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

INDUSTRY 4.0 MATURITY MODEL IN THE CONTEXT OF STATE OF ESPÍRITO SANTO

MODELO DE MATURIDADE DA INDÚSTRIA 4.0 NO CONTEXTO DO ESTADO DO ESPÍRITO SANTO

Raianny Souza Fernandes* E-mail: raiannysouza20@gmail.com
Mário Mestria* E-mail: mmestria@uol.com.br
*Instituto Federal do Espírito Santo (IFES), Campus Vitória, ES, Brazil.

Abstract: The aim of this paper is to develop a manufacturing maturity model for implementing Industry 4.0 technologies. The study was based on the methodology of De Bruin *et al.* (2005). The study contributes by providing insights into how the maturity model can help companies to see their strengths and weaknesses in order to improve the level of maturity of Industry 4.0 in these organizations. The model is specifically developed based on the specified objectives, factors and barriers, addressing the complexity of Industry 4.0 with a focus on manufacturing. To this end, a questionnaire was administered to 25 employees of companies in Espírito Santo, Brazil, with the aim of validating the model found and identifying the level of maturity of the organizations studied. The maturity model found consists of five maturity levels, three dimensions and 27 elements. The questionnaire applied resulted in a maturity level of 59.7%, obtaining an intermediate classification, meaning a partial use of Industry 4.0 technologies in the companies studied. A comparison was made between the Mining, Electrical, IT, Steel and Metallurgy sectors. The results showed that the Steel and Mining sectors have the highest maturity values and the IT and Metallurgy sectors have the lowest Industry 4.0 maturity values. A limitation of the study is the subjectivity inherent in the use of questionnaires. As a future suggestion, it is possible to identify the relationships between the elements presented in the maturity model.

Keywords: Industry 4.0. Maturity Model. Manufacturing companies.

Resumo: O objetivo deste artigo é desenvolver um modelo de maturidade fabril para a implementação de tecnologias da Indústria 4.0. O estudo foi baseado na metodologia de De Bruin *et al.* (2005). Ele contribui ao fornecer insights sobre como o modelo de maturidade pode ajudar as empresas a ver seus pontos fortes e fracos, a fim de melhorar o nível de maturidade da Indústria 4.0 nessas organizações. O modelo é especificamente desenvolvido com base nos objetivos, fatores e barreiras especificados, abordando a complexidade da Indústria 4.0 com foco na manufatura. Para tanto, foi aplicado um questionário a 25 funcionários de empresas do Espírito Santo, Brasil, com o objetivo de validar o modelo encontrado e identificar o nível de maturidade das organizações estudadas. O modelo de maturidade encontrado é composto por cinco níveis de maturidade, três dimensões e 27 elementos. O questionário aplicado resultou em um nível de maturidade de 59,7%, obtendo uma classificação intermediária, significando um uso parcial das tecnologias da Indústria 4.0 nas empresas estudadas. Uma comparação entre os setores de Mineração, Elétrico, de TI, Siderurgia e Metalurgia foi feita. Os resultados demonstraram que os setores de Siderurgia e Mineração apresentam os maiores valores de maturidade e os setores de TI e Metalurgia apresentam os menores valores de maturidade da Indústria 4.0. Uma limitação do estudo é a subjetividade inerente ao uso de questionários. Como sugestão futura, é possível identificar as relações entre os elementos apresentados no modelo de maturidade.

Palavras-chave: Indústria 4.0. Modelo de Maturidade. Empresas de Manufatura.

1 INTRODUCTION

Industry 4.0 or the Fourth Industrial Revolution represents a new paradigm for the digitalization of manufacturing, helping to generate new opportunities for organizations (Monshizadeh *et al.*, 2023).

Industry 4.0 is directly related to the future of manufacturing and achieving a competitive advantage for companies. It presents itself as a form of integration between the real and virtual worlds, through the adoption of cyber-physical systems, the Internet of Things and others, contributing to a greater degree of automation and digitalization of production processes (Silva *et al.*, 2020).

Industry 4.0 is a concept that is growing exponentially, expanding industries' knowledge of the digital manufacturing process. To foster this growth, it is necessary to address the concepts, scope, definition and functionality of Industry 4.0 and a systematic literature review can contribute to this process. In addition, knowing the impacts, functions, capabilities and future trends of Industry 4.0 is valued by international associations, governments, industrial communities and academia (Ghobakhloo *et al.*, 2021).

Silva *et al.* (2023) goes further by saying that Digital Transformation, which used to be treated as a differentiator, is now fundamental for companies to stay in business. Industry 4.0 provides a world in which physical and virtual manufacturing systems cooperate globally and flexibly, with intelligent and connected systems.

Among the main technologies of Industry 4.0 are the Internet of Things, Cyber-Physical Systems, Cloud Computing, Robotics, Augmented Reality, Digital Twin, Industrial Internet of Things, Artificial Intelligence, Virtual Reality, Additive Manufacturing and Blockchain (Mahmoodi *et al.*, 2022).

Ferreira *et al.* (2022) believe that Industry 4.0 promotes a central strategy for enhancing the competitiveness of the manufacturing sector. However, there is still a difficulty in finding tools to help transform companies towards Industry 4.0.

However, a roadmap towards for Industry 4.0 is not yet clearly defined. One tool that can facilitate this understanding is the maturity model, which represents a methodology for monitoring the progress of the initial I4.0 in organizations, guiding their strategic process (Caiado *et al.*, 2021).

This study aims to propose a manufacturing maturity model for the implementation of Industry 4.0 technologies. The aim is to assist companies, professionals and academics in the field to understand the level of maturity of the company's processes related to Industry 4.0, identifying strengths and weaknesses of the implementation process and seeking to improve it.

The study's differential lies in the development of a maturity model aimed at the manufacturing sector in general, providing a diagnosis of the current situation of the companies evaluated.

Therefore, the aim of this work is to provide an initial mapping of the level of maturity of companies in the state of Espírito Santo. In other words, the focus is on understanding how the state of Espírito Santo is positioning itself in relation to Industry 4.0 digital technologies.

The study is organized as follows: the next section deals with the literature review on Industry 4.0 and the maturity models in the literature; section 3 deals with the methodology of the article, with the results found and the discussion in section 4. The last section, Section 5, presents the study's conclusion, including limitations and future suggestions for research on the subject.

