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THE TECHNOLOGICAL AND NON-TECHNOLOGICAL ELEMENTS THAT
CHARACTERIZE INDUSTRY 4.0: A SET OF RESEARCH FROM THE
PERSPECTIVE OF THE BRAZILIAN SCENARIO

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Master thesis presented to the Postgraduate Program in Administration at Centro Universitário Alves Faria, as partial requirement for obtaining the title of Master in Administration.

Professor Advisor: Prof. Dr. Pedro Henrique Rodrigues de Sousa

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I dedicate this work to my beloved wife Elisângela, my sons Fernando, Pedro, Matheus and my daughter Rafaela, my daughters-in-law Emily, Gabrielly and Gabriela, and my grandchildren Arthur and Heitor. To this blessed family who is my main motivation to continue learning day after day.

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Abstract

Originality/Value: In theoretical terms, this work seeks to review the theoretical foundations of Industry 4.0, starting from the ambiguity of the current definition to mapping the technological and non-technological elements of Industry 4.0. In practical terms, this work presents itself as a roadmap for process qualification, demonstrating the distance that the respective organization is from the theoretical model for characterizing Industry 4.0. Field research seeks to map the Brazilian industry scenario regarding the situation of its technological and non-technological elements.

Design/Methodology/Approach: This master thesis seeks to consolidate into a single document three research studies that aim to clarify the Industry 4.0 scenario. Article #1, deals with a bibliometric review to map what was published in the period from 2018 to 2022 about Industry 4.0. Article #2, deals with a bibliographic review to understand the interfaces of Industry 4.0 elements in publications from 2018 to 2023, consolidating a theoretical model for Industry 4.0. Article #3, deals with an empirical study to apply this theoretical model in field research.

Results: The bibliometric research indicates that there are thirty-eight research gaps regarding the characterization of Industry 4.0. The bibliographical research points to Germany's leading role in research and the development of public policies; the evolution of Chinese and South Korean industry based on the German model; and the description of the theoretical model of Industry 4.0 based on ten technological elements and eight non-technological elements. The empirical investigation points out that the level of social development in each region of Brazil does not influence the evolution of Industry 4.0; Brazil presents adherence gaps in the technological and non-technological elements of Industry 4.0; and presents difficulties in the cognitive development of its employees in the face of the needs of the digitalization process.

Keywords: Industry 4.0; Fourth Industrial Revolution; Elements; Theoretical Model; Brazilian Industry.

Resumo

Originalidade/Valor: Em termos teóricos, esse trabalho busca revisar os fundamentos teóricos da Indústria 4.0 partindo da ambiguidade de definição atual até o mapeamento dos elementos tecnológicos e não tecnológicos da Indústria 4.0. Em termos práticos, esse trabalho apresenta-se como um roteiro para qualificação de processos, demonstrando o distanciamento que a respectiva organização se encontra do modelo teórico de caracterização da Indústria 4.0. A pesquisa de campo busca mapear o cenário da indústria brasileira quanto à situação dos seus elementos tecnológicos e não tecnológicos.

Design/Metodologia/Abordagem: Esta dissertação procura consolidar num único documento três estudos de investigação que visam esclarecer o cenário da Indústria 4.0. O Artigo #1 trata de uma revisão bibliométrica para mapear o que foi publicado no período de 2018 a 2022 sobre Indústria 4.0. O Artigo #2 trata de uma revisão bibliográfica para compreender as interfaces dos elementos da Indústria 4.0 nas publicações de 2018 a 2023, consolidando um modelo teórico para a Indústria 4.0. O artigo #3 trata de um estudo empírico para aplicação deste modelo teórico em pesquisa de campo.

Resultados: A pesquisa bibliométrica indica a existência trinta e oito lacunas de pesquisa quanto à caracterização da Indústria 4.0. A pesquisa bibliográfica aponta para o protagonismo da Alemanha nas pesquisas e no desenvolvimento de políticas públicas; a evolução da indústria Chinesa e Sul Coreana pautadas no modelo alemão; e a descrição do modelo teórico de Indústria 4.0 pautado por dez elementos tecnológicos e oito elementos não tecnológicos. A pesquisa empírica aponta que o nível de desenvolvimento social de cada região do Brasil não influencia a evolução da Indústria 4.0; o Brasil apresenta gaps de aderência nos elementos tecnológicos e não tecnológicos da Indústria 4.0; e apresenta dificuldades no desenvolvimento cognitivo de seus colaboradores frente às necessidades do processo de digitalização.

Palavras-chave: Indústria 4.0; Quarta Revolução Industrial; Elementos; Modelo Teórico; Indústria Brasileira.

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List of Abbreviations and Acronyms

ANOVA – Variance Analysis

AI – Artificial Intelligence

AM – Additive Manufacturing

BM – Business Model

CCTV – Closed TV Circuit

CNI – Brazilian Confederation Industry

CD – Concept Drift

CEO – Chief Executive Officer

COVID-19 – Coronavirus disease pandemic - 2019

CPS – Cyber-Physical System

DT – Digital Transformation

EC – Exclusion Criteria

GDP – Gross Domestic Product (*PIB* in Portuguese)

IBGE – Brazilian Institute of Geography and Statistics

ID – Identification number of articles

IND4.0 – Industry 4.0

IoT – Internet of Things

IIoT – Industrial Internet of Things

IPEA – Brazilian Institute of Applied Economic Research

IT – Information Technology

MDCM – Multi-Criteria Decision Methods

MES – Manufacturing Execution System

MHDI – Human Development Index of Municipalities

NT Element – Non-Technology Element (of Industry 4.0)

OECD – Organization for Economic Development Cooperation

OT – Operational Technology

PLC – Programmable Logic Controllers

PRISMA – Preferred Reporting Items for Systematic Review and Meta-Analysis

RFID – Radio Frequency Identification

R&D – Research & Development

SAP – Development Programs for System Analysis (*Systemanalysis Programmentwicklung* in German language)

SBMI – Sustainable Business Model Innovation

SEBRAE – Brazilian Support Service for Micro and Small Businesses

SESI – Brazilian Industry Social Service

T Element – Technology Element (of Industry 4.0)

TPM – Total Performance Maintenance

WCM – World Class Manufacturing

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1 INTRODUCTION

The term Industry 4.0 was born in Germany inspired by the ideas of Henning Kagermann. Born in Braunschweig/Germany in 1947, he graduated in physics and later became a businessman, with the highlight of his career being CEO of SAP. Kagermann's idea was to develop a business model that was capable of boosting the economy of developed countries, preparing their industries for the global supply chain as well as reducing their costs compared to developing countries. This movement was accepted by the majority as a new industrial revolution - an update of the third industrial Revolution, until then, based on the use of automation, for a new business model in which the internet now plays the leading role among the elements of the industry.

Over these twelve years in which we have experienced the Fourth Industrial Revolution (Industry 4.0), the impacts of its evolution have been addressed by scholars, specialists and industry executives in order to improve the interface of expected results. In the same way that on the one hand there is a small skeptical minority that does not believe in the concepts of Industry 4.0 as a new industrial revolution, on the other hand we have scholars dealing with the theme “Industry 5.0”, which would be a new phase that retraces the statistical bases of Industry 4.0 and the search for a more sustainable business model.

1.1 RESEARCH PROBLEM

Ghobakhlo et al. (2021) states that research and studies prior to its publication offer promising contributions to the advancement of what he calls the “Industry 4.0 discipline”, but on the other hand, he confirms that the question of the current *status quo* of Industry 4.0 literature is a question that remains relatively unanswered, particularly regarding how Industry 4.0 and the underlying digital technologies can contribute to various aspects of sustainable development. Culot et al. (2020) in turn, states that, as research on Industry 4.0 advances, it is necessary for the business community to align two implications arising from their study: that Industry 4.0 requires a specific approach to its context, and a multidisciplinary approach to Description. In the meantime, Culot et al. (2020) states that “the technological landscape of Industry 4.0 is still in a state of confusion”. Legitimizing the evidence raised by the authors, indirectly cited so far, a research gap can be established to answer the following question:

- ***Based on the original German concept of Industry 4.0, what are the elements that characterize Industry 4.0 in the Brazilian context?***

Therefore, seeking to answer the question presented, this work has the following objectives.

1.2 OBJECTIVES OF THE STUDY

General Objective:

Considering that: 1) As an industry professional for over twenty-six years, and thus, having experienced the third and fourth industrial revolutions in a practical way, and as a researcher, I need to have a clear answer to what Industry 4.0 is in theoretical terms. 2) As corporative manager of a Brazilian industrial group for six years, I have the responsibility of establishing an evolution journey for the industrial units of this group – both for current companies and for those that will be acquired or installed. 3) The market offers many “solutions” to the demands of Industry 4.0, most of which are expensive, and without a clear approach that relates-to a method or an evolution journey.

Based on these considerations, this work has the general objective of reviewing the theoretical foundations that characterize Industry 4.0 and mapping the Brazilian scenario regarding the status of technological and non-technological elements.

Specifics Objectives:

As for specific objectives, we intend to further investigate the following research gaps:

- A. Current definitional ambiguity, comparing Industry 4.0 with other concepts; for example, smart manufacturing, cloud manufacturing, etc (Culot et al. 2020).
- B. The definitional dimensions and subdimensions characterizing Industry 4.0 in technological and non-technological aspects (Culot et al. 2020).
- C. Define the theoretical foundations of Industry 4.0 (Culot et al. 2020).

1.3 RELEVANCE AND MOTIVATION FOR THE STUDY

This set of research promotes an update regarding the mapping of the scientific record on the characterization of Industry 4.0, starting from the difficulty and ambiguity in defining the theoretical foundations, and the interface of technological and non-technological elements. In this way, it seeks to present a clear, contemporary and unified definition of Industry 4.0, both in theoretical and practical terms.

In theoretical terms, this research seeks to create a theoretical model that responds to possible correlations between technological and non-technological elements to characterize Industry 4.0 in a section of the Brazilian industrial scenario. In practical terms, this study presents itself to the sample as a roadmap for qualifying its processes, demonstrating, in practice, the distance that its respective organization is from the theoretical model for characterizing Industry 4.0. Therefore, it can be stated that this study can benefit researchers, teachers, students and academics interested in exploring the topic, as well as investors, executives, engineers, specialists and consultants from different industrial segments in the search for best practices, tools, equipment and policies for the development of Industry 4.0.

To build a robust theoretical foundation, it was decided to use a bibliometric study followed by a historical bibliographic analysis so that the concepts characterizing Industry 4.0 take on a contemporary research approach.

1.4 STRUCTURE AND ORGANIZATION OF THE TEXT

Therefore, this work seeks to consolidate into a single document three research studies that aimed to clarify the Industry 4.0 scenario. Article #1 deals with a bibliometric review to understand what was published in the period from 2018 to 2022 about Industry 4.0, as well as identifying the main authors, their countries of origin, publications per period, publications per journal, and mainly, establishing the main terminologies. Article #2 deals with a bibliographical review to understand the interfaces of the technological and non-technological elements of Industry 4.0 in publications from 2018 to 2023, thus consolidating a theoretical model for characterizing Industry 4.0. Article #3 deals with an empirical study to apply this theoretical model in survey research in the industry, thus obtaining validation of this model and also an analysis of how far or close the sample is from the modeling for Industry 4.0.

2 ARTICLE #1

Characterization of Industry 4.0 and its research gaps: a bibliometric study

Caracterização da Indústria 4.0 e suas lacunas de pesquisa: um estudo bibliométrico

Caracterización de la Industria 4.0 y sus vacíos de investigación: un estudio bibliométrico

ABSTRACT:

Originality/Value: This work promotes an update regarding the mapping of the scientific record on the term Industry 4.0 by comparing foreign and Brazilian academic productions, seeking to identify the most cited keywords and the record of elements that may present the characteristics of Industry 4.0.

Design/Methodology/Approach: A quantitative research approach was used, using bibliometric research as a method for analyzing scientific production in the period from 2018 to 2022. As a source of articles, scans were carried out in the academic databases, Science Direct, Scielo and Spell, and To search for articles, a combination of terms was used in two search strategies. 91 articles were selected, which, after being classified, resulted in 20 articles, 12 foreign and 8 Brazilian.

Results: According to the results found, it was found that there is a repeatability of keywords about Industry 4.0 in bibliometric studies, whether they come from research directly related to characterization, or from indirect research that presents a specialized techno-scientific approach. Furthermore, twelve studies present 38 gaps capable of deepening a more detailed analysis of the characteristics of Industry 4.0 in theoretical and practical terms. As a future research agenda, it is suggested to deepen the analysis of the technological and non-technological elements of Industry 4.0 and their impacts in the context of sustainability.

Keywords: Industry 4.0; Concept; Definition; Bibliometrics.

RESUMO:

Originalidade/Valor: Esse trabalho promove atualização quanto ao mapeamento do registro científico sobre o termo Indústria 4.0 comparando as produções acadêmicas estrangeiras e brasileiras, buscando identificar as palavras-chave mais citadas e o registro de elementos que possam apresentar as características da Indústria 4.0.

Design/Metodologia/Abordagem: Empregou-se uma pesquisa de abordagem quantitativa, utilizando a pesquisa bibliométrica como método para análise da produção científica no período de 2018 a 2022. Como fonte de artigos, as varreduras foram realizadas nas bases de dados acadêmicas, Science Direct, Scielo e Spell, e para a pesquisa de artigos utilizou-se a combinação de termos em duas estratégias de busca. Foram selecionados 91 artigos, os quais, depois de classificados, chegou-se ao número de 20 artigos, sendo 12 estrangeiros e 8 brasileiros.

Resultados: Conforme os resultados encontrados, constatou-se que há repetibilidade de palavras-chave sobre a Indústria 4.0 em estudos bibliométricos, sejam elas oriundas de pesquisas diretamente relacionadas à caracterização, ou de pesquisas indiretas que apresentam abordagem tecnocientífica especializada. Além disso, doze pesquisas apresentam 38 lacunas capazes de aprofundar uma análise mais detalhada das características da Indústria 4.0 em termos teóricos e práticos. Como agenda de pesquisa futura sugere-se aprofundar análise sobre os elementos tecnológicos e não tecnológicos da Indústria 4.0 e seus impactos no contexto da sustentabilidade.

Palavras-Chave: Indústria 4.0; Conceito; Definição; Bibliometria.

RESUMEN:

Originalidad/Valor: Este trabajo promueve una actualización del mapeo del registro científico sobre el término Industria 4.0 comparando producciones académicas extranjeras y brasileñas, buscando identificar las palabras clave más citadas y el registro de elementos que pueden presentar las características de la Industria 4.0.

Diseño/Metodología/Enfoque Se utilizó un enfoque de investigación cuantitativa, utilizando la investigación bibliométrica como método de análisis de la producción científica en el período de 2018 a 2022. Como fuente de artículos se realizaron escaneos en las bases de datos académicas, Science Direct, Scielo y Spell, y To search. para los artículos, se utilizó una combinación de términos en dos estrategias de búsqueda. Fueron seleccionados 91 artículos que, después de ser clasificados, resultaron 20 artículos, 12 extranjeros y 8 brasileños.

Resultados: De acuerdo con los resultados encontrados, se constató que existe una repetibilidad de palabras clave sobre Industria 4.0 en los estudios bibliométricos, ya sea que provengan de investigaciones directamente relacionadas con la caracterización, o de investigaciones indirectas que presenten un enfoque tecnocientífico especializado. Además, doce estudios presentan 38 lagunas capaces de profundizar un análisis más detallado de las características de la Industria 4.0 en términos teóricos y prácticos. Como futura agenda de investigación, se sugiere profundizar en el análisis de los elementos tecnológicos y no tecnológicos de la Industria 4.0 y sus impactos en el contexto de la sostenibilidad.

Palabras Clave: Industria 4.0; Concepto; Definición; Bibliometría.

Introduction

The term Industry 4.0 emerged in Germany in 2011 with the original title “Industrie 4.0” being presented as the reality of the Fourth Industrial Revolution capable of generating new trends in emerging and disruptive information technology and intelligence (GERMANO et al. 2021).

According to data from CNI – Brazilian Confederation of Industry (2023), industrial activity lost its dynamism in 2023, showing a drop in revenue of around 0.9% and a drop in hours worked in industrial production of around 0.2%, both comparing the months of July/June 2023. The same research also reports that the variables related to the labor market – employment, wage bill and average income – remain stable in this same time reference. In the meantime, the CNI (2023) published a technical article called “Industry 4.0: understand its concepts and foundations” which begins by explaining that the term is related to the Fourth Industrial Revolution, and that it involves a broad system of technologies such as artificial intelligence, robotics, internet of things and cloud computing that are changing forms of production and business models in Brazil and around the world. In the event published by CNI (2023) on “the barriers and opportunities for industry 4.0 in Brazil”, the then Director of Industrial Development at CNI, Mr. Carlos Eduardo Abijoadi states that Industry 4.0 is not limited to the acquisition of equipment and new technologies, but that Industry 4.0 is achieved through the integration of production chains, connectivity, internet of things, big data, artificial intelligence, among others.

Ghobakhloo et al. (2021) states that, although there are several publications that detail the concept, application and pillars of Industry 4.0, it is clear that there is still difficulty in

clarifying the objectives, and mainly in the results to be expected from Industry 4.0. The CNI (2023) states that, in Brazil, it is the profile of medium and small industries to have less flexible specialized equipment, which restricts integration and external connection, and that, in terms of investment in technology, we are on average ten years behind in relation to other OECD – Organization for Economic Development Cooperation countries, with an emphasis on connecting existing automation to digital processes such as 5G and big data analytics.

Ghobakhlo et al. (2021) states that research and studies prior to its publication offer promising contributions to the advancement of what he calls the “Industry 4.0 discipline”, but on the other hand, he confirms that the question of the current *status quo* of Industry 4.0 literature is a question that remains relatively unanswered, particularly regarding how Industry 4.0 and the underlying digital technologies can contribute to various aspects of sustainable development. Culot et al. (2020) in turn, states that, as research on Industry 4.0 advances, it is necessary for the business community to align two implications arising from their study: that Industry 4.0 requires a specific approach to its context, and a multidisciplinary approach to Description. In the meantime, Culot et al. (2020) states that “the technological landscape of Industry 4.0 is still in a state of confusion”.

For Veile et al. (2021), Industry 4.0 implies a comprehensive digitalization and complete interconnection of industrial value creation, including individual companies and entire chains. It also states that these implications impact the conduct of the entire production chain, such as improvements in process efficiency and advances in flexibility, agility, individualization and improvement in the quality of value offers. Kemand (2022) uses the concepts and studies the Industry 4.0 approach in a kind of use of terms and initiatives for a comparison and evolution of forensic techniques and in a correlation with the challenges presented by the CNI (2023). He also states that from the point of view of cybersecurity, the integration of IT¹ and OT² expands the attack surface, due to the lack of acceptable strategies regarding standards and methodologies.

In this same approach, Dreyfus et al. (2021) states that most Industry 4.0 technologies, such as machine learning, artificial intelligence, digital twins, virtual metrology, predictive maintenance and defect-free manufacturing are data-driven technologies, correlating with the same challenges already mentioned here. Veile et al. (2021) consolidates the record that there have been political initiatives and economic programs around the world for the digitalization and interconnection of value creation, from “Industrie 4.0” in Germany, the “Made in China

¹ IT: Information Technologies

² OT: Operational Technologies

2025” effort created by the Chinese government and the “Industry IoT Consortium” promoted by the United States government. Germano et al. (2021) also states that there is no Industry 4.0 consensus on environmental and sustainability issues, since there is no conclusive research that states that the benefits to the environment brought by the adoption of the pillars of Industry 4.0 outweigh the possible environmental impacts that its deployment can generate. In this way, it can be said that studies to characterize Industry 4.0, are essential to clarify, in a practical and theoretical way, the initiatives for its implementation and the due awareness of its impacts.

Methodological Procedures

To achieve the objective proposed in this study, we opted for a quantitative research approach, using bibliometric research as a method. Bibliometrics is a recommended method for analyzing scientific production, as it allows for an overview of the behavior and development of an area of knowledge (ARAÚJO E ALVARENGA, 2011). Data collection covered academic production from 2018 to 2022 and descriptive statistics for their respective analysis.

This period is justified by the attempt to analyze, through more recent studies, the evolution trends in the market-oriented characterization of Industry 4.0, as presented in the vast literature review carried out mainly by Ghobakhloo et. al (2021), which retraces an analysis in the period from 2010 to 2020; and Culot et al. (2020), which runs an analysis back to 2019.

To carry out bibliometric research, three phases of studies were defined, namely: PHASE I, which involves the selection of articles that met the search exclusion criteria; PHASE II, this involves the selection of articles through reading the abstracts, that is, those in which a high correlation is noticed for the objectives of this research; PHASE III involves detailed reading of the entire content of the classified articles. The evolution of these research phases can be seen in Picture 3.

As a source of articles, scans were carried out in academic databases: Science Direct, Scielo and Spell. To search for articles, a combination of terms in two search strategies was used. In the first strategy in the Science Direct, Scielo and Spell databases, the terms ("Industrie 4.0" OR "Industry 4.0") AND ("Concept" OR "Definition" OR "Model") AND ("2018" to 2022") AND ("review OR research"). In the second strategy in the Science Direct, Scielo and Spell databases, the same terms as the first scan were combined, however, written

in Portuguese: ("Indústria 4.0" OR "Industry 4.0") AND ("Conceito" OR "Definição" OR "Modelo") AND ("2018 a 2022") AND ("revisão OR pesquisa"). In both strategies in the Science Direct, Scielo and Spell databases, the term ("Industrie 4.0") was combined in the keyword field of the abstract. Based on these two search strategies, 91 articles were selected, including: Science Direct, capturing the first 50 articles listed on the platform; Scielo, capturing all 30 articles found on the platform; and Spell, capturing all 11 articles found on the platform, as shown in Table 1.

