CONSTRUCTION OF ROADMAPS APPLICABLE TO INDUSTRY 4.0: CASE OF THE BRAZILIAN AND AMERICAN COMPANIES

CONSTRUÇÃO DE ROADMAPS APLICÁVEIS À INDÚSTRIA 4.0: CASO DAS EMPRESAS BRASILEIRAS E AMERICANAS

CONSTRUCCIÓN DE HOJAS DE RUTA APLICABLES A LA INDUSTRIA 4.0: EL CASO DE EMPRESAS BRASILEÑAS Y AMERICANAS

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ABSTRACT

Purpose: This article provides a critical analysis of the adoption of roadmaps applicable to Industry 4.0 of companies have been seeking to modernize their production by new technologies and transforming digital model.

Methodology/approach: This article is a case study of two multinational companies, Company 1, managed by Brazilian entrepreneurs, and Company 2 by Americans. Based on the guidance of external consultants, both of them have formulated and built roadmaps for one of their production lines for the transformation process towards Industry 4.0.

Originality/Relevance: Two reports were generated, one referring to each company, documents that were the basis for this research, and discussing the importance of roadmaps in the digital transformation process.

Key findings: The inferences found in the results and discussion demonstrate the possibilities of the tool in the practical operations of companies, demonstrates how the tool can facilitate digitizing production since it is possible to visualize the relationship between the technological layer of the company with the maturity.

Theoretical/methodological contributions: The roadmap helps align the resources and processes of the organization with its market goals, besides allowing the temporal measurement of actions taking into account the level of technological maturity for the digitization process, it is possible to identify in practice the applicability of roadmaps in the transition to industry 4.0 in a production line.

Keywords: Roadmap. Industry 4.0. Case study. Digital transformation. Maturity. Strategic planning.

RESUMO

Objetivo: Este artigo apresenta uma análise crítica da adoção de roadmaps aplicáveis à Indústria 4.0 por parte das empresas que têm vindo a procurar modernizar a sua produção através de novas tecnologias e da transformação do modelo digital.

Metodologia/abordagem: Este artigo é um estudo de caso de duas empresas, a Empresa 1, gerida por empresários brasileiros, e a Empresa 2 por americanos. Com base na orientação de consultores externos, ambas formularam e construíram roadmaps para uma de suas linhas de produção para o processo de transformação rumo à Indústria 4.0.

Originalidade/Relevância: Foram gerados dois relatórios, um referente a cada empresa, documentos que serviram de base para esta pesquisa, e discutindo a importância dos roadmaps no processo de transformação digital.

Principais conclusões: As inferências encontradas nos resultados e discussão demonstram as possibilidades da ferramenta nas operações práticas das empresas, demonstra como a ferramenta pode facilitar a digitalização da produção já que é possível visualizar a relação entre a camada tecnológica da empresa com a maturidade.

Contribuições teóricas/metodológicas: O roadmap auxilia no alinhamento dos recursos e processos da organização com seus objetivos de mercado, além de permitir a mensuração temporal das ações levando em consideração o nível de maturidade tecnológica para o processo de digitalização, é possível identificar na prática a aplicabilidade dos roadmaps na transição para a indústria 4.0 em uma linha de produção.

Palavras-chave: Roadmap. Indústria 4.0. Estudo de caso. Transformação digital. Maturidade. Planejamento estratégico.

RESUMEN

Propósito: Este artículo ofrece un análisis crítico de la adopción de hojas de ruta aplicables a la Industria 4.0 de las empresas que han estado tratando de modernizar su producción mediante las nuevas tecnologías y la transformación del modelo digital.

Metodología/enfoque: Este artículo es un estudio de caso de dos empresas multinacionales, la Empresa 1, gestionada por empresarios brasileños, y la Empresa 2 por estadounidenses. Basándose en la orientación de consultores externos, ambas han formulado y construido hojas de ruta para una de sus líneas de producción para el proceso de transformación hacia la Industria 4.0.

Originalidad/Relevancia: Se generaron dos informes, uno referido a cada empresa, documentos que sirvieron de base para esta investigación, y en los que se discute la importancia de las hojas de ruta en el proceso de transformación digital.

Principales conclusiones: Las inferencias encontradas en los resultados y discusión demuestran las posibilidades de la herramienta en las operaciones prácticas de las empresas, demuestra como la herramienta puede facilitar la digitalización de la producción ya que es posible visualizar la relación entre la capa tecnológica de la empresa con la madurez.

Aportes teóricos/metodológicos: La hoja de ruta ayuda a alinear los recursos y procesos de la organización con sus objetivos de mercado, además de permitir la medición temporal de las acciones teniendo en cuenta el nivel de madurez tecnológica para el proceso de digitalización, es posible identificar en la práctica la aplicabilidad de las hojas de ruta en la transición a la industria 4.0 en una línea de producción.

Palabras clave: Hoja de ruta. Industria 4.0. Caso práctico. Transformación digital. Madurez. Planificación estratégica.

1 INTRODUÇÃO

The advent of Industry 4.0 (I40) enabled by artificial intelligence, cloud computing, and the internet of things has brought about profound changes in business operations (Burke et al., 2017; Gontijo & Alves, 2019; Morais & Monteiro, 2019; Santos et al., 2019). Traditional production models are being transformed into a digital network modeling that some authors have called the Fourth Industrial Revolution (Schwab, 2016; Burke et al., 2017; Madsen, 2019; Kumar & Nayyar, 2020; Pessôa & Becker, 2020). The European Commission (2017) declared

I40 to be the digitalization process and interconnectivity of the supply chain with business models, products, and services.

The 4.0 concept has penetrated many sectors of society through the digitalization of operations, i.e., transport to the digital world analog operations of companies and people's activities (Schwab 2016; Mazali, 2018; Santos et al. 2019). Another type of transformation is digitization. It is nothing more than popularizing various technological devices (Legner et al., 2017; Queiroz et al., 2019; Santos et al., 2019). For such a digitalization phenomenon, it is not enough to absorb the new digitalizing technologies. It is necessary to develop business models that bring profitability to operations (Madsen, 2019). In this context, the use of the roadmap tool is opportune as the roadmap of activities that guides management in mapping the competencies of companies and offers support in the conduction and management of production processes (Ghobakhloo, 2018; Sarvari et al., 2018; Kumar & Nayyar, 2020).

To facilitate this digital transformation and at the same time help Brazilian companies on the path of innovation, an institution linked to the confederation of industries in Brazil has developed a series of initiatives aimed at adapting the national industrial network to the reality of Industry 4.0. Consultants from this educational institution offered expertise and knowledge to the industries, training people and providing a range of management tools that could attract satisfactory results for companies. In this context, the roadmap methodology is used to identify and develop skills for the collaborative construction of the Digital Transformation Strategy of production lines.

Therefore, through the experience of this work where it involved the relationship between external consultants and the teams of collaborators of the companies, this paper seeks to answer the following question: how roadmaps can help the management in the transition from a non-digitalized production line to the digitized dimension of Industry 4.0? For this purpose, the present authors developed a bibliographic review of roadmaps and Industry 4.0 themes. In a second moment, an analysis of the reports of the consultancy undertaken in two multinational companies was performed.

