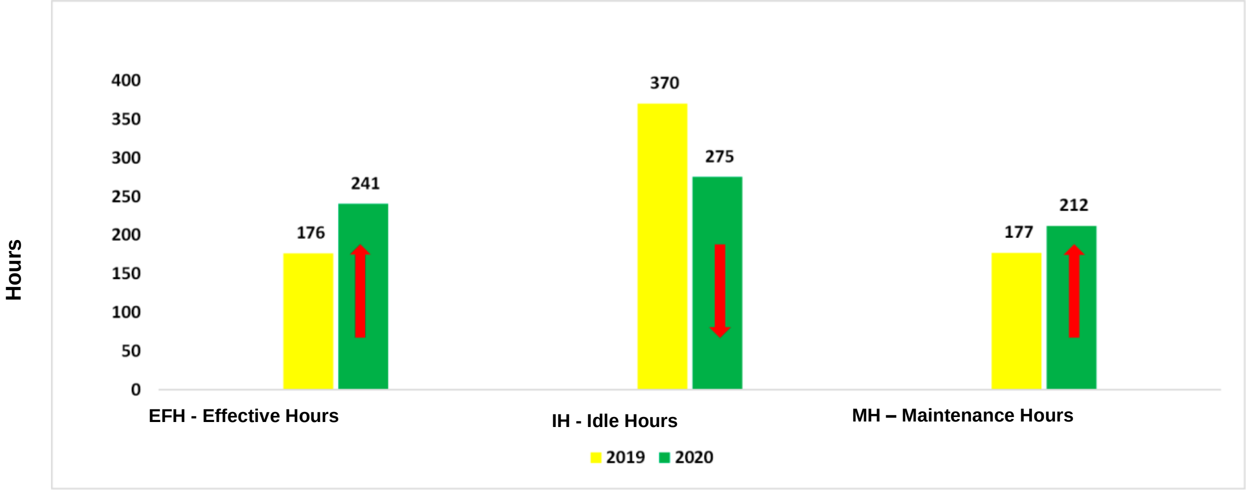
The actions taken showed positive results. Those actions were based on the analysis of the main points of impact on productivity, as well as on the increase in the number of hours used effectively producing and with the largest stock capacity and flexibility in the flow of production with the second pile.

Actions such as releasing buffer pile 02, repowering the conveyor belt circuit of the production system from 8.5 kt/h to 9.2 kt/h, anticipating the removal of compacts from the mining front, and increasing the physical use of the system have contributed directly to productivity increase.

4.6.4 Summary of Analyses

The analysis of the PA indicator shows the need to revisit the process, so that we can improve the PU indicator, which showed a direct impact on the increase in the number of corrective and equipment maintenance hours. Another factor that may have influenced this situation is the increase in productivity, which caused greater use and consequent wear of the equipment. Differential aspects that contribute to a better performance of the maintenance sector, with regard to the increase in available hours for production, can be to improve the preventive maintenance process and seek more resistant materials and of standardized use.

Figure 13 - Comparison graph - 1st semester 2019 x 2020



Source: The author(s) himself(themselves).

The monitoring and control of indicators are necessary because they are directly linked to the production results programmed by the company. Thus, a bad result of such indicators leads directly to a negative image of the company, generating distrust in the consumer market about its ability to honor the sales commitments signed in the ore purchase guarantee contracts that are used by the strategic planning in the preparation of the master production plan. In this way, the operational control sector must use such skills to control, investigate and eliminate waste and optimize available processes and resources, converting them into positive results for the company.

5 CONCLUSIONS

Some works on open pit mining have shown that the IPCC methodology has been the focus of implementation in some mining processes, due to the current characteristics of open pit operations and what will likely occur in the future (Nehring et al., 2018; Nicholls, 2020; Nunes et al., 2019; Paricheh & Osanloo, 2020). However, such studies have focused on investigating aspects of technical, economic and sustainable development, together with a comparative analysis to conventional mining methods, but have not described in detail how the IPCC process works.

In this way, as quality management jointly considers the effects of individual practices on strategic elements related to company objectives. Process quality assessment provides organizations with tools and methods to control and improve these processes (Drummond et al., 2017; Garcia et al., 2015). Furthermore, QA tends to have a positive impact on aggregate organizational performance and performance dimensions such as financial performance, organizational performance, customer service, and product quality (Xu et al., 2020).

