Engineering For Social Change
A. Cooper et al. (Eds.)

doi:10.3233/ATDE240909

Brazilian Digital Transformation Readiness: A Transdisciplinary Engineering Approach in the Automotive Sector

Anderson Suzuki COSTA[a,1], Jorge MUNIZ JR.[a], Timothy P. MUNYON[b], Kristina M. ERIKSSON[b]

[a]*Faculty of Engineering and Sciences, Unesp, Brazil*
[b]*Haslam College of Business, University of Tennessee, US*
[c]*Department of Engineering Science, University West, Sweden*

Abstract. Although widely adopted around the globe, emerging evidence suggests that digitalization investments often underperform. One potential reason is that firms lack organizational readiness to adopt these new technologies. Thus, in this paper, we evaluate both digitalization implementation and digital readiness in the Brazilian auto industry to ascertain how readiness potentially impacts the implementation of new digital technologies and processes. In reviewing the literature on digital transformation in the global automotive sector, a lack of studies was identified on the level of readiness and maturity of the automotive sector in relation to digitalization and innovation brought out by the implementation of Industry 4.0 technologies. To address this gap, a digitalization protocol was drawn up with the aim of verifying the maturity of companies and understanding the degree of readiness for digital transformation. Subsequently, the research was applied to thirteen companies in the automotive sector, including vehicle and engine manufacturers, as well as automotive parts and systems subcontractors in the automotive supply chain. The contribution of this paper identified that the use of digital technologies increases the quality and results of work, facilitates the achievement of objectives, and offers a competitive advantage. Further' advantages come from improving customer experience, increasing innovation through data analysis, improving manufacturing processes, and bringing greater employee engagement. Finally, it is highlighted that this study is aligned with the ninth Sustainable Development Goal (SDG) proposed by the United Nations: Industry, Innovation, and Infrastructure, which seeks to promote inclusive and sustainable industrialization and foster innovation.

Keywords. Transdisciplinary engineering, Digital transformation, Readiness, Digitalization, Automotive

Introduction

This paper aims to evaluate both digitalization implementation and digital readiness in the Brazilian auto industry to ascertain how readiness potentially impacts the implementation of new digital technologies and processes.

[1] Corresponding Author, Email: Anderson.suzuki@unesp.br.

Digital Transformation (DT) concepts are increasingly important for manufacturing companies acting in competitive markets [1]. DT is a change initiative, namely a process of transition from a certain level of digitization to a future state, with a higher digitization level [2]. This definition focuses on the digitalization level, but needs include people, process, strategy, operations, and new business model to fit the new level of DT and the positive impact on productivity. These necessities will be addressed in the literature review and included in the proposed research protocol.

DT requires a comprehensive cross-functional digitalization of processes, products/services, and business models as well as operational and dynamic capabilities [3]. Digitalization is a technological trend that is reshaping all sectors of industry and society. Therefore, it is considered an important and relentless driving force of innovation and disruption that challenges all types of organizations.

There are several challenges that companies must face to implement DT/I4.0 technologies: cloud computing, artificial intelligence (AI), internet of things (IoT) and mobile technologies as well as smart production, big data and predictive analysis, cybersecurity, training, and organizational culture [4]. The concept of Industry 4.0 is the incorporation of machines, workflow, as well as the application of smart networks throughout the production and supply chain [5].

The literature on DT within the industrial sector, both on a global scale and specifically in Brazil, highlights a predominant emphasis on digitalization models targeting initiatives within manufacturing plants, and often neglect to encompass all stages of the digital transformation process. Notably, little attention is devoted to the implementation and consolidation of digital change [3]. The literature review also concerns barrier assessment that can hinder DT implementation [1].

An emerging field is surging and evolves engineering approaches by transcending the technical disciplines, namely Transdisciplinary Engineering (TE) [6]. This new field includes social science to gather essential insights about users and their contexts. TE is fundamentally directed towards addressing ambiguous and socially significant challenges and can be helpful to overcome issues on tackling the critical factors to implement DT. Thus, TE research has gained increased attention within engineering academic literature [7]. Although there is an increasing reference to TE within the literature the term remains without a universally accepted definition [8]. The research question is how transdisciplinary engineering influences DT in the automotive sector?

Readiness or maturity level assessment is a key activity in any DT initiative, as it consists in determining the current level of digitalization of the enterprise and shows how prepared it is to introduce significant changes in the organization [2], and these needs include technical, management and people factors.