2 LITERATURE REVIEW

This section outlines some related work in the context of Industry 4.0 and the dimensions and gaps in the maturity models.

2.1 Industry 4.0

According to Pacchini *et al.* (2019), Industry 4.0 represents a set of digital and physical technologies that add new value and services for customers and organizations.

Dalmarco *et al.* (2019) complement the concept of Industry 4.0 as an approach to integrating various technologies, such as Augmented Reality, Additive Manufacturing, Big Data, Cloud Computing, Cyber-Physical Systems, Cybersecurity, Intelligent Robotics, Simulation and Systems Integration. These technologies can help improve productivity by making production more flexible, optimizing physical layout and improving worker training. Additionally, the efficiency and quality of the production process can increase, as well as improving security with the use of cybersecurity mechanisms. Finally, the authors also mention better decision-making based on data, transforming it into knowledge that can be used by managers.

Culot *et al.* (2020) define Industry 4.0 as a set of technologies and applications that can be implemented based on different characteristics and objectives. It requires a multidisciplinary approach, involving cultural, political, demographic, educational and infrastructural factors.

Kiraz *et al.* (2020) state that Industry 4.0 represents a change in how we produce, automating machines and enabling self-management processes. Furthermore, it offers numerous advantages, such as cost-effectiveness, high speed, efficiency, quality, and simplified communication and processes. In addition, companies can increase their market share by competing and improving customer satisfaction.

Ghobakhloo *et al.* (2021) comment that the digital transformation of I4.0 does not happen quickly, but requires a gradual and complex process of planning and implementing technologies. Due to the complexity of this process, drawing up a strategic plan to manage these implementation requirements is essential for organizations.

2.2 Maturity Models

Maturity models serve as guidelines for organizations to develop transformation competencies when developing change. In other words, they serve as a guide for transformation. At a time when companies are developing and changing their processes and business models to adapt to Industry 4.0, maturity models can help achieve competitive advantage by starting the process of organizational change (Ünal *et al.*, 2022).

For Kirmizi and Kocaoglu (2022), the maturity model helps to increase the adoption rate and facilitates the generation of an initial implementation roadmap, motivating professionals and contributing to the continuous improvement of the journey towards digital transformation. The maturity model is, therefore, a strategic tool that helps facilitate the process of improvement towards digitalization, revealing strengths and weaknesses to design improvement actions.

Thus, some maturity models from the literature focused on Industry 4.0 can be cited and assessed based on the dimensions, their contribution to the study and gaps in the models. Colli *et al.* (2019) address the context of digital transformation by promoting an improvement to the model by Schuh *et al.* (2017), including an assessment following the concepts of the Problem-Based Approach - PBL, with the use of a mediator and a rapporteur to manage the assessment process. In this way, the concepts were applied to three companies, seeking to provide recommendations on the process of implementing Industry 4.0.

Frank, Dalenogare and Ayala (2019) developed a framework with Front-end Technologies and Core Technologies, with well-defined layers. Some companies were then evaluated and grouped into clusters according to the framework's definition.

Gürdür *et al.* (2019) discuss the readiness of Swedish companies for industrial digitalization. Rafael *et al.* (2020) developed a maturity model to accommodate the particularities of SMEs (small and medium-sized enterprises) in the machine tool sector.

Caiado *et al.* (2021) developed a maturity model for Supply Chain Management, seeking to reduce uncertainty and ambiguity in the process through the use of fuzzy logic. Liebrecht *et al.* (2021) adopt a more comprehensive approach, focusing on strategic and economic issues to develop a structured roadmap for I4.0. Asdecker and Felch (2018) develop a model focused on the delivery process.

Dal Forno *et al.* (2023) propose an Industry 4.0 maturity diagnostic tool focused on the textile and clothing sector. The authors define five dimensions for the model: demographics, technologies, strategy, digital skills and benefits of implementation. Table 1 shows a summary of the main studies on the subject.

Table 1 - Comparison of maturity models

Author	Dimensions	Contribution	Gap
(Asdecker; Felch, 2018)	Order processing, storage and delivery.	Study with various experts from different sectors of industry.	Subjectivity of the study.
(Colli *et al.*, 2019)	Governance, Technology, Connectivity, Value creation and Skills.	Proposed approach based on the principles of PBL – Problem-Based Learning.	Improve the evaluation approach.
(Frank *et al.*, 2019)	No dimensions.	Well-defined framework for implementing I4.0.	Very homogeneous company profile.
(Gürdür *et al.*, 2019)	No dimensions.	Readiness level, as well as a robust study on a wide range of companies.	Lack of a structured model.
(Rafael *et al.*, 2020)	Employees, Smart Products, Smart Operations, Data Orientation, Smart Factory, Strategy and Organization.	Maturity model for the machine tool sector.	Need to investigate more companies
(Santos; Martinho, 2020)	Strategy organizational culture; Workforce; Smart Factories; Smart processes; Products and Services.	Model applied to the manufacturing sector, with a holistic view of processes.	Limited validation process.
(Caiado *et al.*, 2021)	No dimensions.	Model for dealing with statistical uncertainty and ambiguity.	Model limited to the Supply Chain Management sector.
(Liebrecht *et al.*, 2021)	No dimensions.	Use of strategic and monetary evaluation for analysis and creation of a roadmap for implementation.	Limited heuristic approach.
(Castelo-Branco *et al.*, 2022)	IT strategy and cybersecurity, enablers, smart factory, value proposition and customer experience.	Comprehensive I4.0 implementation model.	Subjectivity of the study.
(Gajdzik, 2022)	No dimensions.	Direct research with companies in the sector.	Model limited to the steel sector.
(Dal Forno *et al.*, 2023)	Demography, technologies, strategy, digital skills and benefits of the deployment	Diagnostic tool applied to the textile and clothing sector.	It is not possible to generalize the results to an industrial sector.

Source: The Authors (2024).

The literature review returned the articles in Table 1, with a focus on Industry 4.0. Table 1 shows that most of the authors' contributions include studies applied to several companies, with the definition of well-structured maturity models to provide a broad view of the business. However, the main shortcomings are the subjectivity of the studies, the limitation to one sector or industry, and the limitations of the method presented. This could provide some possibilities for the model to be defined in this work. Based on these factors, it was possible to establish the priorities for the maturity model, which are presented below in the methodology.

