# Description of the IPCC mining process and analysis of the profile of productivity losses applied by a mining company in northern Brazil

**Jaci Clayton da Conceição Sousa1**
Federal Rural University of the Amazon
**Rafael da Silva Fernandes** (rafasfer2@ufra.edu.br)
Federal Rural University of the Amazon https://orcid.org/0000-0002-3035-8025
**Rosana Maria do Nascimento Luz**
Federal Rural University of the Amazon https://orcid.org/0000-0003-2650-4875
**Ivanilson Rosa dos Santos**
Federal Rural University of the Amazon
**Beatriz Lorrane Farias da Silva**
Federal Rural University of the Amazon https://orcid.org/0000-0002-9418-6138
**Iamara dos Santos Neto**
Federal Rural University of the Amazon https://orcid.org/0000-0003-4746-9175

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## Abstract

This work presents the description of the IPCC (In-Pit- Crushing and Conveying) mining method and analyze the profile of productivity losses of a mining company in Northern Brazil. A complete description of the IPCC mining and the measurement of the key performance indicators. The description was relevant, as it details this type of Open-Pit mining contributing to the perspective of achieving the annual production goals. Thus, we found that availability represents a greater impact in production, accounting for a total loss of -3,286,656 ton. Hence, it was possible to identify the months on which there were larger losses in ore production. There is a need to investigate the operation performance to improve the PU indicator, which directly impacted the increase in corrective maintenance of the equipment. The dataset was collected from the equipment involved in the mining stage in 2019. The result of this research will help responsible managers implement efforts directed towards the indicator that represents greater loss of productivity. The description of the innovative and operational IPCC method in a single Brazilian mine, which allows greater flow of ore in less time than the conventional method, combines with the identification of months and values of greater productivity losses.

## Introduction

Mining is based on the exploitation of natural resources of the main economically viable minerals and is therefore characterized by an unlimited economic supply. In this respect, we have that mining is an important axis of Brazilian economy, contributing to the creation of jobs and income, fostering the development of local infrastructure, as well as the balance in the country's trade balance (Lima & Teixeira, 2006; ANM, 2020a; Huang et al., 2020), being responsible for much of the GDP growth in Brazil and directly impacts the development of the municipalities where they are located, given the financial compensation for the exploitation of mineral resources – CEFEM (ANM, 2020b), which in the state of Pará was R$ 444,973,850.23 in 2019 (Vale, 2020; Reichl  et al., 2020).

On the other hand, especially to economic and social aspects, the production process generates negative impacts on environmental aspects. Such impacts can bring consequences as air pollution, water scarcity, soil contamination, disposal of toxic waste, and the risk of rupture of tailings dams. (Ayub et al., 2019; Ribeiro et al., 2019; Feliciano & Garcia, 2020; Romero, 2020). Furthermore, it is reasonable to think that the cost/benefit ratio of environmental impacts leads us to a false compensatory feeling, thus, it is necessary to promote the adoption of corporate social responsibility management practices and search for optimal solutions that integrate economic, social and environmental aspects (Nicholls, 2020; Clune & O'Dwyer, 2020; Shen et al., 2018; Gan & Griffin, 2018, Rocha et al., 2021).

In addition to the perspective of a technological evolution that, over the years, has been presenting important innovations in the ore extraction process, strategic elements, as to the objectives of the companies, it should guide the way they distribute their resources in the production process (Mohammadi et al., 2017; Nairn et al., 2020; Pereira & Nunes, 2018; Santos et al., 2020). Therefore, we refer to a quality assessment that, according to (Paladini, 2019) can be based on customers or production costs.

As a way of describing the production chain and, for iron ore to reach the final customer with the required specifications, the initial stage of the mining macroprocess, called the mining stage, is predominantly carried out by the open-pit mining method. The choice of process mainly considers the economic criterion given by the lowest unit cost when considering all operational constraints (Macedo et al., 2001; Barratt & Ellem, 2018; Sane, 2017; Shen et al., 2018, Fernandes et al., 2021a).

It is essential that the exploitation project considers the life of the mine, combined with the sale price minus the cost of exploitation, thus establishing a profit perspective that determines the viability or not of the project (Drummond et al., 2017; Gomes, 2017; Warell, 2018, Fernandes et al., 2021b).

Given the importance of a structured study on the economic viability of the project, the so-called operational impediments should not be forgotten, those which directly impact the performance indicators and, should demonstrate how the sizing and infrastructure of the mine, focusing on the loading and transport of the ore to the primary crusher, influence the attainment of the goals established in the strategic planning of the mine compared to the achieved ones. (Esser, 2010; Santos, et al., 2020; Laurintino et al., 2019; Werk, Ozdemir et al., 2017; Macedo et al., 2001).

In the context of this study and alternatively to the transport of ore from the mining front to the beginning of the processing stage, we have that this stage is typically carried out by "off road" trucks, so the mining technology "In-Pit Crushing and Conveying" (Crushing and transport in pit), called IPCC mining has as main difference to carry out the initial process of crushing the ore within the mine, in other words, it is a mobile crushing system composed of excavator, mobile sizing rig and interconnected conveyor belts. This process brings an important technological and sustainable innovation for mining (Drummond et al., 2017; Clune & O'Dwyer, 2020, Silva et al., 2021).

In this context, the equipment involved in the IPCC have robust structures and require a performance monitoring, requiring a measurement methodology, which is called key performance indicators, KPIs. (Parmenter, 2015; Peral et al., 2017).