After an introduction about the paper's justification and problem to be studied, section 1 presents the literature review, including concepts related to digital transformation, digitization, Industry 4.0, supply chain management (SCM), DT critical factors and readiness/maturity to adopt new technologies and innovations. Section 2 describes the proposed research method, sample characteristics and data processing techniques and tools. Section 3 presents the data analysis using descriptive statistics and section 4 finalizes with contribution of this paper and future research.

1. Digital Transformation

With the world population growth and the scarcity of resources, productivity gains are necessary in the various sectors of the economy. The advent of I4.0 brings technological advances that are encouraging all sectors to undertake digital transformation to increase business productivity, efficiency, and competitiveness [5]. In the case of small and medium-sized enterprises (SME), the challenges faced by them in adopting Industry 4.0 include the need for innovation, investment in digitization and the definition of innovative business models to sustain digital transformation [9].

Several definitions of Digital Transformation or digitalization when reviewing the literature. There are a variety of definitions with each one focusing on different dimensions such as technology, people, process, and business model to name a few [2], [4], [5], [9], [10], [11], [12].

DT integrates digital technologies to accelerate process and sustainability aligned to key elements such as people, process, strategy, technologies, revenues, and extension of the organization to accelerate process. DT refers to the integration of digital technologies in the various areas of a company, impacting its operation, culture, and delivery of value to customers. Sommer et al. defines DT as primarily a strategic transformation [3]. Another definition highlights the people involved in the transformation. It emphasizes how to improve the quality of people's lives at work and how to increase the organizations' performance for people, both developers and product final customers [10].

In summary, the adoption of Industry 4.0 technologies in companies, including those that support digital transformation is a driver of profitability and sustainable growth, allowing the same companies to adapt to the dynamism and globalization of the economy and thus remain competitive in the market. Therefore, digitalization and I4.0 technologies implementation have been shown to provide an efficient contribution to enhancing business efficiency and productivity, generating a sustainable competitive advantage [13]. The expected socioeconomic benefits of these technologies include GDP growth, job creation and improved quality in the industrial and service sectors.

1.1. Digital Transformation Factor

Interest in the topic of digital supply chain (DSC) has increased a lot recently with the incessant search to increase productivity and profitability of companies in both the industrial and services sectors. A quick analysis of the literature shows that the subject of DCS is at an early stage in terms of academic research. The academic literature does not have a consensus and is still limited to research that evaluates the digitalization of organizations in the supply chain (SC) [4].

There are several themes that are fundamental for digital transformation to occur successfully. Some of the most cited in the literature are technology, people, and processes. Several factors were identified for each of the themes mentioned above [4]. In the case of technology, the main factors identified were IT infrastructure and cybersecurity systems. In the people theme, three factors were identified: requalification of digitalization and improvement, digitalization culture and support from senior management. Finally, on the topic of processes, innovation strategy, integrated supply chain, digital innovation management, big data management and data analysis and government regulation were the identified factors.

Over the ten factors researched, the most cited is IT infrastructure. The first investment to implement DSC is the infrastructure to have the appropriate level of

advanced information and communication technology. The second most cited in the research was the integration of SC, which allows real-time data sharing, increased productivity, and high efficiency [14].

These critical factors play a significant role in the successful implementation of traditional SC into digital ones, contributing to better organizational performance.

The importance of implementing Industry 4.0 technologies in creating value for organizations must be highlighted. Digital transformation adds value in several dimensions, including data management, organizational processes, technologies such as connectivity and collaboration tools, organizational culture and governance, leadership, and agility to adapt to new processes, quality of delivery, digital security, digital marketing among others [9].

For digitalization to happen, there are challenges that must be overcome for DT to happen successfully. Among them is the lack of accurate data for monitoring equipment, highlighting the effectiveness of using the Industrial Internet of Things (IIoT). It also highlights the introduction of an object tracking system, aiming to reduce costs, increase accuracy and simplify loss analysis [15]. An important and neglected challenge for organizations is establishing clear visions and goals for digital transformation. Success only comes when companies innovate in their processes, respond to market changes, and adapt to new technologies.

Finally, assessing the level of readiness to implement I4.0 technologies requires a detailed analysis of the current state of companies in terms of digitalization and the next subchapter will describe models and systems studied in the literature as well as case studies.

