International Joint Conference on Industrial Engineering and Operations Management- ABEPRO-ADINGOR-IISE-AIM-ASEM (IJCIEOM 2020)

INDUSTRY 4.0 IN COAL MINING: a comparative study between a traditional and a 4.0 operation

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Abstract. This article aims to analyze the benefits of implementing digital technologies of industry 4.0 in the context of coal mining. The study uses primary bibliography on the theme of industry 4.0 in mining, seeking to verify the advantages in the use of technologies in the industry and to create a conceptual framework to guide the case study. Two mining plants from the same company are the units of analysis. The first follows the historical evolution of the mining process but stopped evolving in the 1980s. The second is a new unit, planned and built within the new mining concepts, linking to them some digital technologies of industry 4.0. In this context, we sought to analyze whether there were improvements in product quality, in the efficiency of the process and in the safety of the operation in the plant that uses digital technologies. This survey was conducted through interviews with managers from both units. The results indicate that the plant with digital technologies has a more homogeneous final product and that it meets the customer's specifications more efficiently, the unit process is linear, safer, and more sustainable concerning the traditional unit.

Keywords: Industry 4.0, Coal mining, Internet of Things.

1 Introduction

Energy is the basis of human living in almost all areas of economic activity [16]. Almost 87% of the world's energy comes from the combustion of fossil fuels, of which about 30% is mineral coal [14]. For many years the coal mining sector has been undergoing restructuring processes, the main objective of which remains the increasing efficiency of coal mining companies [22]. In the coal industry, there is a catchphrase: "Today, it is not difficult to dig but to sell what you have dug." This statement can be analyzed from several aspects, as it encompasses market strategy, sustainability, and external pressures.

Brazilian coal reserves represent about 1% of world reserves, approximately 32 billion tons, which are concentrated in southern Brazil, in the states of Rio Grande do Sul with 89%, Santa Catarina with 10%, and Paraná with 1% [15]. The industry is under pressure to improve mine safety and productivity, adapt to resource scarcity, and provide more effective maintenance strategies for equipment. Advances in sensors, combined with robust analyzes, offers the opportunity to accelerate mining performance and improve the way the process has been conducted [7]. The use of digital technologies from industry 4.0 can bridge these gaps and present solutions to mining problems related to product quality, process efficiency, and safety [20].

Considering that the use of digital technologies contributes to the improvement of processes in organizations, the purpose of this study is to verify if the implementation of digital technologies improves the efficiency of the process, the quality of the product, and the safety of the operation in a coal processing

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plant. For this, a bibliographic survey on the literature on industry 4.0 was carried out within the context of mining. Based on the review, a case study was carried out in two coal mining units, a 4.0 unit with digital technologies such as the internet of things, online analyzers, operation monitoring sensors, and equipment automation, and a traditional unit implemented in the early 1980 years. The study compares the findings in terms of quality, efficiency, and safety of the operation.

2 Literature review

2.1 Coal mining

Mining is an industrial activity that operates units that extract metallic ores and minerals to form a mineralized package of economic interest for the miner [27]. Mineral coal was one of the first fossil fuels to be used in large quantities, and even today, its worldwide exploration is on a large scale [21]. Mining is highlighted in the history of humanity, as the existence and quality of human life depend on production and consumption acquired through the exploitation of mineral resources. Sustainable development also depends on this exploitation, but it can often occur incoherently, triggering social and environmental impacts and conflicts [23]. Coal is considered a dirty fuel due to the high content of gases emitted in its use. On the other hand, society spares no effort to find solutions for energy generation that cause less environmental impact [8], such as, for example, the use of wind energy [1].

Brazilian coal reserves are made up of about 32 billion tons and are located in the south of the country (89 % in the state of Rio Grande do Sul). The low price of this product makes it an attractive option for use as a source of energy generation. Concerning improving the efficiency of beneficiation plants, digital technologies are incorporated, such as cloud computing, internet of things, big data analytics, machine learning, 3D printing, artificial intelligence [5]. Given this, the scenario is configured for the search for cleaner and more efficient production.