2. REFERENCIAL TEÓRICO

The aim was to identify the main concepts and characteristics of Industry 4.0 to understand how the roadmap tool can apply to the digital transformation of a production line. There was also an approach to the maturity of the processes to substantiate the case study analysis.

2.1 Industry 4.0

After the English Industrial Revolution, motivated by the steam machine, industrial productions gained scale in their internal processes inaugurating the First Industrial Revolution (Nuvolari, 2004; Peinado & Graeml, 2007; Schwab, 2016; Santos et al. 2019; Kumar and Nayyar, 2020). This scalability combined with the production of interchangeable parts and electrical energy made possible the second Industrial Revolution, now on American soil (Mokyr & Strotz; 2003; Peinado & Graeml, 2007; Schwab 2016; Mazali, 2018; Santos et al. 2019; Kumar and Nayyar, 2020). With the model of mechanized mass production in electrical systems, a third industrial revolution was triggered by the process of automation of factory yards (Peinado & Graeml, 2007; Pfohl et al., 2015; Schwab 2016; Mazali, 2018; Santos et al. 2019; Kumar & Nayyar, 2020).

However, the technologies characterized as Industry 4.0 phenomenon have broken with the traditional forms and models of companies' production (Schwab 2016; Mazali, 2018; Santos et al., 2019; Kumar & Nayyar, 2020). A milestone for this transformation is the Hanover trade fair in Germany in 2011, when the idea of integrating technologies, simulators, and digital modeling was announced as fundamentally elements of Industry 4.0 (Oesterreich & Teuteberg, 2016; Madsen, 2019; Kumar & Nayyar, 2020; Pessôa & Becker, 2020; Oztemel & Gursev, 2020). Thus, the emergence of Industry 4.0 brings elements of operational transformation to the production environment from a linear or serial model to a global and networked integration dimension (Kusiak, 2018; Morais & Monteiro, 2019; Santos et al., 2019).

Schwab (2016) classified the Fourth Industrial Revolution as a new production model based on digitalization processes. The digitization that converts analog systems into digital platforms can gain another approach. If we think about digitization, adopting digitizing technologies by organizations (Legner et al., 2017; Queiroz et al., 2019). Thoben et al. (2016) observe that the term Industry 4.0 receives the American equivalence of Smart Manufacturing (Intelligent Factory) or Chinese Smart Factory. However, both describe the same phenomenon: the technological integration within the industry, the transformation of the human-machine relationship, and the sensorization of products that allows their traceability (Schluse et al., 2018; Masood & Egger, 2019; Kumar & Nayyar, 2020; Pessôa & Becker, 2020; Oztemel & Gursev, 2020).

The fourth industrial revolution (I40) is then about a transformation in the way data are used, no longer understood as the results of a process, but treats them as process resources

(Pfohl et al., 2015; Kusiak, 2018; Santos et al., 2019). The phenomenon of industry 4.0 encompasses design principles such as interoperability, virtualization, modularity, decentralization, among others (Hermann et al., 2015; Ruppert et al., 2018; Ghobakhloo, 2018; Habib & Chimson, 2019; Kumar & Nayyar, 2020). Technologies such as cloud computing, M2M (machine-to-machine) communication, autonomation, and other intelligent devices that generate segmented data from processes and organizations, are now resources that feed firms' decision-making in the pursuit of competitive advantage.

Industry 4.0 involves the vertical and horizontal integration of internal production and connecting to the market by improving decision-making processes (Feng et al., 2017; Kusiak, 2018; Kroll et al., 2018; Bordeleau et al., 2019; Kumar & Nayyar, 2020). In this context, some authors theorize about some neologisms of the 4.0 phenomenon as Construction 4.0 (Cavalcanti et al., 2018; Simão et al., 2019; Silva Júnior et al., 2020), operator 4.0 (Ruppert et al., 2019) society 4.0 (Mazali, 2018) and others more listed by Madsen (2019). Not by chance, the diffusion of significant dates, intelligent collaboration networks, and other cybernetic systems, as in figure 1, has been studied initially in the field of computer science; but now it is gaining space in manufacturing technology and research on managerial models.

The Intelligent Manufacturing or Industry 4.0 redirects the management so far focused on the production process only, to the category of data analysis and their use along the supply chain. Many industries struggled to build their manufacturing plants in low-cost labor and naturally low-skilled labor. Now, however, the automation associated with digitization frees companies for autonomous production

Ghobakhloo (2018) recalls that this digital transformation requires technological adaptation and a transition of organization models and strategies to change management practices. Thus, the digital transformation towards industry 4.0 is first of all the change from an essentially mechanized or even automated industry model to a company model centered on the optimized use of data (Pfohl et al., 2015 Schwab, 2016; Robles et al., 2016; Kusiak, 2018; Ghobakhloo, 2018; Madsen, 2019; Ruppert et al., 2019; Santos et al., 2019; Kumar & Nayyar, 2020; Pessôa & Becker, 2020; Oztemel & Gursev, 2020). In technical reports from consulting firms such as Deloitte (2015) or even governmental organizations such as WEF (2017) and the European Commission (2017), policies were proposed to foster the digitization of industrial parks. They prove that the use of the roadmap tool becomes indispensable (Ghobakhloo, 2018; Prinsloo et al., 2019; Colli et al., 2019; Caiado et al., 2020).

2.2 Roadmap and Industry 4.0

Initially developed by Motorola in the 1970s, the Roadmap - or Technology Roadmaps (TRM) - is linked to the idea of planning for the future by pooling resources and establishing a roadmap adaptable to the challenges facing the firm (Phaal et al., 2004; Lee et al., 2013; Phaal, 2015 Sarvari et al., 2018, Oliveira et al., 2019). The tool provides management support for the organization's strategic and innovation planning by identifying, selecting, and reconfiguring the company's technology resource base (Sarvari et al., 2018; Oliveira et al., 2019; Vinayavekhin & Phaal, 2020). Roadmaps can also be integrated with other management methodologies such as the PDCA cycle (Barbosa et al., 2020), Six Sigma (Flor Vallejo et al., 2020; Trakulsunti et al., 2020). Sarvari et al. (2018) also highlight that the roadmap tool allows understanding each movement and decision-making in time and the company's needs.

In Industry 4.0, roadmaps have a close relationship with the degree of technological maturity of the organization (Schumacher et al., 2016; Ghobakhloo, 2018; Colli et al., 2019; Caiado et al., 2020). Ghobakhloo (2018) reiterates that roadmaps concerning the maturity of processes and the use of technologies can offer a holistic view of the steps to be adopted by managers in the digital transformation towards industry 4.0. In this maturity scale of Industry 4.0 level, 0 could be described as when data in the organization is registered on paper. As technological resources are integrated into the processes, the organization goes from 0 to level 06, wherein an autonomous and digital way the technologies operate procedures (Kumar & Nayyar, 2020; Colli et al., 2019).