1.2. Digital Transformation Readiness

Improving the state of digitalization in companies is a complex task and understanding each company's state of readiness can increase or decrease the chances of successfully implementing this new way of operating productive organizations. Readiness is a multifaceted issue that cannot be assessed using one factor, dimension, or point of view. Several parameters must be considered when an organization moves towards DSC [4].

Assessing the digitalization readiness of an economic entity is challenging, requiring a system of assessment criteria [16]. Various methods, such as DBA (Digital Business Aptitude) and the Forrester 4.0 digital maturity model, are used based on analytical data and evaluation criteria [17], [18]. The application of DBA method assesses the company's readiness through a metrics system that evaluates the volume of problems in the company. The Forrester 4.0 digital maturity model is frequently used and includes four levels: differentiators, contributors, adopters, and skeptics.

The “Smart Industry Readiness Index – SIRI” from the Singapore Economic Development Council to be used as a standard measuring instrument in relation to company readiness. Standard assessment includes finding market opportunities, anticipating growing market trends, driving productivity to efficiently optimize resources, and supporting safety standards and social needs [5]. The SIRI model indicators include three aspects, Technology, Process and Organization. The three components mentioned are divided into eight main pillars: Operations, Supply Chain, Product Life Cycle, Automation, Connectivity, Intelligence, Structure and Management and Talent Readiness.

Schallmo et al. [19] developed a roadmap for DT for the I4.0 transition that consists of 5 phases. The first phase of the model was applied to a digital transformation project

in a German industry group. The roadmap developed by Issa et al. [1] contains six steps which manufacturing companies can use to create an individual I4.0 framework to help them define the focus for their digitalization process aligned with their readiness level.

Ng et al. [20] created a conceptual framework to guide enterprises to develop action plans for digitalization and this model has five stages with inputs and outputs clearly defined. A model was suggested by Pessl et al. [21] to define organizations maturity level, identify targets and develop an action plan to implement the digital transformation strategy. The roadmap proposes six steps and two of them are key for the implementation success, such as having a kick-off workshop to generate awareness for the initiative and starting with pilot projects and incorporating the obtained experiences in subsequent digitalization ones.

Leone et al. [22] proposed a framework to assist SMEs to integrate I4.0 projects and the methodology consists of three macro-phases: I4.0 maturity assessment, process AS-IS analysis and I4.0 roadmap design, know that the third phase needs to be integrated with the company's strategic vision. Aiming to help companies in the DT process, Rautenbach et al. [23] derived a digital transformation model which has two phases, knowing that phase one includes two sub-phases: value creation assessment, digital organizational profile, and assessment integration & value equation.

Lassnig et al. [24] proposed a digital readiness check (DRC) to better understand the digital maturity in supply chain (SC) and elaborate on main differences between SMEs and large companies. The DRC comprises 4 blocks: Strategy, Employees, Initiation of business transactions and digitalization of the SC. Butt [25] suggested an integrated business-process management framework (IBPM) to support manufacturing plants to implement I4.0. The eleven phases of the framework are: process identification, process discovery, process analysis, process redesign, streamlining business processes, risk management, skill gap analysis, change management, cost-benefit analysis, process validation and implementation and process monitoring and control.

DT readiness in automotive companies and maturity models developed for this sector are rare. One index of digital maturity was deduced by Sommer et al. [3] to measure digitalization and was examined in 167 global automotive companies. The digital maturity index (DMI) consists of four indices: digital activity index, digital business index, operational capability index and dynamic capability index. The four metrics were surveyed using multiple items on a 7-point Likert scale.

Analyzing the literature from consulting firms, three contributions were retrieved from two major ones, named PricewaterhouseCoopers (PwC) and McKinsey (MK). PwC defined the “Blueprint for Digital Success” based on multiple DT projects developed in leading industrial organizations [26]. This model consists of six practical steps: map out I4.0 strategy, create initial pilot projects, define capabilities, become a virtuoso in data analytics, transform into a digital enterprise and plan an ecosystem approach.

It was retrieved from McKinsey two frameworks to help companies to implement a successful digital transformation. MK developed six building blocks of the DT: creating a business-led technology roadmap, developing, and upskilling talent, adopting an agile delivery methodology, shifting to a modern technology environment, focusing on data management and enrichment, driving the adoption and scaling of digital initiatives [27]. MK proposed ten guiding principles of DT dedicated to insurance organizations. The principles are secure senior management commitment, set clear and ambitions targets, secure investments, start with lighthouse projects, appoint a launching team, organize to promote new agile way of working, nurture a digital culture, sequence initiative for quick returns, build capabilities and adopt a new operating model.