3 METHODOLOGY

This article presents the development of an Industry 4.0 maturity model for manufacturing, based on the methodology defined by De Bruin *et al.* (2005). The work is classified as exploratory and descriptive research, developing a maturity model and carrying out a survey in a group of companies in Espírito Santo.

Among the maturity methodologies, De Bruin *et al.* (2005) was chosen because of its descriptive, prescriptive and comparative basis within a given domain. For the authors, these phases of the methodology can generate a deeper understanding of the domain studied, analyzing the current state and seeking substantial improvements. In addition, it can be used in a wide range of organizations, allowing for a valid comparison between them. This methodology can be applied across multiple disciplines, in a generalizable and standardized way. The contributions range from knowledge of the domain, through understanding existing relationships and influences, to the ability to measure and evaluate the domain at a given time. This favors the efficient use of resources to improve understanding of the domain studied, contributing to its development

The De Bruin *et al.* (2005) model consists of a sequence of six steps:

- The first phase consists of scoping the model. This defines the external limits and use of the model, as well as identifying the stakeholders;
- The second phase is design of the model. Here it is important to define the needs of the target audience and how to respond to them. The reason for applying the model, how it can be applied, those involved in the application and what is to be achieved with the model are all questions that must be answered in this phase;
- The third phase is called populating or filling in the model. Here the content is decided, identifying what should be measured and how;

- The fourth phase consists of testing the model, assessing its relevance and rigor. Tools such as interviews, focus groups, interviews and others can be used;
- The fifth phase is deployment, where the model is made available for use;
- The sixth phase is called maintenance, involving the resources needed to maintain and expand the use of the model.

Thus, the scope of the model was defined by Industry 4.0 and its applications in manufacturing. Stakeholders include industry in general, academics in the field of Industry 4.0 who are interested in developing tools to improve its concepts in general, and employees from companies in various sectors whose focus is on implementing Industry 4.0.

The model is applied by means of self-assessment, with the employee themselves answering a questionnaire. The aim is to understand how Industry 4.0 is being implemented in the company, to find its strengths and weaknesses.

The model was populated using a systematic literature review, defining dimensions, elements and maturity levels. The model was tested using questionnaires applied to companies in Espírito Santo. The data was then tabulated and analyzed in order to understand the results presented and thus make the model available for use through publications in journals and other online media.

3.1 Data Collection

To collect the data and compose the model, it was necessary to search the ScienceDirect, Web of Science, Scopus, ACM Digital Library and IEEE Xplore databases. The keywords used for the search were related to Industry 4.0 and maturity models or readiness assessments. Table 2 shows the keywords used to collect the articles.

Table 2 – Keywords used in the research

SEARCH	KEYWORDS
Industry 4.0 models	("maturity model" OR "readiness assessment") AND ("industry 4.0" OR "industrie 4.0" OR "fourth industrial revolution")

Source: The Authors (2024).

3.2 Composition of the maturity model

The maturity model presented is made up of dimensions, elements and maturity levels. The dimensions are described below:

- Strategy, Culture and Organizational Innovation;
- Work Team;
- Technology.

These dimensions are detailed together with the elements of the maturity model, described in Table 3. All 14 questions in the questionnaire derive from the elements of the maturity model described in table 3, with the code referring to the element. In this way, the questionnaire is directly related to the maturity model.

Table 3 - Comparison of maturity models

Dimensions	Elements		Code
Strategy, Culture and Organizational Innovation	Alignment of Organizational Strategy with I4.0 concepts		P.1
	Composition of I4.0 in the business plan		P.2
	Availability of financial resources		P.3
	Promoting innovation and collaboration to generate value		P.4
	Use of KPIs to monitor I4.0		P.5
Work Team	Employee training		P.6
	Knowledge and skills		P.7
	Autonomy and creativity to innovate		P.8
	Flexibility to suggest changes		P.9
Technology	Infrastructure to implement I4.0	Equipment	P.10.1
		Machinery	P.10.2
		Physical Resources	P.10.3
		Digital Resources	P.10.4
	Ability to change your processes in real time based on data		P.11
	Data security		P.12
	Product customization		P.13
	Use of Big Data		P.14.1
	Additive Manufacturing		P.14.2
	Augmented Reality		P.14.3
	Virtual Reality		P.14.4
	Digital Twin		P.14.5
	Autonomous robots		P.14.6
	Cloud Computing		P.14.7
	Artificial Intelligence		P.14.8
	Internet of Things		P.14.9
	Cyber-Physical Systems		P.14.10
	Simulation		P.14.11
	Decision Support Systems		P.14.12
	Sensors and Actuators		P.14.13
	Systems integration		P.14.14

Source: The Authors (2024).

The maturity levels are described below. According to Santos & Martinho (2020), there is no standard or history of levels in maturity models. The last level represents the maximum level of maturity. The previous levels are incremental evolutions until reaching the maximum point of evolution. The authors also add that the ideal is to evolve in a balanced way, which would represent good planning and execution of response actions. Table 4 below shows the maturity level, what this level represents in terms of implementing Industry 4.0 and the weight of the maturity level.

Table 4 - Levels of maturity

Maturity Level	Implementation process	Weight
Specialist	Level of excellence in I4.0 implementation	91-100%
Experienced	Implementation of most I4.0 technologies	76-90%
Intermediate	Partial implementation of the use of I4.0	51-75%
Beginner	Little evidence of I4.0 implementation	31-50%
Nonexistent	No evidence of I4.0 implementation	0-30%

Source: The Authors (2024).

In order to continue with the maturity model project, it was necessary to validate or test the model. To this end, based on the elements of the maturity model described, it was possible to draw up a set of questions in a questionnaire applied online, answered by 25 employees from companies in the Espírito Santo industry. The link to the questionnaire was sent to 30 respondents, with 25 replies received, representing a return rate of 83.3%.

The questionnaire contains questions based on the dimensions, and elements of the maturity model, as well as questions developed by Ferreira (2021), Oliveira Júnior (2018) and Santos (2018), in order to validate the parameters identified. To this end, 14 questions were defined, with answers such as "yes", "yes, partially" and "no". The scale was defined based on a modification of the Thurstone scale (Da Cunha, 2007), adding the answer "yes, partially", seeking greater adherence of the answers when dealing with the maturity model.