KPIs play a crucial role as they provide fast and accurate information, comparing current performance with a goal required to meet business objectives (Parmenter, 2015; Peral et al., 2017). This comparison process is a quality assessment and measures the degree of differentiation of indicators allows the measurement of the impacts of the deviations in physical availability (PA), physical utilization (PU) and productivity. The motivating practical situation is related to the adoption of the IPCC mining method by a Brazilian mining company, in which the performance is measured by the KPIs.

In this context, given the problem presented and the importance of quality assurance, this work carried out a study in a multinational mining company located in the southeast of the state of Pará, which produces several iron ore products and presented, in 2019, a results history of its KPIs divergent from that established by the master production plan. Thus, for the purpose of this study, productivity, PA, and PU are defined as key performance indicators and directly influence production. Hence, this work aims at minimizing the operational impacts that result in non-compliance with the goals established in the master production plan to the detriment of the accomplished.

## Process Description

# Production macroprocess

The assembly of the production plan of a mining company, in the practical impossibility of obtaining a complete separation of mineral constituents, has as a general rule, the attainment of higher iron content (product quality) and, inevitably, also needs to focus on the process, as this implies an increase in the cost of treatment (process quality).

Consequently, the entire production chain should be assessed to identify and treat waste. Along with it, investigating and identifying the causes that influence poor quality costs, whether product or production process is feasible and provides information that supports decision-making. In this sense, we seek to find solutions to control the process and return it to the acceptable variation range, and ones where there has been an effort to improve its quality (Luz & Lins, 2010; Nader, 2013).

Commonly, in mining processes, its macroprocess is given by the mining phases, in which the ore is removed from the mines in its crude form, the processing phase, where the ore goes through stages of physico-chemical treatment to be adjusted to the customer's requirements, the following phase is the shipment, where the material is stored in piles in the storage yards and, then the flow phase is continued, the ore is transported by rail to the seaport, where the pelletization takes place, to be directed to the final customer by ship. (Lovón-Canchumani et al. ,2015). In the problem situation of this work, the process that is presented and studied corresponds to the extraction and mining stage characterized by the adoption of an important innovation in the iron ore mining method, adapting the In-Pit mining to its extraction process, what is called IPCC mining method *(In-Pit Crushing andConveying)*– crushing and belt transport inside the pit.

# IPCC mining method

It is a method of open-pit mining consisting of the integration of the mine and primary crushing inside the pit, in other words, the entire primary system of processing the material removed from the mine is mobile.

Innovation in the ore extraction process considers a mine layout, as show on Figure 1, based on the production flow and composed of a set of equipment: excavator, mobile sizing rig, belt wagon, in some cases portable conveyor belts (PMC-D – Portable Modular Conveyors Type) are also used, bench conveyor, bench connection conveyor, connection conveyor, transfer house and stockpile.

The main objective of the IPCC mining method using mobile crusher is reducing operational costs and environmental impacts created by mineral exploration. Achieving these goals is only possible by reducing the number of transport equipment (trucks) in the production system, since these represent the largest portion of operational costs in conventional mines, because of the high consumption of diesel and tires in its process, which is considered the main cause for the emission of polluting gases in the atmosphere in the mining activity.

The IPCC mining method requires from the design or geometry of the mining a robust technical plan, accommodating within the pit the equipment used in mineral extraction, in other words, the mining planning must take into consideration the demands that the system imposes, especially the time when each installation should be available in a mine site, the blending needs in meeting the quality of the product and the number of options to be mined.

# Equipment used in IPCC mining

The equipment used in IPCC mining is large and requires great technical skill for its handling, extreme attention to the necessary maneuvers and excessive care for the safety of the people involved and the assets.

The main equipment used in IPCC mining are: Electric rope shovel; Mobile sizing rig; Mobile belt wagon (MBW); Bench conveyor (BC); Bench connection conveyor (BCC); Bench conveyor (CC).

Other equipment that is used in IPCC mining aid are: Bulldozer; Backhoe; Grader; *Pipelayers;* Adapted agricultural tractor; Portable modular conveyors type D (PMC-D); Next, we will learn a little about the main equipment that constitutes the production system.

## Electric rope shovel (ERS)

The electric rope shovel is an excavation machine, used in civil construction and mining, as shown in Figure 2.

CAT 7495 cable excavators have a cable closure and dredgers with a capacity of 45m³ (108t to 120t) used to directly power the mobile crushers. They present in their cycle times variables such as: *payload* (t); loading time; turning angle; diggability; travel time and effective productivity.

# Mobile sizing rig;

Known as MSR - Mobile Sizing Rig, a crusher with its own traction system (Figure 3), they have two rollers with diameters of 2.5m and width of 3m and work at a peripheral speed of 7 m/s. They have processing capacity of up to 10,500 t/h when working on lower hardness materials. They can receive materials with a top size of 1,200 mm and aim to reduce this material to 350 mm.

In IPCC mining, these crushers are used on friable material fronts, where the excavator makes the feeding of the crusher hopper, after this material is driven through an apron feeder to the roller crusher that reduces this material up to 350 mm, where the crushed material follows through conveyor belts to the other stages of the process, going through or not by extension equipment (belt wagons) that allow greater flexibility compared with the approximation of the mining materials by the production systems. Below it is picture of roller crushers (Figure 4).

These crushers have a rated capacity of up to 9,500 t/h and the rollers of the crushers have a diameter of 2,500 mm, a width of 3,000 mm and a peripheral speed of up to 7 m/s.

## Mobile belt wagon (MBW)

They are belt wagons used to transport MSR material to the bench conveyor (BC) or bench connection conveyor (BCC), as seen in Figure 5. The relocation of these equipment is carried out through a traction system that has its own tracks, two booms, one receiving and one unloading respectively with receiving and unloading kicks, in addition to a central kick that connects the receiving and unloading belts and a rotating system in which its structure facilitates the fitting with the other equipment.

