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Implementation of a Business Intelligence System in the Brazilian Nuclear Industry: An Action Research

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Abstract

The literature on information systems emphasizes the positive impact of information from business intelligence systems (BIS) on decision-making, especially in highly regulated environments. Assessing BIS effectiveness is vital to understanding its value and significance in improving operational performance and management. However, deploying BIS and understanding how BIS dimensions are interrelated and how they affect the decision-making process in organizations in the nuclear field still need to be explored. In order to address this research gap, this article investigates the process of implementing BIS in a Brazilian company from the nuclear industry using an action research methodology. Results suggest that the use of BIS in decision-making routines allowed company managers to expand their perception of previously neglected information, significantly helping in decision-making and prioritizing actions and/or solutions.

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Keywords: Industry 4.0; Business Intelligence; Data Analytics; Nuclear Industry.

Nomenclature

BI	Business Intelligence
BIS	Business Intelligence Systems
CNEN	National Nuclear Energy Commission
ERP	Enterprise resource planning
ETL	Extract-Transform-Load

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IBAMA	Brazilian Institute for the Environment and Renewable Natural Resources
INB	Brazilian Nuclear Industries
OLAP	OnLine Analytical Processing
RMS	Requisitions of Materials and Services

1. Introduction

In recent years, an extensive growth of data generated by humanity has been observed. In 2020 alone, 64 ZB of new data was created, and more than half was generated by databases of companies and organizations [4, 12]. Therefore, a need arises for organizations to manage this amount of data, and to be able to extract information that is relevant and provides subsidies for strategic decision-making [21, 30, 31, 32, 8, 38, 6, 7]. Given the difficulty in accessing a whole set of data available in the organization in a structured way, companies have used various methodologies, among which Business Intelligence (BI) stands out [3].

BI is considered a process including methods and tools that organizations use to generate/access value information or intelligence that can help them survive and prosper in the global economy, with information as the product that will enable organizations to better analyze the behaviour of their competitors, suppliers, customers, technologies, acquisitions, markets, products and services, and the general business environment [25]. Much of the BI research has examined the ability of support systems to help organizations address challenges and opportunities involving decision-making to create value [39]. However, to help BI achieve its full potential, practitioners and researchers must fully understand how organizations can derive value from Business Intelligence Systems (BIS) [3, 20].

A typical BIS implementation entails various intricate technological, organizational, and procedural challenges, mirroring the characteristics observed in other infrastructure projects. Despite this complexity, there is a significant gap in the critical success factors essential for BIS implementation initiatives. A significant challenge that receives little attention in the literature on BIS adoption concerns acceptance and use at an individual level, which can be attributed to organizational culture or issues related to individual willingness to adopt these systems [2, 42]. Assessing the effectiveness of a BIS implementation process is vital in understanding its value and importance in improving operational performance and information management. However, implementing a BIS and understanding how its dimensions are interrelated and how they affect the decision-making process in organizations in regulatory fields, with information that is constantly audited, still needs to be explored [43, 27].

Despite the growing importance of BIS and its potential benefits, there needs to be more research exploring the specific challenges and opportunities of implementing BIS in organizations operating in highly regulated fields where data is constantly audited. Existing literature on BIS primarily focuses on general organizational contexts, and the unique requirements and complexities faced by regulated industries, such as the nuclear domain, have received limited attention. Therefore, there needs to be a clear gap in the literature regarding the implementation and effectiveness of BIS in organizations within highly regulated environments [29, 9].

While existing literature emphasizes broader organizational factors, this study focuses on the individual dimension of project team willingness to adopt and integrate these systems, recognizing the crucial role of technological advances in industry transformation. By exploring this gap, our study provides initial insights into the complex dynamics influencing BIS adoption in regulated companies and connects with the fundamental principles of Industry 4.0. This strategic intersection enriches our understanding of the individual implications of BIS adoption. It highlights how it aligns with technological innovations and the vision of a more connected and efficient industry, reinforcing our role in expanding knowledge in this area. This study investigates the implementation process of a BIS in a company that is part of Brazilian Nuclear Industries (INB), founded in 1988, to foster the production of nuclear energy in the country, acting in the uranium production chain, having as a final product throughout a production cycle the nuclear fuel that supplies the nuclear power plants in Brazil [23]. The unit studied is responsible for decommissioning activities, where it is necessary to control and monitor the tailings dams and basins, in addition to collecting soil and water samples to ensure control indices established by regulatory bodies such as the National Nuclear Energy Commission (CNEN) and the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA).