The analysis of literature reveals that current models for assessing organizational maturity and readiness for digitalization are still deficient in terms of enhancements, breadth, and empirical validation concerning the development and implementation of action plans. This underscores the need for a more comprehensive model that can be applied across various sectors of the economy.

2. Methodology

The research methodological procedure was applied in four stages: (A) theoretical foundation based on articles on companies' readiness to implement digitalization resulting from Industry 4.0; (B) data collection using a quantitative questionnaire; (C) survey's data was analyzed through the calculation of Cronbach's alpha (CA) as reliability coefficient and (D) results analysis using descriptive statistics and one statistical tool which is alpha to internal consistency of the constructs.

The theoretical foundation (stage A) searched for articles on the Scopus platform (2014-2024) considering the following keywords: Digital transformation; Automotive; Readiness; Maturity; Digitization; Industry 4.0; Digital technology; Transdisciplinary engineering; Technology; Manufacturing; Management. From the Scopus search, 38 articles were found filtered by keywords. After analyzing the article summaries, 12 articles were selected that have greater adherence to the topic of Digital Transformation (DT) and organization's readiness.

The questionnaire uses a five-point scale, ranging from 5 – completely agree to 1 – completely disagree. In addition, questions were asked to better understand the profile of the respondents, such as time at the company, relationship with new technologies and position/function in the company (see Table 1).

Non-probabilistic sample was used in companies in the automotive sector located in several states in Brazil representing 13 different companies (Hyundai, Nissan, Honda, Renault, VW, Toyota, Ford, Maxion, Mahle, Bosch, AVL, Cummins, NSK).

The investigation was conducted through 73 respondents at all levels of the organization, with 59% of respondents working in auto parts companies and 41% in car manufacturers. Respondents work at different levels, from analyst to corporate directors and in the most diverse areas (purchasing, engineering, IT, manufacturing, quality, process, maintenance, innovation, strategy, after-sales, sales, and communication), who are working with the implementation of new technologies in the automobile sector, and 56% of them have more than ten years.

3. Findings

Relative and median frequency distribution for the constructs with the respective Cronbach's alpha of the data collected were calculated (Table 1). Hair et al. indicates that values greater than 0.7 are considered consistent [28]. Thus, Cronbach's alphas (CA) indicate the consistency between the items of the constructs.

Respondents indicate that there is a positive influence between Feelings about Digitalization and the use of digital technologies to increase the quality and results of work, obtaining a favorable judgment (5 - completely agree, 4 - agree) of more than 90% in all items. The results indicate that the use of digital technologies influences (FAD1) the willingness to learn new technologies (96%); (FAD2) digital technologies can

improve work (96%); (FAD3) digitalization offers a competitive advantage (96%); (FAD4) digitization will help achieve goals (92%). Sommer et al. [3] argue that business models digitalization is defined by five components: resource allocation, profit model, value architecture, value proposition and competitive advantages which is aligned with FAD3.

Table 1. Relative and median frequency distribution for each item of the construct (with respective CA)

Constructs (CA)	Affirmation	Frequency (%)					$\bar{X}$
		1	2	3	4	5	
Feelings about digitalization (FAD - 0,94)	I am excited to learn how to use new digital technologies in my work	4	0	0	31	65	5
	I feel like digital technologies can greatly enhance my work	4	0	0	23	73	5
	Digitization can give our company a competitive edge	4	0	0	12	85	5
	Digitization will help our company realize our performance goals	4	0	4	38	54	5
Collaboration with stakeholders (CWS – 0.44)	Suppliers	0	0	0	35	65	5
	Alliance Partners	0	0	19	42	38	4
	Customers	0	0	4	15	81	5
	Competitors	0	23	46	23	8	3
	Government	0	12	23	50	15	4
Vision about digitalization & Strategy (VDS – 0.86)	There is an inspiring vision of how digital technologies can create a new future with shared value	0	8	19	46	27	4
	We have a clear roadmap to use digital technologies to help us deliver our business objectives	0	15	35	35	15	3
	My organization has a clear understanding of how the competitive landscape is changing due to DT	0	8	35	38	19	4
	My organization is good at generating and implementing new ideas to improve performance	4	15	31	35	15	3
	There are well-defined metrics to measure the impact of each innovation on my organization's bottom line	8	31	27	27	8	3
	My organization has already successfully implemented several digital initiatives that improve its products and services	4	8	15	50	23	4
Potential challenges (PC – 0.91)	Lack of a clear digital vision	4	12	54	31	0	3
	Lack of organizational strategy deploying a digital vision	19	8	31	27	15	3
	Competing organizational priorities	8	12	19	35	27	4
	Lack of collaborative culture	8	23	27	35	8	3
	Cultural resistance to change	8	12	27	27	27	4
	Insufficient internal digital skills	0	23	27	35	15	3
	Lack of executive support & leadership buy-in	15	27	23	19	15	3
	Lack of organizational agility	15	15	38	15	15	3
	Satisfaction with status quo	4	27	50	15	4	3
	Lack of entrepreneurial spirit	8	38	27	23	4	3
	Internal politics	12	31	31	19	8	3
	Insufficient funding	12	15	27	35	12	3
	Legal/regulations restrictions	27	35	31	8	0	2
	Security concerns (e.g. data breach)	19	19	31	19	12	3
	Insufficient technology infrastructure	8	15	38	27	12	3
	Customers adoption of digital activities	19	31	31	15	4	2