Table 1: Result of search strategies on scientific platforms

Database		Search Criteria	Total Articles Found
International	Science Direct	TITLE-KEY	50
	Sciello	TITLE-KEY	30
	Spell	TITLE-KEY	11

Source: Prepared by the author

Seeking validation based on reliable research data, PHASE I of article classification began, where the following exclusion criteria were established: EC1, articles only published in academic journal; EC2, time frame from 2018 to 2022 – criteria already established in the search field of research bases; EC3, research and review articles only – criteria already established in the search field of research bases; EC4, Qualis Periodic cut-off classification between classifications A, in extracts A1, A2, A3 and A4; and B1 as registered on the *Qualis Periódico* (2023).

Table 2: Keywords and exclusions criteria

Database	Keywords in Searches	Keywords in Abstracts	Exclusion Criteria [EC] (Classified Articles - PHASE I)
Science Direct	("Indústria 4.0" OR "Industry 4.0") AND ("Concept" OR "Definition" OR "Model") AND ("2018 to 2022") AND ("review OR research") ("Indústria 4.0" OR "Industry 4.0") AND ("Conceito" OR "Definição" OR "Modelo") AND ("2018 a 2022") AND ("revisão OR pesquisa")	("Industrie 4.0")	- EC1: Journal articles only - EC2: Time Frame: 2018 to 2022* - EC3: Research and review articles only* - EC4: Quality Frame: Extracts A to B1** (*) exclusions performed in the platform search field. (**) according to platform: https://sucupira.capes.gov.br
Sciello			
Spell			

Source: Prepared by the author

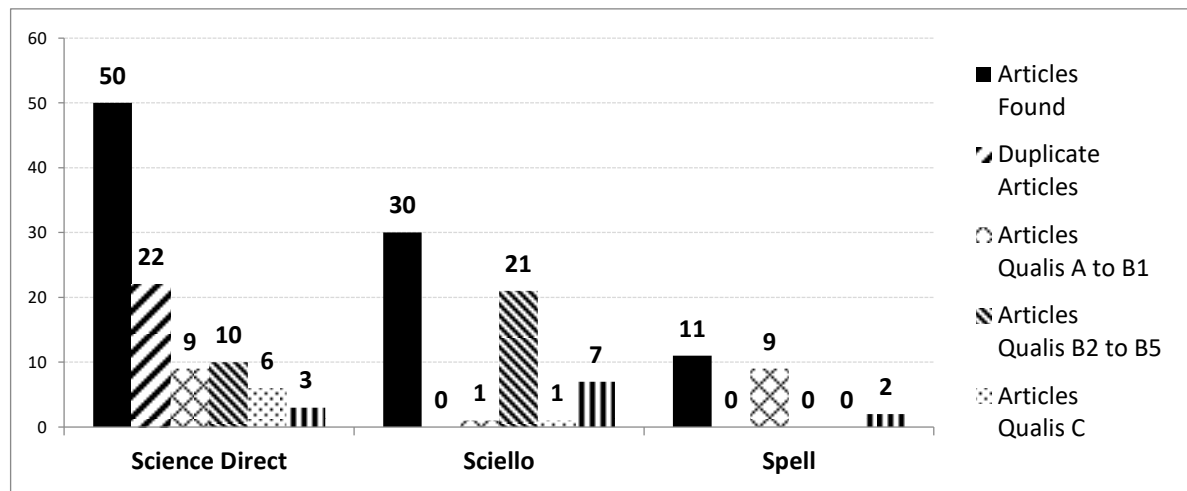
Based on the classification of the articles found, it can be seen that the Science Direct platform is the only one that presents repeatability of publications on the platform itself. In Table 3, it can be seen that 44% of the total articles found on this platform (50), 22 appear duplicates in the list presented by the search criteria presented in Table 2. The highlight of the Sciello platform is the low number of publications with high classification; >B1 on the *Qualis Periódico* (2023); it appears that only 3.3% of the articles found on this platform have a classification >B1, with a further 73% classified between extracts B2 to B5 and C, and another 23% of articles without the aforementioned classification by *Qualis Periódico* (2023). The highlight of the Spell platform is the lowest number of articles found, only 12% of the total, however, it is the platform with the greatest qualitative use, with more than 81% classified >B1 according to the *Qualis Periódico* (2023). Based on PHASE I classification, of the 91 articles selected, 22 of them are classified. A quantitative analysis of the classification data of the articles found can be completely visualized in Table 3, while a qualitative analysis of the level of use by platform with this same data can be viewed in Table 1.

Table 3: Classification of articles found

Database	Articles Found	Duplicate Articles	Articles Qualis A to B1	Articles Qualis B2 to B5	Articles Qualis C	Unrated Articles
Science Direct	50	22	9	10	6	3
Sciello	30	0	1	21	1	7
Spell	11	0	9	0	0	2
TOTAL	91	22	19	31	7	12

Source: Prepared by the author

Graph 1: Level of utilization by database



Source: Prepared by the author

Deepening the analysis of the twelve articles marked as “unrated” by the *Qualis Periódico* (2023), in three of them, a classification can be inferred based on the general classification of the journal in which they were published. In the case of the Sciello platform, the journal “*Palabra Clave*” has an A2 rating, while in both cases of the Spell platform, the journal “*Innovation and Management Review*” has an A2 rating. Once PHASE was completed, 22 articles were classified, representing 24.1% of the total found in the search databases.

Afterwards, the abstracts and registration of all articles classified in Phase began to be read. In Picture 1, you can see the model form used to register articles in what is called PHASE II of classification through reading the abstract.

Picture 1: Scientific article registration form

SCIENTIFIC ARTICLE FORM	
Title:	<i>Transcribed the official title</i>
ID Number:	<i>Defined a protocol number to identify the article in this research</i>
Journal:	<i>Transcribed the name of the journal where the article was published</i>
Database:	<i>Transcribed the name of the research platform</i>
Publication Year:	<i>Transcribed the year of publication</i>

Author/Nationality:	<i>Transcribed the names and nationality of the authors</i>
Keywords:	<i>Transcribed the keywords of the article</i>
Abstract:	<i>Transcribed article abstract</i>

Source: Prepared by the author

By reading the abstracts of the 22 articles classified in Phase I, 20 of them were classified as relevant to this bibliometric research, as it is shown in Table 4. In order to meet the objectives of this study, these 20 classified articles will be fully reviewed in order to identify: the research excerpts, the proposals for characterizing the central theme, the characterization correlations with their respective references, and the research gaps presented.

Table 4: Result of article classification up to PHASE II

Database	Articles Found	Classified Articles PHASE I	Classified Articles PHASE II
Science Direct	50	9	9
Sciello	30	2	2
Spell	11	11	9
TOTAL	91	22	20

Source: Prepared by the author

Results and Discussions

This section will present: the demographic identification of the academic production surveyed, the distribution of academic production in relation to the variables within the scope of Industry 4.0 and the correspondences between the theories used by the studies and the respective structural aspects that refer to Industry 4.0.

Identification and demographics of the academic production surveyed

Of the total number of articles analyzed from Phase II of classification – 20 articles in total, 60% of them were presented in foreign journals, which are listed in Table 5, in alphabetical order, based on the title of the article.

Table 5: Scientific production surveyed in foreign journal

Article ID	Article title, author and year	Journal	Published Language
13	A framework for identifying and analysing industry 4.0 scenarios (Ferreira et al., 2022)	Journal of Manufacturing Systems	English
24	A function-oriented biologically analogical approach for constructing the design concept of smart product in Industry 4.0 (Cao et al., 2021)	Advanced Engineering Informatics	English
3	Behind the definition of Industry 4.0: Analysis and open questions (Culot et al., 2020)	International Journal of Production Economics	English
84	Business model innovation for sustainability: a new framework (Ferlito & Faraci, 2021)	Innovation and Management Review	English
54	Contribution of industry 4.0 technologies to sustainability: a systematic review (Germano et al., 2022)	<i>Palavra Chave</i>	Portuguese
18	Data-based model maintenance in the era of industry 4.0: A methodology (Dreyfus et al., 2021)	Journal of Manufacturing Systems	English
85	Dynamic capabilities and business model innovation in sustainable family farming (Schiavon et al., 2021)	Innovation and Management Review	English
14	Industrial internet of things (IIoT) forensics: The forgotten concept in the race towards industry 4.0 (Keband, 2022)	Forensic Science International	English
2	Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants (Ghobakhloo et al., 2021)	Journal of Cleaner Production	English
17	Proposal of digital twin for testing and measuring of transport belts for pipe conveyors within the concept Industry 4.0 (Fedorko et al., 2020)	Measurement	English
20	Smart mining policy: Integrating fuzzy-VIKOR technique and the Z-number concept to implement industry 4.0 strategies in mining engineering (Poormirzaee et al., 2022)	Resources Policy	English
22	Toward a new era of cooperation: How industrial digital platforms transform business models in Industry 4.0 (Veile et al., 2021)	Journal of Business Research	English

Source: Prepared by the author

The other articles published in Brazilian journals are listed in Table 6, also in alphabetical order, based on the title of the article.

Table 6: Scientific production surveyed in Brazilian journal

Article ID	Article title, author and year	Journal	Published Language
86	Analyzing complexities in the Brazilian soybean supply chain: a systems thinking and modeling approach (Filassi et al., 2021)	RAUSP Management Journal	English
66	Construction of low-cost equipment to wind 3D printer filaments (Andrade et al., 2019)	<i>Química Nova</i>	Portuguese
83	Modeling business processes in company management (Karmanov et al., 2021)	<i>Revista Gestão & Tecnologia</i>	English
89	Paraná economic growth: an approach with the GWR model (Silva & Alves, 2021)	<i>Gestão & Regionalidade</i>	Portuguese
90	Scale of Organizational Structure Components (OCEO): validation evidence of a theoretical model (Trigero-Fernandes et al., 2020)	Brazilian Business Review	Portuguese
81	Hybrid multicriteria and economic engineering model for decision support in fleet management (Dantas, 2021)	<i>Revista de Administração Mackenzie</i>	Portuguese
87	Level of collaboration and knowledge transfer between actors of the innovation ecosystem: the proposition of an analytical model (Nascimento et al., 2022)	International Journal of Innovation	English
88	A conceptual model for the relationship between research and development and innovation management (Souza et al., 2021)	<i>Revista Brasileira de Gestão e Inovação</i>	Portuguese

Source: Prepared by the author

From these selected articles it is clear that there is no repeatability of authors, and as for the journal, there is repeatability in the journals “Innovation and Management Review” and “Journal of Manufacturing Systems” with two publications in each.

The registration of 89 keywords was also identified, of which 7 were repeated, which we can infer that they represent great strength as a definition of Industry 4.0, namely: Industry 4.0 (8 repetitions); Sustainability (3 repetitions); Business Model (2 repetitions); Conceptual Framework (2 repetitions); Digitalization (2 repetitions); Fourth Industrial Revolution (2 repetitions); and Sustainable Development (2 repetitions), which we can see in Graph 2 and in more detail in Picture 2.

in sustainable agriculture, article ID66 which deals with improving the 3D printing process, and article ID14 which deals with IIot technology in forensic analysis – citing these three articles only as an example of others that have the same characteristic. In this way, it can be taken into account that a word cloud like Picture 2 is a relevant representation of what is most cited in this research context, as well as it presented us, through the least cited words, industrial contexts that serve as future reference.

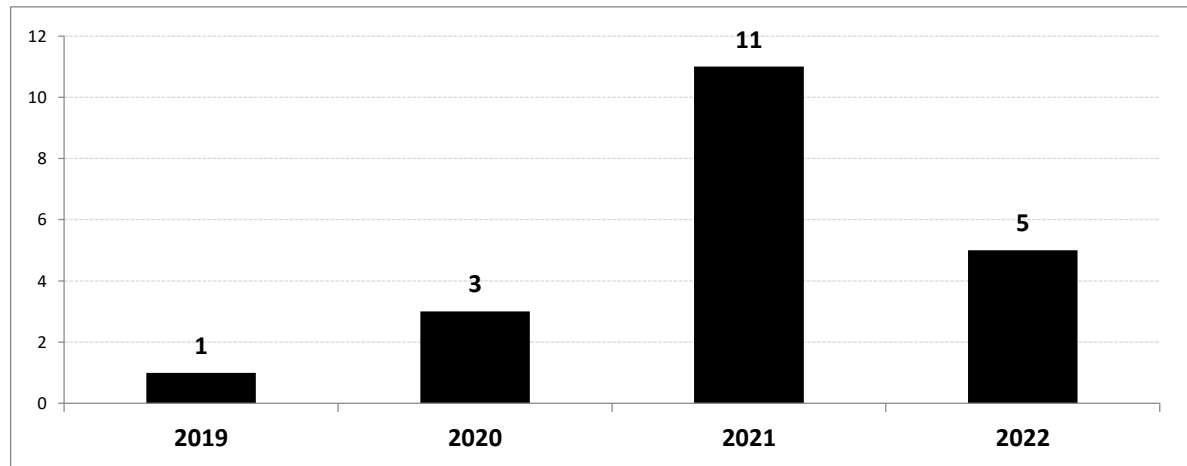
It can be seen that, despite the search only in foreign research bases (Science Direct, Sciello and Spell) as shown in Table 1, and taking into account that the vast majority - 70% of the classified articles - were published in the English language, it is observed that the nationality of the vast majority of authors (40%) is Brazilian. Still in the aspect of nationality, another highlight is the publication of the article ID2 under the title “Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants” published by five researchers from different nationalities (Lithuania, Sweden, Australia, Canada and Lithuania). Thus, we can infer a the great relevance of research on the topic Industry 4.0.

Table 7: Nationality of authors of article ID2

Article ID	Article title, author and year	Journal	Authors / Nationality
2	Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants (Ghobakhloo et al., 2021)	Journal of Cleaner Production	1. Morteza Ghobakhloo / LITHUANIA 2. Masood Fathi / SWEDEN 3. Mohammad Iranmanesh / AUSTRALIA 4. Parisa Maroufkhani / CANADA 5. Manuel E. Morales / LITHUANIA

Source: Prepared by the author

Regarding the temporality of publications, it can be seen from Graph 3 that there was an evolution from 2019 onwards, reaching a peak in the number of publications in 2021, eleven articles published. However, there was a considerable drop in the number of publications in 2022, five articles published, a reduction of more than 54%. This reduction is in line with research by Mourão (2022) which indicates a high drop in other techno-scientific publications due to the high number of publications on the COVID-19 pandemic in 2022, thus affecting the balance of knowledge generation around the world.

Graph 3: Year of publication of classified articles

Source: Prepared by the author

By fully reading the articles selected in Phase II, it can be seen that some of them are directly related to research to define and/or characterize Industry 4.0, which were referred to here as “Research of Group I” (these represent 30% of the total – 6 of 20). On the other hand, there is research that uses the concept of Industry 4.0 with the aim of deepening a specialized techno-scientific approach, that is, here in this bibliometric research, these articles dealt with the presentation of the following specific solutions: modeling business, sustainable agriculture, improvements in 3D printing, digital twins as a proposal for the components industry, economic engineering in fleet management, innovation for knowledge transfer, innovation in R&D, intelligent product design, IoT technology for forensic analysis, organizational structures, regional economic revenue growth and smart mining policy. These surveys were referred to here as “Research of Group II”, representing 70% total – 14 of 20.

Therefore, it can be inferred that the repeated keywords presented in Graph 2 represent the main elements of analysis, both in research with a direct emphasis on contextualization of Industry 4.0 (Group I), as well as in those with an indirect emphasis on contextualization (Group II). The definition of the respective emphasis in each of the articles can be seen in Table 8.

Table 8: Research emphasis of selected articles

Article ID	Article title, author and year	Group	Emphasis
88	A conceptual model for the relationship between research and development and innovation management (Souza et al., 2021)	II - Indirect relationship with characterization of Industry 4.0	Innovation in R&D

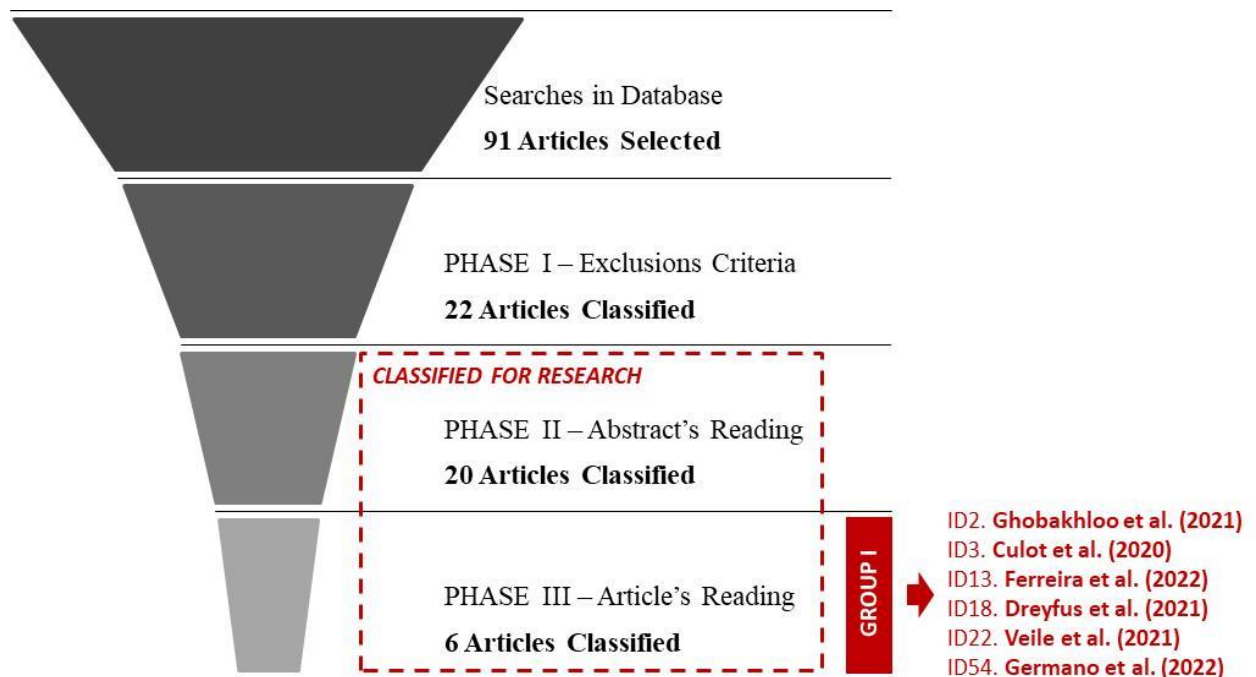
13	A framework for identifying and analysing industry 4.0 scenarios (Ferreira et al., 2022)	I - Direct relationship with characterization of Industry 4.0	Definition and characterization of Industry 4.0
24	A function-oriented biologically analogical approach for constructing the design concept of smart product in Industry 4.0 (Cao et al., 2021)	II - Indirect relationship with characterization of Industry 4.0	Intelligent Product Design
86	Analyzing complexities in the Brazilian soybean supply chain: a systems thinking and modeling approach (Filassi et al., 2021)	II - Indirect relationship with characterization of Industry 4.0	Sustainable Agriculture
3	Behind the definition of Industry 4.0: Analysis and open questions (Culot et al., 2020)	I - Direct relationship with characterization of Industry 4.0	Definition and characterization of Industry 4.0
84	Business model innovation for sustainability: a new framework (Ferlito & Faraci, 2021)	II - Indirect relationship with characterization of Industry 4.0	Business Modeling
66	Construction of low-cost equipment to wind 3D printer filaments (Andrade et al., 2019)	II - Indirect relationship with characterization of Industry 4.0	3D Printing Improvements
54	Contribution of industry 4.0 technologies to sustainability: a systematic review (Germano et al., 2022)	I - Direct relationship with characterization of Industry 4.0	Definition and characterization of Industry 4.0
18	Data-based model maintenance in the era of industry 4.0: A methodology (Dreyfus et al., 2021)	I - Direct relationship with characterization of Industry 4.0	Definition and characterization of Industry 4.0
85	Dynamic capabilities and business model innovation in sustainable family farming (Schiavon et al., 2021)	II - Indirect relationship with characterization of Industry 4.0	Sustainable Agriculture
81	Hybrid multicriteria and economic engineering model for decision support in fleet management (Dantas, 2021)	II - Indirect relationship with characterization of Industry 4.0	Economic Engineering in Fleet Management
14	Industrial internet of things (IIoT) forensics: The forgotten concept in the race towards industry 4.0 (Keband, 2022)	II - Indirect relationship with characterization of Industry 4.0	IoT Technology in Forensic Analysis
2	Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants (Ghobakhloo et al., 2021)	I - Direct relationship with characterization of Industry 4.0	Definition and characterization of Industry 4.0
87	Level of collaboration and knowledge transfer between actors of the innovation ecosystem: the proposition of an analytical model (Nascimento et al., 2022)	II - Indirect relationship with characterization of Industry 4.0	Innovation for Knowledge Transfer
83	Modeling business processes in company management (Karmanov et al., 2021)	II - Indirect relationship with characterization of Industry 4.0	Business Modeling
89	Paraná economic growth: an approach with the GWR model (Silva & Alves, 2021)	II - Indirect relationship with characterization of Industry 4.0	Regional Economic Growth
17	Proposal of digital twin for testing and measuring of transport belts for pipe conveyors within the concept Industry 4.0 (Fedorko et al., 2020)	II - Indirect relationship with characterization of Industry 4.0	Digital Twin Proposal for Industry Component
90	Scale of Organizational Structure Components (OCEO): validation evidence of a theoretical model (Trigero-Fernandes et al., 2020)	II - Indirect relationship with characterization of Industry 4.0	Organizational Structure

20	Smart mining policy: Integrating fuzzy-VIKOR technique and the Z-number concept to implement industry 4.0 strategies in mining engineering (Poormirzaee et al., 2022)	II - Indirect relationship with characterization of Industry 4.0	Smart Mining Policy
22	Toward a new era of cooperation: How industrial digital platforms transform business models in Industry 4.0 (Veile et al., 2021)	I - Direct relationship with characterization of Industry 4.0	Definition and characterization of Industry 4.0

Source: Prepared by the author

According to Table 8, the third and final classification of articles is presented, which is called PHASE III. At this stage, the 6 articles in Group I that have a direct relationship with the characterization of Industry 4.0 are classified, which can be used in this study as a source of data comparison that leads us to achieving the objectives of this bibliometric research, which are highlighted in Picture 3.