2.2 Industry 4.0 digital technologies

The term industry 4.0 emerged in Germany, in 2012, and aims to integrate digital technology systems into production processes, helping to improve production and company management [12]. Among the most used digital technologies in the context of industry 4.0 are cyber-physical systems (CPS), Big Data, Internet of Things (IoT), automation, additive manufacturing, cloud computing, and simulation [13].

Cyber-Physical Systems (CPS) are technologies associated with physical and computational resources capable of interacting with humans [18]. This acquired ability to integrate systems and expand the results of the physical world through computational technologies is a facilitator for greater availability and accessibility of data and information [3].

Big data refers to a large volume of complex and unlinked data from various autonomous sources [32]. These are data sets that cannot be acquired, stored, and managed by standard database software [9]. Due to the rapid development of networks capable of collecting and storing a large amount of data, Big Data has expanded in several areas of knowledge in science and engineering. Big Data can is characterized by three vectors: volume, variety, speed, and value.

The Internet of Things (IoT) deals with linking objects to the Internet, is responsible for connecting people, machines, products, and services, streamlining the flow of information in the process, allowing decision making in real-time, and opening new opportunities for use in the most diverse segments [27]. Supports all types of new information technologies, it gathers information continuously from different sensors and objects, forward it safely and reliably to data centers located in the cloud [29].

Cloud computing is a model that allows universal access to a shared resource network where several configured resources are connected, such as networks, servers, applications that can be quickly supplied and released with minimal interaction from the service provider [6].

Additive manufacturing is a process of creating 3D model products from the union of materials. It usually occurs by adding layers, as opposed to the more usual manufacturing methodologies characterized by material removal. This methodology assists in the improvement and optimization of products but is limited to specific markets that have low volume and personalized production [17].

Simulation can be defined as a simplified representation of a given real-world operation over an established period, as it allows the construction of detailed models that provide a good understanding and analysis of the system [34].

Automation is a prerequisite for industry 4.0, and its implementation in the company must occur before migration to industry 4.0, it refers to the ability to perform tasks without human interaction. In this environment, the equipment interacts alone and controls itself based on the information/guidance received [31]. The most well-known and usual automation system is machine learning. In production systems, they are becoming increasingly autonomous, flexible, and cooperative [4].

3 Methodology

The research method is a comparative case study. A comparative study aims to explore facts and explain them according to differences or similarities. This method generally addresses two points from the same context and seeks to detect what distinguishes them. It is a comparative method that has great breadth in the field of science due to its investigative application, allowing the analysis of real data and from this the deduction of constant, abstract, and general elements [28].

The methodology is adapted from [24], with a smaller sample. The case study can have several objectives, such as: providing a description, testing theory, or generating theory [11]. In the studied scenario, the aim was to test a theory. The study was carried out in three stages: i) survey of the literature on industry 4.0 in mining; ii) structuring the research process; and iii) comparison of results.

The first stage consisted of a survey of the literature seeking to identify the advantages of implementing digital technologies in the field of mining. Based on these findings, the analysis variables and the case selection were defined. For data collection, an unstructured questionnaire was conducted, with exploratory questions. This method is consistent with the theory [11], which states that researchers must formulate a research problem and specify some potentially important variables grounded on empirical literature. However, a case study should avoid establishing relations between variables and theories especially in initial studies.

When the research objective is testing hypotheses, the choice of the sample is crucial in the construction of the cases. An appropriate selection prevents spurious interferences and puts limits on generalization [11]. As this is a comparative study, two units were selected that process the same product, one built in the era of digital technology and the other with more than 30 years of operation.

The company is an anchor tenant [25] of the industrial coal production cluster of the Brazilian state of Rio Grande do Sul. The cluster embraces activities that form an industrial system, in which companies cooperate in logistics but compete in sales. With a focus on coal mining, its business includes two large mining units. The first one was built in the 1980s, with an annual production of around 1.3 million tons/year of crude coal. The traditional unit process is described as 1) The coal is extracted from the mine and transported to the beneficiation plant; 2) Discharges into the main hopper (Mg -1) ; 3) is transferred to the primary crusher (Br-1), where its size reduces to 100 mm; 4) will be reduced again through the secondary crusher (Br-2) to 50 mm; 5) The separation table and the cyclone tower (Jg-1) will separate the product (PI-1) from the waste (RE-1). Whatever is rejected (RE-1) will return to the mine pit; 6) The intermediate product (PI-1) was stored for analysis; 7) Once analyzed will be defined one loading fraction of each cell; 8) The finished product (PA-1) is formed. The process waste (RE-1) routes as raw material for closing the mine, forming a Closed-Loop Supply Chain (CLSC) [26].