The roadmap includes two dimensions: a spatial one divided into three categories (market, product, and technology). Respectively this part aims to respond to the know-how, know-how, and know-how of the organization (Phaal, 2015; Vinayavekhin & Phaal, 2020). Another dimension is the time frame that comprises the chronological time in the course of production operations. The company's specific objectives and goals need to be achieved that, in general, lines involve the Know-when (Phaal, 2015; Sarvari et al., 2018, Vinayavekhin & Phaal, 2020).

In a second moment, the technological bases of the company can be associated with the strategic actions of the organization to achieve the corporate goals through the adjustment of competencies and resources. The roadmap can be structured in a visual diagram (Phaal et al., 2004; Lee et al., 2013; Phaal, 2015). Fig.1 demonstrates the generic structure of the roadmap model divided into its three parts: market (why), product (what), and technology (how), both being horizontally time-oriented (when).

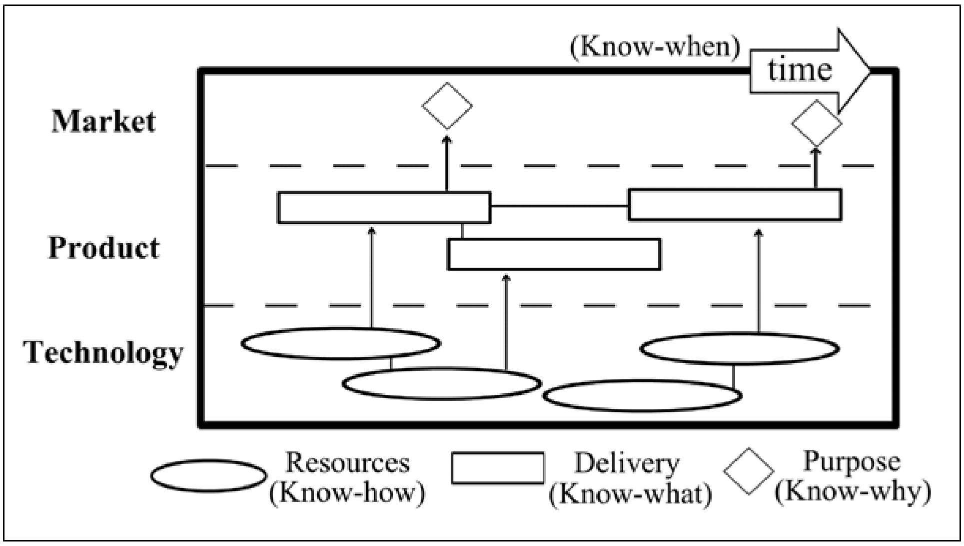

Figure 1. Generic Roadmap Model
Source: Adapted from Phaal et al. (2004).

Phaal (2015) offers two sets of questions that the company needs to ask internally. The first concerns "where do we [as a company] want to go?", "where are we?" and "how can we get there? The second group of questions should ask, "Why do we need to act?", "What can we do?" and "How could I do that? When?". The roadmap shows a close relationship between the "Technology" layer over the top layers in executing business strategies. Where "Market" is regarded as the external area of the organization, that is, the space of perception of customers or users, and also of competitors and society in general, where the company needs to gain a competitive advantage to obtain better results (Phaal, 2015; Sarvari et al., 2018; Vinayavekhin & Phaal, 2020).

The "Product" layer is where the company's internal processes take place, linking operations to operations, forming an internal network of tasks along which performance indicators can be monitored (Lee et al., 2013; Phaal, 2015; Schumacher et al., 2016; Vinayavekhin & Phaal, 2020; Caiado et al., 2020). The "Technology" layer supports the other upper areas of the diagram by providing data and information that facilitate decision making (Barbosa et al., 2020; Flor Vallejo et al., 2020; Trakulsunti et al., 2020; Vinayavekhin & Phaal, 2020). In the "Technology" layer, it is inclusive that Industry 4.0 is advancing with the phenomenon of digitalization through Artificial Intelligence in data analysis (Ghobakhloo, 2018). In this dimension, the degree of technological maturity of the organization can change as more and more digitalizing technologies are adopted (Colli et al., 2019; Caiado et al., 2020).

2.3 Roadmaps and industry maturity models 4.0

In general, strategic planning aims to achieve goals and the prospection of possible scenarios for decision-making aimed at the best performance in the search for competitive advantage (Mintzberg, 1987; Porter, 2008; Sardi et al., 2019). In this context, a roadmap is a tool that allows the visualization of the triggering of activities relating the company's resource bases with organizational competencies in the context of market dynamics. Schumacher et al. (2016) highlighted that in the transition from an organization in a traditional production model to industry 4.0, an evaluation model capable of categorizing the company's activities at maturity levels is required. This evaluation should measure, calculate and classify each process in at least five maturity levels (Lee et al., 2013; Colli et al., 2019; Kumar & Nayyar, 2020).

Sardi et al. (2019) link the high maturity of an organizational process to the volume of data provision in real-time so that self-monitoring of activities and the use of performance indicators are allowed. Thus, using a technological maturity diagnostic model becomes a fundamental element for the digital transformation process (Tutida, Rossetto, Santos & Mazon, 2022). Although several models, Schumacher et al. (2016) discussed a maturity model that would allow scientifically measuring the level of solid data acquisition of companies while making measurements in terms of the company's potential in the transition to industry 4.0. Table 1 presents some of these authors who theorize on the maturity measurement model in the context of industry 4.0.

Table 1. Technological maturity models applied to Industry 4.0

Authors	Proposed levels for measuring maturity
Caiado et al. (2020)	0- nonexistent; 1- conceptual; 2-managed; 3-advanced; 4-self-optimized
Kumar and Nayyar (2020) analyzed at least three maturity models in the context of Industry 4.0	* In terms of Readiness (Moura and Hohl, 2020): 0-outsider; 1-beginner; 2-intermediate; 3-experienced; 4-expert; 5-top performer * In terms of digitization plan: 1st Stage: Digital novice; 2nd Stage: vertical integrator; 3rd Stage: horizontal collaborator; 4th Stage: digital champion. * In terms of connectivity: 1st Stage: evaluation/assessment; 2nd Stage: Upgraded and secure controls and network; 3rd Stage: organized and defined working information capital; 4th Stage: analytics; 5th Stage: Collaboration
Santos and Martinho (2019)	* Level 0: low or no degree of technological implementation; Level 1: pilot actions being planned or being developed for use of technologies; * * Level 2: implementation of actions initiated, with some benefits being observed; Level 3: partial implementation of actions, that enhance the competitiveness of the company; Level 4: advanced implementation of actions, with clear economic returns; Level 5: reference in applying the concepts and implementing the technologies of Industry 4.0.