In this study, the profile of production losses was analyzed, in 2019, as a result of a history of results of its KPIs different from those established by the Production Master Plan, in a multinational mining company located in the southeast of Pará, whose main product is iron ore, as well as a description of the IPCC mining method.

The results were obtained through an analysis of the production process in operation, as well as through a study of all the equipment involved in the IPCC mining method. The quantitative analysis of the database allowed relating and measuring production to the performance indicators analyzed and also showed in which months there was the greatest loss of production.

As regards the PA indicator, there is a need to revisit the process and investigate the good performance of the operation to improve the PU indicator, which directly affected the increase in equipment corrective maintenance hours. Another factor that may have influenced that phenomenon is productivity increase, which led to greater equipment wear. Thus, improving the preventive maintenance process, replacing wear components by others made of materials with higher resistance and the operational standardization of their use can be a differential that will contribute to greater performance of the maintenance sector and, consequently, to greater physical availability for the operation.

Monitoring and control of indicators is necessary, as they are directly linked to the production results scheduled by the company. The non-fulfillment of such indicators has a direct impact on the company’s negative image, generating distrust in the consumer market as regards its ability to honor the sales commitments made in contracts that guarantee the purchase of its product. These data are used by the strategic planning in designing the PMP. Thus, the role played by the operational control sector is justified, collaborating with the advent of production engineering and using such abilities to control, investigate, eliminate waste and optimize processes and available resources, consequently turning them into positive results for the company.

We also consider that this work has research limitations due to the unavailability of access to the operation, caused by the context of COVID-19. However, it is recommended that the work team make use of methodologies such as PDCA and Juran's trilogy, as well as other quality management tools, to investigate potential causes related to the divergences found, as well as establish action plans to minimize such differences.

REFERENCES

ABBAS, J. Impact of total quality management on corporate green performance through the mediating role of corporate social responsibility. **Journal of Cleaner Production,** 242, 118458, 2020.

ABBAS, J. Impact of total quality management on corporate sustainability through the mediating effect of knowledge management. **Journal of Cleaner Production**, *v.* 244, 118806, 2020. DOI: https://doi.org/https://doi.org/10.1016/j.jclepro.2019.118806

BARRATT, T.; ELLEM, B. Temporality and the evolution of GPNs: Remaking BHP’s Pilbara iron ore network. **Regional Studies**, v. 53, n. 11, 2019, 1555-1564. DOI: https://doi.org/10.1080/00343404.2019.1590542

BEN-DAYA, M.; DUFFUAA, S. O.; Raouf, A.; KNEZEVIC, J.; AIT-KADI, D. **Handbook of maintenance management and engineering**, v. 7, 2009. DOI: https://link.springer.com/book/10.1007%2F978-1-84882-472-0

BOKRANTZ, J.; SKOOGH, A.; BERLIN, C.; WUEST, T.; STAHRE, J. Smart Maintenance: a research agenda for industrial maintenance management. **International Journal of Production Economics**, 224, 107547, 2020. DOI: https://doi.org/10.1016/j.ijpe.2019.107547

CAMPOS, J. T. D. G. A. E. A. C.; FERREIRA, A. M. S.; FREIRES, F. G. M. Time variability management and trade-off analysis of quality, productivity, and maintenance efficiency. **Brazilian Journal of Operations & Production Management, v.** 18, n. 4, p. 1-19, 2021. DOI: https://doi.org/https://doi.org/10.14488/BJOPM.2021.018

CHIARINI, A. Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research. **The TQM Journal,** 2020. DOI: https://doi.org/10.1108/TQM-04-2020-0082

CLUNE, C.; O'DWYER, B. Framing engagement that resonates: Organizing advocacy for corporate social and environmental accountability. **European Accounting Review**, v. 29, n. 5, p. 851-875, 2020. DOI: https://doi.org/https://doi.org/10.1080/09638180.2020.1746374

DARESTANI, S. A., GANJI, M.; IMANNEZHAD, R. What are the key determinants of maintenance performance? **Production**, 30, 2020. DOI: https://doi.org/10.1590/0103-6513.20190155