The remainder of this paper is organized as follows. Section 2 provides a background review of the literature on BI and BIS; the adopted methodology is described in section 3. The Section 4 presents the results. Finally, Section 5 presents the conclusions of the research and suggests future study topics.

2. Background

2.1. Business Intelligence

The concept of BI was initially introduced by Luhn [24], which replaced other terms such as Executive Information Systems and Management Information Systems [40]. The term BI refers to a management philosophy and tool used to help organizations manage and refine business information to make more effective business decisions. Overall, BI refers to relevant information that describes the business environment, a systematic process by which organizations acquire, analyze, and disseminate information from internal and external sources significant to their business activities and decision-making [34].

The purpose of BI is to help control information flow inside and outside the organization by identifying and processing data into condensed and valuable management information and intelligence. Thus, BI can be considered the critical class of systems for data analysis and reporting that provides managers at various levels of the organization with timely, relevant and easy-to-use information enabling them to make better decisions [37, 36].

BI can support complex decision-making and help solve complex, semi-structured or poorly structured problems [2]. Examples of BI tools include that software and solutions that are provided by vendors such as Microsoft's Power BI®, SAP's with NetWeaver Business Warehouse®, Tableau's with Tableau Software®, Google Data Studio® from Google, among others [17, 44].

Currently, BI is seen as an architecture that gathers and stores data and analyzes it using analytical tools, facilitating reporting, queries and delivery of information and knowledge that ultimately enables organizations to improve decision-making. In the last years, the use of BI as a decision-support tool has attracted significant attention from industry and academia to support decision-making. It is especially due to its ability to provide information, with emphasis on specialized capabilities in the form of integrated systems that are linked to a data warehouse and are designed to facilitate the analysis of stored data in support of ad hoc managerial decision-making [33, 10, 39, 5, 2, 14].

BI drives business success for many organizations. Numerous arguments can be found to support the benefits of BI, including its ability to provide organizations with faster and more accessible information, thereby improving business processes and decision-making. Furthermore, BI enables organizations to identify opportunities and threats in the market by fostering collaboration with customers, suppliers, and competitors [29, 9].

2.2. Business Intelligence Systems

In general, BIS provides information through the integration of databases from different business fields, where the idea is to combine different data sets from sources that can provide new insights that should lead to better decision-making. It is mainly seen as a support tool, where data is collected, stored and transformed into value information [35, 5]. The role of BIS is to convert data into useful information and, through human analysis, into knowledge [28].

Ain et al. [2] postulate that a BIS is composed of the following essential components (see Fig. 1):

1. Extract-Transform-Load (ETL) tools transfer data from operational or transaction systems to data warehouses.
2. Data warehouses provide some space for the thematic storage of aggregated and analyzed data.
3. OnLine Analytical Processing (OLAP) tools allow users to access, analyze, model business problems, and share the information stored in data warehouses.
4. Data mining tools determine patterns, generalizations, regularities and rules in data resources.
5. Reporting tools and ad hoc surveys allow the creation and use of different summary reports.