Colli et al. (2019)	None; Basic; Transparent; Aware; Autonomous; Integrated
Asdecker and Felch (2018)	1st Basic digitization (non-digitalized process); 2nd Cross-department digitization (information exchange between departments through a system); 3rd horizontal and vertical digitization (digitized processes); 4th Full digitization (fully digitized company); 5th Optimized full digitization (digital collaboration involving internal corporate elements, suppliers and customers)
Sjödin et al. (2018)	Level 1. Connected Technologies; Level 2. Structured data gathering and sharing; Level 3. Real-time process analytics and optimization; Level 4. Smart and predictable manufacturing;
Schuh et al. (2017)	1st: Computerization; 2nd: Connectivity; 3rd: Visibility; 4th: Transparency; 5th:Predictive capacity; 6th:Adaptability
Ganzarain and Errasti (2016)	Initial; Managed; Defined; Transform; Detailed BM

Source: Elaborated by the authors.

In general, the authors promote a model of technological maturity divided into five levels. A sixth is called 0, where the organization has its operations recorded on paper not yet enabled for digital transformation. A certain basic level of technological readiness is required for an organization to move towards a productive digital platform so that the management can carry out the rearrangements pointed out by roadmaps (Ghobakhloo, 2018; Colli et al., 2019; Santos & Martinho, 2019; Kumar & Nayyar, 2020; Moura & Hohl, 2020; Caiado et al., 2020). The production lines need to be computerized or in an essential degree of digitalization (Schuh et al., 2017; Ganzer, Biegelmeyer, Oliveira, Camargo, & Olea, 2017; Asdecker & Felch, 2018; Kumar & Nayyar, 2020). Therefore, it is expected that the maturity measurement model will have a certain practical level in organizations. Managers are clear about the state of the technologies and procedures that enable the company to adapt to digitization.

Finally, space "Technology" is reserved for the representation of technological resources that feed all the upper areas of the table, providing data and information that facilitate decision-making. In this last layer, Industry 4.0 is advancing with the digitalization phenomenon that has enabled the applicability of Artificial Intelligence in data analysis and, consequently, valuable support in the construction of strategic planning, as demonstrated by Ghobakhloo (2018).

2.3.1 Use of Roadmap in the transition to Industry 4.0

In general, strategic planning aims at success by setting goals and prospecting scenarios for decision-making focused on better performance and the search for competitive advantage, as demonstrated by Mintzberg (1987), Porter (2008), and Sardi, Garengo, and Bititci (2019). In this context, a Roadmap is a tool that allows the triggering of activities linked to each other. Schumacher et al. (2016) pointed out that an evaluative model is required to categorize the company's activities into maturity levels in the transition from an organization to industry 4.0. Roadmaps can supply this need since the tool categorizes each technological and process element in their respective maturity levels.

This evaluation should measure, calculate and classify each process in one of the five levels of maturity - as Lee, Phaal, and Lee (2013) pondered. Sardi, Garengo, and Bititci (2019) link the high maturity of a process intending to provide real-time data, allow self-monitoring of activities, and use performance indicators. Schumacher, Erol, and Sihn (2016) discussed a maturity model that would scientifically allow the acquisition of reliable data from companies to measure the company's potential in the transition to industry 4.0. A process maturity model is also crucial for the practical level of organizations so that managers are clear about the actual state of the technologies and procedures that enable the company to adapt to digitization.

3. METHODOLOGY

The study is based on the results of two consulting firms in the digital transition process in their production lines. This digital transition had referenced the use of the roadmap tool that the consultants adapted to the realities of the respective companies. Moreover, through the consultancy and qualitative bibliographic research results, the data were discussed and inferred relevant applications for management in the context of industry 4.0.

The consultancy took place in four moments. In the first, there were alignment meetings, technical visits, and leveling workshops. The consultants were advisors to the teams of each company previously selected by management - the meetings took place internally, each team in its respective company. In the second stage of the consultancy, the consultants guided the teams in evaluating the level of digital transition maturity of each stage of the productive processes. The score demonstrated in table 2 - Levels 1, 2, and 3 are digitalized processes. While at levels 4 and 5, the operations and production lines are qualified for Industry 4.0.

Table 2. Score of the maturity ramp

Scoring	Positioning in the Maturity Ramp	
Up to 1.9 points	Level 1: Optimization	**Digitalization**
From 2.0 to 2.9 points	Level 2: Sensorization and Connectivity	
From 3.0 to 3.9 points	Level 3: Visibility and Transparency	

From 4.0 to 4.9 points	Level 4: Predictive Connectivity	**Industry 4.0**
Above 5 points	Level 5: Flexibility and Adaptability	

Source: Lopes (2019).

It is essential to highlight that this determination of the level of maturity happened by the brainstorming technique considering the vision of technicians and managers familiar with the production line and the scrutiny of the consultants regarding the values given by the team. These questions from the consultants were essential to ensure the solidity of the maturity level of the processes.

The use of the roadmap tool during the consultancy took place in four stages. In the first, there were alignment meetings, technical visits, and leveling workshops. The consultants were advisors of the teams of each company - the meetings took place internally each team in their respective company. In the second stage, the consultants guided the teams regarding assessing the digital transition maturity level of each stage of the production processes under study. In the third stage, he certified that the maturity indices of the respective companies were adequate to the reality established by the team.

Table 3 shows the ramp of the maturity index used as a reference for the classification of processes and operations of Companies 1 and 2. It is essential to highlight that this determination of the level of maturity happened by the brainstorming technique considering the technicians' view and managers familiar with the production line and went to the consultants' scrutiny regarding the values given by the team. These questions from the consultants were essential to ensure a solid level of process maturity.

Finally, in the fourth stage, the company's digital transformation strategy was built collaboratively, taking into account management goals and objectives. In this stage, the roadmap tool provided a strategic vision in a timeline for decision-making regarding the maturation of processes, technologies, and procedures.

Because of the above and using the authors Creswell (2007) and Yin (2014) as a reference, the present study can be classified as exploratory, given the investigative nature of using the roadmap tool in the transition to industry 4.0 of the two companies in question. Exploratory research allows the study of the topic from various angles, obtaining qualitative and quantitative data that enable understanding the phenomenon in focus highlight Lakatos and Marconi (2003) and Prodanov (2013).

The characteristics of the two target corporations can be compared in Table 3, both companies are in the Federal State of Santa Catarina, in the southern region of Brazil.

Table 3. General description of the participating companies

Description	Company 1	Company 2
Founded in	1961	1960
Type of Company	Brazilian Multinational	American Multinational
Market	Small appliances / appliances / Bicycles / Construction	Automotive: Pulleys / Bearings / Planetary / Tensioners / Impellers
Important Notes	The company has more than 36,000 points of sale in South America and 1,400 technical assistance points in Brazil. Their products can be found in department stores and supermarkets.	53% of what it produces is exported, the company is very sensitive to car production and has 15 global customers in the USA, China, India and Germany.
Productive Structure	It has 150 thousand meters of factory distributed in several productive lines with diversified characteristics among them with specific professionals and dedicated machines.	40,000 meters factory frames, cold forming presses, 250 CNC machines, plastic injection machines and assembly lines.
Row selected for the Case Study	Gourmet Ovens	Pulleys
Research focus team	Professionals from various departments	Professionals from various departments

Source: Prepared by the authors

In this case, data from secondary sources are used since the information offered by the employees of each company was primarily treated by the consultants and later ordered in reports. However, it is a relevant document in the study of the applicability of the roadmap tool. Although the consultants obtained the primary data, the work of this article stands out for the interpretation, evaluation, and applicability of the case studies in the process of transition and digital transformation of the industries.