This scale assigns the values described below:

- Yes, with a value of 1
- Yes, partially, with a value of 0.5
- No, with a value of 0.

Each answer is associated with a value on the scale and multiplied by its weight. At the end is the average of the 25 respondents' answers, based on the number of times they answered "Yes", "Yes, partially" and "No" to each question.

The checkbox questions have a weight of 0 or 1. This simplification was made due to the number of items in questions 10 and 14, in order to reduce the size of the questionnaire and because it was considered important to find out whether or not the items are present in the company, with "Yes" or "No" answers.

Equation 1 shows the values required for the result of the local maturity index (I_l), with *a* representing how many times the answer "Yes" was used and *b* representing how many times the answer "Yes, partially" was used.

$$I_l = \frac{(1a+0,5b)}{25} \quad (1)$$

After assigning weights to the element questions, the average of the data obtained is calculated to find the maturity value of the dimensions. Next, the overall maturity value was found using a simple average of the dimension values.

4 RESULTS AND DISCUSSION

The study was carried out with 17 companies in Espírito Santo. A total of 25 professionals completed the assessment. Figure 1 shows the positions held by the respondents. Based on the results, it can be seen that the majority of participants work in positions related to analysis, management, coordination, direction and engineering.

Figure 1 - Position of respondents

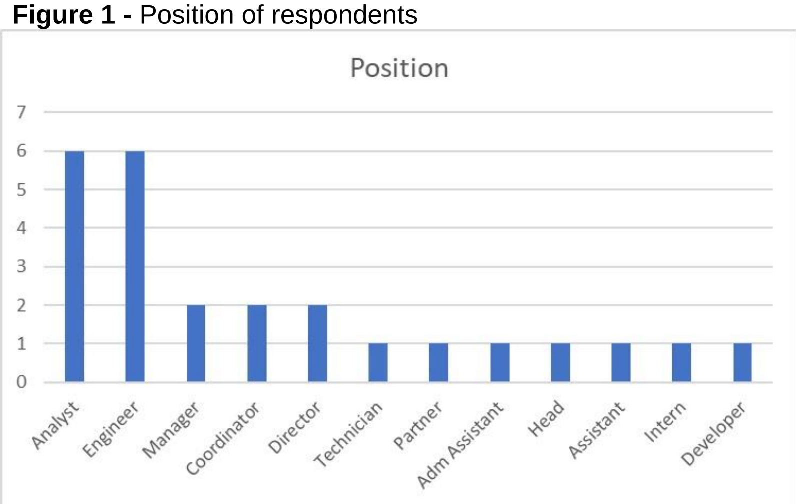


Figure 2 shows the sector of the companies studied.

Figure 2 - Sector of the companies studied

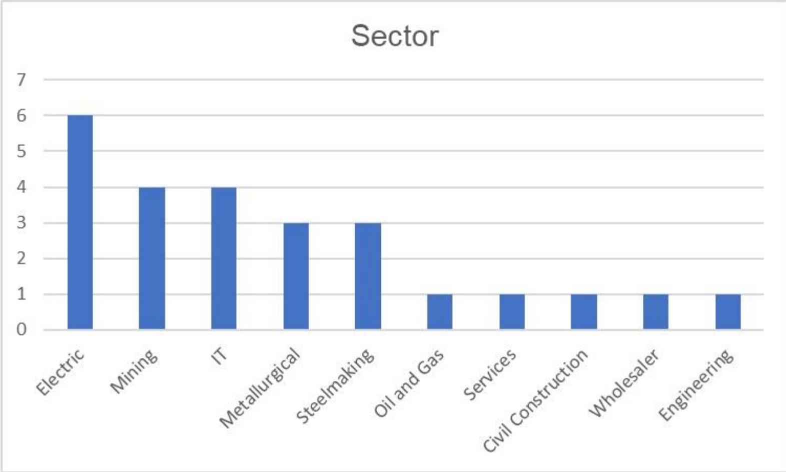


Figure 2 shows that the most cited business sectors are Electricity, Mining, IT, Metallurgy and Steel. This response is to be expected given Espírito Santo's profile in terms of its share of the economy and the more developed technological context of these sectors.

Table 5 shows the results of the questionnaire, presenting the data based on the questions and the number of "Yes", "Yes, partially" and "No" answers.

Questions 10 and 14 are dealt with in a specific way, as they are "tick box" type questions, with more than one possible alternative, and are shown in tables 6 and 7. It should also be noted that these "tick box" type questions only have two answer alternatives, "Yes" or "No", and therefore do not have the weight assigned to the "Yes, partially" answer (Value 0.5).

Table 5 - Results of the questionnaire

P.1	**Quantity**	**P.2**	**Quantity**	**P.3**	**Quantity**
Yes	12	Yes	14	Yes	13
Yes, partially	10	Yes, partially	9	Yes, partially	9
No	3	No	2	No	3
P.4	**Quantity**	**P.5**	**Quantity**	**P.6**	**Quantity**
Yes	18	Yes	10	Yes	6
Yes, partially	5	Yes, partially	2	Yes, partially	10
No	2	No	13	No	9
P.7	**Quantity**	**P.8**	**Quantity**	**P.6**	**Quantity**
Yes	9	Yes	10	Yes	18
Yes, partially	9	Yes, partially	13	Yes, partially	6
No	7	No	2	No	1
P.11	**Quantity**	**P.12**	**Quantity**	**P.3**	**Quantity**
Yes	13	Yes	18	Yes	15
Yes, partially	7	Yes, partially	3	Yes, partially	9

No	5	No	4	No	1

Source: The Authors (2024).

Table 6 shows the results of question 10. The Table contains the number of affirmative answers for the items described, with a maximum of 25 answers for each item. Table 7 shows the results of question 14.

Table 6 - Question 10 - results

P.10	Quantity	Percentage (%)
Machinery	9	36
Equipment	14	56
Physical Resources	17	68
Digital Resources	22	88

Source: The Authors (2024).