Picture 3: Article classification funnel



Source: Prepared by the author

Publications classified in Phase III represent the greatest interest for this bibliometric study. Article ID2 by Ghobakhloo et. al (2021) presents a bibliometric and systematic review of the concepts that they determine as “value drivers”, both in the aspect of sustainability, as well as implementation success. It is worth highlighting the fact that Morteza Ghobakhloo, of Lithuanian origin, is the author of several recent research studies on Industry 4.0. Article ID3 by Culot et. al (2020) presents an analysis of what they call “open questions” that are behind

the definition of Industry 4.0, being an Italian vision of the original German concept, Industrie 4.0, correlated with the analysis of almost one hundred definitions and concepts used for Industry 4.0. In this work, the authors claim to “break each definition into underlying technological and non-technological elements” serving as a basis for categorization. Article ID13 by Ferreira et. al (2022) presents the context of Industry as a business model. Article ID18 by Dreyfus et. al (2021) presents a methodological model that guarantees the maintenance of an industrial model based on data in order to ensure that, over time, there are no deviations that move the sample away from the fundamental concepts of the Industry 4.0 target. Article ID22 by Veile et. al (2021) presents a German study that aims to establish a new era of cooperation using digital platforms capable of transforming the business model of industries through digital platforms and the industrial internet of things (IIot). Finally, article ID54 by Germano et. al (2022) presents a Brazilian view on the impacts of Industry 4.0 technology in the context of sustainability through the application of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology to other existing research.

If a parallel is drawn between articles ID2 and ID3, and even considering that they are bibliometric research with different time frames, a significant number of keywords are repeated in the interest of characterizing the elements of Industry 4.0, namely: Sustainability, Digitalization, Fourth Industrial Revolution, Sustainable Development, Machine Learning, Industrial Internet of Things, Smart Manufacturing, Innovation, Innovation Management, Digital Transformation.

Regarding research gaps, it is clear that, of the twenty articles classified in Phase III, 38 research gaps for future studies are recorded, as can be seen in Table 9. For the purpose of control and indication for future studies, all gaps mapped in the articles classified in Phase III were registered with an “ID” identifier from number 1 to number 38.

Table 9: Research gaps of selected articles

Article ID	Author, Year	Research Gap	Gap ID
2	Ghobakhloo et al., 2021	How can Industry 4.0 contribute to the sustainable industrialization of less developed economies?	1
		How does Industry 4.0 stand in relation to continuing inequality on a global scale?	2
		To what extent can Industry 4.0 contribute to sustainable consumption behavior at the smart consumer level?	3

		Do smarter, more complex, personalized, yet more affordable products, thanks to the advantages of Industry 4.0, cause over consumption and rebound effect?	4
		What is the role of Industry 4.0 in making human settlements and cities sustainable?	5
		Industry 5.0 initiatives focusing on sustainability and the human being as a strategic priority for future industries (European Commission proposal): How does Industry 4.0 position itself against the polarization of the labor market? How is Industry 4.0 positioned against the issue of the digital divide and the risk of social disruption? How can human-centered solutions and ethical behavior be introduced in Industry 4.0 and its digital technologies?	6
3	Culot et al., 2020	Current definition ambiguity, comparing Industry 4.0 with other concepts (e.g. smart manufacturing, cloud manufacturing, etc.)	7
		The definitional dimensions and sub-dimensions characterizing Industry 4.0 in technological and non-technological aspects.	8
		Define the theoretical foundations of Industry 4.0.	9
14	Keband, 2022	Identification of IIot-centered solutions from a forensic point of view.	10
		Changing IIoT ecosystems are bereft of digital forensics – complexity due to device regulation, integration process and technological evolution.	11
		As OT and IT persist, stipulate technical baselines that can bring processing models closer to integration points given what is sometimes a case of distributed systems.	12
		Lack of forensic approach centered on IIot or future manufacturing 4.0 which makes it difficult to detect attacks.	13
18	Dreyfus et al., 2021	The links between solution elements selection and CD characteristics needs to be developed more.	14
		More advanced methods to identify CD characteristics should be explored.	15
		The methodology should be adapted for extreme constraints such as limited measurement possibility.	16
22	Veile et al., 2021	Shed light on pre-phases, e.g., analyzing strategies on how to attract new users from a provider's perspective.	17
		Longitudinal studies would extend our study's perspective and help uncover temporal variations in relationships and BMs.	18
		Analyze platforms that were not successful and that disappeared over time, uncovering success determinants.	19
		Studies quantitatively may verify our results in terms of BM changes and also may focus on efficiency gains in information sharing, growth in value creation, and decreases in transaction costs.	20
		Examine to what extent platforms have the potential to transform the holistic industrial value creation structure and, therefore, bridge macro- and micro perspective.	21
		Investigate how results differ for varying platform characteristics, e.g., platform size.	22
		Investigate platform agreements that require additional considerations.	23

		Investigating platforms are part of wider ecosystems, but their interplay with the environment and their underlying dynamics are not understood fully yet, calling for further research efforts to gain a comprehensive picture.	24
		Develop a consensus definition of platform that synthesizes existing definitions and develops a comprehensive classification scheme for platform BMs, thereby advancing the current state of research.	25
24	Cao et al., 2021	Investigating a computer-aided biological prototype modeling approach capable of providing accessible scientific knowledge for engineering applications would provide an efficient measure for designers to define and solve design problems in analog biological processes.	26
		Use other methods designed to support the MCDM process for comparison with the proposed evaluation method to develop more sophisticated evaluation approaches.	27
		Investigate how Industry 4.0 enabling technologies, such as DT, have the potential to solve design problems in other phases of the smart product.	28
54	Germano et al., 2022	Impacts of industry 4.0 on sustainability, especially regarding the exploration of implementation experiences already implemented, so that one has access to real results and that knowledge of these results enables both safer decision-making by organizations that study the possibility of becoming adapt to this new context, in terms of support for the creation of public policies that favor the best scenario, by government officials.	29
84	Ferlito and Faraci, 2021	Use the methodology to understand the applicability and appropriateness of our framework in different contexts and smaller and larger companies.	30
		Develop a metrics system for each element of the framework to measure value delivery and value captured by the business. Consequently, this could lay the groundwork for future quantitative SBMI studies, a segment of business model studies that is less important than qualitative empirical studies.	31
85	Schiavon et al., 2021	Separately analyze each component and dimension of BMs in different contexts considering significant changes, such as those caused by the COVID-19 pandemic.	32
		In-depth investigation of agency and governance aspects and the relationship between agroecosystem actors in the global south.	33
86	Filassi et al., 2021	Explain complex problems in agribusiness systems through the evaluation of cradle-to-grave and internal market SSC, as well as the comparison of Brazilian SSC with other countries of similar territorial extension and strong agricultural competitiveness, such as the USA.	34
87	Nascimento et al., 2022	Study ecosystems established by the maturity of university-industry collaboration in the world and adopt them as a reference to seek to adapt the main characteristics for the creation of a model or guideline for the Brazilian context, considering the results of this article.	35
90	Trigero-Fernandes et al., 2020	Develop path analyzes among the six latent components to verify possible causal relationships between them.	36
		Check the ability of these six components to relate to elements that influence the organizational structure, such as commitment, strategy, environment, size, technology and strategic choice.	37
		Replication of this scale for other samples in different contexts (such as: sectorial, regional and cultural) to verify its generalization and replicability.	38

Source: Prepared by the author

It is worth highlighting the fact that four publications (20% of the total) account for 58% of the research gaps, with emphasis on the publication by Veile et al. (2021), which, alone, represents 24% of the recorded research gaps. On the other hand, eight publications (40% of the total) do not present a research gap.

Final considerations

The present study sought, as a general objective, to analyze international and national scientific production related to the term Industry 4.0. Among the specific objectives, we sought to compare foreign and Brazilian academic productions, seeking to identify the most cited keywords and the record of elements that may present the characteristics of Industry 4.0. For this, a quantitative research approach was used, using bibliometric research as a method for analyzing scientific production in the period from 2018 to 2022.

The evidence from this bibliometric review indicates that the results of the three phases of article classification, namely: in Phase I (exclusion criteria), the use of 24.1% of the articles were found (22 in total); in Phase II (reading the abstract), 90.1% of the articles classified in Phase I were used (20 in total); in Phase III (article reading), there was use of 30% of the articles classified in Phase II (6 in total). Those classified in Phase III are those that represent a high correlation with the objective of this study.

This study demonstrates that scientific publications from the analyzed period strive to offer the academic and professional community, both in theoretical and practical terms, a clear and unified definition of Industry 4.0. Through the articles classified in this research, it can be concluded that there is a repeatability of keywords about Industry 4.0 in bibliometric studies, whether they come from research directly related to characterization, or from indirect research that presents a specialized technoscientific approach. Furthermore, twelve studies present 38 gaps capable of deepening a more detailed analysis of the characteristics of Industry 4.0 in theoretical and practical terms. Based on Picture 2, we present the 10 most used keywords in the context of research on Industry 4.0, which are: Sustainability, Digitalization, Fourth Industrial Revolution, Sustainable Development, Machine Learning, Industrial Internet of Things, Smart Manufacturing, Innovation, Innovation Management and Digital Transformation.

There is a limitation of this study regarding the analysis of the evolution in publications by Brazilian authors on the characterization of Industry 4.0, in relation to authors of other nationalities. The study by Ghobakhloo et al. (2021) points out that 4.08% of

researchers on the characterization of the term Industry 4.0 are of Brazilian nationality (7th position behind Germany, Italy, United Kingdom, India, United States and China). This study shows that 40% of researchers are of Brazilian nationality (1st position ahead of Canada, Italy, Sweden, Australia, China, Germany, Iran, Lithuania, Norway, Russia, Slovakia and Switzerland). However, this study cannot infer that there was an increase in the number of publications by Brazilian authors on the characterization of Industry 4.0, thus, there is a research gap with a view to identifying/mapping the evolution of publications by Brazilian authors on the characterization of Industry 4.0 in relation to authors of other nationalities, grouped by stakeholders and/or international blocks or not.

Still as a future research agenda, we intend to deepen the analysis of the technological and non-technological elements of Industry 4.0 and their impacts in the context of sustainability and other strategic issues of the top management of organizations, in this study mapped as Gaps ID7, ID8, ID9 and ID29 in Table 9.

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3 ARTICLE #2:

The Technological and Non-Technological Elements of Industry 4.0: a bibliographic study and a theoretical model

Os Elementos Tecnológicos e Não Tecnológicos da Indústria 4.0: um estudo bibliográfico e um modelo teórico

Los Elementos Tecnológicos y No Tecnológicos de la Industria 4.0: un estudio bibliográfico y un modelo teórico

ABSTRACT:

Originality/Value: This research has the general objective of reviewing the theoretical foundations of Industry 4.0 and its interface with technological and non-technological elements. Regarding specific objectives, we intend to further investigate the following gaps in the research by Culot et. al (2020): current definitional ambiguity, comparing Industry 4.0 with other concepts, for example, smart manufacturing, cloud manufacturing, etc.; the defining dimensions and sub-dimensions that characterize Industry 4.0 in technological and non-technological aspects; identification of the theoretical foundations of Industry 4.0.

Design/Methodology/Approach: To respond to these gaps, it was decided to carry out a historical analysis through qualitative research, using bibliographic research as a method for analyzing scientific production in the period from 2018 to 2023. As a source of articles, scans were carried out in academic databases, Science Direct, Scielo, Spell and Google Scholar. 232 articles were selected and another 16 articles among the most cited on Google Scholar, thus, totaling 248 scientific articles analyzed.

Results: As the main evidence of this bibliographical review, Germany's leading role in pioneering research, in the development of public policies and in the vanguardism of globally recognized German companies and organizations stands out; the movement of Chinese and Korean industry towards the challenges of Industry 4.0 based on the German model; the description of the technological and non-technological elements of Industry 4.0; and the presentation of a theoretical model composed of eighteen descriptive attributes as a reference

for Industry 4.0. As a future research agenda, it is suggested to explore the theoretical description and empirical value of each technological element of Industry 4.0.

Keywords: Industry 4.0; Fourth Industrial Revolution; Elements; Attributes; Historical-Integrative Review.

RESUMO:

Originalidade/Valor: Este trabalho tem como objetivo geral revisar os fundamentos teóricos da Indústria 4.0 e sua interface com elementos tecnológicos e não tecnológicos. Quanto aos objetivos específicos, pretendemos investigar mais profundamente as seguintes lacunas na pesquisa de Culot et. al (2020): ambiguidade de definição atual, comparando a Indústria 4.0 com outros conceitos, por exemplo, manufatura inteligente, manufatura em nuvem, etc; as dimensões e subdimensões de definição que caracterizam a Indústria 4.0 em aspectos tecnológicos e não tecnológicos; identificação dos fundamentos teóricos da Indústria 4.0.

Design/Metodologia/Abordagem: Para responder a essas lacunas, optou-se pela execução de uma análise histórica através de uma pesquisa de abordagem qualitativa, utilizando a pesquisa bibliográfica como método para análise da produção científica no período de 2018 a 2023. Como fonte de artigos, as varreduras foram realizadas nas bases de dados acadêmicas, Science Direct, Scielo, Spell e Google Acadêmico. Foram selecionados 232 artigos e mais 16 artigos entre os mais citados do Google Acadêmico, totalizando assim 248 artigos científicos analisados.

Resultados: Como principais evidências desta revisão bibliográfica, destaca-se o protagonismo da Alemanha no pioneirismo das pesquisas, no desenvolvimento de políticas públicas e no vanguardismo de empresas e organizações alemãs globalmente reconhecidas; o movimento da indústria chinesa e coreana frente aos desafios da Indústria 4.0 pautados no modelo alemão; a descrição dos elementos tecnológicos e não tecnológicos da Indústria 4.0; e a apresentação de um modelo teórico composto de dezoito atributos descritivos como referência para Indústria 4.0. Como agenda de pesquisa futura, sugere-se explorar a descrição teórica e o valor empírico de cada elemento tecnológico da Indústria 4.0.

Palavras-Chave: Indústria 4.0; Quarta Revolução Industrial; Elementos; Atributos; Revisão Histórica-Integrativa.

RESUMEN:

Originalidad/Valor: Esta investigación tiene como objetivo general revisar los fundamentos teóricos de la Industria 4.0 y su interfaz con elementos tecnológicos y no tecnológicos. En cuanto a objetivos específicos, pretendemos investigar más a fondo las siguientes lagunas en la investigación de Culot et. al (2020): ambigüedad definitoria actual, comparando Industria 4.0 con otros conceptos, por ejemplo, fabricación inteligente, fabricación en la nube, etc.; las dimensiones y subdimensiones definitorias que caracterizan a la Industria 4.0 en aspectos tecnológicos y no tecnológicos; identificación de los fundamentos teóricos de la Industria 4.0.

Diseño/Metodología/Enfoque: Para dar respuesta a estos vacíos, se decidió realizar un análisis histórico a través de una investigación cualitativa, utilizando la investigación bibliográfica como método de análisis de la producción científica en el período 2018 a 2023. Como fuente de artículos se realizaron escaneos en bases de datos académicas, Science Direct, Sciello, Spell y Google Scholar. Se seleccionaron 232 artículos y otros 16 artículos entre los más citados en Google Scholar, totalizando así 248 artículos científicos analizados.

Resultados: Como principal evidencia de esta revisión bibliográfica destaca el papel protagónico de Alemania en la investigación pionera, en el desarrollo de políticas públicas y en el vanguardismo de empresas y organizaciones alemanas mundialmente reconocidas; el movimiento de la industria china y coreana hacia los retos de la Industria 4.0 basada en el modelo alemán; la descripción de los elementos tecnológicos y no tecnológicos de la Industria 4.0; y la presentación de un modelo teórico compuesto por dieciocho atributos descriptivos como referencia para la Industria 4.0. Como agenda de investigación futura, se sugiere explorar la descripción teórica y el valor empírico de cada elemento tecnológico de la Industria 4.0.

Palabras Clave: Industria 4.0; Cuarta Revolución Industrial; Elementos; Atributos; Revisión Histórico-Integrativa.

Introduction

The term “Industry 4.0” emerged in Germany in 2011 with the original title “Industrie 4.0” being presented as the reality of the fourth industrial revolution capable of generating new trends in emerging and disruptive information technology and intelligence. (GERMANO et al. 2021). Ghobakhloo et al. (2021) states that, although there are several publications that detail the concept, application and elements of Industry 4.0, it is clear that there is still

difficulty in clarifying the objectives, and mainly in the results to be expected from Industry 4.0.

The CNI – Industrial Brazilian Confederation (2023) states that, in Brazil, it is the profile of medium and small industries to have less flexible specialized equipment, which restricts integration and external connection, and that, in terms of investment in technology, we are on average ten years behind in relation to other OECD - Organization for Economic Development Cooperation - countries, with an emphasis on connecting existing automation to digital processes such as 5G and big data analytics.

Ghobakhloo et al. (2021) states that research and studies prior to its publication offer promising contributions to the advancement of what he calls the “Industry 4.0 discipline”, but on the other hand, he ratifies that the *status quo* is a question that remains relatively unanswered, particularly, on how Industry 4.0 and the underlying digital technologies can contribute to various aspects of sustainable development. Culot et al. (2020) in turn, states that as research on Industry 4.0 advances, it is necessary for the business community to align two implications arising from their study: that Industry 4.0 requires a specific approach to its context, and a multidisciplinary approach to Description. In the meantime, Culot et al. (2020) states that “the technological landscape of Industry 4.0 is still in a state of confusion”. For Veile et al. (2021), Industry 4.0 implies a comprehensive digitalization and complete interconnection of industrial value creation, including individual companies and entire chains. It also states that these implications impact the conduct of the entire production chain, such as improvements in process efficiency and advances in flexibility, agility, individualization and improvement in the quality of value offers. Keband (2022) uses the concepts of the Industrial Internet of Things (IIot), the interconnectivity of processes that he calls IT and OT (Information Technology and Industrial Operational Technology, respectively) and studies them as an Industry 4.0 approach to a kind of use of the these terms and initiatives to evolve and improve forensic techniques. In correlation with the challenges presented by the CNI (2023), Keband (2022) states that, from a cybersecurity point of view, the integration of IT and OT expands the attack surface due to the lack of acceptable strategies regarding standards and methodologies.

On October 2012, Plattform Industrie 4.0³ was created, functioning as a network that seeks to shape the digital transformation in production, seeking to elevate Germany as a major

³ The Industry 4.0 Platform network involves companies and their workforce, trade unions, associations, science and politics to promote digital transformation in Germany through the following framework: standardization; technology and research; security of networked systems; legal framework; work projects; digital business models.

competitive production center, using digitalization as a process for society as a whole that can only be achieved through research and dialogue (Plattform Industrie 4.0, 2023). According to data from this platform, the implementation of Industry 4.0 is a complex project: the more processes the economy digitalizes and connects to a network, the more interfaces emerge between the different actors.

Objective

Therefore, this article has the general objective of reviewing the theoretical foundations of Industry 4.0 and its interface with technological and non-technological elements. As for specific objectives, we intend to further investigate the gaps exposed in the research by Culot et. al (2020): current definitional ambiguity, comparing Industry 4.0 with other concepts, for example, smart manufacturing, cloud manufacturing, etc.; the defining dimensions and sub-dimensions that characterize Industry 4.0 in technological and non-technological aspects; identification of the theoretical foundations of Industry 4.0.

Methodological Procedures

To achieve the objective proposed in this study, we opted for a historical analysis through qualitative research, using bibliographical research as a method. Bibliographic research is a recommended method for analyzing scientific production, as it allows the use of materials accessible to the general public, and the published material can be a primary or secondary source (VERGARA, 2016). Its main advantage is that it allows researchers to have instruments capable of analyzing a much wider range of phenomena than they could directly research (GIL, 2017). Data collection covered academic production from the period 2018 to 2023, a period justified by the attempt to analyze, through more recent studies, the evolving trends in the market-oriented characterization of Industry 4.0.