BIS encompasses a wide range of analytical and information gathering, consolidation, analysis and access solutions in a way that enables company users to make better decisions. To that effect, it uses tools to explore data warehous-

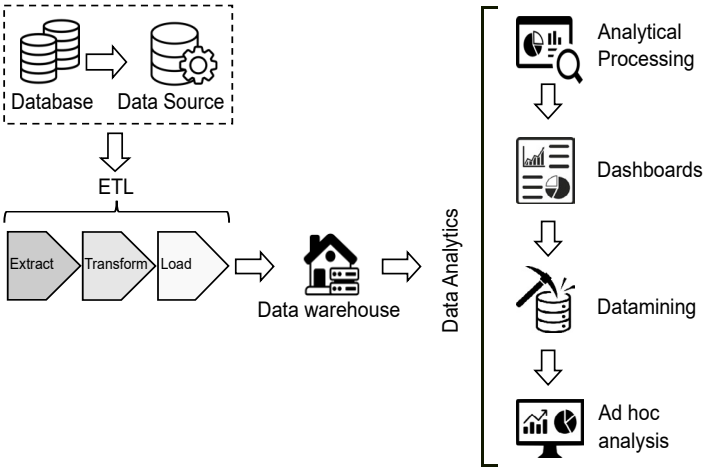


Fig. 1: Main components of a BIS and their relationships.
Source: Adapted from Ain et al. [2].

ing, database querying and reporting. The key is to consolidate data from multiple sources into an enterprise data warehouse [16, 42].

Successful BIS implementations promote a data-driven organizational culture, encompassing various processes that require a robust infrastructure and extensive resources and offering analysis solutions, ad hoc queries and predictive capabilities [42]. From [42], the factors that lead to the failure of BIS implementation can be classified into three perspectives: (1) Technical perspective - it is related to a business-oriented, scalable and flexible technical structure with data quality and integrity criteria; (2) Organisational perspective - it is directly related to management support, organizational culture and the adequate availability of resources; (3) Process perspective - it is related to user involvement and change management during the evolutionary process of implementing a BIS.

Although user resistance to adopting BIS has been addressed in the literature, its lack is still notable in highly regulated companies [16]. In these organizations, where compliance with strict regulations is essential, research into individual acceptance and use of BIS is scarce or practically non-existent. This is due to the complexity of regulated companies when implementing changes to their processes and technologies and the need to ensure that implementations comply with all applicable regulations. Therefore, the need to address this gap in the literature is urgent in these companies, where user resistance can have significant implications for compliance and operational efficiency.

2.3. Business Intelligence in regulated industries

In the regulated environment in which companies from various sectors operate, data and information management are fundamental to achieving success, guaranteeing compliance, and, most importantly, establishing solid governance [9]. The success we refer to encompasses operational efficiency and maintaining the organization's reputation and credibility in a strictly regulated environment [22].

BI is emerging as a crucial ally for regulated companies as it expands their ability to collect, analyze and visualize data efficiently and accurately. BI enables these companies to make data-driven decisions, identify trends, and strengthen information governance by ensuring data quality and consistency. In addition, by facilitating the secure sharing of data between departments and stakeholders, BI contributes to operational agility, promoting efficiency and security in a highly regulated environment [19].

In addition to the success factors examined earlier concerning implementing BIS, especially in regulated industries, Henckaerts et al. [22] identifies several challenges, including Regulatory Compliance, Data Security, Audit and Traceability, Integration with Existing Systems, Documentation and Approvals, and Training and Awareness. These elements play a crucial role in ensuring the effective deployment of BIS in regulated environments, contributing to improved data governance and operational excellence.

Current literature on the use of BI in regulated companies highlights a research gap as it predominantly investigates the technical dimensions of BIS development [26, 18, 22, 19], and workflow configuration from a process-oriented point of view [1, 41, 15]. While these studies offer insights into the implementation and functionality of the systems, there needs to be more investigations that address issues related to the organizational perspective, particularly concerning the acceptance and adaptation of these technologies by organizational actors. Specifically, a deeper exploration is required, focusing on corporate stakeholders' acceptance and assimilation of these technologies. The absence of research about aspects within regulated environments signifies a substantial research opportunity. This is particularly pertinent as the effective adoption of the BIS in such contexts depends not only on technical attributes but also on the assimilation of the organization's members – an essential factor in achieving compliance objectives and operational excellence.

3. Methodology

This research uses the action research method, defined as an approach in which the action researcher and a client collaborate to diagnose the problem and develop a solution based on the diagnosis [11].