Inaugurated in 2018, the second mining hub was an installed capacity of 2.3 million tons/year. In this unit 4.0, the beneficiation process is described by the steps below: 1) The coal is extracted from the mine and transported to the beneficiation plant; 2) Discharges into the main hopper (Mg-1) ; 3) is transferred to the primary crusher (Br-1), reduces to a dimension of 100 mm; 4) will be reduced again through the secondary crusher (Br-2) to 50 mm; 5) The online analyzer (A1) will classify it into 4 types of intermediate products (PI). Whatever is rejected (RE-1) will return to the mine pit; 6) The remaining three intermediate products (PI-1,2,3) will be taken up by gravity; 7) The mixture will pass through the second online analyzer (A2). A2 will adjust the flow rate of the PI until it can form the standard finished product (PA-1); 8) The finished product (PA-1) is formed. Likewise, this unit also makes use of the CLSC with waste (RE-1) [26].

From the selection of the units of analysis, the aspects that will be addressed in the case study are pointed out. It seeks to assess the importance of digital technologies in the process, which are the learning and management opportunities resulting from this implementation and whether the aspects related to quality, efficiency, safety, maintenance, and economy, found in the literature, are influenced by the technologies. Table 1 shows the interview script developed.

Table 1 - Interview script

Interest Items	Definition and Reference	Interview script
Importance of Technology	The insertion of digital technologies allows greater flexibility, adaptability, and efficiency in the systems. The systems are autonomous and connected, allowing self-configuration [12], [19], [2].	Question the impact of technology or its lack on the interviewed company
Learning and Management	The insertion of digital technologies allows a series of benefits for companies such as ease in adapting new products, reducing risk and failures, qualifying human resources, accurate data, and in real-time. This information can be used for strategic planning and decision making [33], [19].	Check if the company perceives learning opportunities with the use of technologies and how they are used Check if the technologies provide data that assist in improving the process and how they are exploited
Aspects influenced	The incorporation of technologies in production processes directly contributes to improving product quality, process efficiency, safety, and equipment maintenance. This has a positive impact on the company's economy [20], [5], [29].	To which of the parameters does technology make the most contribution: Quality, Efficiency, Safety, Maintenance, and Economy

4 Analysis and discussion of results

After the data collection methods were structured, and the analysis units were selected, the interviews for data collection began. In the plant with digital technologies, seven people were interviewed, namely: a production supervisor, a maintenance supervisor, a production and maintenance engineer, a production manager, a mining engineer, and two customers who receive the product from this unit. The interviews were recorded, then transcribed and analyzed by the Atlas.ti program for creating a cloud of the words that appear most frequently in these speeches.

It is possible to identify that words such as quality, safety, technology, sensors, maintenance, information, and data frequently appear in the texts. These are directly linked to the techniques and the advantages acquired by their use.

Then five people were interviewed who work at the plant that does not have digital technologies, but who know the project and operation of the other company. In these interviews, the objective was to understand how the process takes place in the unit where they operate, what are the most relevant differences that are perceived in relation to the process existing in the other unit and what the interviewees' perception of digital technologies is. The director of both units, the geologist responsible for the companies, a plant production supervisor, and two customers who receive the product from this plant, participated in the interviews. The interview process took place in the same way. The findings show what terms such as quality, process, information, and technology are repeated, but the word Candiota should be highlighted, it frequently appears in speeches because it deals with the city where the plant is located with digital technologies. The expressions refer much to this unit and the advantages that exist for the use of technologies.

The perceived quality of the final product is different from one customer to another. The customer who receives products from the technological plant claims no quality problems, stating the homogeneity of the product due to the small variability in its process. The customer who receives the product from the typical plant reports precisely the opposite. It reports a persistent lack of homogeneity, many times with a quality standard higher than specified. This lack of continuity harms the process.