In IPCC mining this equipment allows for a better physical arrangement of the mining, facilitating the positioning of the excavator and the crusher in the mining front. This makes the physical arrangement possible at different levels of bench, ensuring a longer residence time of the belt wagon (MBW).

## Bench conveyor (BC)

They are belts mounted on flexible modules that allow drag according to the configuration of the mining. These belts in addition to the drag, are easy to assemble and disassemble, so whenever necessary they can be disassembled and reassembled at different levels, maintaining the configuration of the productive system.

They are composed of counterweight (XXT concrete structure, tail, squides, modules, load rollers, return rollers, impact rollers, belt stretching system, scrapers, drive drum, return drum, belt guide pulley, drive/thruster motors, rails, belt, electrical cables, communication cables, transfer drive, discharge chute, plus safety devices (emergency stop switches, belt misalignment switch, low speed switch, tear detector).

These belts (Figure 6) allow the mining to be configured on 3 bench levels. Since they must maintain a connection with the crusher, either through extension belts or directly, always depending on the approach or level of bench in which it is compared to the sizing rig (MSR).

## Bench connection conveyor (BCC)

They are belts that connect the bench conveyors to the bench connection conveyors. They are composed of counterweight (4296t concrete structure, tail, skdes, modules, load rollers, return rollers, impact rollers, belt stretching system, scrapers, drive drum, return drum, belt guide pulley, drive/thruster motors, rails, belt, electrical cables, communication cables, transfer drive, discharge chute, unactuated grinding machine (NDHC), plus safety devices (emergency stop switches, belt misalignment switch, low speed switch, tear detector). These belts (Figure 7) are configured to have a longer residence time compared to the bench conveyors, but may undergo shortening, prolongation or change of level according to the development of the mine.

## Bench conveyor (CC)

Bench connection conveyors (Figure 8) are composed of a movable head used to unload material into the stockpile feeding belt or transfer to the transport circuit to the sterile piles. They are equipped with a telescopic conveyor, used to distribute the ore in piles or silos.

The movable head moves using a drive system, rack-and-pinion type, an independent drive unit and a hydraulic claw for positioning.

The bench connection conveyor presents in its composition a belt that moves by friction due to the rotation of the drive drum, drive drum, return drum, load rollers, return rollers, motor drive system, counterweight stretching system, movable head translation system, cleaning accessories (primary, secondary, and tertiary scraper) and safety accessories (emergency switches, misalignment switches, normal stop switch, low speed sensors and conveyor position sensors).

# Open pit mine using the IPCC method

## Production process

The mine consists of four production systems and has a layout composed of an electric excavator (ERC), a mobile roll crusher (BM), a mobile belt wagon (MBW), bench conveyor (BC), a bench connection conveyor (BCC) and a Bench conveyor (CC), as well as a fifth line where material from the opening of the mining fronts (BoxCut) is carried out to the production systems.

Initially, after the opening of the pit through mobile equipment (excavator and trucks) and infrastructure (bulldozer) due to local geology, IPCC equipment is positioned. The electric excavator ploughs the material on the bench and feeds the crusher hopper (MSR) which then unloads the crushed material into the belt wagon (in case there is a need to have a belt wagon in the system configuration), then it unloads the material into the bench conveyor (BC), which proceeds to the bench connection conveyor (BCC), and then to the bench conveyor (CC) until it reaches the stockpile where it is partially stored until it is transported by long distance belt conveyor to the processing plant.

In order to have an ideal physical arrangement for production, there is a need to drag the bench conveyor, an activity called trackshift. This drag allows the MSR to work at different levels compared to the bench conveyor, it being made more flexible through the use of the belt wagon (MBW).

There are three possible configurations for IPCC mining: [1] upper bench; [2] intermediate bench; [3] lower bench.

The bench conveyor (BC) is mounted on the intermediate bank, then the excavator (ERS), the mobile roller crusher (BM) and the belt wagon (MBW) are positioned in the BoxCut and, finally, it is mined to the maximum range of the equipment, limited by the upper bench and berm limit established in the geotechnical premises. Figure 9.

After finishing the mining there is a need to move the excavator and mobile crusher to the upper bench, keeping the belt wagon (MBW) in the intermediate bench. The mining is carried out to the extent allowed by the maximum range of the equipment in the upper bench. Figure 10.

Finally, the ERC and BM equipment are moved back to the intermediate bench and the mining is carried out up to its maximum range. During the second stage of the mining of the intermediate bench, mobile equipment perform the opening of the lower bench (Figure 11), where IPCC equipment will be moved after the end of intermediate mining.

After finishing the mining on the lower bench, there is a need to drag the bench conveyor, i.e., the trackshift.

## Trackshift operation

Trackshift operations meet configuration and material quality needs in the mine and can be of two distinct ways: belt with parallel movement and belt with pivoted movement (radial or fan), the difference being based on the movement of the belt to be performed during the belt drag activity.

As seen in Figure 12 the drag activity in parallel, the bench conveyor undergoes a drag that is parallel to the bench connection conveyor, while in the pivoted activity, the bench conveyor undergoes an angular drag in relation to its discharge point on the bench connection conveyor.

To carry out the movement of the bench conveyor (BC) the modules with rails fixed to the set are hoisted for the trackshift through a special device coupled to the bulldozer. This device allows that while moving the tractor, already coupled to the rail, the drag of the modules for the change of track is performed with light movements and in parallel avoiding breakage. This technique takes the rail (and the belt) to a lateral shift at the tractor location of approximately 500-600 mm. Tractors repeat these steps continuously until the belt has been moved to the desired location. At the end of the drag, the bench conveyor is aligned, using the "hoist arm" device with topographic markings as reference.