Action research is a methodology that seeks action or understanding on a problem simultaneously, using a cyclical process alternating between action and critical reflection, continually refining methods, data and interpretations, converging on a better understanding of what is happening. In addition, it is also participatory and qualitative [13, 11].

Figure 2 presents the steps for the execution of the present research. Overall, the research was organized in three cycles after the first survey and diagnosis of the problem addressed by the study. Each cycle (including all phases in Fig. 2) resulted in a BIS report with eighteen pages of visual representations, including a general report provided to the engineering team. The cycles were carried out from March to July 2022.

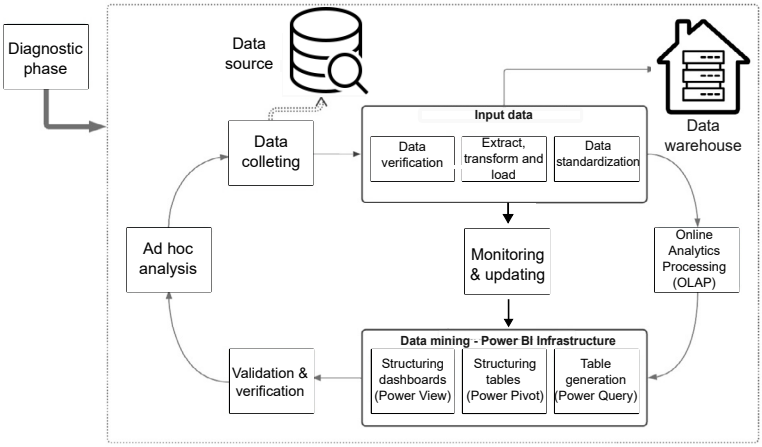


Fig. 2: Structure of an applied action research.

Initially, four engineers from the researched company defined the activities that could be monitored and measured to develop the BIS. Then began the collection and organization of available data in the ERP software, in addition to repositories and internal files of the company, government websites, and individual notes of managers. After this stage, alignment meetings were held to define the information that would be visually presented. For the creation of the visuals and reports, the tool used was Power BI® standard version, through which relationships between the tables were developed, along with the interface part for presenting the information. The company's team of engineers defined the Power BI® software as a result of the software usage licenses made available.

4. Results

We organized the data sets distributed over several servers using the ETL (extract, transform and load) tool to standardize and remove errors and missing or blank data, qualifying and making it fit. This process was done in the query structure available in the Power Query function of Power BI®. After this, a database with 32 tables was generated, among which several levels of relationships were processed in the Power Pivot part, a tool that makes it possible to model data by establishing dynamic relationships between tables. Integrating the 32 tables allowed the creation of a BIS structure with fifteen pages of reports, indicated in Figure 3.

To illustrate the operation of the developed application, the following panels were selected: (1) Monitoring Mine Shaft; (2) Requisitions of Materials and Services (RMS); (3) Drum Overpacking; (4) Monitoring I and Monitoring II; (5) Safety Inspection I and Safety Inspection II.

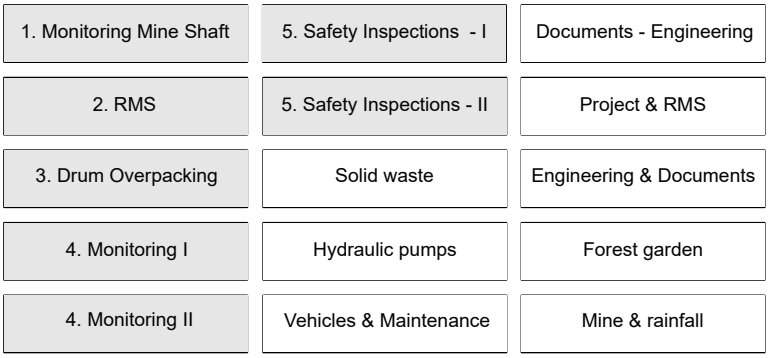


Fig. 3: Interface BIS

These reports stand out due to the need for regulated controls defined by inspection agencies. Items 1, 2 and 3 are identified in Figure 4, while items 4 and 5 are represented in Figure 5. Both figures 4 and 5 are illustrative due to confidentiality reasons.