DRUMMOND, P.; ARAUJO, F.; BORGES, R. Meeting halfway: Assessing the differences between the perceptions of ERP implementers and end-users. **Business Process Management Journal,** 2017. DOI: https://doi.org/https://doi.org/10.1108/BPMJ-05-2016-0107

FERNANDES, R. D. S.; SOUSA, L. R. C. D.; SANTOS, T. L. D. Analysis, investigation and evaluation of quality management in the mining process: a case study on divergencies in iron ore stock deviations. **Revista Produção Online,** v. 21, n. 3, p. 770-793, 2021. DOI: https://doi.org/10.14488/1676-1901.v21i3.4252

GACKOWIEC, P.; PODOBIŃSKA-STANIEC, M.; BRZYCHCZY, E.; KÜHLBACH, C.; ÖZVER, T. Review of key performance indicators for process monitoring in the mining industry. **Energies**, v. 13, n. 19, p. 5169, 2020. DOI: https://doi.org/10.3390/en13195169

GARCIA, S.; CINTRA, Y. C.; DE SOUZA RIBEIRO, M.; DIBBERN, B. R. S. Qualidade da divulgação socioambiental: um estudo sobre a acurácia das informações contábeis nos relatórios de sustentabilidade. **Revista Contemporânea de Contabilidade,** v. 12, n. 25, p. 67-94, 2015. DOI: https://doi.org/https://doi.org/10.5007/2175-8069

ISO 9001. **Quality management systems - Fundamentals and vocabulary.** In (pp. 59). Rio de Janeiro: ABTN Catalogo, 2015.

JURAN, J. M. The quality trilogy. **Quality progress**, v. 19, n. 8, 1986, p. 19-24.

LOVÓN-CANCHUMANI, G. A.; LIMA, F. M. D. R. D. S.; OLIVEIRA, P. P. D. Avaliação do ciclo de vida na mineração: estudos da produção de minério de ferro. In C. C. Peiter (Ed.), **Série Estudos e Documentos.** Centro de Tecnologia Mineral - Ministérios da Ciência, Tecnologia e Inovação, 2015. http://mineralis.cetem.gov.br/bitstream/cetem/1923/1/sed-89.pdf

MOHAMMADI, M.; RAI, P.; GUPTA, S. Performance evaluation of bucket based excavating, loading and transport (BELT) equipment–an OEE approach. **Archives of Mining Sciences**, v. 62, n. 1, 2017. DOI: https://doi.org/http://dx.doi.org/10.1515/amsc-2017-0008

NAIRN, R. W.; LABAR, J. A.; OXENFORD, L. R.; SHEPHERD, N. L.; HOLZBAUER-SCHWEITZER, B. K.; ARANGO, J. G.; TANG, Z.; DORMAN, D. M.; FOLZ, C. A.; MCCANN, J. I. **Toward sustainability of passive treatment in legacy mining watersheds: operational performance and system maintenance**. Proc. IMWA 2020.

NEHRING, M.; KNIGHTS, P.; KIZIL, M.; HAY, E. A comparison of strategic mine planning approaches for in-pit crushing and conveying, and truck/shovel systems. **International journal of mining science and technology,** v. 28, n. 2, p. 205-214. DOI: https://doi.org/https://doi.org/10.1016/j.ijmst.2017.12.026

NICHOLLS, J. A. Integrating financial, social and environmental accounting. **Sustainability Accounting, Management and Policy Journal**, v. 11, 4, p.745-769, 2020. DOI: https://doi.org/https://doi.org/10.1108/SAMPJ-01-2019-0030

NUNES, R. A.; DELBONI, H.; TOMI, G. D.; INFANTE, C. B.; ALLAN, B. A decision-making method to assess the benefits of a semi-mobile in-pit crushing and conveying alternative during the early stages of a mining project. **REM-International Engineering Journal,** 72, p. 285-291, 2019. DOI: https://doi.org/https://doi.org/10.1590/0370-44672018720109

OSANLOO, M.; PARICHEH, M. In-pit crushing and conveying technology in open-pit mining operations: a literature review and research agenda. **International Journal of Mining, Reclamation and Environment,** v. 34, n. 6, p. 430-457, 2020. DOI: https://doi.org/https://doi.org/10.1080/17480930.2019.1565054

OTTO, T.; MUSINGWINI, C. A compliance driver tree (CDT) based approach for improving the alignment of spatial and intertemporal execution with mine planning at open-pit mines. **Resources Policy,** 69, 101826, 2020. DOI: https://doi.org/10.1016/j.resourpol.2020.101826

PALADINI, E. P. **Gestão e avaliação da qualidade**: uma abordagem prática. São Paulo: Atlas.