After finishing the process of changing the track of the modules, the belt, which is the entire electrical part, is reassembled and commissioned, thus tests are performed to verify failures and necessary adjustments. The delivery of the belt for operation is only made after verifying that there are no failures and impediments to the operation.

## Materials And Methods

# Production schedule

The production information is stored in a database through a software used for production control and monitoring, information which was provided for study purposes.

The methodology, periodicity of monitoring and the improvement actions will redirect the indicator to the goal, in particular, the monitoring of indicators occurs daily, and it is carried out by the process control team.

In 2019, the production system had a production schedule of 18,051,425.8 ton, however, it produced 13,526,587.5 ton and this represents a deficit of 4,524,838.3 ton, in other words, the system delivered 73.82% of what was expected, representing a deficit of 26.18% compared to the scheduled amount.

Before further investigating all possible causes that impacted the poor performance of the system related to production in 2019, it will be necessary a detailed study of the indicators, how the classification of calendar hours is made and their distribution by category, making it possible to compare the program with what was performed through graphs generated from the information extracted from the database. It is important to emphasize that for the study to be assertive in its results, the database needs to be reliable and faithful to what is performed in the field.

# Key performance indicators

Key performance indicators (KPI) are measures that assist in managing and evaluating the quality during the production process and provide consistent information that supports the decision-making process. In the context of mining and this work, three KPIs are presented: physical utilization rate (PU), physical availability (PA) and productivity. Thus, even though indicators have great variation from company to company, (Xenos, 1998) states that the basic concept remains unchanged.

To better exemplify these indicators, Table 1 relates operating time and the equations (1) e (2), represent the calculation of PU and PA respectively.

**Table 1.** Operating time.

<table>
<tr><th colspan="5">Equipment usage and availability rate</th></tr>
<tr><td colspan="5">Total operating time</td></tr>
<tr><td colspan="4">Working time</td><td>(1)</td></tr>
<tr><td colspan="3">Scheduled operating time</td><td>(2)</td><td rowspan="4"></td></tr>
<tr><td colspan="2">Time available for operation</td><td>(3)</td><td rowspan="3"></td></tr>
<tr><td>Actual operating time</td><td>(4)</td><td rowspan="2"></td></tr>
</table>

Source: Adapted from Xenos (1998).

Where: (1) Scheduled non-operating time; (2) Preventive maintenance time; (3) Equipment fault repair time; and (4) Process delays.

$$Physical\ availability = \frac{Time\ available\ for\ operation}{Working\ time} \qquad (1)$$

Physical availability (PA) is one of the six world-class indicators (Peral et al., 2017). Simply put, PA can be defined as how available the equipment is to perform its functions during a given period. The calculation formula for physical availability varies according to the productive sector and companies and, in the mining sector, one of the formulas is demonstrated in the equation (2):

$$PA = \frac{CH - MH}{CH} \qquad (2)$$

Where *CH* is the calendar hours and maintenance hours.

In a different manner, the physical utilization rate (PU) considers operational aspects, over which the maintenance team has no influence. Hence, the utilization rate represents how maintenance and production together are taking advantage of the productive capacity of their means of production. In the mining sector we can reformulate the calculation according to the equation (3):

$$PU = \frac{effective\ hours}{available\ hours} \qquad (3)$$

In conclusion, the productivity indicator is the simplest one, and it represents the total mass produced in the time available for operation, i.e.:

$$Productivity = \frac{total\ mass\ produced}{effective\ hours} \quad (4)$$

# Calendar hours – CH

The calendar hours presented refer to 2019, i.e., 365 days represented in hours totaling 8,760 hours. These hours grouped according to the occurrence of the events and according to the set of equipment that compose the system, can be subdivided into 3 classes: working; stop and relocated. From there, these are classified into categories of hours, 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).

Figure 13 shows the representation of the calendar hours of the production system sorted by category.

Provided the classification of hours, it is necessary to identify them according to the performance indicator to which each category refers.

As we already know, for the indicator of physical availability - PA we have the hours in maintenance, i.e., it means that the system was non-operating for some maintenance activity, be it preventive or corrective. So, we can say that CMH, SPH and NSPH fall into this category of hours.

For the indicator of physical use - PA that refers to the hours available for operation, we can classify the EFH, IIH and EIH. IIH and EIH are considered as impacts on the hours available for operation.

For the Productivity Indicator, we can highlight the EFH which refers to the hours in which the system performed production, so it is possible to compare the scheduled productivity with the productivity performed and identify the bottlenecks that led to the non-fulfillment of the target.

The production schedule for the production system in the year 2019, 8760 calendar hours and the key performance indicators are presented in Note that to produce 18,051,425.8 ton, a productivity of 6,165 ton/h was estimated, with a PA of 78.5% and PU of 42.6%.

Table 2. Note that to produce 18,051,425.8 ton, a productivity of 6,165 ton/h was estimated, with a PA of 78.5% and PU of 42.6%.

**Table 2.** Production indicators production system 2019.

| Production Indicators | Scheduled | Performed |
|---|---|---|
| Physical availability – PA | 78.48% | 72.16% |
| Physical utilization – PU | 42.60% | 36.01% |
| Productivity | 6164.62 t/h | 5942.92 t/h |
| Production | 18051425.82 t/y | 13526587.47 t/y |

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

When comparing the scheduling data with the data performed, it is possible to observe that productivity closed at 5.943 t/h, which represents 96.4% of the program, thus, we know that the productivity loss was 3.6% lower than expected.