In the third stage, we tried to certify that the maturity indexes of the respective companies were adequate to the reality established by the team through the questions that the consultants asked the teams did not touch the consistency of the note. Finally, in the fourth stage, the digital transformation strategy of the production line was built in a collaborative way between the teams and the consultants, taking into account the goals and objectives of the management. In this stage, the roadmap tool was used to provide strategic support and planning of management actions considering the maturity of processes, procedures, and technologies.

4. RESEARCH RESULTS

Initially, it was determined the degree of general maturity of each company and its Strategy and Organization, business models, products, and services, and, finally, the level of maturity of the manufacturing and supply chain, Figure 2.

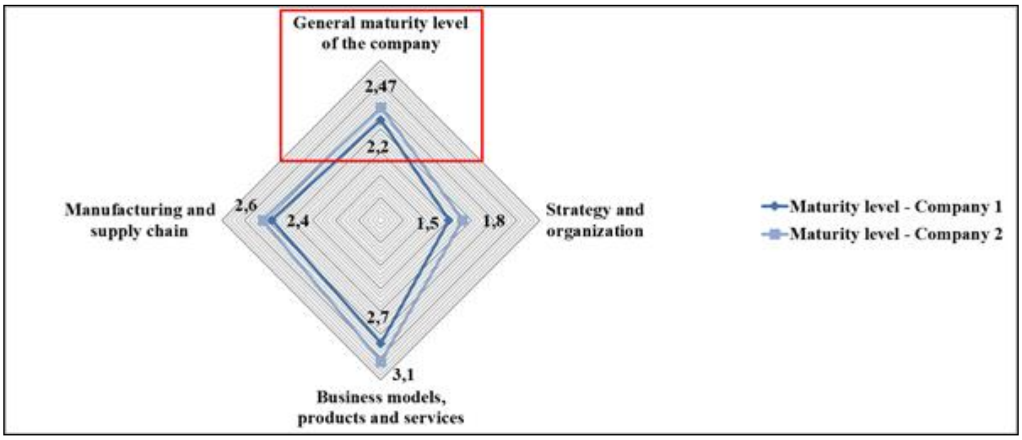

Figure 2. General and segmented maturity of the companies
Source: Prepared by the authors

Figure 2 shows that Company 2 has a higher degree of maturity in Industry 4.0 than Company 1. It may be related to the high level of exposure to global competition that Company 2 has compared to Company 1. However, in percentage terms, the two companies do not distance themselves significantly. However, Company 2's business models are more mature, possibly driven by the demands of the automotive market. Fig. 6 shows a list of enabling technologies applicable to the production lines of the respective companies' case study noting their existence and degree of utilization.

However, in percentage terms, the two companies do not differ significantly. Nonetheless, it is observed that the business models of Company 2 are more mature, possibly driven by the demands of the automotive market. Table 4 reveals a list of Enabling Technologies applicable to the production lines of the case study of the respective companies, observing their existence and degree of use.

Table 4. List of enabling technologies for companies

Technologies Enabling		
Description	Level of use	
	Company 1	Company 2
Sensors / actuators	Low	High
Internet of Things (IoT)	Nonexistent	Low
Computer systems	Medium	High
Mobile Applications	Nonexistent	Nonexistent
Big Data Analytics	Nonexistent	Nonexistent
Cloud computing for data storage	Nonexistent	Low
Communication between M2M machines	Low	Nonexistent

Autonomous Robots	---	Nonexistent
Collaborative Robots	Nonexistent	Nonexistent
Additive Manufacturing / 3D Printing	Nonexistent	Does not apply
Simulation of manufacturing processes	Nonexistent	Nonexistent
Layout simulation	Nonexistent	Nonexistent
Real-time layout simulation	Nonexistent	Nonexistent

Source: Prepared by the authors.

Table 4 offers a group of technologies that can add value to the production line of both firms. However, due to financial, engineering, or even lack of opportunity factors, they are still underused and disconnected from each other, as shown in Table 5. Most of the data is entered manually, being sensitive to the subjectivity of employees and therefore exposed to inconsistencies in the results.

Table 5. Circulation of data within production plants

Type of data and forms of collection		
Description	**Status**	
	Company 1	**Company 2**
Stock storage data	Yes, manually	Yes, manually
Cycle time of processes	Yes, manually	Yes, manually
Equipment occupancy rate	No	Yes, manually
Loss volume	Yes, manually	Yes, manually
% of errors	Yes, manually	Yes, manually
Occupancy rate of human resources	No	Yes, manually
Setup time	No	Yes, manually
OEE	No	Yes, manually
Machine maintenance data (eg.: temperature, vibration etc.)	No	Yes, manually

Source: The authors

Table 5 reveals the absence of automatic data circulation, fundamental aspects for the plant’s competitiveness, such as percentage of errors, setup time, *Overall Equipment Effectiveness* (OEE), and machine maintenance data, when accounted for, which demonstrates the low connectivity of the productive plants. This perception is confirmed in Table 6 when one sees the non-use of the Machine Data Acquisition (MDC) and the Manufacturing Execution Management System (MES).

Table 6. List of systems and their respective usage levels within companies

Conditions of use of the system and its condition of integration with the exchange		
Description	**Level of use**	
	Company 1	**Company 2**
CAD - Computer-Aided Design	Not used	It is used without interface with the central system
MDC - Machine Data Acquisition	Not used	Not used
PDA - Acquisition of Manufacturing Data	Not used	It is used, with interface with the central system
PPS - Production Planning System	It is used, with interface with the central system	It is used, with interface with the central system

PDM - Product Data Management	Not used	It is used without interface with the central system
SCM - Supply Chain Management	It is used without interface with the central system	It is used, with interface with the central system
ERP - Enterprise Resource Management	It is used, with interface with the central system	It is used, with interface with the central system
PLM - Product Lifecycle Management	Not used	It is used without interface with the central system
MES - Management System for the Execution of Manufacturing Processes	Not used	Not used

Source: Prepared by the authors.

The conditions of use of the systems, shown in table 5, corroborates the perception of a productive park still disconnected and of fragmented processes. Although Company 2 has a relevant use of systems, the absence of an interface with the central system in Product Data Management (PDM) weakens the consolidation of the digitizing phenomenon of Industry 4.0. This weakness is confirmed by the degree of maturity in using internal and external data during the modeling of businesses, products, and services.

According to Table 6, companies are in the same degree of data interconnectivity in designing businesses, products, and services. That is to say, many of the business and industrial actions still follow the “feeling” and subjectivity of professionals, devoid of the analytical support of artificial intelligence.

Table 7. Overview of the maturity level of companies' business models

Model of Business, product and service		
Description	**Company 1**	**Company 2**
Collaboration with partners	1	4
Collaboration with suppliers	2	4
Collaboration with customers	2	4
Multiplicity of sales channels	5	2
Information collection and interactions across multiple channels with customers	3	3
Use of internal data to define the business model for products and services	3	2
Use of external data to define the business model for products and services	3	3

Source: Prepared by the authors.