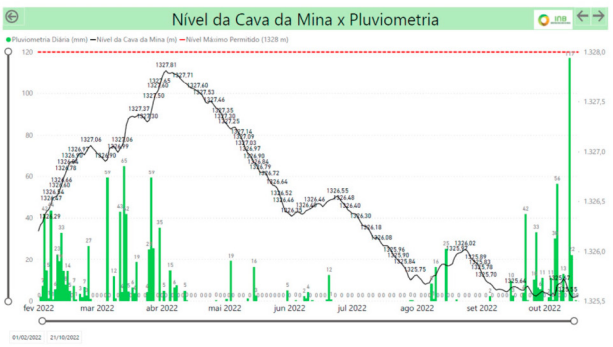
Figure 4a reports the panel of the Mine Shaft level with rainfall. Figure 4b presents the general data of materials and service requisitions (RMS), which gathers information on input purchases and contracting of specialized services. Figure 4c indicates the levels of control for storing drums containing waste that pose a radiological risk. The drums are constantly monitored to ensure safety for the company, society, and the environment.

Figure 5 show the dashboard created for monitoring the dams. It was created to illustrate the daily status of barrages I and II, as shown in Figures 5a and 5b, and the progress of compliance with the safety recommendations by the auditors reporting their status and what is the highest priority reported in the Figures 5c e 5d.

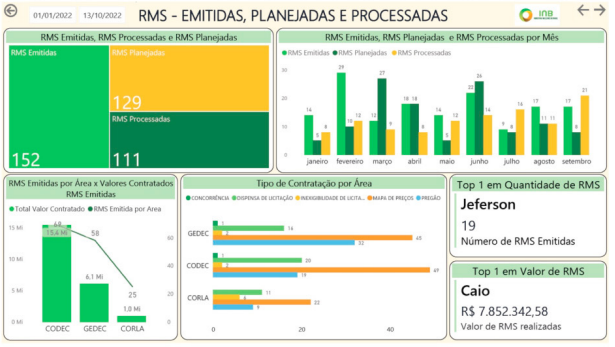
In summary, the data collected from the different representations were organized in their respective folders and modeled for the creation of panels in the BI tool. Thus, it generated many tables and established relationships in Power BI®. Due to their complexity, the systematization of data collection and the development of dashboards were the activities that required the most time. The support of managers and collaborators was crucial in achieving these stages. After implementing the proposed BIS, the managers of the studied areas were questioned about the changes and improvements. Table 1 indicates the evaluation of the four managers involved in the project regarding the study developed.

With positive feedback from the unit managers and employees, we achieved the goal regarding the development of BIS. Part of the developed reports is presented in the company's main building, where everyone can check the progress of the activities through televisions available in the common areas, which increases integration within the teams, especially for those who are somehow connected to the activities represented. Before the BIS was developed, there was no way to visualize the data of the activities in the study, which made it difficult to understand and analyze to take action.

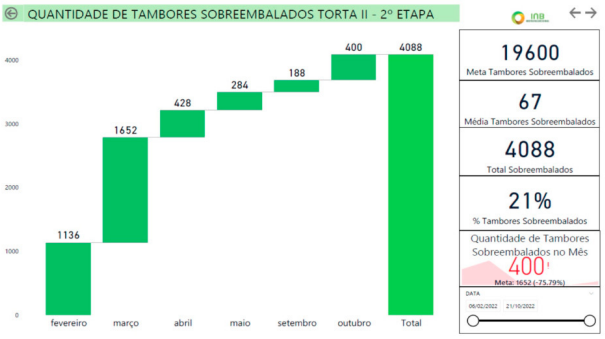
Implementing the BIS was aligned with the company's specific needs, ensuring compliance with technical requirements and the organization's operational and strategic demands. In addition, the new BIS improved internal communication, providing a secure environment for sharing data and reports. This strengthened alignment with the



(a) Mine Shaft level



(b) Requisitions of materials and services (RMS)