	Employees lack of ability to use digital technologies (e.g. cloud, social, mobile, analytics)	15	19	27	27	12	3
Leadership, talent & systems (LTS – 0.87)	Our leaders act as role models facilitating the transformation to a digital-centric organization	0	4	50	35	12	3
	There is a team established with clear responsibilities and procedures to stimulate digital initiatives	4	8	19	38	31	4
	My organization has the required expertise and staff to use digital technologies effectively	4	12	38	38	8	3
	Key roles have been identified in my organization that either support the digital transformation	4	4	27	42	23	4
	The is an understanding of digital competencies that employees and leaders must have to be successful	4	27	27	27	15	3
	Our business units and functions are well connected to each other via digital platforms	8	12	23	35	23	4
	My organization is using digital to improve the efficiency of employees and expand our network	4	4	19	54	19	4
Increase competitive advantage (ICA – 0.81)	Enhance the customer experience	0	19	12	46	23	4
	Increase innovation based on data analysis	0	8	19	38	35	4
	Improve data driven decision making	4	8	15	35	38	4
	Improve and transform processes	8	4	15	31	42	4
	Improve workforce engagement	0	4	19	46	31	4
	Improve agility of the organization	0	8	12	35	46	4

Regarding success in the organization and dependence on stakeholders (CWS), respondents indicate that there is a positive influence between success in the organization and collaboration with stakeholders, obtaining a favorable judgment (5 - completely agree, 4 - agree) in four of the five items. The results indicate that suppliers (CWS1 - 100%), strategic partners (CWS2 - 81%), consumers (CWS3 - 96%) and the government (CWS5 - 65%) have a positive influence on the company's success. On the other hand, competition (CWS4) has a neutral influence for 46% of respondents. Many DT models recommend the involvement of internal and external stakeholders such as customers and business partners in distinct phases of DT to have a successful implementation [2].

In the construct on vision about digitalization and strategy, interviewees indicate a positive influence obtaining a favorable judgment (5 - completely agree, 4 - agree) in three of the six items. They are the inspiring vision of digital technologies (VDS1 – 73%), the organization's clear vision of the changing environment (VDS3 – 58%) and the company has already implemented digital initiatives (VDS6 – 73%). Defining a clear change vision and strategy is a key change management and digital transformation activity [2]. In two items, a clear roadmap for the use of digital technologies (VDS2 – 50%) and the company generates and implements innovative ideas (VDS4 – 50%), half of the interviewees judged the influence of the item favorably. In the item well-defined metrics to measure TD impact (VDS5), 65% judged the influence on digitalization vision and strategy to be neutral or negative.

In the Potential Challenges (PD) items, respondents rated them on a scale from 1 (not a barrier) to 5 (extreme barrier). As the scale talks about levels of barriers, it was found that most items were rated between 2 (small), 3 (moderate) and 4 (large). In this construct, 17 items were evaluated, so some of them will be highlighted. Considering the combination of neutral and positive evaluations (scale from 3 to 5), the following items stand out: lack of digital vision (85%), lack of organizational strategy (73%), mismatched organizational priorities (81%), cultural resistance to change (81%), insufficient

technological infrastructure (77%). Neutral or negative evaluations (scale from 1 to 3) were found in the items digital activities adopted by consumers (81%), legal and regulatory restrictions (92%), satisfaction with the status quo (81%), lack of entrepreneurial spirit (73%) and internal politics (73%). Some key barriers of DT studied by Borovkov et al. are like the findings of construct such as outdated technologies, lack of usage of digital production technologies and insufficient elaboration of the regulatory framework [16].