As a source of articles, scans were carried out in academic databases: Science Direct, Scielo and Spell and search on Google Scholar. To search for articles, a combination of terms in two search strategies was used. In the first strategy in the Science Direct, Scielo, Spell and Google Scholar databases, the terms ("Industrie 4.0" OR "Industry 4.0") AND ("Concept" OR "Definition" OR "Model") AND ("2018 to 2023") AND ("review OR research"). In the second strategy in the Science Direct, Scielo and Spell databases, the same terms as the first scan were combined, however, written in Portuguese: ("*Indústria 4.0*" OR "Industry 4.0") AND ("*Conceito*" OR "*Definição*" OR "*Modelo*") AND ("*2018 a 2023*") AND ("*revisão* OR

pesquisa"). In both strategies in the Science Direct, Scielo and Spell databases, the term ("Industrie 4.0") was combined in the keyword field of the abstract. Based on these two search strategies, 238 articles were selected, including: Science Direct, capturing the first 116 articles listed on the platform; Scielo, capturing all 36 articles found on the platform; and Spell, capturing all 11 articles found on the platform; Google Scholar, capturing the 75 most cited articles on the platform, as it is shown in Table 1.

Table 1: Result of search strategies on scientific platforms

Database		Search Criteria	Total Articles Found
International	Science Direct	TITLE-KEY	116
	Scielo	TITLE-KEY	36
	Spell	TITLE-KEY	11
	Google Scholar	TITLE-KEY	75

Source: Prepared by the author

Seeking validation based on reliable research data, PHASE I of article classification began where the following exclusion criteria were established: EC1, articles only published in academic journal; EC2, time frame from 2018 to 2023 – criteria already established in the search field of research bases; EC3, research and review articles only – criteria already established in the search field of research bases; EC4, Qualis Periodical cut-off classification between classifications A, in extracts A1, A2, A3 and A4; and B1 as registered in *Qualis Periódico* (2023).

Table 2: Key words and exclusions criteria

Database	Keywords in Searches	Keywords in Abstracts	Exclusion Criteria [EC] (Classified Articles - PHASE I)
Science Direct	("Industrie 4.0" OR "Industry 4.0") AND ("Concept" OR "Definition" OR "Model") AND ("2018 to 2023") AND ("review OR research")	("Industrie 4.0")	- EC1: Journal articles only - EC2: Time Frame: 2018 a 2023* - EC3: Research and review articles only* - EC4: Quality Frame: A to B1**
Scielo			
Spell			
Google Scholar			

Source: Prepared by the author

Afterwards, the summaries and registration of all articles classified in Phase I began to be read. In Picture 1, you can see the model form used to register articles in what is called PHASE II of classification, through reading the summary.

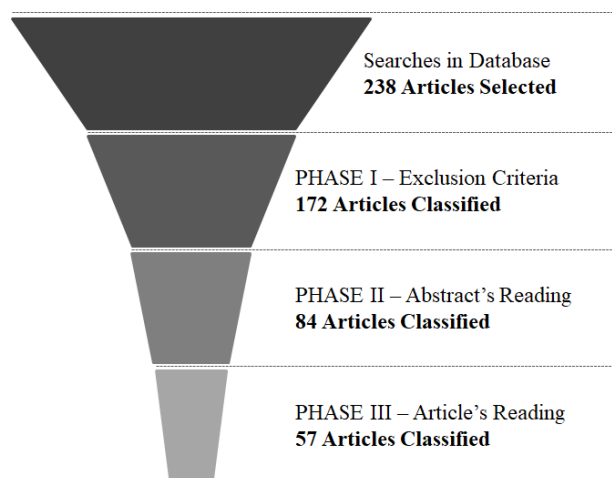
Picture 1: Scientific article registration form

SCIENTIFIC ARTICLE FORM	
Title:	<i>Transcribed the official title</i>
ID Number:	<i>Defined a protocol number to identify the article in this research</i>
Journal:	<i>Transcribed the name of the journal where the article was published</i>
Database:	<i>Transcribed the name of the research platform</i>
Publication Year:	<i>Transcribed the year of publication</i>
Author/Nationality:	<i>Transcribed the names and nationality of the authors</i>
Keywords:	<i>Transcribed the keywords of the article</i>
Abstract:	<i>Transcribed article abstract</i>

Source: Prepared by the author

By reading the summaries of the 172 articles classified in Phase I, 57 of them were classified as relevant to this bibliographic research, which will be fully reviewed in order to identify: the research excerpts, the proposals for characterizing the central theme, and the characterization correlations with their respective references.

Picture 2: Article classification funnel



Source: Prepared by the author

Bibliographic Review

In this section, the dialogue between the authors referenced in this research will be presented, seeking to establish the elements of foundation and characterization of Industry 4.0 and the relations of ambiguity in the terms presented by them.

1. History and Definitions of Industry 4.0

The first industrial revolution occurred in Europe in the second half of the 18th century (between 1700 and 1860), with the installation of mechanical production, revolutionizing the means of production driven by steam engines, hydraulic energy and mechanization. The second industrial revolution occurred in the United States from 1870 (until 1969), with the electrification and division of labor, a phase that marks the implementation of Taylorism and the beginning of the assembly lines and mass production by Henry Ford. The third industrial revolution occurred around 1970, also called the digital revolution, where the use of advanced electronics and technological information brought a great leap forward in industrial automation. At this time, machines began to have a greater proportion between “manual” work and “intellectual” work. The fourth industrial revolution arises with the advancement of the internet and robotic intelligence with the concept of an intelligent production model, capable of promoting information management and business strategies through data integration, optimizing and facilitating operations across the entire chain of manufacturing, aiming to develop a project to increase productivity and sales in German industry. This fourth industrial revolution was originally called in German as “Industrie 4.0” and translated throughout the world from the English term, “Industry 4.0” (CORDEIRO et. al 2023; GERMANO et. al 2021; GHOBAKHLOO et. al 2021; VEILE et. al 2021; FUCHS 2018; COSMIUC and PETRISOR 2018).

Kagermann and Wahlster (2022) present in their research the beginnings of publications on the term Industry 4.0, giving it a historical record of its birth in the face of the three previous industrial revolutions. According to these authors, the initial article on Industry 4.0 and the Internet of Things towards the fourth industrial revolution was published in German, on April 1, 2011, shortly before the opening of the Hanover Fair under the impact of the global financial crisis, and with the motivation of making the German economy more resilient and competitive through adaptability and resource efficiency. Fuchs (2018), in addition, presents the concept of Industry 4.0 based on the five years prior to his research - 2013 to 2017, where, according to this author, was the period of great discussions among

Germans in order to ratify the terms Industry 4.0 and Industrial Internet of Things (IIoT), as constituent elements of the fourth industrial revolution. According to its definition, Industry 4.0 is a context that propagates the combination of the Internet of Things, Big Data, social media, cloud computing, sensors, artificial intelligence, robotics and the application of the combination of these pillars to production, distribution and use of physical goods.

According to data from Plattform Industrie 4.0 (2023), through the publication called “2030 Mission Statement for Industry 4.0”, Industry 4.0 refers to an intelligent network of machines and processes in industry with the help of information and communication technology, and in this context, the central technology is not the computer, but the internet. This is how the term Internet of Things (IoT) arises, which, in industry, refers to machine-to-machine communication and production facilities that are becoming increasingly intelligent. Cozmiuc and Petrisor (2018) state that Industry 4.0 was presented in 2013 as a proposal, referring to possible future technologies and business models that could make production in high-cost countries, such as Germany and the United States, competitive and profitable. For Lee et. al (2022), Industry 4.0 represents the interconnection of people, objects and intelligent machines, the use of service-oriented architectures and the composition of services and data from different sources into new business processes, and by making a critical analysis of the Chinese industry. He states that, in the beginning, it was just a technological revolution in the automation infrastructure with pre-determined results for machines and self-adaptive learning environments. However, through research on the topic from a “future of the manufacturing industry”, new responses were given to the concept previously practiced, moving towards digitalization and new business models that create values at the same time. The authors state that, since then, “Industrie 4.0” has become a buzzword in China, and there has been a rush to learn, implement and practice Industry 4.0 technologies and methodologies in industry.

According to data published in Plattform Industrie 4.0 (2023), when referring to “what is Industry 4.0?”, it states that “people, machines and products are directly linked to each other: the fourth industrial revolution has begun!”. As seen so far, most scholars understand Industry 4.0 as a transformation process that leads to smarter factories and smarter products. Given this, the first hypothesis is presented.

Hypothesis H1: the level of social development in each region of Brazil influences the evolution of Industry 4.0.

Aiming to enable execution in practical terms, data from Plattform Industrie 4.0 (2023) informs that there are many ways for companies to use smart networks, and these possibilities are presented in Table 3.

Table 3: Ways for companies to use smart grids

1	Flexible Production	Many companies are involved in the production of a product and contribute step by step to the creation of a product. Connected digitally, these steps can be better coordinated and the use of machines can be better planned.
2	Factory Convertible	In the future, production lines will be built in modules. They can be quickly assembled for a task. Productivity and cost-benefit ratio are improved, individualized products can be manufactured in small quantities at affordable prices.
3	Customer-Centered Solutions	Consumers and producers are getting closer. Customers can help design products according to their wishes - for example, sneaker elements themselves can be designed and adapted to the individual shape of the foot. At the same time, smart products that have already been delivered and in use can send data to the producer. With usage data, the producer can improve its products and offer new services to the customer.
4	Optimized Logistics	Algorithms calculate optimal delivery routes, machines independently inform you when they need new material – the smart network enables an optimal flow of goods.
5	Use of Data	Data about the production process and the status of a product are gathered and evaluated. Data analysis provides insights into how a product can be manufactured more efficiently. Even more important: it is the basis for completely new business models and services. For example, elevator manufacturers can offer their customers “predictive maintenance”: elevators are equipped with sensors that continuously send data about their condition. Wearing out can be detected and resolved before it causes elevator failure.
6	Circular economy that saves resources	Products are visualized throughout their entire lifecycle based on data. The way in which materials can be recycled is already determined in the project.

Source: Plattform Industrie 4.0

Cozmiuc and Petrisor (2018) report in their research that Siemens claims to already be a world leader in automation, and that it also intends to be a world leader in digitalization. To this end, in 2013, Siemens presented its intention to shape and lead Industry 4.0, and defined the characterization bases for Industry 4.0.

Table 4: Characterization of Industry 4.0 by Siemens

1	Communities of machines that organize themselves.
2	Products and machines that communicate with each other and exchange commands.
3	Unfinished products that send the data necessary for their processing to machines.
4	Factories that optimize and control their processes largely by themselves.
5	Supply chains that automatically cooperate with each other.
6	Software for interconnection between development, production and maintenance of a product.
7	They present a level of organization and control of the entire value chain throughout the product life cycle.
8	It covers all phases, from idea and order to development and production, delivery of a product to the end customer, to recycling of related services.
9	Increasingly oriented to the individualized desires of customers.

Source: Cosmiuc and Petrisor (2018) – adapted by the author

2. Industry 4.0 Interfaces

The articles classified for this research point to Industry 4.0 interfaces with technological elements, called “technologies” or “pillars”, and non-technological elements, these mainly linked to “human interface in the process”. Table 5 and Graph 1 present the main technological interface elements with Industry 4.0. In this list, the order of citation of each technological element in the aforementioned article was respected, and organized in the table in order of publication, from oldest to newest.

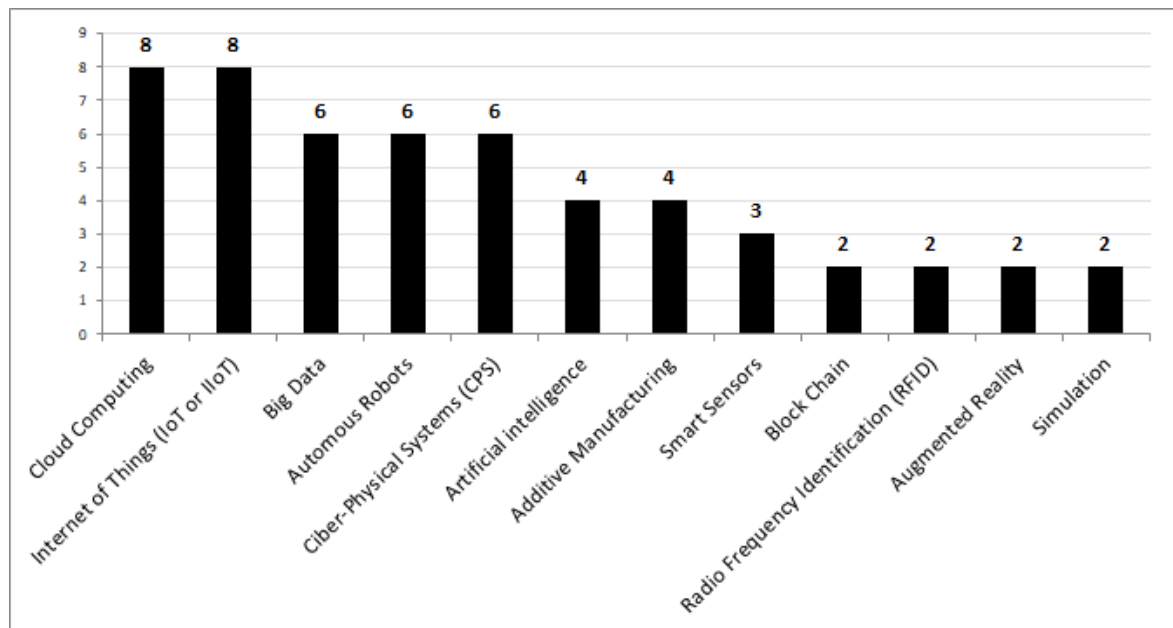
Table 5: Technological interface elements with Industry 4.0

Author(s)	Year	Country	Technological Elements
Fuchs	2018	Germany	Internet of Things, Big Data, Social Media, Cloud Computing, Sensors, Artificial Intelligence, Robotics.
Kamble et. al	2018	Estados Unidos	Cyber-Physical Systems, Cloud Computing, Internet of Things.
Tim Stock et. al	2018	Germany	Cyber-Physical Systems, Cloud Computing, Digital Twin.

Vaidya et. al	2018	India	Big Data, Autonomous Robots, Simulation, Integration Systems, Internet of Things, Cyber-Physical Systems, Cloud Computing, Additive Manufacturing, Augmented Reality.
Müller et. al	2019	Germany	Cyber-Physical Systems, Internet of Things, Smart Manufacturing.
Saniuk et. al	2021	Poland	Cyber-Physical Systems, Internet of Things, Cloud Computing, Cognitive Computing, Artificial Intelligence.
Teixeira and Tavares-Lehmann	2022	Brazil and Portugal	Autonomous Vehicles, 3D Printing, Advanced Robotics, New Materials, Internet of Things, Data, Blockchain, Sensors, Radio Frequency Identification, Digital Platforms, Research Biology, Genetics and Nanotechnology.
Cannavacciuolo et. al	2023	Italy	Massive Digitalization, Big Data, Advanced Robotics, Adaptive Automation, Additive Manufacturing, Precision Manufacturing, Modeling and Simulation, Artificial Intelligence, Nanotechnology Materials.
Cordeiro et. al	2023	Brazil	Radio Frequency Identification, Big Data, Cloud Computing, Smart Sensors, Machine Learning, Robotics, Additive Manufacturing, Artificial Intelligence, Augmented Reality, Internet of Things.
Peter et. al	2023	South Africa	Cyber-Physical Systems, Internet of Things, Big Data, Cloud Manufacturing, Virtual and Augmented Reality, Advanced Robotic Systems, Additive Manufacturing and 3D Printing Technology.
Sreenivasan and Suresh	2023	India	Additive Manufacturing, Big Data, Blockchain, Cloud, Industrial Internet of Things, Simulation.

Source: Prepared by the author

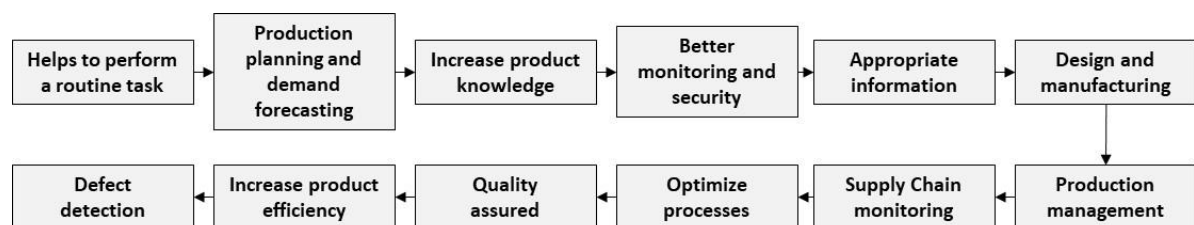
Graph 1: Technological interface elements with Industry 4.0 with repeatability



Source: Prepared by the author

In his research, Fuchs (2018) presents the term Industry 4.0 as a “German ideology” that seeks to create a new technological paradigm that promises economic growth. With the economic results of German industry in hand, Fuchs (2018) presents a list of ten reasons why someone should be skeptical about Industry 4.0, and concludes his work by stating that, 170 years after the publication “The German Ideology” written by Karl Marx and Friederich Engels, “we live in the age of digital capitalism that has created its own peculiar forms of ideology”, and defines that: “Industry 4.0 is an ideological ghost formed in the collective brain of the contemporary bourgeoisie” and that “aims to promote new forms of accumulation, control and class struggles from above”. However, Javaid et. al (2022), make an analysis from a completely opposite point of view, proposing that Artificial Intelligence (AI) is the main contribution to the recent development of Industry 4.0, and in this way, industries are focused on improving the consistency of products, productivity and reduced operational costs, and they want to achieve this through the collaborative partnership between robotics and people. The authors also state that AI technologies are gradually achieving the objectives of Industry 4.0, for the most part, through the massive use of algorithms that help predict changes and thus, enable decision-making based on a competitive management model – a view similar to that of Peinl et. al (2023) who present an empirical study of the implementation of the MES system (Manufacturing Execution System) as a proposed solution for Industry 4.0 based on algorithmic software for executing the strategic operational planning of small and medium-sized companies. Picture 3 presents significant AI applications for implementing Industry 4.0.

Picture 3: Artificial intelligence applications for implementing Industry 4.0



Source: Javaid et. al (2022) – adapted by the author

Given this, the second hypothesis is presented.

Hypothesis H2: in Brazil, there is a relevant gap in adherence to the technological elements of Industry 4.0.

Non-technological interfaces are linked to the interrelationship of the human factor in the Industry 4.0 process. For LPB da Silva et. al (2022), based on the changes caused by the technological interfaces of Industry 4.0, it becomes necessary to understand how these changes affect people management, including the application of digital technologies to their routine tasks. As already seen here, if the objective is to reach the pinnacle of a smart factory and products, Butschan et. al (2019) state that it is necessary to develop cognitive and procedural skills in individuals who promote digital transformation processes in the industry, and in the meantime, these authors state through their research that “surprisingly, social skills have only a small influence on the implementation of technologies IIoT”. In this same approach to development for continuous improvement of people and processes, Arey et. al (2019) present an analysis of lean manufacturing as a digital value stream for process improvement, presenting data from their research that “Lean Manufacturing and Industry 4.0 can be presented as antecedent and precedent, the former as a facilitator of the latter and reciprocally”.

The research by Teixeira and Tavares-Lehmann (2022) brings to light a non-technological element focused on national policies and strategies in a study applied in the European Union. Its emphasis is based on the principle that the digitalization of processes in Industry 4.0 “directly affects markets, the job market and social structures”. This research compared exclusive public policies to the development of Industry 4.0 in 27 European countries, emphasizing the pioneering policies of the German government, creating a state agenda based on three axes: growth and employment; access and participation; trust and security. In this research, there is also emphasis on the work promoted by Plattform Industrie 4.0 due to the “relevance of international cooperation” since “the challenges for consolidating Industry 4.0 cross borders, and the digitalization of production occurs throughout the entire value chain”. In Table 6, there is a summary with the elements of Industry 4.0.

Table 6: Elements of Industry 4.0

TECHNOLOGICAL ELEMENTS	NON TECHNOLOGICAL ELEMENTS
1. Cloud computing 2. Internet of Things (IoT or IIoT) 3. Big Data 4. Atonomous Robots 5. Cyber-Physical Systems (CPS) 6. Artificial intelligence 7. Additive Manufacturing 8. Smart Sensors 9. Block Chain 10. Radio Frequency Identification (RFID) 11. Augmented Reality 12. Simulation (Fuchs 2018; Kamble et. al 2018; Tim Stock et. al 2018; Vaidya et. al 2018; Müller et. al 2019; Saniuk et. al 2021; Teixeira and Tavares-Lehmann 2022; Cannavacciuolo et. al 2023; Cordeiro et.al 2023; Peter et. al 2023; Srenivasan and Suresh 2023)	1. Understanding how changes affect people management (LPB da Silva et. al 2022). 2. Applying digital technologies to routine tasks (LPB da Silva et. al 2022). 3. Develop cognitive and procedural skills in individuals (Butschan et. al 2019). 4. Operational excellence management model - Lean Manufacturing, as a process facilitator (Arey et. al 2019). 5. Development of strategic public policies (Teixeira and Tavares-Lehmann 2022). 6. Development of a fairer and more sustainable society by fostering a symbiotic/collaborative relationship between human and robot - Industry 5.0 (Coelho et. al 2023; Fuchs 2018; Lu et. Al 2022).