PARICHEH, M.; OSANLOO, M. Concurrent open-pit mine production and in-pit crushing–conveying system planning. **Engineering optimization**, v. 52*, n.* 10, p. 1780-1795. DOI: https://doi.org/https://doi.org/10.1080/0305215X.2019.1678150

PARMENTER, D. **Key performance indicators**: developing, implementing, and using winning KPIs. John Wiley & Sons, 2015.

PEREIRA, L.; NUNES, N. Performance evaluation in non-intrusive load monitoring: Datasets, metrics, and tools—A review. **Wiley Interdisciplinary Reviews: data mining and knowledge discovery**, v. 8, n. 6, e1265, 2018. DOI: https://doi.org/https://doi.org/10.1002/widm.1265

REICHL, C., SCHATZ, M.; ZSAK, G. World mining data. **Minerals Production International Organizing Committee for the World Mining Congresses,** v. 32, n. 1, p. 1-261, 2014. DOI: http://www.world-mining-data.info/wmd/downloads/PDF/WMD2020.pdf

ROCHA, C. S.; CARDOSO, E. L. D. S. S.; FERNANDES, R. D. S.; BRANCO, N. C. N. M.; LUZ, R. M. D. N. Quality assessment of divergences causes in weighing copper ore at a mining company in the amazon region. **International Journal of Development Research**, v. 11, n. 8, p. 49633-49639, 2021. DOI: https://doi.org/10.37118/ijdr.22578.08.2021

SANE, R. Beneficiation and agglomeration of manganese ore fines (an area so important and yet so ignored). **Materials Science and Engineering Conference Series**, 2018.

SANTOS, M. S.; PINTO, T. V.; JÚNIOR, Ê. L.; COTA, L. P.; SOUZA, M. J.; EUZÉBIO, T. A. Simheuristic-based decision support system for efficiency improvement of an iron ore crusher circuit. **Engineering Applications of Artificial Intelligence,** 94, 103789, 2020. DOI: https://doi.org/https://doi.org/10.1016/j.engappai.2020.103789

SHEN, X.; CHEN, L.; XIA, S.; XIE, Z.; QIN, X. Burdening proportion and new energy-saving technologies analysis and optimization for iron and steel production system. **Journal of Cleaner Production,** 172, p. 2153-2166, 2018. DOI: https://doi.org/https://doi.org/10.1016/j.jclepro.2017.11.204

SILVA, A. S.; MEDEIROS, C. F.; VIEIRA, R. K. Cleaner Production and PDCA cycle: Practical application for reducing the Cans Loss Index in a beverage company. **Journal of Cleaner Production,** 150, p. 324-338. DOI: https://doi.org/https://doi.org/10.1016/j.jclepro.2017.03.033

SOUSA, J. C. D. C.; FERNANDES, R. D. S.; LUZ, R. M. D. N., SANTOS, I. R. D.; SILVA, B. L. F. D.; SANTOS NETO, I. D. Description of the IPCC mining process and analysis of the profile of productivity losses applied by a mining company in northern Brazil. **Reaserch Square**, 2022. DOI: https://doi.org/https://doi.org/10.21203/rs.3.rs-1308199/v1

WÅRELL, L. An analysis of iron ore prices during the latest commodity boom. **Mineral Economics**, v. 31, n. 1, p. 203-216, 2018. https://doi.org/https://doi.org/10.1007/s13563-018-0150-2

XENOS, H. G. **Gerenciando a manutenção produtiva**: Melhores práticas para eliminar falhas nos equipamentos e maximizar a produtividade. Falconi Editora, 2014.

XU, L.; PENG, X.; PAVUR, R.; PRYBUTOK, V. Quality management theory development via meta-analysis. **International Journal of Production Economics**, 229, 107759, 2020. DOI: https://doi.org/10.1016/j.ijpe.2020.107759

Artigo recebido em: 26/05/2022 e aceito para publicação em: 22/12/2022
DOI: https://doi.org/10.14488/1676-1901.v22i2.4661