Table 7 - Question 14 - results

P.14	Quantity	Percentage (%)
Use of Big Data	10	40
Additive Manufacturing	3	12
Augmented Reality	9	36
Virtual Reality	11	44
Digital Twin	5	20
Autonomous robots	9	36
Cloud Computing	18	72
Artificial Intelligence	11	44
Internet of Things	11	44
Cyber-Physical Systems	3	12
Simulation	14	56
Decision Support Systems	12	48
Sensors and Actuators	11	44
Systems integration	16	64

Source: The Authors (2024).

From this dataset, a series of conclusions can be drawn. In the next topic, the answers to each question and what they represent for the context of companies of Industry 4.0 are presented.

From this information, it is possible to find the maturity index of the elements, the dimensions and the overall maturity index, respectively, in Table 8, Table 9 and Table 10.

Table 8 - Local maturity index of the elements

Question	**P.1**	**P.2**	**P.3**	**P.4**	**P.5**	**P.6**	**P.7**	**P.8**	**P.9**
Index	68%	74%	70%	82%	44%	44%	54%	66%	84%
Question	P.10.1	P.10.2	P.10.3	P.10.4	P.11	P.12	P.13	P.14.1	P.14.2
Index	36%	56%	68%	88%	66%	78%	78%	40%	12%
Question	P.14.3	P.14.4	P.14.5	P.14.6	P.14.7	P.14.8	P.14.9	P.14.10	P.14.11
Index	36%	44%	20%	36%	72%	44%	44%	12%	56%
Question	P.14.12	P.14.13	P.14.14						
Index	48%	44%	64%						

Source: The Authors (2024).

From this data, it is possible to construct a radar graph, presenting the information in such a way as to understand the strengths and weaknesses of the dimensions and elements, represented by Figure 3.

Figure 3 - I4.0 radar graph

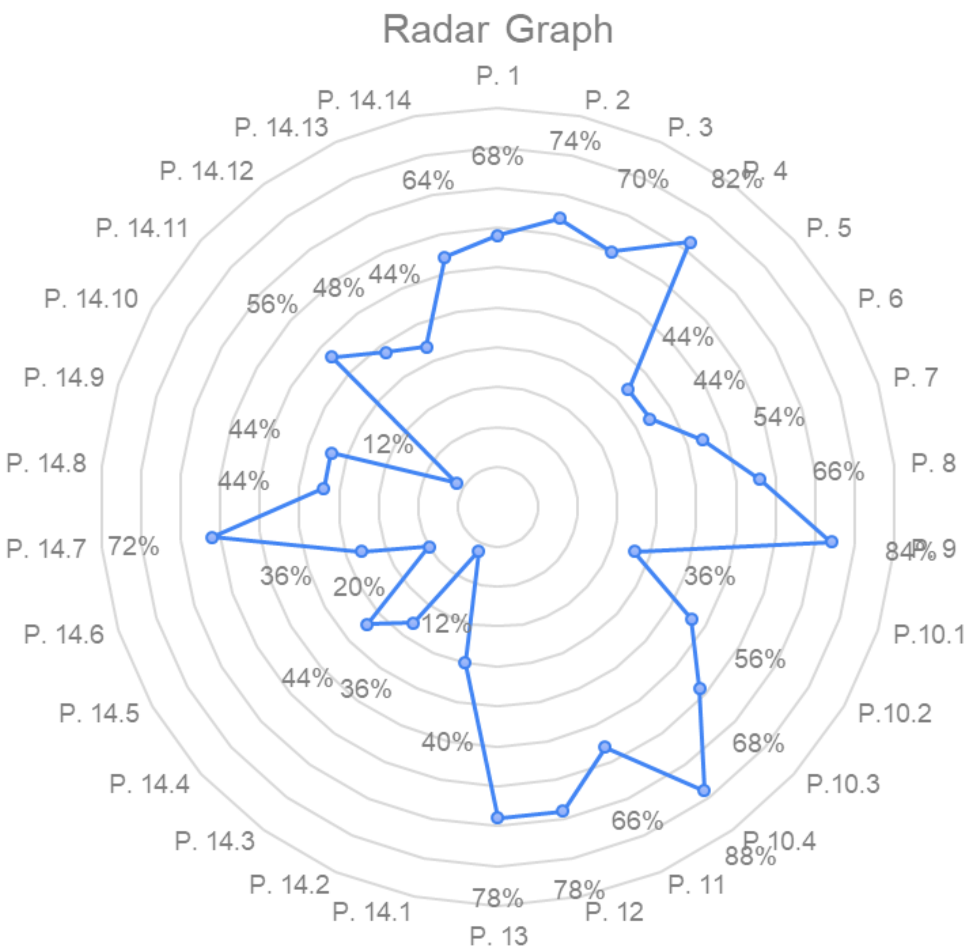


Table 9 is shown below. It is important to remember the classification given in Table 3, in which questions 1 to 5 are allocated to the "Strategy, Culture and Organizational Innovation" dimension, questions 6 to 9 are allocated to the "Work Team" dimension and questions 10 to 14 are allocated to the "Technology" dimension. In this way, it is possible to obtain information about how these dimensions are being approached by the organizations.

Table 9 - Maturity index of the dimensions

Dimension	**Index (%)**	**Maturity Level**
Strategy, Culture and Organizational Innovation	67,6%	Intermediate
Work Team	62,0%	Intermediate
Technology	49,6%	Beginner

Source: The Authors (2024).

The radar chart for the three dimensions is shown below. Each point on the radar chart shows the code of the element that belongs to the dimension. Figure 4 shows the radar chart for the first dimension, "Strategy, Culture and Organizational Innovation".

Figure 4 - Radar graph of the Strategy, Culture and Organizational Innovation dimension

The radar graph helps us to better understand the strengths and weaknesses of a subject under study. In the case of Figure 4, it can be seen that P.4 has the best result among the elements in the first dimension. On the other hand, P.5 has the lowest score, which may indicate a weak point in the companies that needs improvement.

Looking at Table 3, it can be seen from the codes that P.4 represents the element of "Promoting innovation and collaboration to generate value", demonstrating that innovation and collaboration are important factors for the organizations studied, and are considered the most important for organizational strategy. On the other hand, P.5 shows the lowest result, indicating that "Use of KPIs to monitor I4.0" is not a strengthened item for the companies.

Figure 5 shows the radar chart for the second dimension, "Work Team".