In relation to the Leadership, talents, and systems (LTS) construct, the results indicate that there is a positive influence through favorable judgment (5 - completely agree, 4 - agree) between the items and the impact on the company's digitalization. An example of this positive influence is the existence of a team with clear responsibilities (69%), definition of clear roles to support TD (65%), use of digitalization to improve employee efficiency (73%). In the Smart Industry Readiness Index proposed by Sari et al. [5] talent readiness is the workforce's ability to integrate innovation in the DT to be successful and is divided into two dimensions, learning & development, and leadership competence.

Increasing competitive advantage (ICA) has a positive influence through favorable judgment (5 – critical motivation, 4 – important motivation) on all evaluated items. They are improving the customer experience (69%), increasing innovation through data analysis (73%), improving decision-making processes through data (73%), improving, and transforming processes (73%), improving employee engagement (77%) and improving the organization’s agility (81%). Digitalization has become increasingly important in the automotive industry as a strategy to remain competitive and can be seen in greater customer loyalty via e-commerce and digital tracking of his journey [3].

4. Conclusions

The result of the study analyzes transdisciplinary elements as psychological, motivational, and behavioral factors that influence the process of preparation and readiness of companies for digital transformation (DT) in the Brazilian automotive sector. More precisely, the study examines the effects of constructs on the implementation process of DT utilizing technologies associated with the fourth industrial revolution, commonly referred to as Industry 4.0.

It was identified in the research that the use of digital technologies increases the quality and results of work, facilitates the achievement of objectives, and offers a competitive advantage. Additionally, the research revealed that engaging in collaboration with suppliers, strategic partners, and consumers positively influences the success of the organization.

In terms of digitalization strategy and vision, having an inspiring vision of digital technologies and changes in the corporate environment were the items with the best evaluations. When assessing the potential hurdles in adopting digitalization, the primary barriers highlighted in the study include absence of a clear vision of DT, lack of strategic planning, resistance to cultural change, and inadequate technological infrastructure.

In the leadership and talent construct, it was identified that there was a team responsible for DT with clear responsibilities and the use of new technologies to improve employee’s efficiency. The study concluded that enhancing competitive advantage serves as a crucial aspect for integrating new digital technologies. This advantage stems from enhancing customer experiences, fostering innovation via data analysis, streamlining processes, and boosting employee engagement.

References

[1] A. Issa, B. Hatiboglu, A. Bildstein, et al., Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment., *Procedia CIRP*, 2018, vol. 72, pp. 973–978.

[2] N. Bellantuono, A. Nuzzi, P. Pontrandolfo, and B. Scozzi, Digital Transformation Models for the I4.0 Transition: Lessons from the Change Management Literature, *Sustainability*, 2021, 13, no. 23, 12941.

[3] S. Sommer, H. Proff, and H. Proff, Digital transformation in the global automotive industry, *Int. J. Automotive Technology and Management*. 2021, vol. 21, no. No. 4, pp. 295-321.

[4] A. Aamer, C.R. Sahara, and M.A. Al-Awlaqi, Digitalization of the supply chain: transformation factors, *Journal of Science and Technology Policy Management*, 2023, vol. 14, no. 4, pp. 713–733.

[5] I. Sari, D. Tricahyono, and D. Indiyati, E-Supply Chain Management Readiness Analysis by Using the Smart Industry Readiness Index, *Quality-Access to Success*. 2023, vol. 25, no. 198.

[6] M. Peruzzini, et al., Special issue on 'transdisciplinary approaches to digital manufacturing for industry 4.0.' *International Journal of Computer Integrated Manufacturing*, 2020, vol. 33(4), pp. 321–324.

[7] S. Lattanzio, A. Nassehi, et al., Concepts of transdisciplinary engineering: a transdisciplinary landscape, *International Journal of Agile Systems and Management*, 2021, vol. 14, no. 2, pp. 292-312.

[8] R.J. Lawrence, Deciphering Interdisciplinary and Transdisciplinary Contributions, *Transdisciplinary Journal of Engineering & Science*, 2010, vol. 1, no. 1, pp. 111–116.