Table 7 offers a summary diagnosis of the internal processes and external demands of each company. In other words, Company 1 stands out for its high degree of sales channels and limited partnerships with its customers, suppliers, and business partners. At the same time, Company 2 presents a significant partnership with its stakeholders, although with a limited multiplicity of sales channels. Curiously, both have similar levels of data treatment, indicating that in operational terms and discounting the specificities of each company’s type of business, the jump from maturity 3 to maturity 4 in data treatment is a relevant challenge for both businesses.

Each company has prepared a list of strategic actions to put the production lines in a condition to be digitized, raising the level of maturity in the space of time. Fig.9 and 10 relate the necessary organizational actions with their due deadlines and degrees of urgency to achieve previously established strategic goals when selecting the production line for digital transformation. Each activity presents a level of maturity by the respective teams of the company's employees.

Therefore, the sequences of activities and execution deadlines were established based on subjective criteria described in the methodology section. They were considering the level of severity, urgency, and trend of the tasks, the GUT matrix, and reinforcement by the collaborators' perception of the maturity of that determined action or activity.

The team of each company prepared a list of strategic actions to place the production lines in a condition to be digitalized, raising the level of maturity in a period. Tables 8 and 9 list the necessary organizational actions with their due deadlines and degrees of urgency to achieve the strategic goals previously established when the production line for digital transformation is selected. Each activity has a maturity level measured by the respective teams of employees of the companies.

Table 8. List of strategic actions for the digital transformation of Company 1

Strategic Objectives: Company 1 Gourmet Oven Segment		**Develop new products**						
		New business models for products						
#	**DESCRIPTION ACTION**	Level Maturity	G	U	T	GUT	Sequence	Deadline
1	Perform strategic planning of the Company 1	1	5	5	5	125	1	A
2	Develop Lean Culture	1	5	5	4	100	2	
3	Develop and evaluate suppliers	1	4	5	4	80	3	
4	Develop Embedded Systems team	3	4	4	4	64	4	
5	Define stock and trade policy	1	4	3	5	60	5	
6	Provide information in real time (basic: initial information to support decision making)	2	5	4	2	40	6	
7	Improve and systematize the database of information on customer suggestions and complaints	1	4	3	3	36	7	B
8	Develop products able to capture information about their use directly from the end customer	3	3	3	3	27	8	C
9	Develop product customization competence, demanded directly by the end customer	3	3	3	3	27	8	
10	Implement and systematize Big Data solution with a focus on market information	3	3	3	3	27	8	B
11	Develop competence and systematize the simulation application of processes in order to obtain agility for process change	1	4	3	2	24	11	
12	Provide real-time information (advanced, strong integration between machines, equipment and systems)	3	3	3	2	18	12	C

13	Develop and provide a servitization business model where products will offer self-diagnosis and remote assistance options	3	2	3	2	12	13	
14	Automatic Kanban in the system	1	3	3	1	9	14	B

Source: The authors.

Table 9. List of strategic actions for the digital transformation of Company 2

Strategic Objectives: Company 2 Pulley Segment		**Productivity (3MODs flow reduction)** **Lead time (between 14-16 days)** **Ability to serve the market**						
#	**DESCRIPTION ACTION**	Level Maturity	G	U	T	GUT	Sequence	Deadline
1	Increase the connectivity of the manufacturing plant	2	5	4	4	80	1	A
2	Ensure data synchronization according to physical movement	3	5	5	3	75	2	
3	Map and develop “4.0” skills	5	4	3	3	36	4	
4	Segment communication networks	2	3	3	3	27	8	
5	Apply scenario simulation based on the theory of restrictions. (focus on planning)	3	3	3	3	27	8	
6	Deploy WMS in the semi-finished warehouse (warehouse 6)	3	3	3	2	18	11	
7	Automate spring and roller assembly	3	3	3	2	18	11	
8	Make improvements in the workplace	1	3	3	1	9	15	
9	Perform predictive maintenance	4	3	4	3	36	4	B
10	Get market forecasting tools	4	4	3	3	36	4	
11	Simulate processes to seek optimization opportunities	1	3	3	3	27	8	
12	Control machining tool life	4	3	2	2	12	14	
13	Develop freewheel system with expert partners	1	3	3	1	9	15	
14	Extend integration between systems	3	4	3	4	48	3	C
15	Perform correction automatically by the machine itself	5	3	3	4	36	4	
16	Perform automatic inspection	4	3	3	2	18	11	
17	Develop digital model for visibility of the productive flow	3	2	2	1	4	17	

Source: The authors.

These two lists are present in the consultants’ reports, and their structuring has referenced the roadmaps tool. It comprises activities in their temporal aspects between December 2018 to December 2019, where actions initiated in three months correspond to the “A” term. Actions initiated between 4 and 6 months are called the “B” term, and actions initiated between 7 to 9 months ahead are called the “C” term.

It is noted that this list refers to the beginning of activities. That is to say that their sequencing follows a path-dependence. This dependence was counterbalanced by the GUT indexes and the degree of maturity of the activity in the transition to an appropriate line the industry 4.0 established short and long terms.

5. DISCUSSION AND ANALYSIS OF RESULTS

Given the better degree of maturity of Company 2 concerning Company 1, respectively 2.47 and 2.20, its goal of using the transition to industry 4.0 as an element of productivity gain is justified. Company 2's pulley production is exposed to competition from Chinese manufacturers that reduce commercial mark-up. The automation and digitalization of its processes will reduce lead time and improve the capacity of service in the market. On the other hand, Company 1, which supplies gourmet ovens to the Brazilian domestic market, is exposed to consumption trends. What Company 1 seeks in the transition to industry 4.0 is again in innovation in using databases and synergy between the digitalized systems.

In this context, the present authors who have elaborated roadmap models of the respective companies' fig. 3 and 4, applicable to the transition to industry 4.0.