Source: Prepared by the author

Still regarding non-technological elements, the research trends of Fuchs (2018) have triggered a series of new studies presented with the concept of “Industry 5.0”. Lu et. al (2022) state that there is a lack of understanding of the essence of human-centered production, although there are significant research efforts to improve the physical and cognitive well-being of operators. Coelho et. al (2023) mention that the first research to use the term “Industry 5.0” was published in 2016, and that in 2018, it still seemed premature to establish a fifth industrial revolution. However, his research concludes that the term “Operator 4.0”, at the time used to adjust the role of the human being in a sustainable way in Industry 4.0, now permeates a scenario where the human being “returns to the industry and co-works with robots”, and in this way, the concept of Industry 5.0 overlaps with the concept of Operator 4.0 in the Industry 4.0 approach of the time. Thus, Coelho et. al (2023) conclude that Industry 5.0 is “a revolution to promote a fairer and more sustainable society, in which there is a symbiotic/collaborative relationship between the human and the machine/robot”. Given this, the third hypothesis is presented.

Hypothesis H3: in Brazil, there is a relevant gap in adherence to the non-technological elements of Industry 4.0.

3. Impacts of Industry 4.0

Fuchs (2018) states that, the German Ministry of Economy estimated that, over a period of ten years there would be a market potential for Industry 4.0 technologies of almost 45 billion euros. However, this research does not take investment costs into account and maintenance that reduce real profits, and thus, as in a marketing strategy, tend to overestimate the potential positive economic effects of their application. Sung (2018) simultaneously analyzes the Industry 4.0 scenario in South Korea with the same concern regarding the results, stating that in order to be successful, it is necessary for the central government to promote a profound review of the country's economic systems so that the industry can respond appropriately. more flexible to changes imposed by technological and non-technological elements, as well as developing concrete and viable actions for the transition of economic and social systems with a view to accommodating innovative changes, and also establishing infrastructure for the government to lead initiatives.

Regarding sustainability, Grybauskas et. al (2022) state that despite being diverse, the results of the existing literature are fragmented and quite inconsistent on the subject, and further confirm that knowledge about the social transformation of Industry 4.0 provides only “a vague understanding of the critical issues in this transformative process”, and thus, that a “complete review of the topic is highly necessary”. Along the same lines, Saniuk et. al (2022) state that the COVID-19 pandemic showed that the current level of digitalization of processes – technological elements of Industry 4.0, avoided a deep crisis in several areas of the economy and education. However, at the same time, “it exposed the problems of human adaptation to digitalization and the lack of industry resilience to the disruption of global supply chains”. Given this, the fourth hypothesis is presented.

Hypothesis H4: Brazilian industry presents difficulties in the cognitive development of its employees in light of the needs of the digitalization process.

4. Theoretical Model

Based on the references researched, the organization of a spreadsheet with eighteen descriptive attributes is presented, capable of serving as a reference to measure the status of the industry in relation to the elements of Industry 4.0 (Table 7). When evaluating a sample on each of the attributes presented, the higher its strength scale means that the closer the

sample will be to the expected results for each element of Industry 4.0. These attributes can also be considered as a basic point for exploring a scale advancement capable of measuring the evolution of Industry 4.0 in empirical terms.

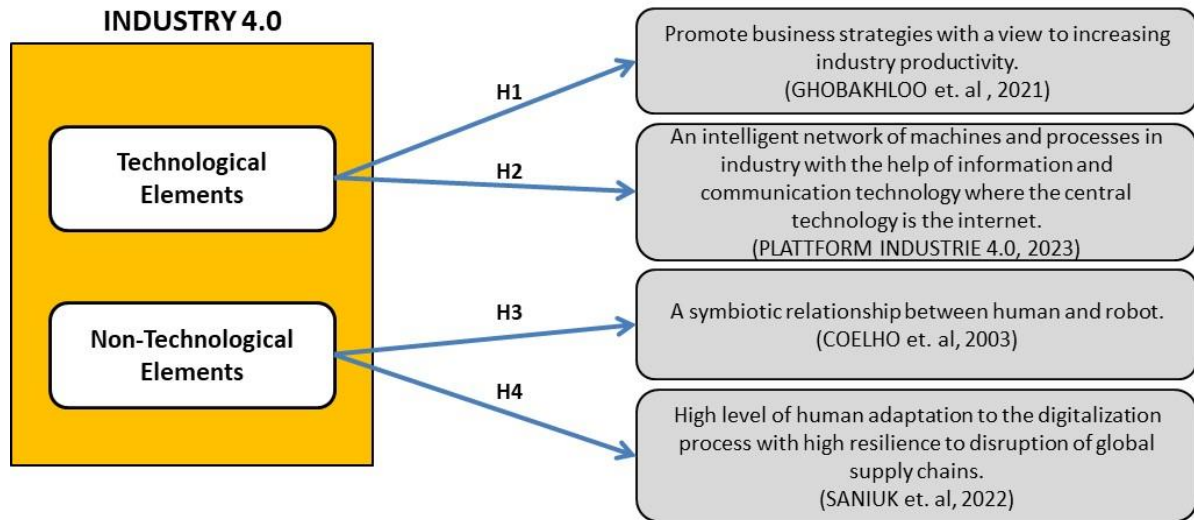
Table 7: Attributes for Industry 4.0 characterization

ELEMENT	ATTRIBUTE	SOURCE
Technological	1 - Use of Artificial Intelligence and algorithmic systems for calculation, simulation and process management.	Fuchs; Javaid et. al; Plattform Industrie 4.0; Peinl et. al; Saniuk et. al; Vaidya et. al
Technological	2 - Automation of machine information regarding unfinished product needs.	Cozmiuc e Petrisor; Peinl et. al
Technological	3 - Integrated system for product development and monitoring, delivery and recycling.	Cozmiuc and Petrisor; Plattform Industrie 4.0
Technological	4 - Use of Big Data.	Cannavacciuolo et. al; CNI; Fuchs; Sreenivasan and Suresh; Vaidya et. al
Technological	5 – Use of Autonomous Robots.	Cordeiro et. al; Fuchs; Peter et. al; Teixeira and Tavares-Lehmann; Vaidya et. al
Technological	6 – Use of Internet of Things (IoT ou IIoT).	Fuchs; Müller et. al; Plattform Industria 4.0; Peter et. al; Saniuk et. al; Vaidya et. al
Technological	7 – Use of Cloud Computing.	Fuchs; Kamble et. al; Sreenivasan and Suresh; Tim Stock et. al; Vaidya et. al
Technological	8 – Tested protocols regarding Cybersecurity.	Keband; Vaidya et. al
Technological	9 – Use of Augmented Reality.	Cannavacciuolo et. al; Cordeiro et. al; Peter et. al; Vaidya et. al
Technological	10 – Use of Additive Manufacturing.	Cannavacciuolo et. al; Cordeiro et. al; Müller et. al; Peter et. al; Vaidya et. al
Non Technological	11 – Policy for the development of cognitive and procedural skills.	Butschan et. al; Coelho et. al; Saniuk et. al
Non Technological	12 – Mapping employees' difficulties regarding the digitalization process.	Arey et. al; Saniuk et. al
Non Technological	13 – Speed of machine planning coordination.	Plattform Industrie 4.0; Veile et. al
Non Technological	14 – Active participation of customers in flexible product development.	Cozmiuc and Petrisor; Plattform Industrie 4.0
Non Technological	15 – Management model based on continuous process improvement (ex.: Lean Manufacturing).	Arey et. al; Javaid et. al
Non Technological	16 – Preparation for possible disruptions in global supply chains.	Cozmiuc and Petrisor; Saniuk et. al
Non Technological	17 – Clarity of impacts in terms of sustainability and implementation costs.	Fuchs; Grybauskas et. al
Non Technological	18 – Identification of opportunities for the development of public policies on digital transformation.	Sung; Teixeira and Tavares-Lehmann

Source: Prepared by the author

Based on the characterization of technological and non-technological elements, a theoretical model is established to correlate the hypotheses raised with the main expectations regarding Industry 4.0 (Picture 4).

Picture 4: Theoretical model for characterizing Industry 4.0



Source: Prepared by the autor

5. Final Considerations

The present study sought, as a general objective, to review the theoretical foundations of Industry 4.0 and its interface with technological and non-technological elements. As for specific objectives, we intend to further investigate the gaps exposed in the research by Culot et. al (2020): current definitional ambiguity, comparing Industry 4.0 with other concepts, for example, smart manufacturing, cloud manufacturing, etc.; the defining dimensions and sub-dimensions that characterize Industry 4.0 in technological and non-technological aspects; identification of the theoretical foundations of Industry 4.0.

As the main evidence of this bibliographical review, we can firstly highlight Germany's leading role not only in pioneering research, but also in the development of public policies for the development of Industry 4.0 by its government, which serve as a reference for international cooperation, and even in the meantime, the vanguardism of globally recognized companies, in this case Siemens, as a relevant supplier of technology for digital transformation, and likewise, Plattform Industrie 4.0, which can be seen in several references in this section: an agency development company highly recognized for its work in bilateral

collaborations. The second highlight is the movement of Chinese and South Korean industry to face the challenges of Industry 4.0 based on the German model, including presenting strategies to local governments for developing technology and flexibility for Industry 4.0 operations. The third highlight is the description of the technological interface elements with Industry 4.0 (Table 5); From the selected sources, it can be inferred that the understanding of technological elements is directly related to how much has already been researched as well as the reality of technological evolution in each country mentioned, and not necessarily in the year of publication of the aforementioned article.

The vast majority of publications selected in this research indicate that there are twelve technological elements of Industry 4.0 (Table 6), elements that were cited in full by researchers from Brazil, India and South Africa, while researchers from Germany, the United States and Poland cite a much smaller number of technological elements. Still within this highlight, this research responds to the first research gap raised by Culot et. al (2020), where through Table 5 it is clear that the terms “smart manufacturing” and “cloud manufacturing” are just two technological elements that cannot be confused with the term “Industry 4.0”, which covers ten other technological elements. In other words, equalizing these terms means empowering the terms “smart manufacturing” and “cloud manufacturing”, or reducing/simplifying the term “Industry 4.0”. The fourth highlight is the description of the non-technological interface elements with Industry 4.0 (Table 6); which, from the selected sources, can be inferred that the relationship between man versus systems and programs is the crucial point in the implementation of Industry 4.0, whether due to the impact that technological changes have on workers' routines and the quality of the organizational climate when carrying out routine tasks, mastery of public policies and involvement in operational excellence programs as facilitators of the evolution process.

Finally, this study presents in Section 4 a theoretical model composed of eighteen descriptive attributes (Table 7) that can be used in future empirical research in order to serve as a reference for measuring Industry 4.0, or represent a basic point to explore the advancement of scale into a more in-depth theoretical model. As a future research agenda, it is suggested to explore the theoretical description and empirical value of each technological element of Industry 4.0.

There is a limitation of this research regarding the study of the concept called “Industry 5.0”. There is already countless research in this regard, and while there is consensus on a definition that states studies relating to the humanization of the human-machine interface, there is great difficulty in stating that this is a new industrial revolution.

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4 ARTICLE #3:

The role of technological and non-technological elements in the evolution of Industry 4.0 in Brazil: an empirical investigation

O papel dos elementos tecnológicos e não tecnológicos na evolução da Indústria 4.0 no Brasil: uma investigação empírica

El papel de los elementos tecnológicos y no tecnológicos en la evolución de la Industria 4.0 en Brasil: una investigación empírica

ABSTRACT:

Originality/Value: This work presents itself as a process qualification roadmap, demonstrating, in practice, the distance that a given sample is in relation to the attributes for characterizing Industry 4.0. In this way, it benefits researchers interested in the topic, as well as investors, executives, engineers, specialists and consultants from different industrial segments in the search for best practices, management tools, equipment and policies for the development of Industry 4.0.

Design/Methodology/Approach: To test the influence of the hypotheses raised, it was decided to carry out quantitative research, classified as descriptive, using field surveys as an investigation method. Data collection was carried out through a structured questionnaire with a Likert scale sent to 120 companies covering the five geographic regions of Brazil, from which 100 valid questionnaires were received. The data analysis procedures are Descriptive Statistical Analysis, Multiple Linear Regression and Analysis of Variance.

Results: According to the results found, the level of social development in each region of Brazil does not influence the evolution of Industry 4.0; Brazil presents adherence gaps in the technological and non-technological elements of Industry 4.0; Brazilian industry presents difficulties in the cognitive development of its employees in the face of the needs of the digitalization process; the comparison of results by region of Brazil and by industrial segment shows a significant difference in the results of Industry 4.0.

Keywords: Industry 4.0; Technological Elements; Non Technological Elements; Brazilian Industry; Digitalization Infrastructure.

RESUMO:

Originalidade/Valor: Esse trabalho se apresenta como um roteiro de qualificação de processos, demonstrando, na prática, a distância que uma determinada amostra está em relação ao modelo teórico de caracterização da Indústria 4.0. Dessa forma, beneficia pesquisadores interessados no tema, bem como a investidores, executivos, engenheiros, especialistas e consultores dos diversos segmentos industriais na busca por melhores práticas, ferramentas de gestão, equipamentos e políticas para o desenvolvimento da Indústria 4.0.

Design/Metodologia/Abordagem: Para teste da influência das hipóteses levantadas, optou-se pela execução de uma pesquisa quantitativa, classificada como descritiva, utilizando o levantamento de campo como método de investigação. A coleta de dados foi feita através de um questionário estruturado com escala Likert enviado a 120 empresas contemplando as cinco regiões geográficas do Brasil, as quais foram recebidos 100 questionários válidos. O procedimento de análise de dados são a Análise Estatística Descritiva, a Regressão Linear Múltipla e a Análise de Variância.

Resultados: Conforme os resultados encontrados, o nível de desenvolvimento social de cada região do Brasil não influencia a evolução da Indústria 4.0; o Brasil apresenta gaps de aderência nos elementos tecnológicos e não tecnológicos da Indústria 4.0; a indústria brasileira apresenta dificuldades no desenvolvimento cognitivo de seus colaboradores frente às necessidades do processo de digitalização; a comparação dos resultados por região do Brasil e por segmento industrial apontam diferença significativa no resultado da Indústria 4.0.

Palavras-Chave: Indústria 4.0; Elementos Tecnológicos; Elementos Não Tecnológicos; Indústria Brasileira; Infraestrutura de Digitalização.

RESUMEN:

Originalidad/Valor: Este trabajo se presenta como una hoja de ruta de calificación de procesos, demostrando, en la práctica, la distancia que se encuentra una muestra determinada en relación al modelo teórico de caracterización de la Industria 4.0. De esta manera, beneficia a investigadores interesados en el tema, así como a inversionistas, ejecutivos, ingenieros, especialistas y consultores de diferentes segmentos industriales en la búsqueda de mejores

prácticas, herramientas de gestión, equipos y políticas para el desarrollo de la Industria 4.0.

Diseño/Metodología/Enfoque: Para comprobar la influencia de las hipótesis planteadas, se decidió realizar una investigación cuantitativa, catalogada como descriptiva, utilizando como método de investigación las encuestas de campo. La recolección de datos se realizó a través de un cuestionario estructurado con escala Likert enviado a 120 empresas de las cinco regiones geográficas de Brasil, de las cuales se recibieron 100 cuestionarios válidos. Los procedimientos de análisis de datos son Análisis Estadístico Descriptivo, Regresión Lineal Múltiple y Análisis de Varianza.

Resultados: Según los resultados encontrados, el nivel de desarrollo social de cada región de Brasil no influye en la evolución de la Industria 4.0; Brasil presenta brechas de adherencia en los elementos tecnológicos y no tecnológicos de la Industria 4.0; La industria brasileña presenta dificultades en el desarrollo cognitivo de sus empleados ante las necesidades del proceso de digitalización; la comparación de resultados por región de Brasil y por segmento industrial muestra una diferencia significativa en los resultados de la Industria 4.0.

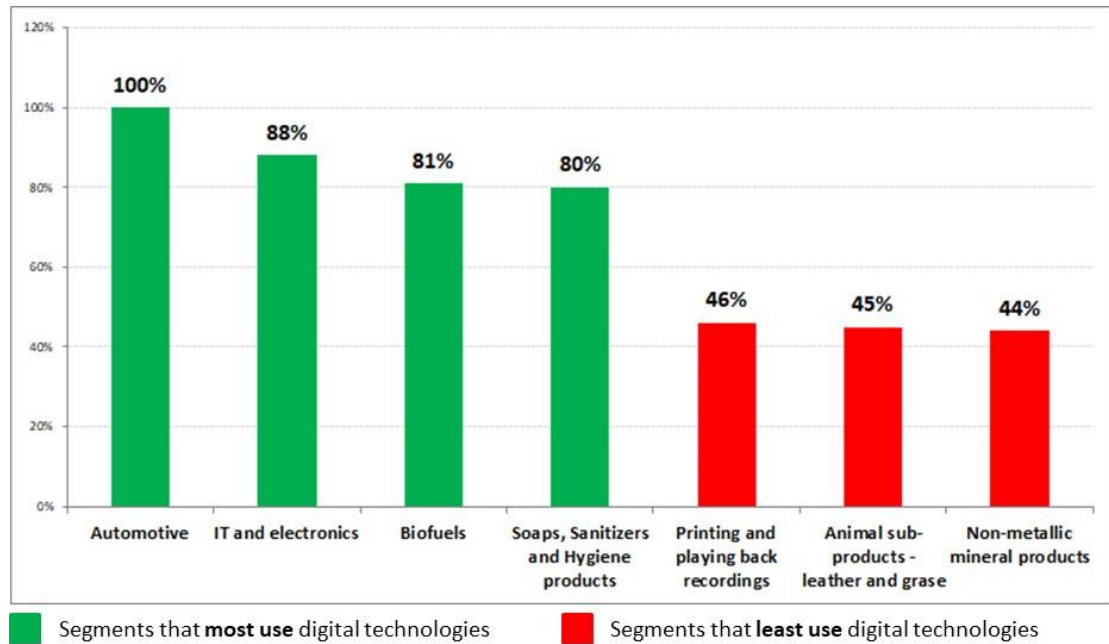
Palabras Clave: Industria 4.0; Elementos Tecnológicos; Elementos No Tecnológicos; La industria brasileña; Infraestructura de Digitalización.

Introduction

“Brazilian industry is more digital than it was five years ago. If, in 2016, less than half (48%) made use of any of the digital technologies analyzed, in 2021, the percentage rose up to 69%”. This is what the National Confederation of Industry [CNI]⁴ states, according to the work called “Industry 4.0 Special Survey” led by Samantha Cunha – Industrial Policy Manager at CNI. This research was carried out with more than a thousand companies and found eighteen types of digital technologies at different stages of the industrial production chain. Among the main benefits recognized in the adoption of these digital technologies is “advanced productivity, improved product quality and reduced production costs”. The research also states that “the complexity of digital technologies has an effect on their adoption”, and therefore, despite 69% of the sample stating that they use digital technologies, some industrial segments use a greater number of technologies in their processes, as seen in

⁴ The National Confederation of Industry (CNI) is the highest organizing institution for the Brazilian industrial sector. It coordinates a system made up of 27 industry federations in the states and the Federal District - to which 1,016 employers' unions are affiliated - and manages the National Service for Industrial Learning (SENAI), the Social Service for Industry (SESI) and the Euvaldo Lodi Institute (IEL). It was created on August 12, 1938 by an initiative of four industry federations: São Paulo, Minas Gerais, Rio Grande do Sul and Rio de Janeiro.

Graph 1.

Graph 1: Companies that use at least one digital technology

Source: CNI (2023) – adapted by the author

Regarding Industry 4.0 expectations, Ghobakhloo et. al (2021) claim to be the “promotion of business strategies with a view to increasing industry productivity”. Plattform Industrie 4.0 (2023) claims to develop “an intelligent network of machines and processes in industry with the help of information and communication technology where the central technology is the internet”. Coelho et. al (2023) state that it is “a symbiotic relationship between the human and the robot”. Finally, Grybauskas et. al (2022) state that “knowledge about the social transformation of Industry 4.0 provides only a vague understanding of the critical issues in this transformative process”.

Even in the face of technically structured expectations, some questions are raised by Industry 4.0 scholars, such as the quote from Ghobakhloo et. al (2021), who state that research and studies prior to its publication offer promising contributions to the advancement of what he calls the “Industry 4.0 discipline”. Therefore, on the other hand, he confirms that the *status quo* is a question that remains relatively unanswered , particularly, on how Industry 4.0 and the underlying digital technologies can contribute to various aspects of sustainable development. In the practical aspects of the topic, Culot et al. (2020) state that the “Industry 4.0 technological landscape is still in a state of confusion”.

Given such statements, this empirical study has the general objective of quantifying the Industry 4.0 scenario by mapping the status of technological and non-technological

elements of Brazilian industry in comparison with the attributes for characterizing Industry 4.0 presented in Table 1. As for the specific objectives, this research aims to: 1) Test the influence of the hypothesis that the level of social development in each region of Brazil influences the evolution of Industry 4.0; 2) Evaluate the assumption that in Brazil there is a relevant gap in adherence to the technological elements of Industry 4.0; 3) Evaluate the assumption that in Brazil there is a relevant gap in adherence to the non-technological elements of Industry 4.0; and 4) Evaluate the assumption that Brazilian industry presents difficulties in the cognitive development of its employees given the needs of the digitalization process.