For the indicator of physical availability - PA, the performance was 72.2%, in other words, it closed the year with a loss of 8.02%. Physical use - PU closed in 36% which represents 15.5% lower than the program of 42.6%.

To detail the factors that impacted the non-fulfillment of the production in 2019, we will start to stratify the data of the productive system, demonstrating through tables and graphs all the events that occurred according to the classification of hours indicating their impacts on the established indicators.

Continuing the analysis of the data provided by the production data storage software, it is possible to verify information regarding the production achieved, the failures that occurred in the equipment and the sector responsible for the failure. The company uses a program that details all halts in production classifying them by indicator. Information such as physical availability - PA, physical utilization - PU and productivity can be generated by selecting the desired report, the reference period and the type of equipment, because the database stores all the information of the production systems.

## Results And Discussion

# Loss profile of indicators

We already know that the productive system did not meet its production target for 2019, so we will analyze its performance indicators. In Figure 14 it is possible to calculate the production loss by performance indicators, verifying the representativeness in tons for each indicator. It is noted that PA represents greater impact on production loss, accounting for a total loss of -3,286,656 ton/2019 and indicates that the system under analysis is relatively unavailable to perform its functions, in other words, the system was inoperative due to maintenance time beyond the scheduled.

As the preventive hours were scheduled and considered within the production planning, we will consider here the surplus to the scheduled for the hours of corrective maintenance as failures and direct impacts on the PA indicator.

# Monthly detailing and preliminary analysis of indicators

By unfolding the production schedule of the productive system, it is possible to identify in which period the scheduled goal was not reached, thus enabling a breakdown of the points where there was a significant difference. Hence, justifying a study of key performance indicators, demonstrating the main failures and their impacts on achieving the scheduled production.

## Productivity

Figure 15 shows the relationship between performed and planned productivity, it is possible to realize that productivity has its worst performance in March, April, June and August and it presented a recovery in the other months. However, it is worth mentioning that the low performance of April may result from the seasonal period and thus did not reach the target of the year for this indicator.

Some factors can directly influence productivity, among them we can highlight the seasonal period, bench height, lithology of the material drawn, area with unstable material, restriction of hourly rate of the posterior circuit, compact material (jaspilite and compact hematite), quality or control of blending and operator training.

## Physical availability – PA

This indicator shows the period in which the system is available for operation considering a percentage of calendar hours according to the day, in other words, if a day has 24 hours and the planning and maintenance control budgeted 90% PA, we say that the equipment has 21.6 hours available for production. Figure 16, shows the comparison between the accomplished and the scheduled for the productive system in 2019, and a PA of 78.5% was budgeted for the year, which represents 6874h available for operation and a PA of 72.2% was accomplished, representing 6321h with a deficit of 553h.

The monthly analysis of physical availability (PA) allows us to verify in which months there was a greater loss in this indicator, for example, in November the system had its worst performance performing 44.7% of a scheduled of 76.4%. The execution of a broader analysis leads us to the need for monitoring and control of maintenance indicators, identifying and classifying failures.

As the preventive hours were scheduled and thus considered within the production planning, we will consider here the surplus to the scheduled for the hours of corrective maintenance as failures and direct impacts on the PA indicator. Classifying them by sector, we have: mechanics, electrical, vulcanization, instrumentation, automation, networks and lines, radio and dispatch.

## Physical utilization – PU

This indicator intends on showing the period in percentage that the system was used when available for operation. Figure 17 shows the monthly performance during 2019 for the indicator of physical use - PU of the productive system. Note that this indicator had its worst performance in April and its best performance in May.

## Conclusions

Several studies in the literature indicate that the IPCC methodology has received more attention due to the current characteristics of open-pit mining operations and what is expected to occur in the future. (Nehring et al., 2018; Nunes et al., 2019; Paricheh and Osanloo, 2020; Osanloo & Paricheh, 2020). However, those studies focus on technical, economic and sustainable development aspects, along with comparative analysis to conventional mining methods and lack detailed descriptions of the process.

Thus, since quality management collectively considers the effects of individual practices on strategic elements related to the objectives of companies, quality assessment allows organizations to be equipped with instruments and methods of control and improvement of processes. (Garcia et al., 2015; Tornelli, 2017; Drummond et al., 2018). In addition, QMS tends to have a positive impact on aggregated organizational performance and performance dimensions, including financial performance, organizational performance, customer service and product quality. (Xu et al., 2020).

In this study, it was presented the description of the IPCC mining method adopted by a multinational mining company located in the southeast of the state of Pará, which produces several iron ore products. Given a history of results of its KPIs diverging from that established by the master production plan, the profile of productivity losses in the year 2019 was analyzed.

The results were obtained through extensive analysis of the production process in operation, as well as the survey of all equipment involved in the IPCC mining method. The quantitative analyses of the database allowed the measurement of production related to the performance indicators analyzed and indicate the months in which there were greater losses of production.

Regarding the PA indicator, there is a need to revisit the process, investigating the good performance of the operation to improve the PU indicator, which directly impacted the increase in the hours spent on corrective maintenance of the equipment. Another factor that may have influenced this phenomenon is the increase in productivity, causing greater wear of the equipment. Thus, improving the preventive maintenance process, the search for more resistant materials and the standard of use of these can be a differential that collaborates for a better performance of the maintenance sector to increase the hours available for production.