Figure 5 - Radar graph of the Work Team dimension

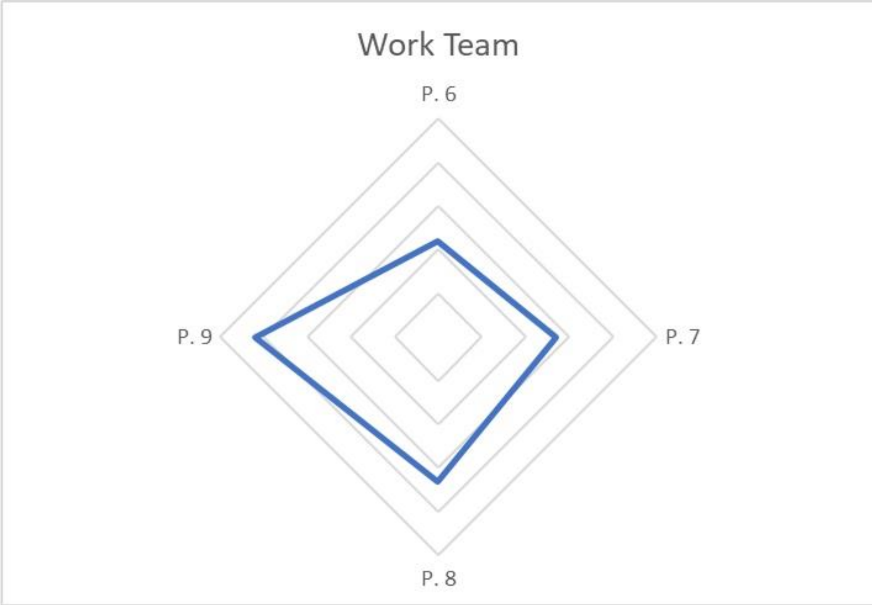
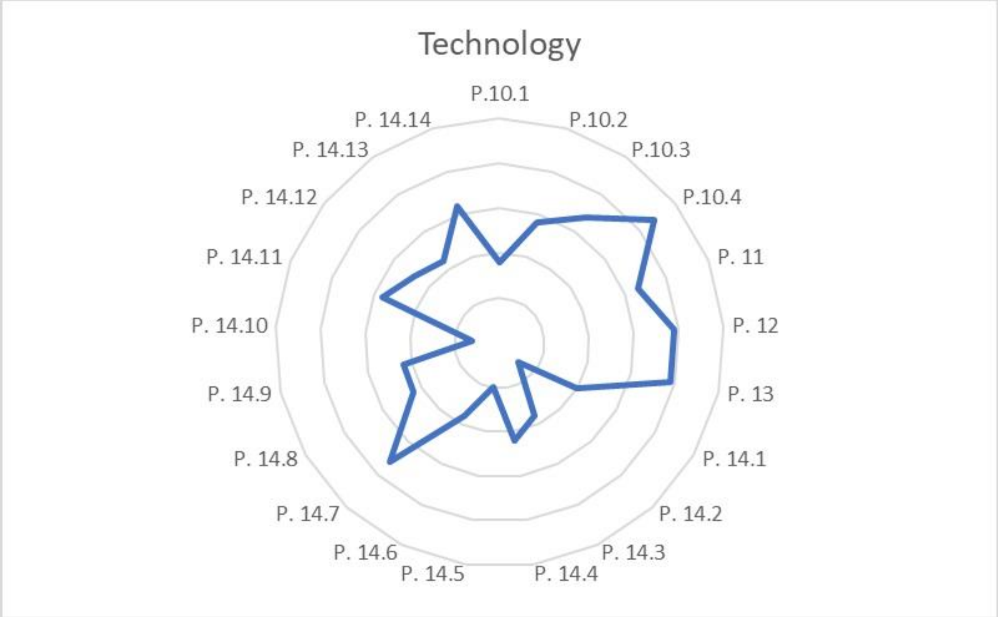


Figure 5 shows P.9, which stands for "Flexibility to suggest changes", as the most prominent item. This means that the work team does not encounter any barriers to making suggestions that lead to changes in the organization. The items with the lowest indicators are P.6 and P.7, which indicate "Employee training" and "Knowledge and skills" respectively. This means that the workforce still lacks the training and knowledge and skills needed to deal with the transformations of Industry 4.0. For these companies, these factors can become limiting factors in the implementation of I4.0 technologies, since workers are an important part of the process of organizational change towards excellence in I4.0.

Figure 6 shows the radar chart for the third dimension, "Technology".

Figure 6 - Radar graph of the Technology dimension



Based on Figure 6, it can be seen that the items that stand out most positively are P.10.4, P.12 and P.13. Looking at Table 3, one can see that the first represents the "Digital Resources" sub-item of the "Infrastructure for implementing I4.0" item. This means that the infrastructure available to most of the companies studied falls under the heading of digital resources, which could be cloud storage resources, software and others. The second item is "Data Security", showing that the organization is concerned about data privacy and security, with a view to preventing leaks and intrusions. Menezes *et al.* (2022) addresses the need to deal with information security issues in Industry 4.0, due to the large amounts of information created, processed and manipulated by production processes. The third item is "Product customization", which shows a concern for designing products according to customers' specifications and needs, promoting greater loyalty.

One item with a low value is P.10.1, which corresponds to the "Equipment" needed for the infrastructure to implement I4.0. This could mean that the costs are significant for the organizations, that they are not considered necessary or the organizations are more concerned about investing in digital resources, due to the ease of implementation, little need for physical space, labor to operate this equipment and reduced costs. The items with the lowest value are P.14.2, P.14.3, P.14.5, P.14.6 and P.14.10. These items represent, respectively, "Additive Manufacturing", "Augmented Reality", "Digital Twin", "Autonomous Robots" and

"Cyber-Physical Systems". This could mean that these technologies are not yet being widely implemented due to a lack of information about their use, a lack of training in the technology, a lack of qualified operators, high implementation costs and other possibilities.

These responses should be highlighted, since the digital technologies mentioned are essential and represent the core of Industry 4.0. It can be seen that there is still an intermediate use of most of the technologies mentioned, with few positive highlights and some negative ones.

The overall maturity index is given by the simple average of the dimensions described above, which returns a value of 59.7%, as described in Table 10.