Table 1: Attributes for Industry 4.0 characterization

ELEMENT	ATTRIBUTE	SOURCE
Technological	1 - Use of Artificial Intelligence and algorithmic systems for calculation, simulation and process management.	Fuchs; Javaid et. al; Plattform Industrie 4.0; Peinl et. al; Saniuk et. al; Vaidya et. al
Technological	2 - Automation of machine information regarding unfinished product needs.	Cozmiuc e Petrisor; Peinl et. al
Technological	3 - Integrated system for product development and monitoring, delivery and recycling.	Cozmiuc and Petrisor; Plattform Industrie 4.0
Technological	4 - Use of Big Data.	Cannavacciuolo et. al; CNI; Fuchs; Sreenivasan and Suresh; Vaidya et. al
Technological	5 – Use of Autonomous Robots.	Cordeiro et. al; Fuchs; Peter et. al; Teixeira and Tavares-Lehmann; Vaidya et. al
Technological	6 – Use of Internet of Things (IoT ou IIoT).	Fuchs; Müller et. al; Plattform Industria 4.0; Peter et. al; Saniuk et. al; Vaidya et. al
Technological	7 – Use of Cloud Computing.	Fuchs; Kamble et. al; Sreenivasan and Suresh; Tim Stock et. al; Vaidya et. al
Technological	8 – Tested protocols regarding Cybersecurity.	Keband; Vaidya et. al
Technological	9 – Use of Augmented Reality.	Cannavacciuolo et. al; Cordeiro et. al; Peter et. al; Vaidya et. al
Technological	10 – Use of Additive Manufacturing.	Cannavacciuolo et. al; Cordeiro et. al; Müller et. al; Peter et. al; Vaidya et. al
Non Technological	11 – Policy for the development of cognitive and procedural skills.	Butschan et. al; Coelho et. al; Saniuk et. al
Non Technological	12 – Mapping employees' difficulties regarding the digitalization process.	Arey et. al; Saniuk et. al
Non Technological	13 – Speed of machine planning coordination.	Plattform Industrie 4.0; Veile et. al
Non Technological	14 – Active participation of customers in flexible product development.	Cozmiuc and Petrisor; Plattform Industrie 4.0
Non Technological	15 – Management model based on continuous process improvement (ex.: Lean Manufacturing).	Arey et. al; Javaid et. al
Non Technological	16 – Preparation for possible disruptions in global supply chains.	Cozmiuc and Petrisor; Saniuk et. al

Non Technological	17 – Clarity of impacts in terms of sustainability and implementation costs.	Fuchs; Grybauskas et. al
Non Technological	18 – Identification of opportunities for the development of public policies on digital transformation.	Sung; Teixeira and Tavares-Lehmann

Source: Prepared by the author

In theoretical terms, this empirical study observes the technological and non-technological elements of Industry 4.0. In practical terms, it is presented to the sample as a roadmap for qualifying its processes, demonstrating, in practice, the distance that its respective organization presents itself in relation to the attributes for characterizing Industry 4.0. Therefore, it can be stated that this study can benefit researchers, teachers, students and academics interested in exploring the topic, as well as investors, executives, engineers, specialists and consultants from different industrial segments in the search for best practices, tools, equipment and policies for the development of Industry 4.0 as a business model.

Methodological Procedures

1. Characterization of the Research

To achieve the objective proposed in this study, we opted for a quantitative research approach, classified as descriptive, using the field survey as the design of the investigation method. Regarding the approach to the nature of the data, Creswell (2010) establishes that quantitative research is a means of testing objective theories by examining the influence between variables. Such variables, in turn, can be measured systematically by instruments, so that numerical data can be analyzed by statistical procedures. Regarding descriptive classification, Gil (2017) states that descriptive research aims to describe the characteristics of a given population or phenomenon, and can also be designed to identify possible relationships between variables, i.e. in a practical way, this descriptive classification can be used to study the characteristics of a group, the level of service or agreement with the service or characteristics provided, or also to survey the opinions, attitudes and beliefs of a population. As for the research method, the field survey, also called survey, is characterized by Gil (2017) by the direct interrogation of people whose behavior you want to know. Basically, information is requested from a significant group of people about the problem studied and then, through quantitative analysis, conclusions corresponding to the data collected are obtained.

2. Data Collection Procedures

In view of carrying out quantitative research, the data collection procedure is based on a structured questionnaire with a Likert scale and which was carried out in accordance with the research schedule presented in Table 2.

Table 2: Research schedule

#	ACTIVITIES	2022												2023												2024			
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
1	Elective and Mandatory Subjects			●	●	●	●		●	●	●	●	●																
2	Preparation of the Pre-Research Project:				●	●	●																						
2.1	→ Research Problem Formulation:				●	●	●																						
2.2	→ Study Objectives Definition:				●	●	●																						
2.3	→ Pre-Project Exam - Professor Advisor						●																						
3	Theoretical Deepening							●	●	●	●	●	●																
4	Research Problem Preparation:													●	●	●	●	●	●	●	●	●	●	●	●				
4.1	→ Relevance and Motivation for the Study													●	●	●	●	●	●	●	●	●	●	●	●				
4.2	→ Structure and Organization of the Text														●	●	●	●	●	●	●	●	●	●	●				
4.3	→ Research Method Design																●	●	●	●	●	●	●	●	●				
4.4	→ Definition of Case Units																		●	●	●	●	●	●	●				
4.5	→ Protocol Preparation																			●	●	●	●	●	●				
4.6	→ Project Exam - Professor Advisor																							●	●				
5	Qualification Exam																									●			
6	Survey Research:																										●		
6.1	→ Data Collection																										●		
6.2	→ Data Analysis and Interpretation																										●		
6.3	→ Report Writing																										●		
7	Final Exam																											●	

Source: Prepared by the author

The logic for choosing informants is not statistical sampling, but rather the logic of the need to compare the practices carried out by the industries that make up the sample, and comparison with the theoretical model established regarding the technological and non-technological elements of Industry 4.0. Therefore, non-probabilistic reference sampling was adopted (HAIR et. al, 2005).

The strategy for accessing informants is by sending research questionnaires directly to each of them. These informants are specialist professionals, employees of the respective organizations, who have full control of industrial asset management, and who belong to the researcher's professional network. Thus, one hundred and twenty questionnaires were sent covering the largest possible number of industrial segments considering the five geographic regions of Brazil: Midwest, North, Northwest, South and Southeast, of which, one hundred questionnaires were answered and considered valid.

For the process of preparing the questionnaire, observable and measurable indicators were specified that represent the characterization attributes of Industry 4.0, namely: use of artificial intelligence and algorithm systems for calculation, simulation and process

management; automation of machine information regarding unfinished product needs; integrated system for product development and monitoring, delivery and recycling; use of big data; use of autonomous robots; use of the internet of things (IoT or IIoT); use of cloud computing; tested protocols regarding cybersecurity; use of augmented reality; use of additive manufacturing; policy for the development of cognitive and procedural skills; mapping employees' difficulties regarding the digitalization process; speed of machine planning coordination; active participation of customers in flexible product development; management model based on continuous process improvement (e.g. lean manufacturing); preparation for possible disruptions in global supply chains; clarity of impacts in terms of sustainability and implementation costs; identification of opportunities for the development of public policies on digital transformation.

Thus, eighteen individual items were established, nine related to technological elements (T) and another nine related to non-technological elements (NT). These indicators have scores measured using a five-point Likert scale for evaluate: A) Intensity of Agreement with the indicator, starting from “1 – Totally disagree”, “2 – I Disagree”, “3 – I do not agree or disagree”, “4 – I Agree”; “5 – I totally agree”. B) Frequency Intensity with the indicator starting from “1 – Never”, “2 – Rarely”, “3 – Occasionally”, “4 – Frequent”, “5 – Very Frequent”. C) Intensity of the Assessment Degree with the indicator, starting from “1 – Terrible”, “2 – Bad”, “3 – Normal”, “4 – Good”, “5 – Great”.

The indicators were determined so that the more advanced the sample is in the attributes for characterizing Industry 4.0, the higher its final score will be. As eighteen indicators are recorded, it means that the sample that reaches 90 points (100%) will be the portrait of a company fully compliant with the elements of Industry 4.0, while if a given sample reaches 18 points (20%) it will be the portrait of a company at the lowest level of adherence to the elements of Industry 4.0.

The questionnaire qualified for field research can be seen in Appendix A, which, in addition to the evaluative questions, has research fields that make it possible to analyze the data in a section by: (1) Region of Brazil; (2) State of Brazil; (3) Industrial Segment; (4) Company Size Group according to the SEBRAE (2023) classification: “up to 19 employees – Microcompany”; “from 20 to 99 employees – Small Business”; “from 100 to 499 employees – Medium-sized Company”; “over 500 employees – Big Company”. The questionnaire is also capable of qualifying interviewees regarding their position in the company, education, and length of professional experience.

3. Data Analysis and Interpretation Procedure

Data analysis procedures follow Descriptive Statistical Analysis, Multiple Linear Regression and Analysis of Variance [ANOVA]. Descriptive Statistical Analysis is the initial stage of data analysis and aims to describe the observed data. In its function of describing data, it is responsible for obtaining, organizing, reducing and representing statistical data in order to help describe the observed phenomenon. Variance Analysis is an approach to comparing data with different averages between different groups, and, thus allows the identification of patterns and trends with complex and varied data (HAIR et. al, 2005; CRESWELL, 2010).

4. Sample Characterization

In order to maintain the confidentiality of the name, logos and acronyms of the organizations and their interviewees, all companies involved in this research receive random identification coding of the LLNNN type (Letter/Letter/Number/Number/Number), as presented in Appendix B, so that, only the researchers obtain the real identification data, which, under no circumstances, will be disclosed to any involved or interested parties.

Table 3 presents the profile of the interviewees in terms of education, length of experience inside and outside the company analyzed, and the macro hierarchical position that the interviewee has within the company.

Table 3: Profile of interviewees

Education	Frequency	Percentage
Inconcluded Graduation	2	2.0%
Concluded Graduation	13	13.0%
Inconcluded Post-Graduation	8	8.0%
Concluded Post-Graduation	77	77.0%
Total	100	100.0%
Experience Time	Frequency	Percentage
Up to 5 years	6	6.0%
From 6 to 10 years	15	15.0%
From 11 to 15 years	29	29.0%
From 16 to 20 years	15	15.0%
Over 21 years	35	35.0%
Total	100	100.0%
MacroOffice	Frequency	Percentage

Director	4	4.0%
Manager	43	43.0%
Coordinator	23	23.0%
Supervisor	6	6.0%
Specialized Technician	24	24.0%
Total	100	100.0%

Source: Prepared by the author

Table 4 presents the profile of the companies in terms of size according to the SEBRAE classification (2023), the distribution by geographic region of Brazil, and the respective industrial segment to which the company belongs. It also highlights the fact that all geographic regions of Brazil are included in the research, namely: Midwest, North, Northeast, South and Southeast. To facilitate the understanding of the scope of this research in relation to the size of Brazil, which is the largest country in Latin America, and the fifth largest country in the world, Picture 1 demonstrates this breadth by marking the Brazilian states included in the field research, and therefore, its grouping in one of the five geographic regions of Brazil. What is also noteworthy is the classification by industrial segment in which segments are repeated in different groups, for example, the “Beverage and Food” segment group, and the “Foods” segment group. Despite the common term “Foods”, not there is a way to combine them into the same group because they are completely different industrial segments.

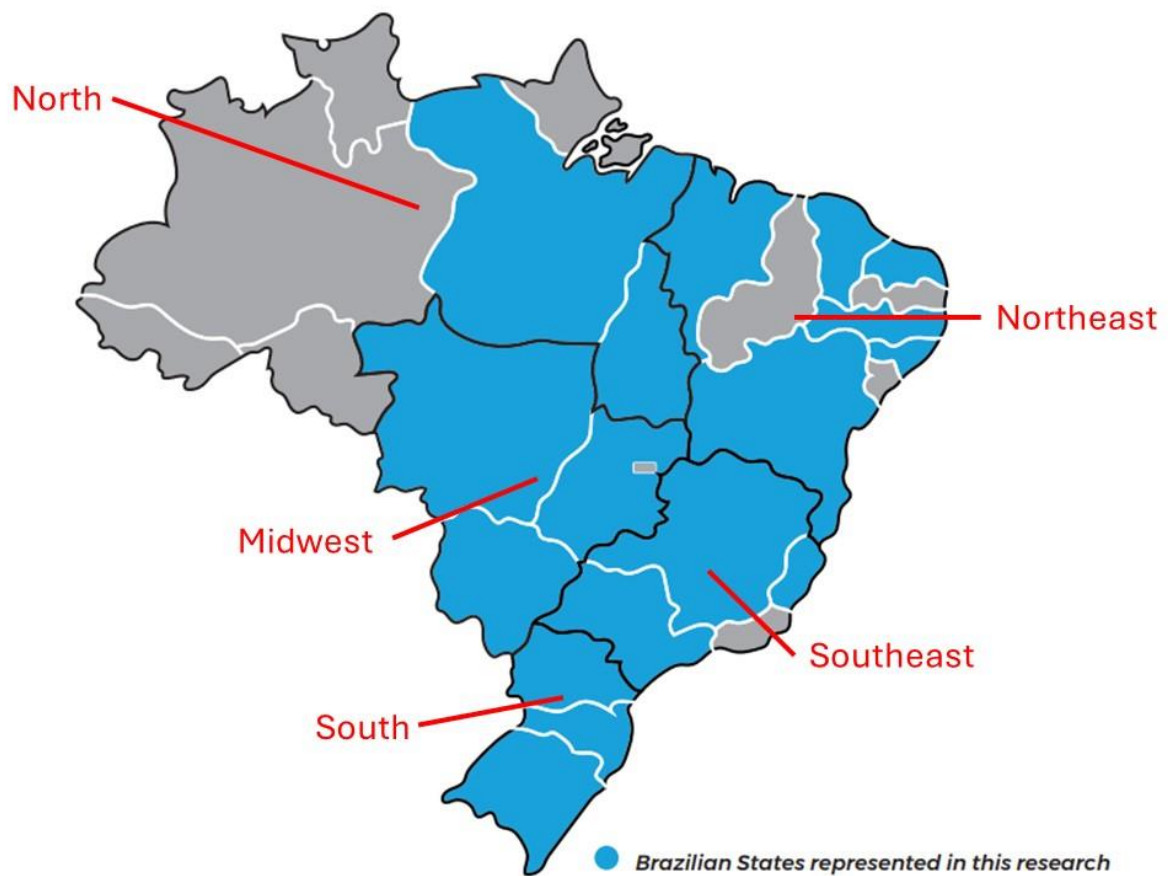
Table 4: Company profile – survey research cases

Size of Companies	Frequency	Percentage
Micro	0	0.0%
Small	2	2.0%
Average	23	23.0%
Big	75	75.0%
Total	100	100.0%
Brazilian Region	Frequency	Percentage
Midwest	43	43.0%
North	6	6.0%
Northeast	12	12.0%
South	23	23.0%
Southeast	16	16.0%
Total	100	100.0%
Industrial Segment	Frequency	Percentage
Animal Nutrition	1	1.0%
Animal Sub-Product – Grease	1	1.0%

Automotive	7	7.0%
Beverage and Foods	16	16.0%
Cement	1	1.0%
Cosmetics and Nutrition	1	1.0%
Fertilizers, Seeds and Animal Nutrition	7	7.0%
Foods	19	19.0%
Fuels	1	1.0%
Industrial Equipment and Engineering	4	4.0%
Packaging	5	5.0%
Paper, Cellulose	11	11.0%
Pharmaceutical	10	10.0%
Plastic	1	1.0%
Sanitizers and Hygiene Products	9	9.0%
Textile	1	1.0%
Wood	5	5.0%
Total	100	100.0%

Source: Prepared by the author

Picture 1: Geographic regions of Brazil covered in the research



Source: Prepared by the author

Data Analysis and Interpretation

In this section, the results obtained in the field phase of the research are presented and discussed. Initially, the efficiency rate of the data collection process is presented, which, according to data in Table 5, organized in alphabetical order by industrial segments, shows the receipt of one hundred questionnaires, which results in an efficiency of 83.3% of the questionnaires sent.

Table 5: Data collection efficiency

Industrial Segments	Submitted Questionnaires	Answered Questionnaires	Efficiency Rate
Animal Nutrition	1	1	100.0%
Animal Sub-Product – Grease	1	1	100.0%
Automotive	15	7	46.7%
Beverage and Foods	17	16	94.1%
Cement	1	1	100.0%
Chemical	1	0	0.0%
Cosmetics and Nutrition	3	1	33.3%
Fertilizers, Seeds and Animal Nutrition	7	7	100.0%
Foods	21	18	85.7%
Fuels	1	1	100.0%
Industrial Equipment and Engineering	4	4	100.0%
Packaging	6	6	100.0%
Paper, Cellulose	12	11	91.7%
Pharmaceutical	11	10	90.9%
Plastic	1	1	100.0%
Sanitizers and Hygiene Products	11	9	81.8%
Sugar and Ethanol	1	0	0.0%
Textile	1	1	100.0%
Wood	5	5	100.0%
TOTAL	120	100	83.3%

Source: Prepared by the author

The Table 6 presents the eighteen questions applied in the questionnaire and the respective research results with a general average of 67.7% of achievement of the Industry 4.0 characterization scale, with an average standard deviation of 21.4%.

Table 6: Applied questions and the overall research result

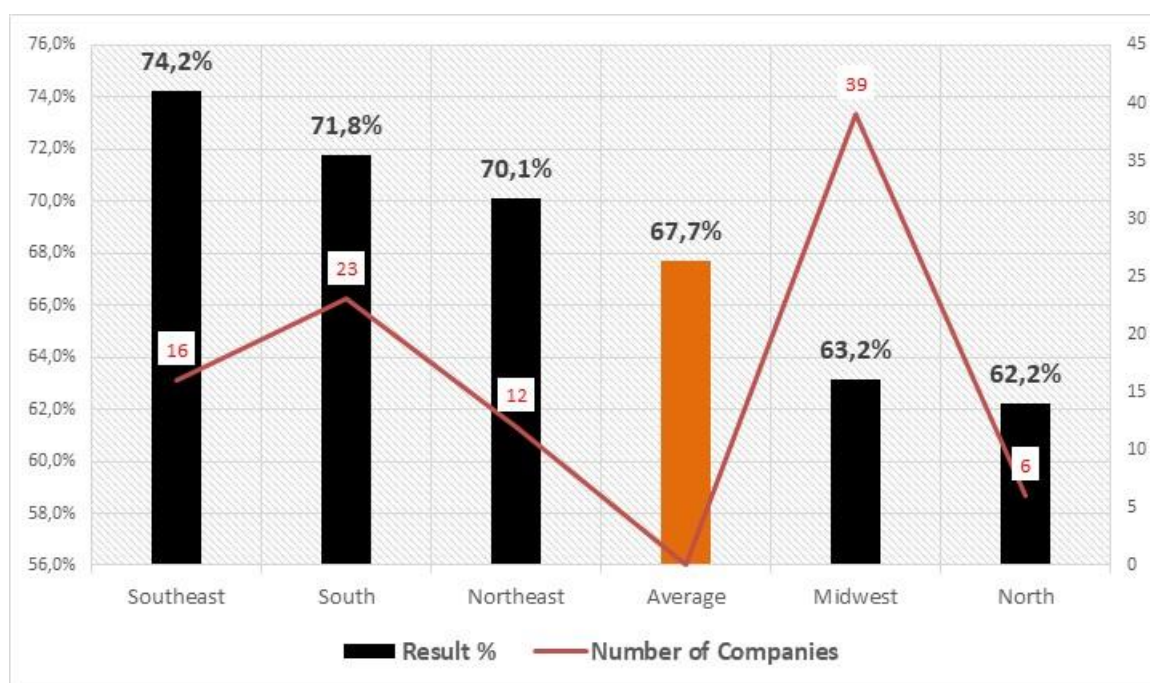
Technological Elements	Mean ($\bar{x}$)	S.D. (s)
Q1 - The company uses an ANDON-type system that informs about the generation of problems on the line.	64,2%	28,6%
Q2- The company's Information Technology area has initiatives related to Big Data.	70,2%	23,5%
Q3 - The company's Manufacturing areas have evolved with the use of Autonomous Robots.	56,6%	28,0%
Q4 - The company's Manufacturing areas have evolved with the use of the Internet of Things in the aspect of exchanging information between machines.	69,6%	23,7%
Q5 - The company's Information Technology area has initiatives related to the topic of Cloud Computing.	78,6%	18,0%
Q6 - The company has a team of Information Technology specialists capable of meeting the demands of Industry 4.0.	70,2%	23,5%
Q7 - The company has initiatives to use Augmented Reality, that is, it uses technology that superimposes virtual elements on our vision of reality.	47,0%	24,8%
Q15 - How often does the company use artificial intelligence for process management? E.g.: intelligent surveillance systems (CCTV), route applications, virtual reality glasses, etc...	60,8%	23,9%
Q16 - How often does the company have initiatives to use Additive Manufacturing, that is, does it use 3D Printing technology, for example?	49,6%	23,2%
Non Technological Elements	Mean ($\bar{x}$)	S.D. (s)
Q8 - In the company, the Manufacturing areas can quickly coordinate production replanning when there is any problem or customer demand.	78,0%	17,9%
Q9 - The company uses a management model based on operational excellence, such as Lean Manufacturing, TPM or WCM.	77,6%	22,6%
Q10 - The company is prepared for a possible disruption in the process of acquiring inputs and raw materials.	70,2%	19,8%
Q11 - I have knowledge of public policies for the development of industrial innovation.	71,2%	17,8%
Q12 - I consider that I have knowledge about the concepts of Industry 4.0.	78,2%	13,7%
Q13 - How often does the company control the product phases, from development, manufacturing, delivery and recycling?	88,8%	15,4%
Q14 - How often do customers actively participate in new product development?	67,6%	23,6%

Q17 - In the company, the development of cognitive and procedural skills necessary for the Industry 4.0 digitalization process is...	62,4%	18,3%
Q18 - In the company, actions that minimize employees' difficulties regarding the Industry 4.0 digitalization process are...	57,6%	18,9%
TOTAL	67,6%	21,4%

Source: Prepared by the author

Next, the stratified results of the field research are presented. It is confirmed that the percentage results mean the level of adherence of the sample (or the Brazilian region, or the Brazilian State) are in accordance with the attributes of Industry 4.0. In other words, 100% means fully adherent to the attributes of Industry 4.0, while 20% means a low level of adherence to the attributes of Industry 4.0. In Graph 2, the results of the mapping of Industry 4.0 elements by region of Brazil are observed. The Southeast region has the group of companies with the highest results adhering to Industry 4.0 (74.2%), a result 9.7% higher than the national average and 19.2% higher than the North region, last placed with 62.2%.