The difference in the homogeneity of the product is directly related to the use of digital technologies, in the technology company, the process of selection and composition of the final product is carried out with online analyzers and in the other company manually. Respondents from the technology unit say that the use of this technology is crucial to ensure the quality that must be delivered to the customer. In traditional drive, respondents reinforce the customer complaint regarding the quality and claim that only reach with online analyzers, manually it is impossible to prevent variability. This statement corroborates [30], who affirm that one of the principles of the integration of digital technologies, which is to allow business and engineering processes to become more flexible and efficient and have the capacity to produce with high quality and low cost.

Safety is one of the company's priorities in compliance with existing standards and also to guarantee the quality of life of its employees. Therefore, this was one of the identified contributions to which technologies also added value. The technological company integrated sensors with different functions, replacing labor in risky operations and paralyzing operations when an anomaly is identified. The finding corroborates [27], who affirm that digital technologies such as IoT guarantee safe and adequate working conditions in mining, contributing to improving the efficiency of the industry.

The automatic shutdown of operations, when is identified as an anomaly, also contributes to preventive maintenance, which for this unit is a crucial activity. According to the interviewed production and maintenance engineer, the use of sensors for fault detection contributes to the reduction of equipment loss. Maintenance is considered a crucial activity for this unit due to its location. They are more than 5 am in the capital, where are the suppliers of the most critical parts and repairs and even the simplest are only acquired the 2hs plant, therefore, anticipate any maintenance that causes process stop is very significant. This concept confirms what has already been mentioned [10] when affirm that the stable and efficient operation of mining equipment is essential to guarantee the operation and that digital technologies based on IoT can contribute to the elaboration of a plan predictive maintenance by changing the maintenance mode of mine equipment ensuring safe and efficient operation for the equipment.

A significant point that appears in comparison to reports of a plant in relation to another is the number of people working in the process and the degree of their experience. The technological plant is made up of an extremely lean team, with 90 employees, and with less than a year of experience. In contrast, in the typical plant, with 160 employees, the most influential people in the process have more than ten years of experience.

In the context of the interviews, one of the curiosities was to know if for the interviewees the plant would have the same performance without all the embedded technologies. The 100% answer from them is no. According to them, this project demands a quality of the final product that can only be achieved when you have a deposit of higher quality than the existing one or when you can work hard on the process to reach that quality and work on the process at that level without all the existing technology. It’s not possible.

The responses comply with the first item of interest to researchers: the importance of technology for the organization. The insertion of digital technologies allows greater flexibility, adaptability, and efficiency in the systems. The systems are autonomous and connected, allowing self-configuration [12], [19], [2]. The answers confirm that the implementation of technologies affects the organization in terms of quality, safety, efficiency, and maintenance. A summary of the responses obtained by the interviews, in each of the units, is presented in table 2.

Table 2 - Summary of responses to the first item of interest in the survey

Findings Unit 4.0	Traditional Unit Findings
Without the technology embedded in the plant, it would not be possible to achieve the unit's performance.	The final product undergoes constant variations in the level of quality.
Online analyzers guarantee the final product quality within the specified	There is a loss of equipment and significant maintenance expenses.
The existing sensors in the plant help in the safe operation of the unit, preventing accidents.	
The existing sensors in the plant help to maintain the unit's operation avoiding losses.	The equipment guarantees the safety and service of the NR 12 but has been adapted and some make the operation difficult.
Online analyzers and machine automation contribute to reducing the number of people needed in the process and their level of experience (less than a year).	The plant has a robust team with an average experience of ten years.

The second item of interest is the impact of technology on the learning and management of organizations. To this end, they were asked whether organizations perceive learning opportunities with the use of technologies, how they explore this aspect, and whether technologies provide data that help improve the process and how they are used. The interviewees understand the importance of technologies and the excellent performance acquired by the organization due to them. Still, they point out some improvements that can improve the operation. One of these is to improve the interpretation of the data collected by the sensors. Also, the technologies provide a range of information that is not being processed and used, and that has the potential to be used for the development of improvement programs, maintenance schedules, and process monitoring.