Table 10 - Overall Maturity index

Item	Index (%)	Maturity Level
General Index	59,7%	Intermediate

Source: The Authors (2024).

The general maturity level, as can be seen in Table 4, is defined as an intermediate level of maturity, which means that the practices of Industry 4.0 technologies are partially applied in the companies.

Thus, it is possible to understand that the group of companies studied in Espírito Santo generally shows evidence of intermediate implementation of Industry 4.0 technologies.

Next, the responses obtained will be analyzed at a sectoral level, evaluating the Mining, Electrical, Information Technology, Metallurgy and Steel sectors. It was decided to evaluate these sectors because of their economic importance for the state, as well as the fact that a greater number of responses to the questionnaire were obtained.

In the Mining sector, four employees took part in the questionnaire.

It was possible to find a maturity index for the dimensions, described in Table 12.

Table 11 - Maturity index of the dimensions - Mining sector

Dimension	Index (%)	Maturity Level
Strategy, Culture and Organizational Innovation	87,5%	Experienced
Work Team	62,5%	Intermediate
Technology	62,5%	Intermediate

Source: The Authors (2024).

These results show more expressive values than those for the general case, highlighting the "Strategy, Culture and Organizational Innovation" dimension, which is at the experienced maturity level. This means that the sector has a great deal of implementation of I4.0 technologies in this respect. The overall maturity index for the Mining sector is described in Table 13.

Table 12 - Overall Maturity index

Item	Index (%)	Maturity Level
General Index	70,8%	Intermediate

Source: The Authors (2024).

Thus, despite having a higher overall maturity index, the Mining Sector is still at the intermediate level.

In the Electrical sector, six employees took part in the questionnaire.

Table 13 - Maturity index of the dimensions - Electrical sector

Dimension	Index (%)	Maturity Level
Strategy, Culture and Organizational Innovation	70,0%	Intermediate
Work Team	66,7%	Intermediate
Technology	54,8%	Intermediate

Source: The Authors (2024).

The overall maturity index for the Electrical sector is described in Table 13.

Table 14 - Overall Maturity index

Item	Index (%)	Maturity Level
General Index	63,8%	Intermediate

Source: The Authors (2024).

Thus, it can be seen that, despite having an overall maturity index slightly above the general one, the Electricity Sector is at an intermediate level, below the Mining sector in terms of I4.0 maturity.

In the Information Technology (IT) sector, four employees took part in the questionnaire.

Table 15 - Maturity index of the dimensions - IT sector.

Dimension	Index (%)	Maturity Level
Strategy, Culture and Organizational Innovation	52,5%	Intermediate
Work Team	78,1%	Experienced
Technology	44,6%	Beginner

Source: The Authors (2024).

Unlike the other sectors, the IT sector has the "Work Team" with the highest maturity value, at the experienced level. This is due to the high level of qualification already expected and characteristic of the sector. The overall maturity index for the IT sector is described in Table 13.

Table 16 - Overall Maturity index

Item	Index (%)	Maturity Level
General Index	58,4%	Intermediate

Source: The Authors (2024).

The results show an intermediate level of maturity for the IT sector. In other words, although the qualification of employees is notably higher than in the other cases, the use of digital technologies is well below what is expected for the sector.

In the Metallurgy sector, three employees took part in the questionnaire.

Table 17 - Maturity index of the dimensions - Metallurgy sector

Dimension	Index (%)	Maturity Level
Strategy, Culture and Organizational Innovation	43,3%	Beginner
Work Team	37,5%	Beginner
Technology	26,2%	Nonexistent

Source: The Authors (2024).

The overall maturity index for the Metallurgy sector is described in Table 13.

Table 18 - Overall Maturity index

Item	Index (%)	Maturity Level
General Index	35,7%	Beginner

Source: The Authors (2024).

The values presented by the Metals sector are well below the general case in all the dimensions studied. The results show a beginner's level of maturity for the metallurgy sector.

In the Steel sector, three employees took part in the questionnaire.

Table 19 - Maturity index of the dimensions - Steel sector

Dimension	Index (%)	Maturity Level
Strategy, Culture and Organizational Innovation	83,3%	Experienced
Work Team	62,5%	Intermediate
Technology	73,8%	Intermediate

Source: The Authors (2024).

The results show that the dimensions of the steel sector have values above the general case for "Strategy, Culture and Organizational Innovation" and "Technology". The overall maturity index for the Steel sector is described in Table 13.

Table 20 - Overall Maturity index

Item	Index (%)	Maturity Level
General Index	73,2%	Intermediate

Source: The Authors (2024).

The results show an intermediate level of maturity for the steel sector, very close to the experienced level.

These figures show that most of the positive points are in the Steel and Mining sector and fewer in the IT and Metallurgy sector. It was hoped that digital technologies would be more widespread in the IT sector, due to its proximity to the technological factor. It is clear that Mining and Steel, which are strong in the state of Espírito Santo, are well placed in terms of digital technologies. Metallurgy has some problems when it comes to technology, being far below the other figures.

5 CONCLUSION

Industry 4.0 presents countless possibilities for organizations, increasing production, reducing costs and improving the quality of their products. The complexity involved in developing and planning Industry 4.0 technologies can be a challenge for organizations, which must seek ways to better understand their processes and thus identify ways to facilitate the adoption of these technologies. Its technologies can help organizations gain competitive advantages, leading to better outcomes across all sectors of the organization.

Due to the complexity of implementing Industry 4.0, various tools can assist companies in implementing these technologies. The maturity model can be an important tool in this regard, as it helps companies to understand their maturity process towards manufacturing excellence. This article sought to develop a maturity model applied to companies in Espírito Santo, in order to contribute to the understanding of Industry 4.0.

The model presented was developed using the methodology of De Bruin *et al.* (2005), and consists of three dimensions - Strategy, Culture and Organizational Innovation, Work Team and Technology, 27 elements and five levels of maturity - Inexistent, Beginner, Intermediate, Experienced and Expert.

The maturity model served as the basis for drawing up a questionnaire with 14 questions, which was applied to 25 employees from 17 companies in the state of Espírito Santo, Brazil. The level of maturity found for the companies studied was intermediate. With the Strategy, Culture and Innovation dimension showing the best results and the Technology dimension showing the worst results, which placed it at a lower level, beginner.