(c) Overpacking operation drums

Fig. 4: Overview of the Mine Shaft, RMS, and overpacking operation drums panels

Table 1: BIS effectiveness evaluation

Position	Quotation/comment
Plant Manager	"I notice that the information displayed on the big screen arouses the interest of many employees, who stop to observe it for minutes. I do the same, and the motivation is the amount of relevant and accessible information quickly and clearly. Monitoring the acquisitions/contracting processing has enabled actions to increase our efficiency in managing a substantial amount of long bidding processes within a budget year with an annual cycle. I would also highlight the facilitation of communication of dynamic budget demands with managers involved in fundraising".
Engineering Supervisor	"The BIS developed became excellent tools for succinct and mainly illustrative disclosure of data monitoring or monitoring of structures to all company employees and visitors, but especially to regulatory bodies, demonstrating greater transparency to the process and greater agility in the transfer of knowledge. Besides the dissemination of information, the tools developed are also used to control processes and documentation, allowing the traceability of engineering documents issued by the company itself or contracted companies and identifying the primary information referring to the papers. Finally, the newsletters significantly assist decision-making and prioritization of actions or solutions to be pursued".
Coordinator 1	"I consider that the activities carried out contributed to improving budget planning, making it more feasible. It contributed to improving the management of requisition processing, and facilitating action-taking by managers. The creation and dissemination of performance indicators of the sectors I consider to be a milestone for the culture of quality and involvement of employees in the ongoing actions and objectives of the Unit".
Coordinator 2	"The novelty of disseminating information using the company's database drew attention, including enhancing the activities of all sectors, such as work orders, dam monitoring, and pluviometry, among others. The information layout was didactic and clear, showing objective information about the INB routine".

company's governance policies and promoted transparency and collaboration between departments. In addition, BIS improved internal communication and governance, setting a new standard of efficiency in sharing information with the regulatory bodies that regularly audit the company in question. With the ability to generate detailed reports accessible in real-time, BIS has enabled the organization to respond promptly to requests from regulatory bodies, guaranteeing total transparency and compliance with the regulations in force.