The monitoring and control of indicators is necessary, since these are directly linked to the production results planned by the company. Failure to achieve these directly impact a negative image, generating a distrust in the consumer market about its ability to honor the sale commitments signed in ore purchase guarantee agreements, which are used by strategic planning in the preparation of the master production plan. Hence, the role of the operational control sector is justified by collaborating with the advent of production engineering and using abilities of containment, investigation, elimination of waste and optimization of processes and resources available, converting them into positive results for the company.

We consider that this work also presents limitations of investigation due to the unavailability of access to the operation because of the COVID-19 context. However, it is recommended that the work team make use of methodologies such as PDCA, Juran trilogy among other quality management tools to investigate potential causes related to divergences found, as well as establishing action plans that minimize such differences.

# Declarations

**Competing Interests:** The authors declare that they have no competing interests.

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# Figures

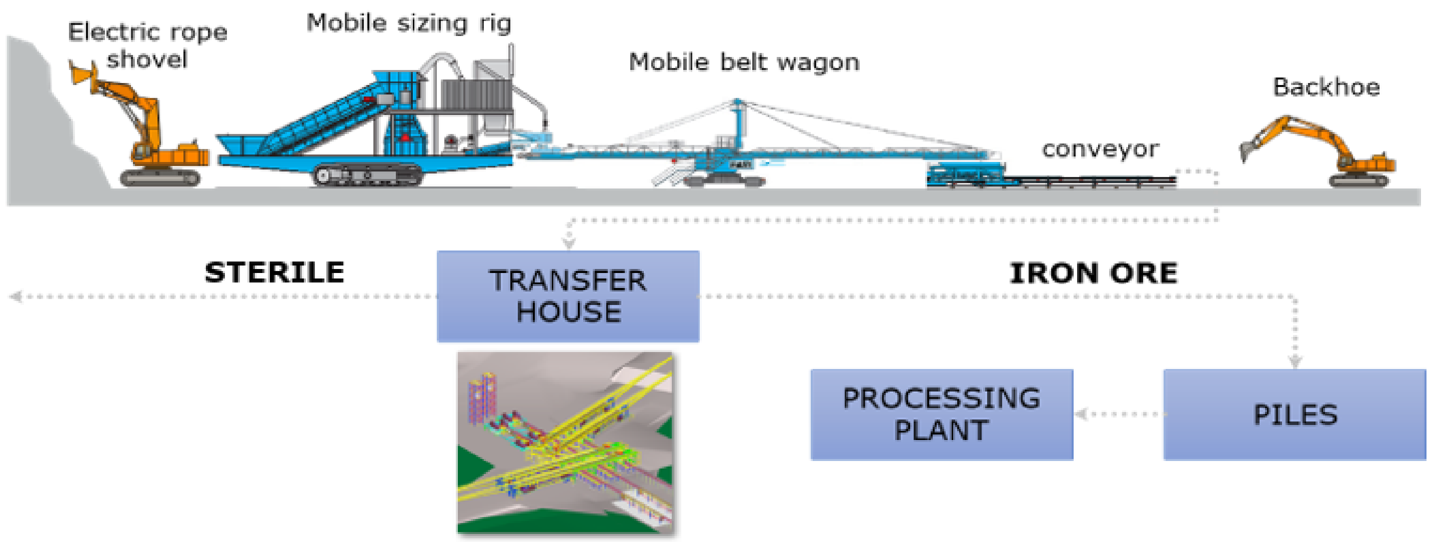



**Figure 1**

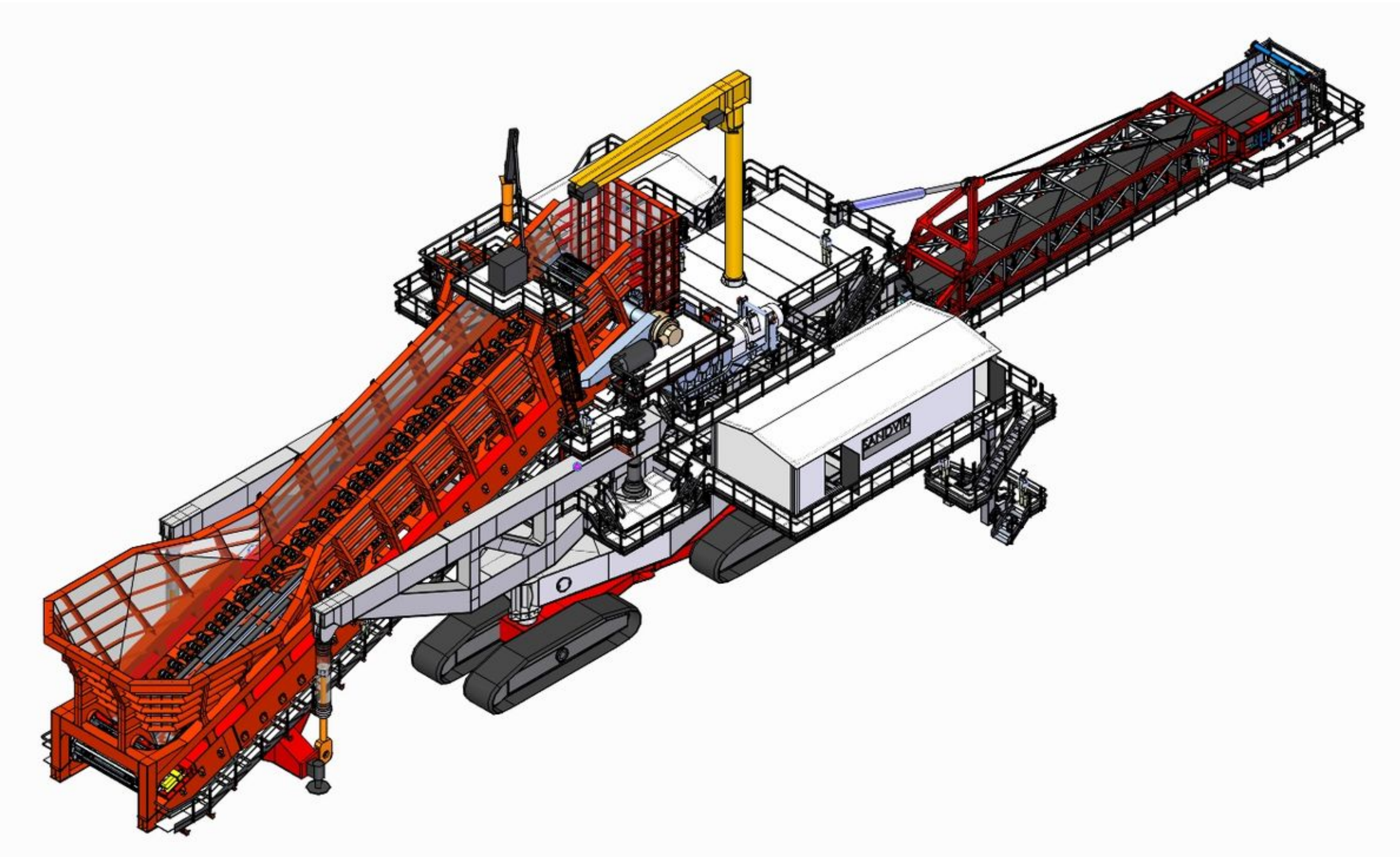
IPCC mining layout.