The conclusion is that companies should focus more on issues involving the use of KPIs to monitor I4.0 in the strategic context, as well as improving issues involving employee training and existing knowledge and skills within the work team context. The implementation of technologies such as "Additive Manufacturing", "Augmented Reality", "Digital Twin", "Autonomous Robots" and "Cyber-Physical Systems" technologies could also be improved, as they are the least valuable in the technological context.

There was also an excellent level of promoting of innovation and collaboration to generate value in the strategic context, as well as flexibility to suggest changes in the context of the work team. These points are positive, as they present the issue of innovation and flexibility in companies, demonstrating that they are able to seek out and analyze the general context in order to promote changes as needs arise. In addition, issues involving structure, the use of digital resources, as well as concerns about data security and products customization emerge as highlights in the technological context. The results show that organizations are seeking to implement I4.0 technologies, presenting an intermediate maturity value, with both positive and negative points highlighted.

A comparison was also made between the Mining, Electrical, IT, Steel and Metallurgy sectors. The Steel and Mining sectors were found to have the highest overall values, with the IT and Metallurgy sectors having the lowest values. The "Strategy, Culture and Organizational Innovation" dimension stands out in the Mining and Steel sectors, with an "Experienced" maturity level. The "Work Team" dimension stands out in the IT sector and the "Technology" dimension stands out in the Steel sector. The lowest value is in the "Technology" dimension in the Metallurgy sector, well below the other values and showing little adherence to I4.0 digital technologies.

These results can be explained by the large share and importance of the Mining and Steel sectors in the state of Espírito Santo, with large multinational companies investing heavily in I4.0 digital technologies.

The IT sector was expected to achieve more significant results due to the growth in recent years of startups and companies focused on the pillars of I4.0, but this has not happened. Despite demonstrating greater employee capacity, knowledge and skills, there is still little expression in terms of maturity.

A limitation of the study is the subjectivity inherent in the use of questionnaires. In addition, the relationships between the elements presented in the maturity model were not studied further. As future suggestion, it is possible to identify the relationships between these elements, seeking to understand how each item can influence the general maturity context, as well as carrying out a study with experts to corroborate the elements found. Beyond, as future work, we propose a study to use the Data Envelopment Analysis for efficiency checks and comparisons between groups in various domains.

Another suggestion involves applying this model to a larger number of companies, involving players from various industries across the country, in order to better understand where the process of innovation and continuous improvement is at in organizations when it comes to implementing Industry 4.0 technologies.

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Autores

Raianny Souza Fernandes
Received the graduate degree in Production Engineering from the Federal Institute of Espírito Santo, Campus Cariacica, ES. Master's student in Sustainable Technologies at the Federal Institute of Espírito Santo, Vitória Campus, ES. Expertise in the following areas: Industry 4.0, maturity models, digital technologies, physical layout, continuous improvement, lean manufacturing.

Mário Mestria
Received the Doctor degree in Computer Science from the Fluminense Federal University. He is currently a Titular Professor at the Federal Institute of Education, Science and Technology of Espírito Santo, Campus Vitória, ES. He is permanent member of the Master in Sustainable Technologies, Campus Vitória. He has experience in the areas of Computer Science, Electrical Engineering, and Production Engineering with emphasis on Combinatorial Optimization, Computational Intelligence, and Operational Research. He works mainly on the following topics: metaheuristics, hybrid methods, location problems, clustered travelling salesman problem, industry 4.0, layout of manufacturing, set covering problem, algorithms, smart grids, and virtual reality.

Artigo recebido em: 26/01/2024 e aceito para publicação em: 24/05/2024
DOI: https://doi.org/10.14488/1676-1901.v24i2.5151

Annex 1 - Questionnaire

Industry 4.0 Maturity Survey

You are being invited to take part in the research "Assessing the maturity of Industry 4.0 in companies in Espírito Santo" under the responsibility of Prof. Dr. Mário Mestria and master's student Raianny Souza Fernandes. This invitation is due to the fact that you are part of a company that uses Industry 4.0 technologies and can contribute to improving understanding of the maturity of companies in adopting these technologies. It is important to note that the respondent's personal answers will be protected and kept confidential.

E-mail:

Name:

Position:

Company:

STRATEGY, CULTURE AND INNOVATION

1) Does the company have a strategy/plan for implementing Industry 4.0 technologies?

a) Yes

b) Yes, partially

c) No

2. Industry 4.0 is part of the company's business strategy.

a) Yes

b) Yes, partially

c) No

3. The company invests in Industry 4.0 technologies.

a) Yes

b) Yes, partially

c) No

4. The company promotes innovation in its strategy for generating value.

a) Yes

b) Yes, partially

c) No

5. The company has KPIs for monitoring Industry 4.0 technologies in its production processes.

a) Yes

b) Yes, partially

c) No

WORK TEAM

6. The work team has received training for the changes generated by Industry 4.0 in your company.

a) Yes

b) Yes, partially

c) No

7. The work team has the knowledge and skills to implement Industry 4.0 technologies.

a) Yes

b) Yes, partially

c) No

8. The work team has the autonomy and creativity to work with Industry 4.0.

a) Yes

b) Yes, partially

c) No

9. The work team is open to suggesting changes in the production process to stimulate innovation.

a) Yes

b) Yes, partially

c) No

TECHNOLOGY

10. Does the company have the infrastructure to implement Industry 4.0 enabling technologies?

( ) Equipment

( ) Machinery

( ) Physical resources

( ) Digital resources

11. The company uses data to make changes in real time.

a) Yes

b) Yes, partially

c) No

12. The company focuses on the security of the data obtained in its production process.

a) Yes

b) Yes, partially

c) No

13) The company customizes its products according to customer needs.

a) Yes

b) Yes, partially

c) No

14. The company implements technologies:

( ) Big Data

( ) Additive Manufacturing

( ) Augmented Reality

( ) Virtual Reality

( ) Digital Twin

( ) Autonomous Robots

( ) Cloud Computing

( ) Artificial Intelligence

( ) Internet of Things

( ) Cyber-Physical Systems

( ) Simulation

( ) Decision Support Systems

( ) Sensors and Actuators

( ) Systems Integration