Another point raised in the integration of systems (the plant into the mine) will allow to see in real-time what is being excavated and to prepare the process for receiving the material. This information can be used for strategic planning and decision making [33], [19]. In the same way, the integration of the client will allow him to follow the process and the quality of what he is receiving. Table 3 presents a summary of the responses collected in each of the units.

Table 3 - Summary of responses to the second item of interest in the survey

Interview script	Findings Unit 4.0	Traditional Unit Findings
Check if the company perceives learning opportunities with the use of technologies and how they are used.	Opportunity for improving the integration of the mine, the plant and the client for monitoring and real-time adjustments of the process. This Unit has little time in operation and is creating performance indicators to be able to follow the process in the future just by looking at the panels.	The unit's indicators are based on historical data and periodically monitored.
Check if the technologies provide data that assist in improving the process and how they are exploited	Online analyzers allow for real-time monitoring of the quality of the product being shipped to the customer and allow for quick process adjustments to meet specifications. Sensors provide a range of data that could be used for scheduling maintenance and continuous improvement processes.	The quality sent to the customer is done by sample (takes around 14h to be ready) after the customer has already received the product, adjustments are delayed and late. Preventive maintenance is carried out using historical data.

The last is the incorporation of technology in mining contributes to the improvement of quality, the efficiency of the process and the safety of the operation [20]. As a result, there is a reduction in costs and an increase in revenues. Therefore, five factors were listed: quality, process, safety, economy, and maintenance. Respondents were asked to order an increasing ranking of these elements according to their opinion, those who felt able to answer this question and the list of their responses are shown in table 4.

Table 4 - Summary of responses to the third item of interest in the survey.

Unit	Production supervisor	Prod/Maint. Engineer	Production manager	Mining engineer	Director
Unit 4.0	Production Quality Safety Economy Maintenance	Safety Economy Quality Production Maintenance	Quality Safety Production Economy Maintenance	Safety Quality Production Maintenance Economy	
Traditional Unit	Quality Economy Safety Production Maintenance				Quality Production Economy Maintenance Safety

5 Conclusions

The purpose of this study was to compare the impact of the use of digital technologies in mining. For this purpose, two coal production units were compared in terms of quality, efficiency, and safety. This comparison was made through the compilation of data collected in interviews with the direction of the units, managers who work directly related to the processes and customers of each unit.

The results show that the unit that has digital technologies presents a product with higher quality and homogeneity that is perceived and reported by the customer. The customer of this unit reports that he does not have problems with variation in the quality of the product received or lack of product, so his safety stock is only 10 hours. The customer of the traditional unit aims to perceive peaks and valleys in the quality of the product and lack of security about a delivery, which means that his safety stock is approximately 20 days.

The process in Unit 4.0 is considered more efficient because it has a reduced number of people and has less experience in processing and delivering a larger quantity of a product and with a higher quality specification than the traditional unit. According to the managers of this unit, this is only possible due to the online analyzers and sensors in the plant that provide information in real-time, allowing quick adjustments.

The existing sensors, in addition to helping to improve product quality and efficiency, are of utmost importance for the safety of the process, enabling the identification of anomalies to paralyze the operation and avoid accidents and losses. Also, the sensors collect data that can be used for scheduling maintenance, monitoring process performance, and continuous improvement projects.

One of the improvements to be carried out in the future and that was pointed out by the interviewees is the need for integration between the exploration mine, the processing plant, and the end customer. This would be the ideal operation of the process and would allow decision making in real-time by anyone of the parties. Exploring the impact of systems integration, its benefits, and its cost ratio is a window of opportunity for continuing this study.

In addition to all the benefits pointed out by users, which are achieved by the integration of digital technologies, there is also a change in the operation process in this unit, which was carried out with water and started to be carried out dry. This change in the process directly contributes to sustainability by not using a natural resource and avoiding the possibility of accidents. Despite its great importance, this topic that refers to the impact of changing the process to improve sustainability was not addressed in this work, and it becomes an interesting gap to be explored in future works.

6 References

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