Graph 2: Mapping of IND4.0 elements by Region of Brazil



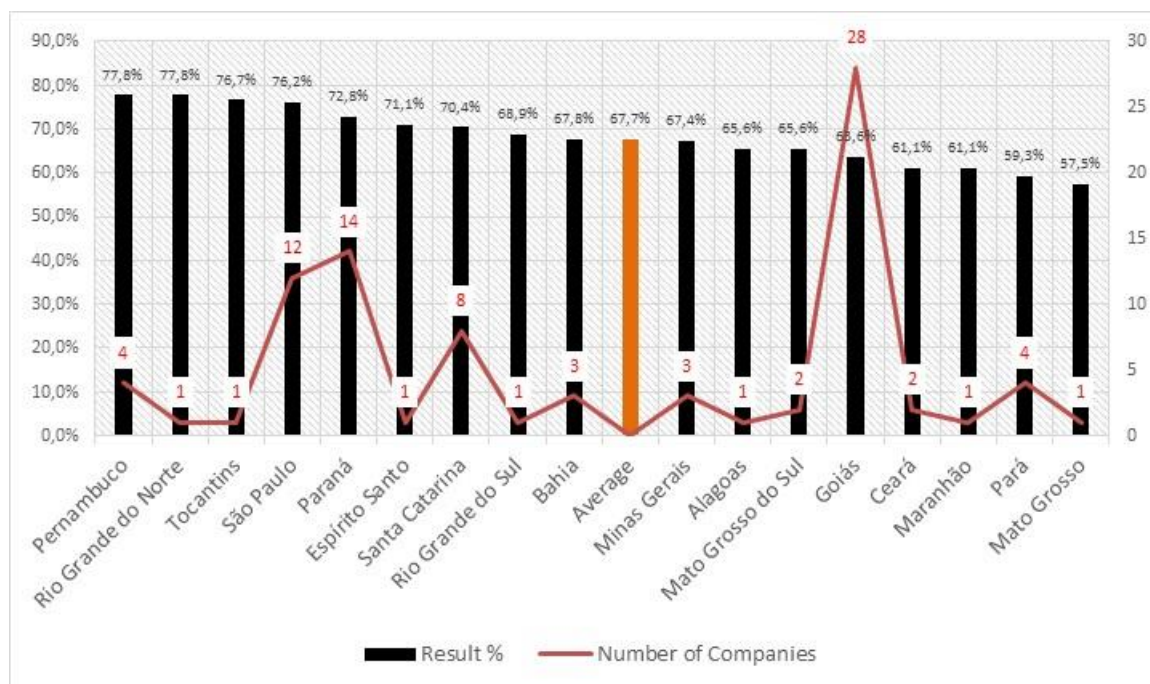
Source: Prepared by the author

The result of the ranking of Brazilian States presented in Graph 2 is not in line with the result of the social statistics presented by the Brazilian Institute of Geography and Statistics [IBGE], which, according to its study called “Human Development in Brazilian Macroregions” (IBGE, 2016), the ranking of the average municipal human development index⁵ [MHDI] of Brazilian regions is ordered in the following sequence: Southeast (1st - 0.766); Midwest (2nd - 0.757); South (3rd - 0.754); North (4th - 0.667); and Northeast (5th - 0.663). In other words, the region with the lowest social development in Brazil (the Northeast) is the third best result of adherence to Industry 4.0, being 5.8% behind the first place (Southeast), however, 3.4% above the Brazilian average and 11.2% of the worst placed (North). Overall, when we compare these two indicators, the Southeast region remains in first place, however, a complete change in the positions of the other geographic regions of Brazil.

When stratifying the data by geographic regions, Graph 3 presents the research results ordered by Brazilian states. It is worth highlighting the fact that, although Graph 2 points out that the Southeast region is in first place in the ranking by region, Graph 3 shows that the first two placed by State are from the Northeast region (Pernambuco and Rio Grande do Norte), and the Third place is a state in the North region (Tocantins). Another highlight is the fact that, of the seventeen Brazilian states involved in the research, nine of them (52.9%) have a result higher than the Brazilian average.

⁵ HDMI: The Municipal Human Development Index is a measure composed of indicators of three dimensions of human development: longevity, education and income. The index varies from 0 to 1. The closer to 1, the greater the human development. The Brazilian HDI follows the same three dimensions as the Global HDI - longevity, education and income, but goes further: it adapts the global methodology to the Brazilian context and the availability of national indicators (PNUD Brazil, 2024).

Graph 3: Mapping of IND4.0 elements by States of Brazil

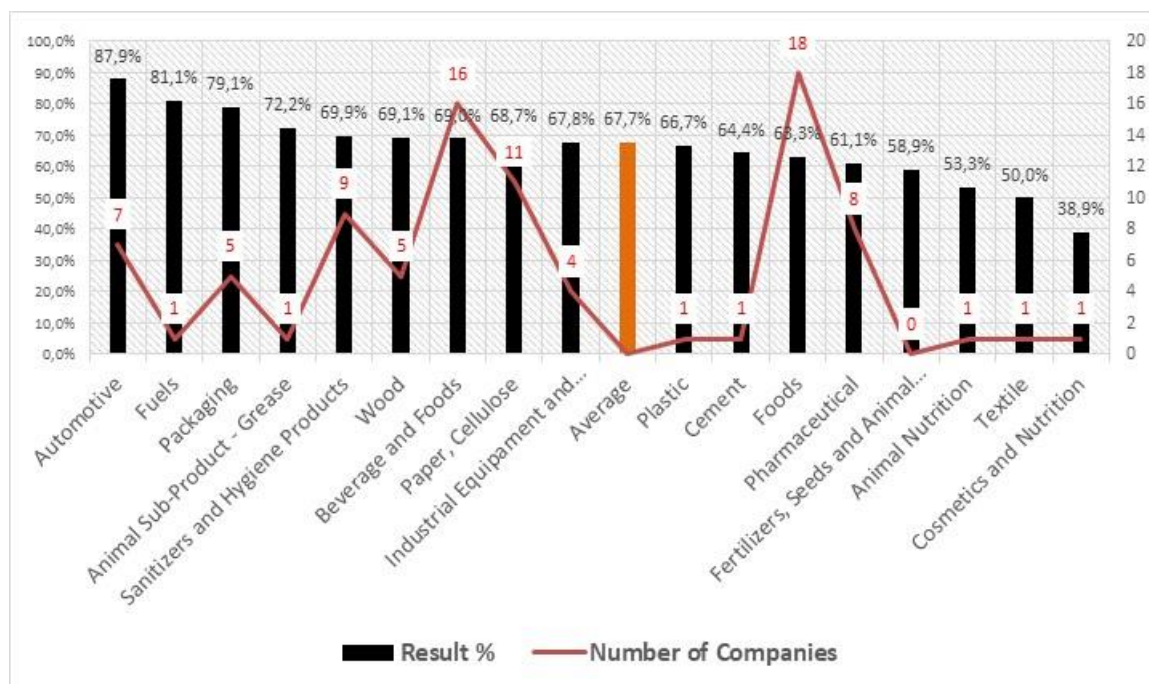


Source: Prepared by the author

It is important to highlight that the ranking presented in Graph 3 refers to the section of this research on the elements of Industry 4.0. Data from the National Confederation of Industry [CNI] in its report on “industry profile in the states” show that the State of São Paulo has an Industrial GDP worth R\$ 518.3 billion (26% of Brazil's Industrial GDP), while the of the State of Pernambuco has an Industrial GDP worth R\$40.7 billion – data from research in 2021.

Graph 4 presents the results of this research classified by the industrial segments researched. The Automotive segment leads the ranking with 87.9% adherence to Industry 4.0 elements, thus corroborating the CNI data in Graph 1. On the other hand, the research shows the Animal Sub-Product sector in fourth position with 72.2 % adherence to Industry 4.0 elements – 6.6% above the national average and 85.6% above last place. According to data from the CNI survey in Graph 1, this segment is among the last placed as those that least implement Industry 4.0 elements.

Graph 4: Mapping of IND4.0 elements by industrial segment



Source: Prepared by the author

Stratifying the data by industrial segments, Table 7 presents the research results ordered by grouping of results. 40 groups of results cataloged from A to AN are recorded, with emphasis on Group AB made up of 11 companies with a result of 58.9%; Group Z made up of 8 companies with a result of 61.1%; and Group D made up of 6 companies with a result of 86.7%. This table is very useful so that survey respondents can identify their respective result using their company's LLNNN code. It appears that, of the one hundred samples in this research, forty-eight of them have results superior to the Brazilian average. The spotlight is the company with code CO821 in the Automotive segment, with a result of 94.4% adherence to the elements of Industry 4.0, thus appearing as the best case in this research.

Table 7: Mapping of IND4.0 elements by result group

Group	ID Code	Result %	Number of Companies
A	CO821	94.4%	1
B	CT826	92.2%	1
C	AK212, BX518	88.9%	2
D	AN215, BA337, BW517, CG629, CM649, DN986	86.7%	6
E	BY519	85.6%	1
F	AT331, AU332, CN650	84.4%	3

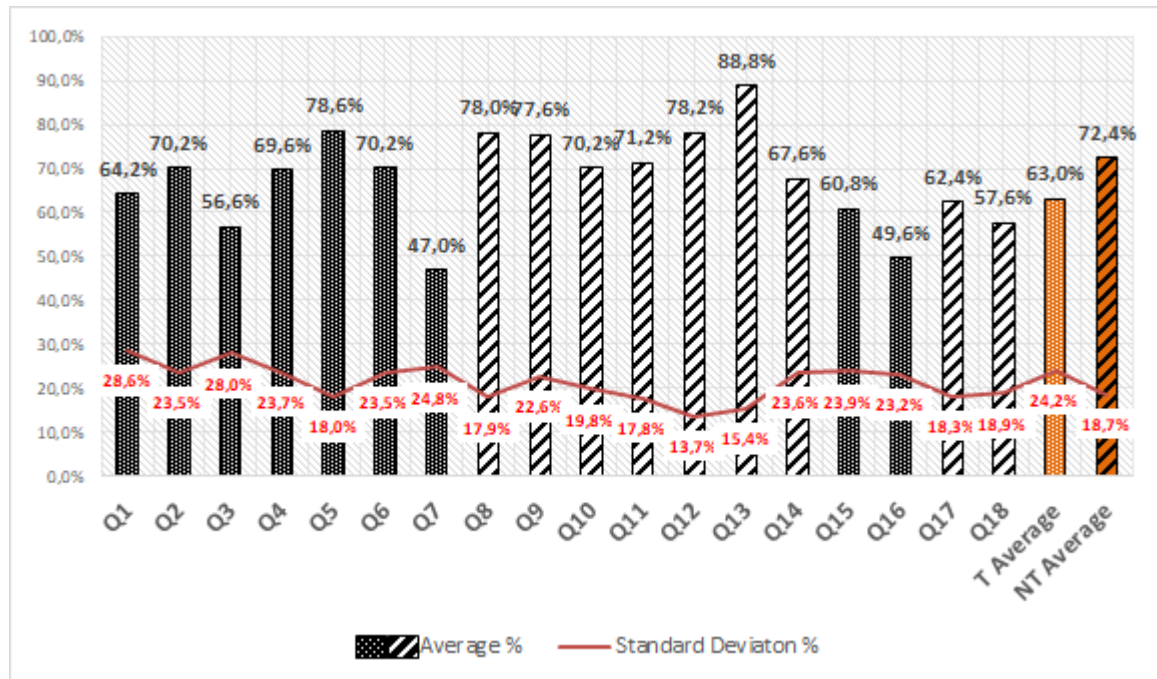
G	AJ211, DS751	83.3%	2
H	DU794	82.2%	1
I	AY335, CH630, CI645	81.1%	3
J	DI911, DT753	80.0%	2
K	BE450	78.9%	1
L	BZ520	77.8%	1
M	BN458, CZ831, DK258	76.7%	3
N	CX830, DC906	75.6%	2
O	BG452, BR512	74.4%	2
P	AP217, AR220, CD626, DW236	73.3%	4
Q	AM214, CQ823, CR824, DM587	72.2%	4
R	BQ511, CA623, DF909, DG910, DL124	71.1%	5
S	AV333, CE627	70.0%	2
T	AQ219, DA904	68.9%	2
Average		67.7%	
U	BT514, CB624	66.7%	2
V	AI109, CW828	65.6%	2
W	BB338, BV516	64.4%	2
X	CC625, CY829	63.3%	2
Y	AZ336, CL648	62.2%	2
Z	AP218, BU515, CJ646, CK647, DB905, DE908, DJ864, DP234	61.1%	8
AA	AL213, CF628, DD907, DH011	60.0%	4
AB	AA901, AB802, AC703, AD604, AE505, AF406, AG307, AW334, CP822, DX413, DZ887	58.9%	11
AC	AO216	57.8%	1
AD	BM457	56.7%	1
AE	BO459, BP510, CS825	55.6%	3
AF	BD340, BF451, BO782	54.4%	3
AG	BJ455, DV566	53.3%	2
AH	AH208	52.2%	1
AI	BL456	51.1%	1
AJ	AS330, BH453	50.0%	2
AK	BI454, CV827	48.9%	2
AL	BC339	46.7%	1
AM	DY179	38.9%	1
AN	BS513	32.2%	1

Source: Prepared by the author

In Graph 5, the comparative result of the mean and standard deviation of each question is verified, with the visual identification of the questions that represent the technological elements [T] of Industry 4.0 (Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q15 and Q16) and the non-technological elements [NT] of Industry 4.0 (Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q17 and Q18). The following highlights: 1) Q13 on total control of product phases is the question most in line with Industry 4.0 with an average of 88.8%. 2) Q7 on the use of augmented reality is

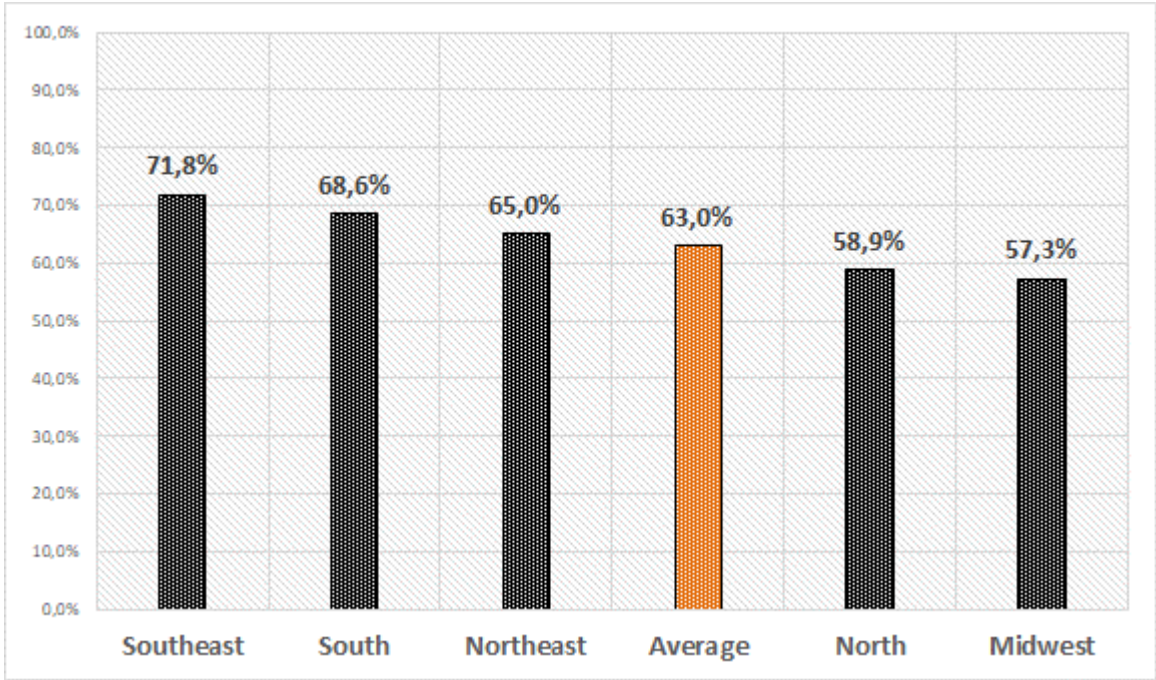
the question least adherent to Industry 4.0 with an average of 47%. 3) Q1 on the use of ANDON is the question with the highest standard deviation among companies with a result of 28.6%. 4) The average of questions related to the non-technological elements of Industry 4.0 is 12.9% higher than the questions related to the technological elements of Industry 4.0.

Graph 5: Comparison of results by question



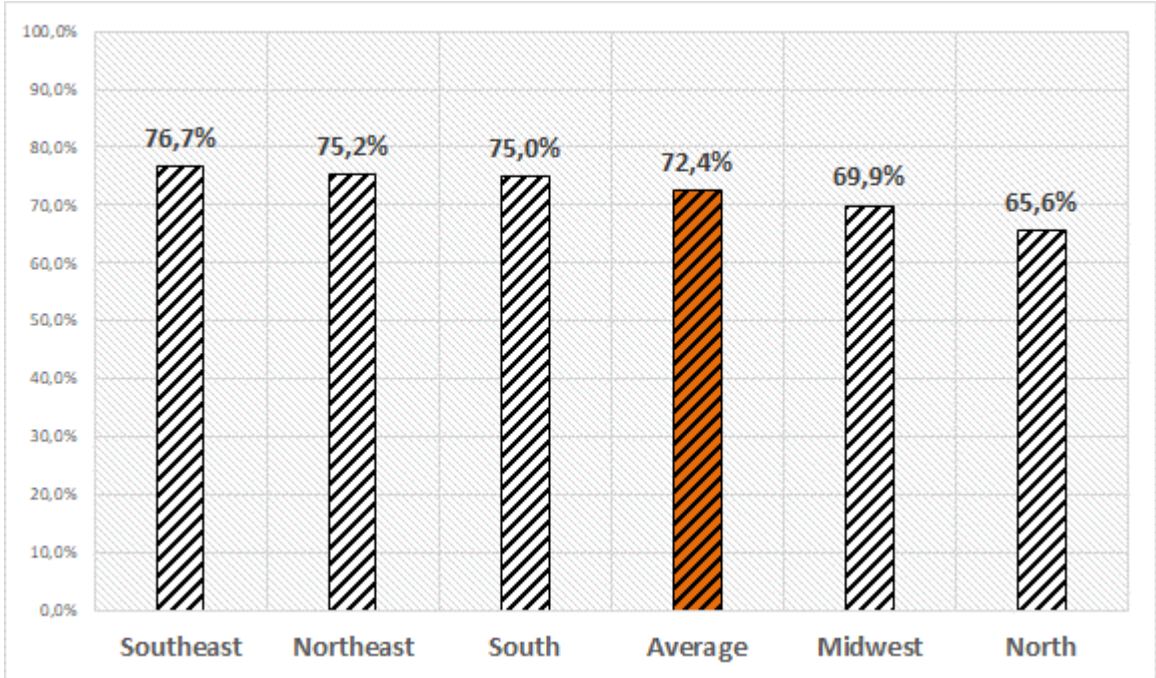
Source: Prepared by the author

Graph 6: IND4.0 Technological Elements by Region of Brazil



Source: Prepared by the author

Graph 7: IND4.0 Non-Technological Elements by Region of Brazil



Source: Prepared by the author

Table 8: Multiple linear regression calculation to validate H1

SUMMARY OF RESULTS

Regression Statistics	
Multiple R	0,19417606
R-squared	0,037704342
Adjusted R-squared	0,036096944
Standard error	0,236418755
Observations	1800