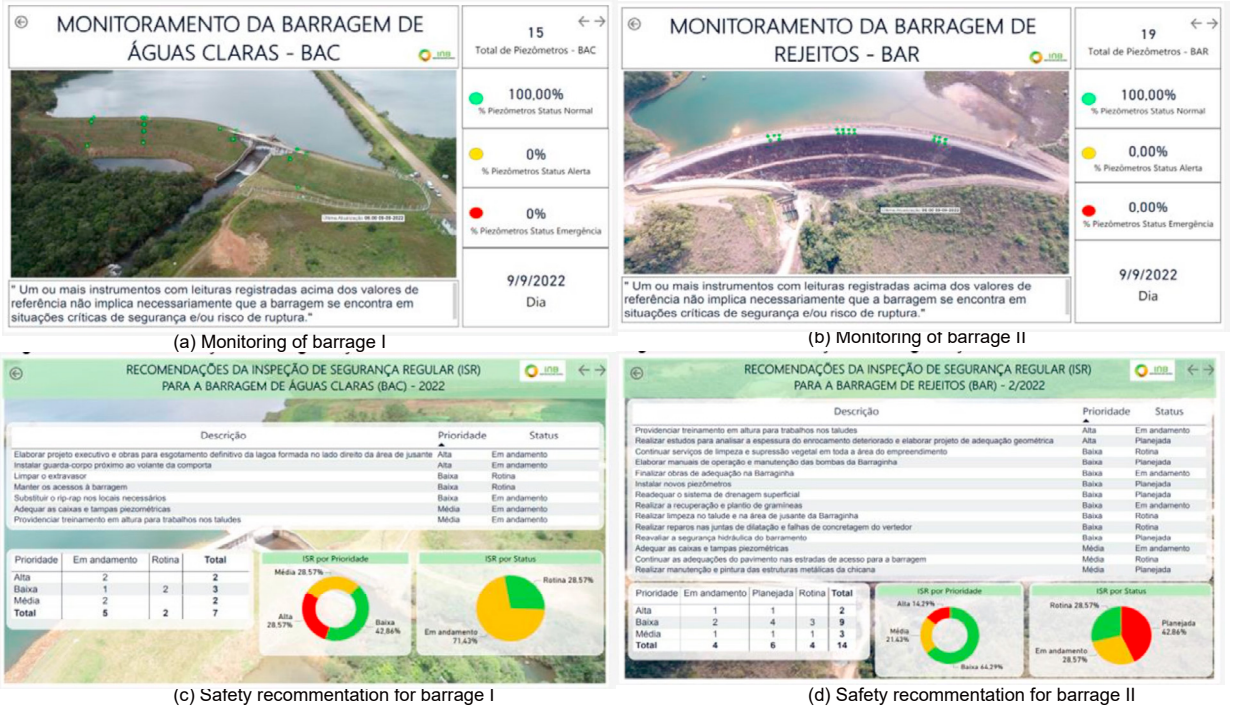


Fig. 5: Overview Barrages Reports

Companies in regulated environments must grant auditors access to internal data until an audit or investigation is carried out. This generates risks that damage the organizations' internal processes, as data can be compromised in this time frame. The BIS developed used available and collected on-site data, generating reports in a public way for better decision-making and prioritization of investigation resources. For example, data collection from the sensor that records the pressure and temperature of the mine shafts are done and updated simultaneously in reports connected directly to the BIS tool, which allows a velocity of access and accuracy of information for decision-making from both strategic and auditing points of view.

Besides the support in signal recognition from sensors or on-site collection, the proposed BIS also allows the company to continuously monitor the ongoing alignment process between the business model and the new material requisitions, enabling it to manage expenses that would probably affect the business model due to waste of financial resources; the proposed BIS enables monitoring of the main internal variables that are more sensitive to external influences.

As a limitation, the initial barriers in defining priority activities for the initial versions of the BIS stand out. Furthermore, this highlighted the absence or insufficiency of data in preparing dashboards since some mapped processes needed historical information, which prevented comparisons between periods. Data collection, at the beginning of the development, encountered some adversities concerning updates because those responsible for filling the daily data had to be reminded many times of the importance of keeping updates for the reports generation.

5. Conclusion

This paper analyzes the BIS development and implementation process for a regulated company in the nuclear sector in Brazil. The research investigation goes beyond exploring the benefits. It presents an insight into organizational acceptance challenges relating to BIS. With the examples highlighted, it was possible to see that access, availability and accuracy of the information make BIS a fundamental tool for the company in the future. Through the BIS, it was possible to develop graphic panels, guiding managers daily in decision-making and serving as a reference for good management to regulatory bodies. In addition, the BIS was able to intensify the flow of information through

the propagation of representations via the company's television system, allowing all to be quickly informed on all activities covered by the application.

It was observed that from this study, the BIS was used to generate useful knowledge for the research company, transmuting data into relevant information for all stakeholders. As a proposal for future work, it is suggested to deepen the use of BI and the development of BIS structures in other areas of the researched company and propose its use in other companies of the group seeking to improve automation of the data collection system and knowledge on the best way to visually represent activities in nuclear companies. Therefore, using BI solutions can improve planning and control activities, including in regulated companies, as the availability of timely and accurate information and data positively affects cost management, the reporting system, and the reliability of the audit process. BIS can produce, from corporate databases, a wide range of useful pre-specified reports to support planning and control activities.

We articulate the practices presented in this article to indicate how BIS as a management tool helped generate and access information since several factors were involved during the development process. Thus, while considering the impact of BIS, we observed that those involved in the project perceived what was being developed in a positive way.

While existing literature often focuses on broad organizational factors, this study explores the individual dimension of BIS adoption, recognizing the critical intersection of technology and organizational culture. We show that BIS implementation aligns a company's internal processes with the vision of Industry 4.0, enhancing efficiency, transparency, and connectivity. This research offers a comprehensive and practical approach to BIS adoption in regulated companies, showcasing its role in driving the transition to innovative Industry 4.0 principles. This unique approach underscores the significance of the human element in digital transformation and broadens our understanding of the individual implications of BIS adoption in this ever-evolving context.

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