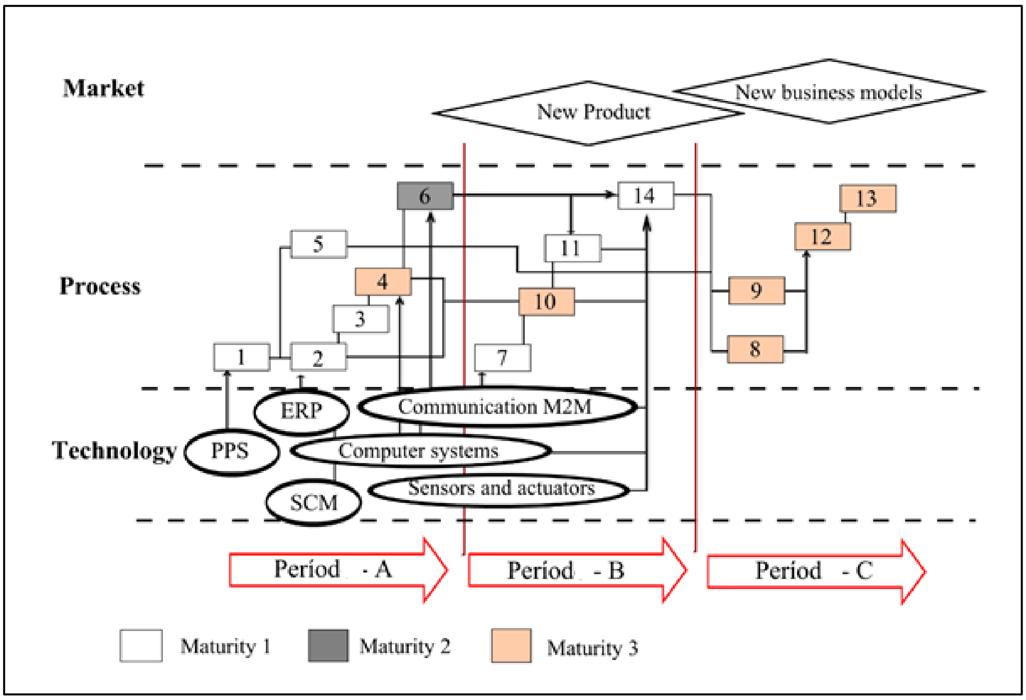

Figure 3. Roadmap suggestion for Company 1

Source: Prepared by the Authors

The roadmap of figure 3 allows Company 1 to visualize its fundamental activities' low level of maturity, such as implementing the Lean culture (process 2) and evaluating suppliers (process 3). While other processes such as systematization of significant dates (action 10) and service (action 13) and customization (action 9) of products are shown in higher levels in terms of maturity. For these processes to improve their maturity levels and gain synergy, it is necessary to advance in technological resources that facilitate the exchange of data such as PDM's (product data management, PDA's (manufacturing data acquisition), and MDC's (machine data acquisition).

The new product development environment in industry 4.0 depends on optimal connectivity between an intelligent cyber-system, a standardized interface capable of operating data in various formats that communicate intelligent machines to productive dynamics (Legner et al., 2017; Kusiak, 2018; Santos et al., 2019; Pessôa & Becker, 2020; Oztemel & Gursev, 2020; Noronha, Martins, Lietti & Silva 2023).

Furthermore, the roadmaps of fig. 8 and 3 reveal that Company 1 has limited technical support to the activities in general, as already commented in fig.6 and reinforced by the observations of fig. 8. The presence of machine-to-machine communication signals that some processes have devices for interconnectivity, but the absence of artificial intelligence feeding the data processes can compromise the accuracy of the information. Therefore, at this point, the digital transition is necessary mainly in the treatment of data, which in the case of Company 1, is still not working.

The roadmap in diagram format, as in figure 3, allows the identification of the interference relationship between the technological layer and the other upper layers. The fourth industrial revolution has as proposal the digitalization of this layer. Above all, it is a data revolution. The indicators present on the market layer are sensitive to the arrangements of the inferior layers. That is, the dynamism of the market should lead to new internal arrangements of the organizations. Processes can be expanded or deleted, replaced or remodeled (Alvarenga Neto & Choo, 2011; Franceschetto ,2022).

As discussed in the theoretical reference, the digital transition more than the absorption of new technologies. It is also new models of strategies and organizations (Ghobakhloo, 2018; Madsen, 2019; Ruppert et al., 2019; Santos et al., 2019; Kumar & Nayyar, 2020). The flow of information that flows from the market to within companies is worked on in the process layer and accommodated in the technology layer (Trakulsunti et al., 2020; Vinayavekhin & Phaal, 2020). The management of production and technology demands not only the monitoring of indicators in compelling terms but also readiness and maturity in data processing (Ghobakhloo, 2018; Colli et al., 2019; Santos & Martinho, 2019; Kumar & Nayyar, 2020; Moura & Hohl, 2020; Caiado et al., 2021; Furr, Ozcan & Eisenhardt, 2022; Castilhos, 2021).

This high maturity can be developed within the six design principles for industry 4.0: such as interoperability, virtualization, modularity, decentralization, among others (Hermann et al., 2015; Ruppert et al., 2018; Ghobakhloo, 2018; Habib & Chimson, 2019; Kumar & Nayyar, 2020). The jump from low maturity to high maturity is linked to the use of data that are collected, analyzed, and sent in real-time for decision-making (Sardi et al., 2019). A fast and efficient response reduces errors and waste by bringing more accuracy to the information circulating within companies (Mana et al., 2018; Noronha, Martins, Lietti, & Souza Vieira 2022; Alves, 2023).

In Fig. 4, it is possible to visualize the resources of Company 2 and observe how they are correlated. The time aspect identified by the lower arrows, also present in the diagram of Company 1, conveys the idea of movement and dynamism, knowing that these roadmap representations are flexible and adaptive. As the market changes, new arrangements need to be made in the two lower layers.

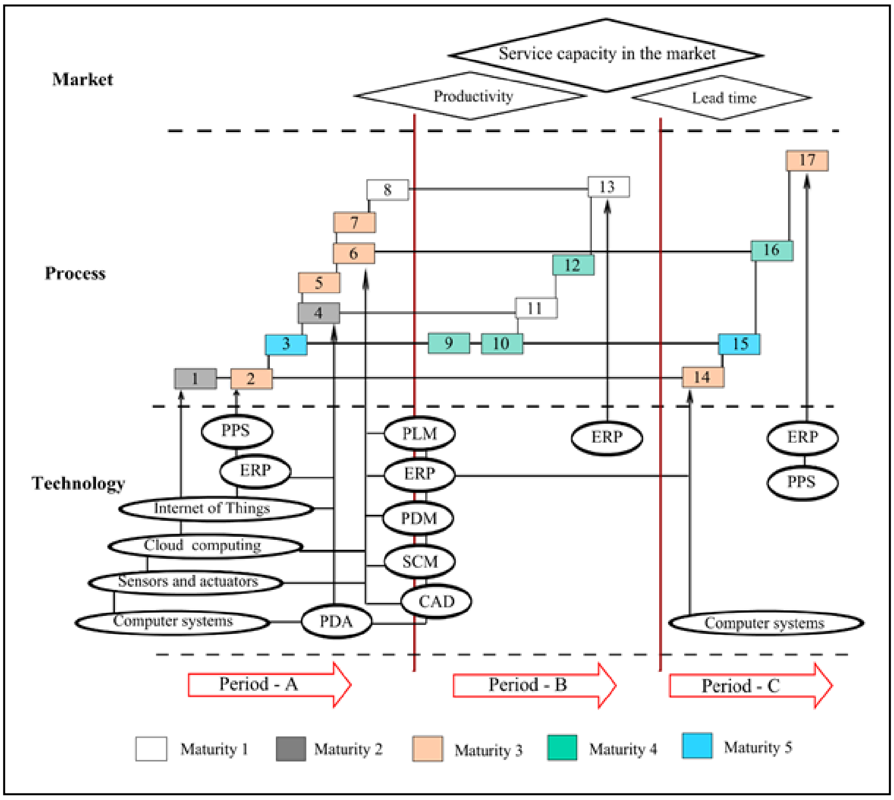

Figure 4. Suggested Roadmap for Company 2
Source: The authors

It is natural, therefore, as Schumacher et al. (2016) rightly pointed out, that the use of a roadmap in the digital transition is only a map that needs to evaluate the resources that industry 4.0 offers. Besides the sustainability of the business model, the compatibility with the company's strategies, and whether the strategy adopted for the digital transformation is solid enough. Company 1 represents a type of company that technology and production managers need to act as gatekeepers of external knowledge into the organization. In other words, digital transformation operators need to go beyond the mechanical level of the processes. They need to discover gaps in information, skills, and abilities and fill them with knowledge external to the organization. Fig 3 shows that Company 1 still has little digitalization of processes and limited digital network operation.