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

**Figure 2**

Electric rope shovel 7495 CAT.

Source: Caterpillar




### Figure 3

Mobile sizing rig.

Source: Sandvik

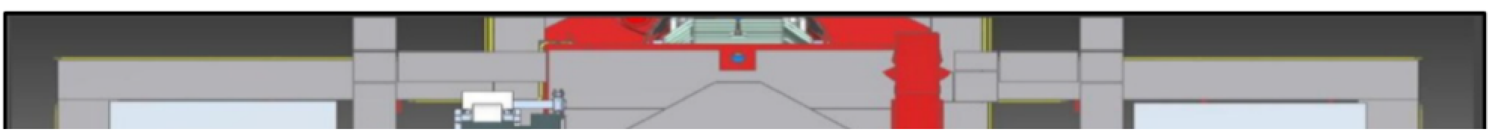


**Figure 4**

Roller crusher

Source: Sandvik


**Figure 5**

Mobile Belt Wagon (MBW).

Source: Sandvik

**Figure 6**

Bench conveyor.

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

**Figure 7**

Bench connection conveyor.

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

**Figure 8**

Bench conveyor.

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

**Figure 9**

Mining on intermediate bench.

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

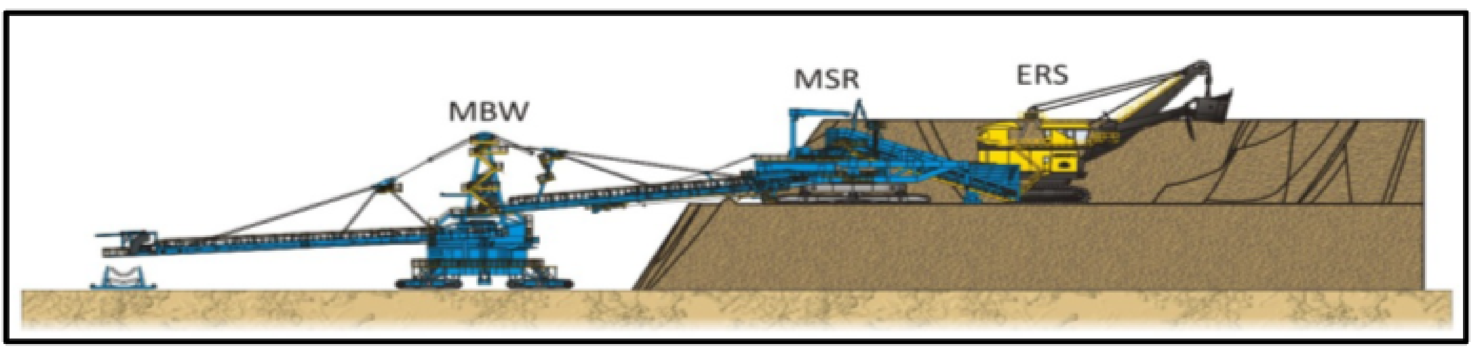



**Figure 10**

Mining on upper bench.

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

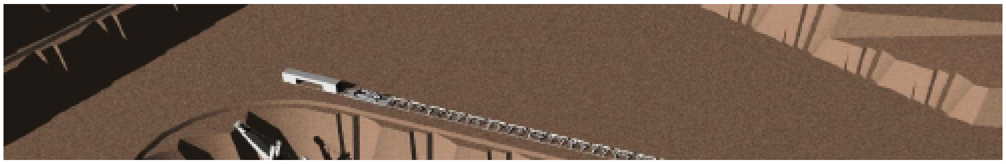


**Figure 11**

Mining on lower bench.