[9] K. Bhatt and S.M. Kumar, Reindustrialization Using Industry 4.0 Maturity Models in Msmes and Tenets of Digital Transformation Phases., *2022 Fourth International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT)*. *IEEE*, Mandya, India, 2022, pp. 1–6.

[10] A.L.A.C. Venâncio, et al., Technology prioritization framework to adapt maintenance legacy systems for Industry 4.0 requirement: an interoperability approach, *Production*, 2022, vol. 32, e20210035.

[11] P.C. Verhoef, T. Broekhuizen, Y. Bart, et al., Digital transformation: A multidisciplinary reflection and research agenda., *Journal of Business Research*, 2021, vol. 122, pp. 889–901.

[12] L. Lachvajderová and J. Kádárová, Industry 4.0 Implementation and Industry 5.0 Readiness in Industrial Enterprises, *Management and Production Engineering Review*, 2022, pp. 102–109.

[13] E.V. Dudukalov, I.V. Terenina, M.V. Perova, and D. Ushakov, Industry 4.0 readiness: the impact of digital transformation on supply chain performance., *E3S Web of Conferences*, 2021, vol. 244, p. 08020.

[14] F. Iddris, Digital Supply Chain: Survey of the Literature, *International Journal of Business Research and Management*, 2018, vol. 9, no. 1, pp. 47–61.

[15] M.A. Komissarova, et al., Attitude to the Assessment of Digitalization Methods of Russian Industrial Companies, *IOP Conference Series: Earth and Environmental Science*, 2021, vol. 666, no. 6, 062058.

[16] A. Borovkov, O. Rozhdestvenskiy, E. Pavlova, et al., Key Barriers of Digital Transformation of the High-Technology Manufacturing: An Evaluation Method, *Sustainability*, 2021, vol. 13, no. 20, 11153.

[17] N.A. Orlova, APPROACHES TO THE ASSESSMENT OF SMALL INDUSTRIAL ENTERPRISES READINESS FOR THE DIGITAL ECONOMY., *Vestnik Universiteta*, 2020, no. 2, pp. 26–34.

[18] O. Valdez-de-Leon, A Digital Maturity Model for Telecommunications Service Providers, *Technology Innovation Management Review*, 2016, vol. 6, no. 8, pp. 19–32.

[19] D. Schallmo, C.A. Williams, and L. Boardman, DIGITAL TRANSFORMATION OF BUSINESS MODELS — BEST PRACTICE, ENABLERS, AND ROADMAP, *International Journal of Innovation Management*. vol. 21, no. 08, p. 1740014, 2017.

[20] H.Y. Ng, P.S. Tan and Y.G. Lim, Methodology for Digitalization - A Conceptual Model., *IEEE Inter. Conference on Industrial Engineering and Engineering Management (IEEM)*, 2018, pp. 1269–1273.

[21] E. Pessl, Roadmap Industry 4.0 – Implementation Guideline for Enterprises, *International Journal of Science, Technology and Society*, 2017, vol. 5, no. 6, p. 193.

[22] D. Leone and A. Barni, Industry 4.0 on Demand: A Value Driven Methodology to Implement Industry 4.0, In: B. Lalic, et al. (eds.) *Advances in Production Management Systems,* 2020, pp. 99–106.

[23] W.J. Rautenbach, et al., The development of a conceptual model for enabling a value-adding digital transformation: A conceptual model that aids organisations in the digital transformation process, *2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. pp. 1–10.

[24] M. Lassnig, et al., A digital readiness check for the evaluation of supply chain aspects and company size for Industry 4.0, *Journal of Manufacturing Technology Management*, 2022, vol. 33, no. 9, pp. 1–18.

[25] J. Butt, A Conceptual Framework to Support Digital Transformation in Manufacturing Using an Integrated Business Process Management Approach, *Designs*, 2020, vol. 4, no. 3, p. 17.

[26] G. Reinhard, V. Jesper, and S. Stefan, Industry 4.0: Building the digital enterprise, *PwC 2016 Global Industry 4.0 Survey*, 2016, pp. 1–34.

[27] C. Angevine, J. Keomany, J. Thomsen, and R. Zemmel, *Implementing a digital transformation at industrial companies*, McKinsey Global Publishing, 2021, pp. 1–8.

[28] J.F. Hair, W.C. Black, B.J. Babin, R.E. Anderson, and R.L. Tatham, *Análise multivariada de Dados*. Bookman, Porto Alegre, 2009.