Company 2 presents a high level of maturity in the processes and a more advanced and robust technological structure than Company 1. It is worth noting that strategic objectives such as increasing productivity by reducing production phases, reducing lead time, and improving market service capacity require expanding product monitoring considering its life cycle and data management. Another observation is the intricate information system that permeates all activities. However, about IoT, Cloud Computing, and M2M communication technologies, Company 2 has a low number of technologies even in possession of a very active ERP system.

Although Company 2 is at a more advanced technological maturity level than Company 1. They were using IoT, cloud storage, sensors, and actuators communicating with computer systems such as PDA's, PPS (production planning system), SCM (supply chain management), and ERP. At the same time, data circulation in the plant is manual. Stock data, setup time, machine maintenance, and process cycle time are fed into the systems manually. Few processes in the pulley line of Company 2 are at a level 1 of maturity, i.e., devoid of sensorization and connectivity. Of these, only process 8, "making improvements at the workstation," has been framed in the short-term type A.

However, it is possible to observe some inconsistencies in the maturity evaluation of Company 2's team in process 15, "automatically perform correction itself," and in-process 3 "map and develop skills 4.0". Knowing that the circulation of data occurs, nothing is automated, and cloud computing, although present, is used infrequently, and the non-existence of M2M communication, autonomous robots, or even collaborative. The level 5 of maturity of process 15 is not necessarily related to the phenomenon of digitization, but the automation that involves the electronic systems of the machines, therefore still the third industrial revolution. In this context, the automatic correction of the machine is the technology of the logical programming of a central electronic, but still devoid of artificial intelligence, that takes decisions from data of the cybernetic network.

In front of the diagram in fig. 12, the productivity of Company 2 was achieved with the removal of manual practices in the circulation of data within the organization, besides enabling big data technologies, expanding the use of IoT (Internet of Things), and the programs for simulating layouts, real-time and production processes. Another critical step is to determine which technologies can be critical to the maturation of processes. Sarvari et al. (2017) highlight that roadmaps allow planning the next steps in the digital transformation from the definition of the strategy for the 4.0 industry to its implementation.

Thus, it is possible to see that the most significant benefit of the Roadmap tool is to provide an overall vision, a whole articulated in favor of a goal and strategic objectives. In fig. 11 and 12, the activities, technologies, and goals can be mobile, dynamic within the quadrants, re-editable in terms of times and rearrangement of strategies. The roadmap can be built physically or digitally so that its operationalization is as practical as possible so that the employees involved can contribute remodeling processes and actions. The tool is not focused on providing problem solutions but to meet needs, identify technological gaps that the wealth of expertise and know-how of the team can be met from ideas and proposals, which can be observed relevant once placed in the roadmap and applicability.

As Lee et al. (2013), Phaal (2015), Sarvati et al. (2018), and Oliveira et al. (2019) pointed out, the roadmap tool helps to build the company's overall vision. The inferences from the diagrams offer the opportunity for adjustments in management terms for both companies. Regarding technological maturity for Industry 4.0, the roadmap presents an interesting diagram to visualize gaps and deficiencies since the adoption of technologies requires accurate knowledge of the dynamics of production processes (Silva Junior, Santos & Souza, 2021).

6. FINAL CONSIDERATIONS

In search of an answer, technology is an attentive and growing aspect given to Industry 4.0. Since the manufacture and production of products, the search for intellectual labor is becoming increasingly important in advancing the industry and the modern economy. Intelligent technology is considered an essential future perspective in research and application. It adds value to various products and systems, applying cutting-edge technologies to traditional products in manufacturing and services (Ferro De Guimarães , Severo & Dorion, 2023). Product service systems will continue to replace traditional product types. The main concepts, leading technologies, and applications worldwide are covered in this document. Future research and applications are highlighted after a systematic review. We hope that this article can inform and inspire researchers and industry professionals to contribute to the advancement of the production industry. We also hope that the concepts discussed in this article will generate new ideas to carry out the long-awaited Fourth Industrial Revolution.

Therefore, the study presented relevant answers to the question: how can roadmaps help management transition from a non-digitalized production line to the digitized dimension of Industry 4.0? The roadmap diagram allows visualizing the deficiencies and limitations of the production processes in terms of maturity step, dimension of the intra-organizational connection network, besides presenting technological gaps that affect the achievement of the goals. For future research, we suggest the study in other areas of society where the concept of industry 4.0 is advancing as construction 4.0, logistics 4.0, or university 4.0. Many aspects of the roadmap tool need to be adjusted in terms of technological maturity leveling or even the dynamics of rearrangements between the three roadmap layers to achieve corporate goals.

Santos, Santos, and Silva Júnior (2019) identified in Industry 4.0 the breaking point for a new period of production management. Schwab (2016) classified the Fourth Industrial Revolution, a new production model based on the digitization of processes. Thoben, Wiesner, and Wuest (2016) note that the term Industry 4.0 receives the American equivalence of Smart Manufacturing or Smart Factory. However, both describe the same phenomenon: technological integration within the industry, the transformation of the human-machine relationship, and product sense, allowing their traceability (Silva Junior, Santos, & Souza, 2021).

Along with the evolution of emerging technologies, several concepts related to the fourth industrial revolution have also evolved. Among the main ones are demand customization, digitalization of business processes, including product development, manufacturing, and delivery processes. The transience of technologies is quickly overcome due to connectivity between machines and other business systems. Because of the decentralization of decisions made by autonomous systems, the increase in the analytical capacity of data in real-time. The digitization of products supported by intelligent embedded systems, connectivity technologies, and the agile reconfigurability of layouts are emerging technologies (Caiado & Quelhas, 2019).

As Donovan et al. (2016) stated, the importance of roadmaps is one way to reduce some challenges associated with the development of industrial, analytical capabilities, including the management of heterogeneous technologies and platforms, formation of multidisciplinary teams, training, among others. Some challenges are amplified when there are no methods to measure the current level of capacity and strategically identify the areas that need improvement. This work focused on developing a tool to quantify the maturity in the use of industrial, analytical capacities.

Ultimately, future research prospects for intelligent manufacturing in the era of Industry 4.0 are in the following areas seen as business gaps: a generic structure with roadmaps for intelligent manufacturing, creating a control tool for data-driven intelligent manufacturing models, man-to-man collaboration machine, and intelligent manufacturing application.

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