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

**Figure 12**

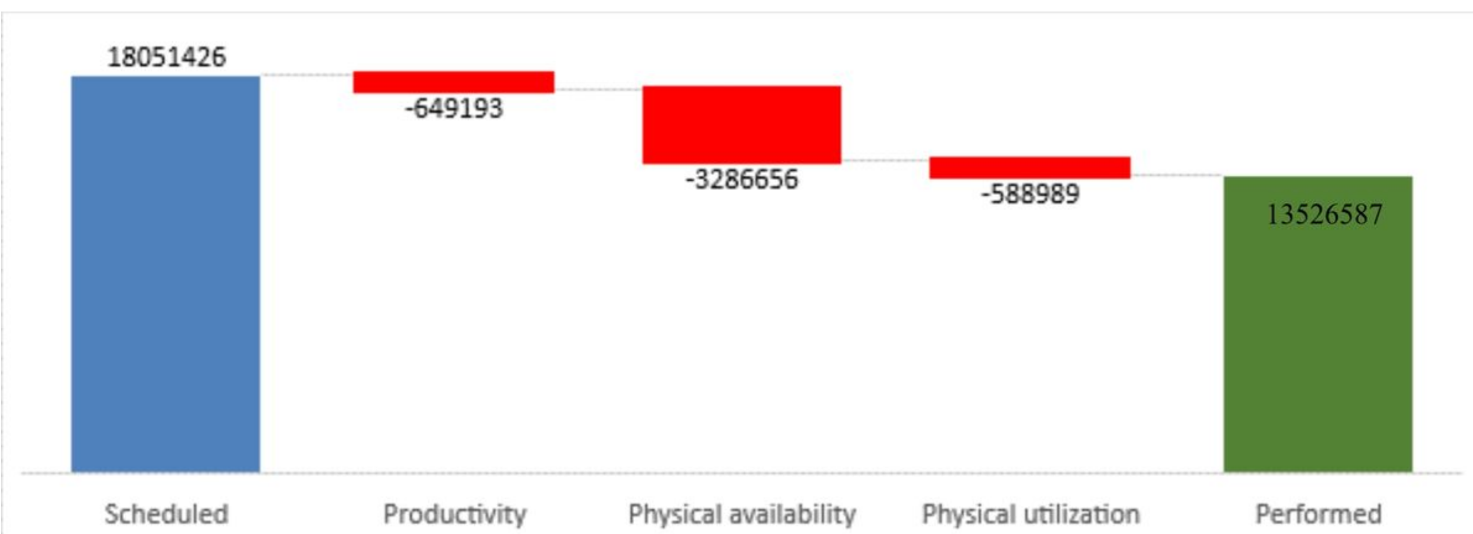
Comparison between parallel and pivoted trackshift.

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

**Figure 13**

Calendar hours graph – CH.

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



## Figure 14

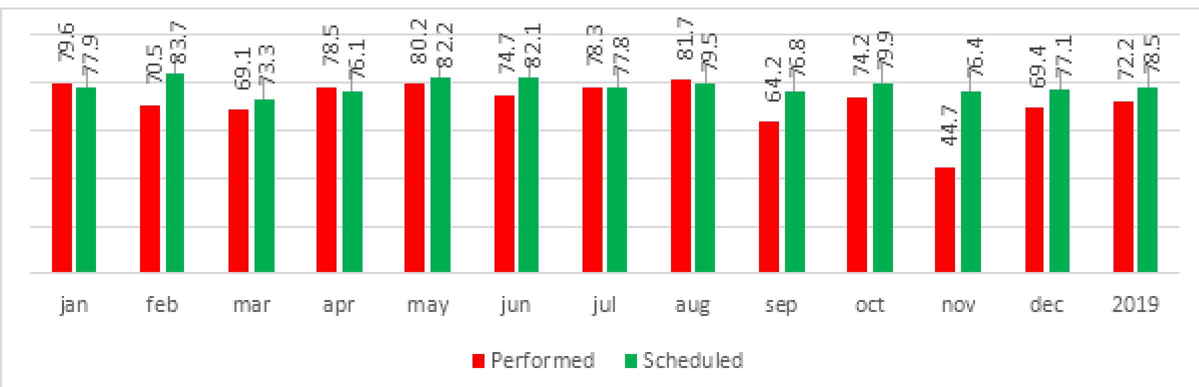
Production indicators productive system 2019.

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

## Figure 15

Performed vs. planned productivity 2019.

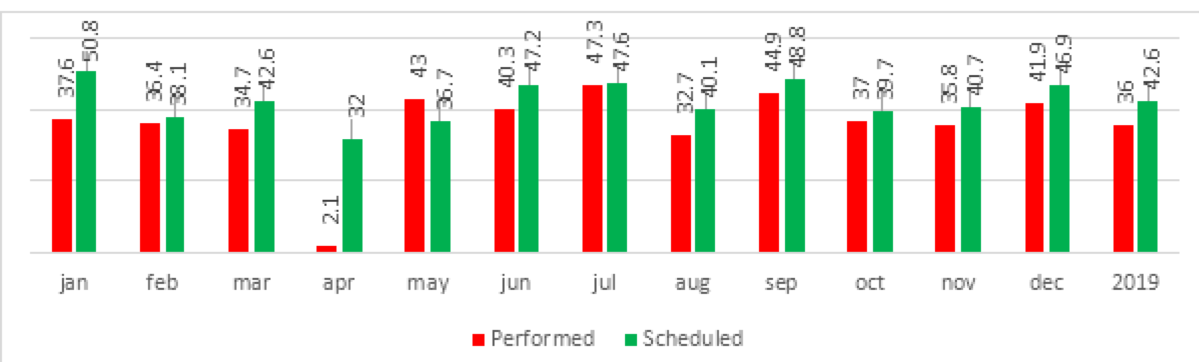
Source: The author(s) himself(themselves).




## Figure 16

Physical availability – PA.

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




## Figure 17

Physical utilization.

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