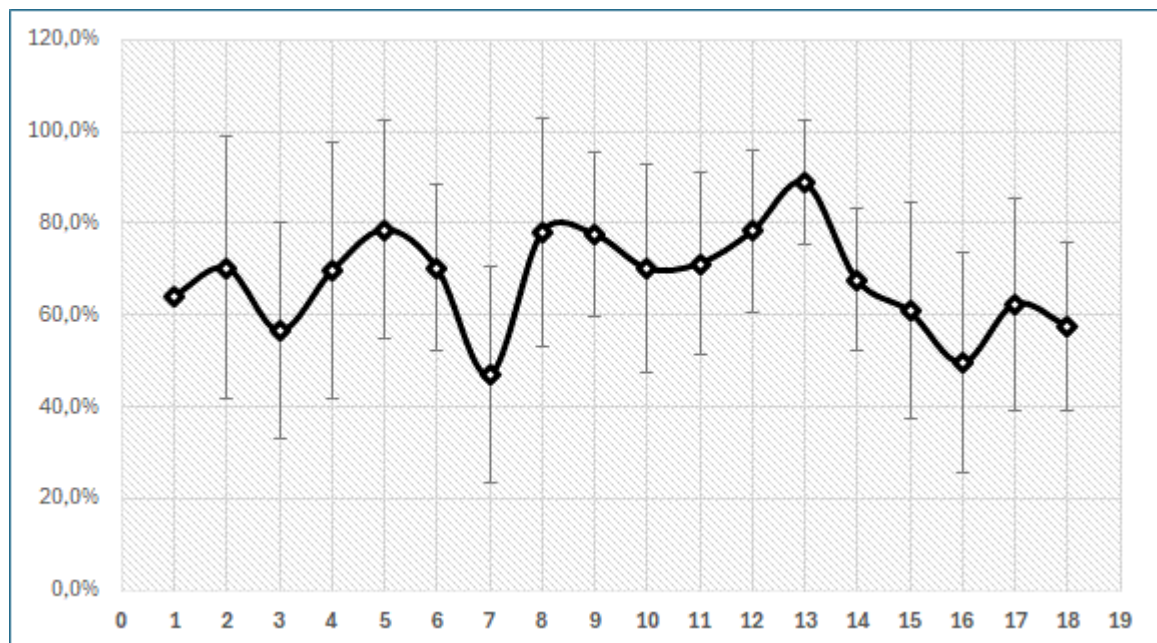
ANOVA

	gl	SQ	MQ	F	F de significação
Regression	3	3,933263382	1,311087794	23,45675453	6,83227E-15
Residue	1796	100,3853144	0,055893828		
Total	1799	104,3185778			

	Coefficients	Standard Error	Stat t	P-value	95% lower	95% higher	Less than 95,0%	Higher than 95,0%
Intersection	-0,825999425	0,466445663	-1,7708374	0,076757329	-1,740832644	0,088833795	-1,740832644	0,088833795
MHDI Longevity	3,663299115	0,968603558	3,782041769	0,000160639	1,763590784	5,563007445	1,763590784	5,563007445
MHDI Income	-5,057462176	0,611849486	-8,265859969	2,66288E-16	-6,257473838	-3,857450513	-6,257473838	-3,857450513
MHDI Education	3,470823234	0,575588657	6,030041061	1,98516E-09	2,341929419	4,59971705	2,341929419	4,59971705

Source: Prepared by the author

Graph 8: Multiple linear regression calculation to validate H1



Source: Prepared by the author

Table 9: ANOVA single factor by region of Brazil

Anova: single factor

ABSTRACT

Group	Score	Sum	Average	Variance
Midwest	43	27,15555556	0,631524548	0,014843799
North	6	3,733333333	0,622222222	0,009777778
Northeast	12	8,411111111	0,700925926	0,00860737
South	23	16,51111111	0,717874396	0,015092471
Southeast	16	11,87777778	0,742361111	0,015954218

ANOVA

Source of variation	SQ	gl	MQ	F	P-value	F critical
Between groups	0,220576186	4	0,055144047	3,914264911	0,005502098	2,467493623
Inside groups	1,338357147	95	0,01408797			
Total	1,558933333	99				

Source: Prepared by the author

Table 10: ANOVA single factor by industrial segment

Anova: single factor

ABSTRACT

Group	Score	Sum	Average	Variance
Automotive	7	6,155555556	0,879365079	0,002527925
Fuels	1	0,811	0,811	#DIV/0!
Packaging	5	3,955555556	0,791111111	0,002802469
Animal Sub-Product - Grease	1	0,722	0,722	#DIV/0!
Sanitizers and Hygiene Products	9	6,288888889	0,698765432	0,009705075
Wood	5	3,455555556	0,691111111	0,002
Beverage and Foods	16	11,04444444	0,690277778	0,008985597
Paper, Cellulose	11	7,555555556	0,686868687	0,010785634
Industrial Equipament and Engeneering	4	2,711111111	0,677777778	0,047901235
Plastic	1	0,667	0,667	#DIV/0!
Cement	1	0,644	0,644	#DIV/0!
Foods	19	12,02222222	0,632748538	0,009059996
Pharmaceutical	10	6,111111111	0,611111111	0,027270233
Fertilizers, Seeds and Animal Nutrition	7	4,122222222	0,588888889	0
Animal Nutrition	1	0,533	0,533	#DIV/0!
Textile	1	0,5	0,5	#DIV/0!
Cosmetics and Nutrition	1	0,389	0,389	#DIV/0!

ANOVA

Fonte da variação	SQ	gl	MQ	F	P-value	F critical
Between groups	0,652063531	16	0,040753971	3,729933154	3,92847E-05	1,766862186
Inside groups	0,906874045	83	0,010926193			
Total	1,558937576	99				

Source: Prepared by the author

In Table 11 you can see the consolidation of the results of this research grouped and classified in alphabetical order by the regions of Brazil. The data in column B represents the average result per region regarding adherence to Industry 4.0 elements (average of all results from the one hundred companies surveyed), where the Southeast region presents the best result with 74.2% and the North region the worst result with 62.2%. The data in column C and D represent, respectively, the average result by region of Brazil regarding adherence by technological and non-technological element. The data in column E represents the average result of questions Q17 and Q18 which are related to the topic “cognitive development necessary for the digitalization process”. The result in column F indicates the result of the Municipal Human Development Index (MHDI) of the regions of Brazil - a study carried out by IPEA (2016), and in columns G, H and I are the breakdown of the composition of this indicator measuring the results stratified by: longevity, income and education.

Table 11: IND4.0 Consolidation of survey research results by Region of Brazil

	A	B	C	D	E	F	G	H	I
1	Brazilian Region	IND4.0 Result	Tech. Elements	Non Tech. Elements	Q17/Q18 Average	MHDI Total	MHDI Longevity	MHDI Income	MHDI Education
2	MIDWEST	63,2%	56,7%	69,6%	57,9%	75,7%	83,9%	77,6%	66,5%
3	NORTH	62,2%	58,9%	65,6%	60,0%	66,7%	79,6%	67,0%	55,7%
4	NORTHEAST	70,1%	65,0%	75,2%	60,0%	66,3%	78,2%	65,6%	56,9%
5	SOUTH	71,8%	68,6%	75,0%	61,3%	75,4%	84,8%	76,4%	66,2%
6	SOUTHEAST	74,2%	68,6%	75,0%	61,3%	76,6%	84,5%	77,3%	68,8%

Source: Prepared by the author

In Table 12 you can see the consolidation of the results of this research grouped and classified in order of the best result of the industrial segments. This data can be analyzed in parallel with data from the CNI survey (Graph 1) and corroborate the excellent result of the Automotive segment (first place in both surveys), the Fuel segment (second place in both surveys), and the Sanitizing and Hygiene Products segment (fifth place in this survey with a result 3.14% higher than the general average and fourth place in the CNI survey). However, this research shows a divergence in the results of the Animal Sub-Product – Grease segment, fourth place in this research with a result 6.23% higher than the general average, and second-to-last place in the CNI research, representing the sector as one of the least used digital technology. It can also be inferred that this divergence is due to the number of samples from

this segment, after all, this research has a sample from the Animal Sub-Product – Grease segment, which is the company code AM-214 located in the Midwest region, while in the CNI research, we do not have evidence of the number of samples or their respective geographic location for absolute comparison purposes.

Table 12: IND4.0 Consolidation of survey research results by Industrial Segment

	A	B	C	D	E
1	Segment	IND4.0 Result	Tech. Elements	Non Tech. Elements	Q17/Q18 Average
2	Automotive	87,9%	90,8%	85,1%	68,6%
3	Fuels	81,1%	82,2%	80,0%	70,0%
4	Packaging	79,1%	81,3%	76,9%	82,0%
5	Animal Sub-Product - Grease	72,2%	68,9%	75,6%	60,0%
6	Sanitizers and Hygiene Products	69,9%	63,5%	76,3%	55,6%
7	Wood	69,1%	71,6%	66,7%	74,0%
8	Beverage and Foods	69,0%	64,4%	73,6%	57,5%
9	Paper, Cellulose	68,7%	61,2%	76,2%	60,0%
10	Industrial Equipament and Engeneering	67,8%	63,9%	71,7%	55,0%
11	Plastic	66,7%	66,7%	66,7%	50,0%
12	Cement	64,4%	53,3%	75,6%	60,0%
13	Foods	63,3%	55,3%	71,2%	61,6%
14	Pharmaceutical	61,1%	56,7%	65,6%	57,0%
15	Fertilizers, Seeds and Animal Nutrition	58,9%	51,1%	66,7%	50,0%
16	Animal Nutrition	53,3%	40,0%	66,7%	50,0%
17	Textile	50,0%	44,4%	55,6%	40,0%
18	Cosmetics and Nutrition	38,9%	35,6%	42,2%	20,0%

Source: Prepared by the author

Regarding the specific objectives, the influence of the hypothesis and the evaluation of the assumptions were tested, the result of which, based on the data analysis, it can be inferred that:

1) Test the influence of the hypothesis that the level of social development in each region of Brazil influences the evolution of Industry 4.0 – the hypothesis is refuted. As can be seen in Table 8, the R-squared is 0.0377, which represents a very low correlation between the independent variable (evolution of Industry 4.0), in relation to the dependent variable (MHDI

results for each region of Brazil). It is also verified that the statistic is validated since the P-value is less than 0.05.

2) Evaluate the assumption that in Brazil there is a relevant gap in adherence to the technological elements of Industry 4.0 – the assumption is confirmed. Using data from Graph 5, the average standard deviation between the technological elements of Industry 4.0 is 24.2% and an average result of 63.0%, a value 6.94% lower than the global average result of 67.7%.

3) Evaluate the assumption that in Brazil there is a relevant gap in adherence to the non-technological elements of Industry 4.0 – the assumption is confirmed. Using data from Graph 5, the average standard deviation among the non-technological elements of Industry 4.0 is 18.7%. Using Graph 8, you can verify a dispersion analysis that presents high standard deviation values per question in relation to the average result.

4) Evaluate the assumption that Brazilian industry presents difficulties in the cognitive development of its employees given the needs of the digitalization process – the assumption is confirmed. Based on the results of questions Q17 and Q18, it is observed that the general average of adherence to the non-technological element is 60.0%, a value 11.3% lower than the national average, with an average standard deviation of 18.6%. These results are far below other questions from this same survey, as well as expectations for results in the industry in general.

For the purpose of comparing the results obtained by region of Brazil, it can be seen from Table 9 that the F value is 3.914, while the F-critical value is 2.467; also, the P-value is 0.0055 with a significance level of 5%. Thus, it is concluded that the result of the variance is h_1 , which confirms that there is a significant difference in the result of Industry 4.0 by region of Brazil.

For the purpose of comparing the results obtained by industrial segment, it can be seen from Table 10 that the F value is 3.729, while the F-critical value is 1.766; also, the P-value is 3.928E-05 with a significance level of 5%. Thus, it is concluded that the result of the variance is h_1 , which confirms that there is a significant difference in the result of Industry 4.0 by industrial segment.

Conclusions

In this study, a quantitative research approach was applied, classified as descriptive, using a field survey (survey) as an outline of the investigation method, with the general objective of mapping the status of technological and non-technological elements of Brazilian

industry in comparison with the theoretical model of Industry 4.0. The data collection procedure was based on a structured questionnaire with a Likert scale sent to centers and twenty companies covering the five geographic regions of Brazil, from which one hundred valid questionnaires were received, thus achieving 83.3% efficiency in data collection.

There is a limitation of this research, the fact that it is a non-probabilistic sample, which does not allow generalizations for the population as a whole. A second limitation is the comparison of the Industry 4.0 result in relation to the MHDI by Brazilian region. This comparison may bring distortions when compared with other geographic areas, such as the respective metropolitan regions. A third limitation is the number of samples per Brazilian region. This research collected thirty-nine samples in the Midwest region, twenty-three in the South region, sixteen in the Southeast region, twelve in the Northeast region, and six in the North region. A more balanced selection of samples between Brazilian regions can provide results with a better comparison effect. A fourth limitation of this research that at the same time appears as a gap, which is the purity of the evaluation of the technological and non-technological elements of Industry 4.0. The interviewees are specialist executives from the respective companies researched, therefore, it can be inferred that an external investigation carried out by a competent professional will bring greater fidelity to the real status of the sample compared to the theoretical model of Industry 4.0. Also as a limitation of this research, it is clear that the average adherence of the result of question Q12 on “level of knowledge about Industry 4.0 concepts” is 78.2% with an average standard deviation of 13.7%, which we can infer that this is a low result given the level of responsibility expected from interviewees in the management process of the respective industrial asset.

Still as a research gap, it is suggested to deepen the studies in order to define degrees of adherence to Industry 4.0 for each specific industrial segment, that is, to establish what is the expected level of evolution for each industrial segment, regardless of the geographic region in which the sample is installed.

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APPENDICES

APPENDIX A – Qualified Questionnaire

	MESTRADO PROFISSIONAL em ADMINISTRAÇÃO	Invite you to participate in the research that aims to gather information about Industry 4.0. Your participation is voluntary and will consist of answering twenty questions. The expected time to complete the questionnaire is 5 to 10 minutes.
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Free and Informed Consent Form

This research is a study linked to the Master's Program at Centro Universitário Alves Faria (UNIALFA). The objective of the research is to identify the influences of technological and non-technological elements in the characterization of Industry 4.0. The answers given and your individual data will be kept absolutely confidential. At any time, you can request information about the research via email: wagner.guedin@grupoiosealves.com.

Read the items carefully and record the option that best describes your opinion. Thank you for your collaboration.

☐ I have read the information above and I agree to participate in the research.

SURVEY QUESTIONNAIRE

A) Identification and Qualification

COMPANY CODE:

COMPANY REGION:

COMPANY SEGMENT:

B) Questionnaire

Select **ONLY ONE** answer for each question.

Questions with AGREEMENT DEGREE scale:

Q1	The company uses an ANDON-type system that informs about the generation of problems on the line.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree nor disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q2	The company's Information Technology area has initiatives related to Big Data.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q3	The company's Manufacturing areas have evolved with the use of Autonomous Robots.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q4	The company's Manufacturing areas have evolved with the use of the Internet of Things in the aspect of exchanging information between machines.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q5	The company's Information Technology area has initiatives related to the topic of Cloud Computing.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q6	The company has a team of Information Technology specialists capable of meeting the demands of Industry 4.0.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q7	The company has initiatives to use Augmented Reality, that is, it uses technology that superimposes virtual elements on our vision of reality.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q8	In the company, the Manufacturing areas can quickly coordinate production replanning when there is any problem or customer demand.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q9	The company uses a management model based on operational excellence, such as Lean Manufacturing, TPM or WCM.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q10	The company is prepared for a possible disruption in the process of acquiring inputs and raw materials.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q11	I have knowledge of public policies for the development of industrial innovation.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree
Q12	I consider that I have knowledge about the concepts of Industry 4.0.	☐ 1 - Totally disagree ☐ 2 - I disagree ☐ 3 - I do not agree or disagree	☐ 4 - I agree ☐ 5 - I totally agree

Questions with FREQUENCY DEGREE scale:

Q13	How often does the company control the product phases, from development, manufacturing, delivery and recycling?	☐ 1 - Never ☐ 2 - Rarely ☐ 3 - Occasionally	☐ 4 - Frequent ☐ 5 - Very frequent
Q14	How often do customers actively participate in new product development?	☐ 1 - Never ☐ 2 - Rarely ☐ 3 - Occasionally	☐ 4 - Frequent ☐ 5 - Very frequent
Q15	How often does the company use artificial intelligence for process management? E.g.: intelligent surveillance systems (CCTV), route applications, virtual reality glasses, etc...	☐ 1 - Never ☐ 2 - Rarely ☐ 3 - Occasionally	☐ 4 - Frequent ☐ 5 - Very frequent
Q16	How often does the company have initiatives to use Additive Manufacturing, that is, does it use 3D Printing technology, for example?	☐ 1 - Never ☐ 2 - Rarely ☐ 3 - Occasionally	☐ 4 - Frequent ☐ 5 - Very frequent

Questions with EVALUATION DEGREE scale:

Q17	In the company, the development of cognitive and procedural skills necessary for the Industry 4.0 digitalization process is...	☐ 1 - Terrible ☐ 2 - Bad ☐ 3 - Normal	☐ 4 - Good ☐ 5 - Great
Q18	In the company, actions that minimize employees' difficulties regarding the Industry 4.0 digitalization process are...	☐ 1 - Terrible ☐ 2 - Bad ☐ 3 - Normal	☐ 4 - Good ☐ 5 - Great

SIZE COMPANY CLASSIFICATION (SEBRAE, 2023): ☐ Up to 19 employees - Micro Company ☐ From 20 to 99 employees - Small Company ☐ From 100 to 499 employees - Average Company ☐ 500 employees or more - Big Company	INTERVIEWED QUALIFICATION: Office (<i>read</i>): → Education (<i>select</i>): → Professional experience, inside and outside the company (<i>select</i>): →
COMPLETION OF THE QUESTIONNAIRE AND BOOK DRAW If you wish to participate in the draw for the book " Lean Maintenance - João Paulo Pinto - Ed. Lidel/SP" fill in your email below (<i>optional</i>):	

APPENDIX B – Coding of Companies participating in the research

No.	ID CODE	SEGMENT	BRAZILIAN REGION
1	AA901	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	MIDWEST
2	AB802	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	MIDWEST
3	AC703	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	MIDWEST
4	AD604	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	MIDWEST
5	AE505	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	SOUTH
6	AF406	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	MIDWEST
7	AG307	FERTILIZERS, SEEDS AND ANIMAL NUTRITION	MIDWEST
8	AH208	FOODS	MIDWEST
9	AI109	PHARMACEUTICAL	MIDWEST
10	AJ211	PHARMACEUTICAL	MIDWEST
11	AK212	AUTOMOTIVE	MIDWEST
12	AL213	BEVERAGE AND FOODS	MIDWEST
13	AM214	ANIMAL SUB-PRODUCT - GREASE	MIDWEST
14	AN215	PHARMACEUTICAL	SOUTHEAST
15	AO216	FOODS	NORTH
16	AP217	BEVERAGE AND FOODS	SOUTHEAST
17	AP218	BEVERAGE AND FOODS	NORTH
18	AQ219	BEVERAGE AND FOODS	SOUTH
19	AR220	BEVERAGE AND FOODS	NORTHEAST
20	AS330	FOODS	NORTH
21	AT331	PAPER, CELLULOSE	NORTHEAST
22	AU332	PAPER, CELLULOSE	SOUTH
23	AV333	FOODS	MIDWEST
24	AW334	SANITIZERS AND HYGIENE PRODUCTS	MIDWEST
25	AY335	FUELS	MIDWEST
26	AZ336	PAPER, CELLULOSE	SOUTH
27	BA337	FOODS	NORTHEAST
28	BB338	CEMENT	SOUTHEAST
29	BC339	INDUSTRIAL EQUIPAMENT AND ENGINEERING	SOUTH
30	BD340	FOODS	SOUTH
31	BE450	AUTOMOTIVE	SOUTH

32	BF451	PHARMACEUTICAL	SOUTHEAST
33	BG452	FOODS	SOUTH
34	BH453	TEXTILE	MIDWEST
35	BI454	BEVERAGE AND FOODS	MIDWEST
36	BJ455	PHARMACEUTICAL	MIDWEST
37	BL456	INDUSTRIAL EQUIPMENT AND ENGINEERING	MIDWEST
38	BM457	FOODS	NORTH
39	BN458	FOODS	MIDWEST
40	BO459	PAPER, CELLULOSE	SOUTH
41	BP510	PAPER, CELLULOSE	SOUTH
42	BQ511	WOOD	SOUTHEAST
43	BR512	PAPER, CELLULOSE	MIDWEST
44	BS513	PHARMACEUTICAL	MIDWEST
45	BT514	PLASTIC	MIDWEST
46	BU515	FOODS	MIDWEST
47	BV516	FOODS	MIDWEST
48	BW517	AUTOMOTIVE	SOUTH
49	BX518	AUTOMOTIVE	SOUTH
50	BY519	AUTOMOTIVE	SOUTH
51	BZ520	BEVERAGE AND FOODS	NORTHEAST
52	CA623	BEVERAGE AND FOODS	NORTH
53	CB624	BEVERAGE AND FOODS	NORTHEAST
54	CC625	PAPER, CELLULOSE	SOUTHEAST
55	CD626	BEVERAGE AND FOODS	NORTHEAST
56	CE627	PACKAGING	NORTHEAST
57	CF628	SANITIZERS AND HYGIENE PRODUCTS	NORTHEAST
58	CG629	INDUSTRIAL EQUIPMENT AND ENGINEERING	SOUTH
59	CH630	SANITIZERS AND HYGIENE PRODUCTS	SOUTH
60	CI645	SANITIZERS AND HYGIENE PRODUCTS	MIDWEST
61	CJ646	FOODS	MIDWEST
62	CK647	FOODS	MIDWEST
63	CL648	FOODS	MIDWEST
64	CM649	BEVERAGE AND FOODS	MIDWEST
65	CN650	BEVERAGE AND FOODS	SOUTHEAST
66	CO821	AUTOMOTIVE	SOUTHEAST
67	CP822	PAPER, CELLULOSE	MIDWEST
68	CQ823	PAPER, CELLULOSE	MIDWEST
69	CR824	PAPER, CELLULOSE	SOUTH
70	CS825	FOODS	SOUTHEAST
71	CT826	AUTOMOTIVE	SOUTHEAST
72	CV827	PHARMACEUTICAL	MIDWEST
73	CW828	BEVERAGE AND FOODS	NORTHEAST
74	CY829	BEVERAGE AND FOODS	NORTHEAST
75	CX830	SANITIZERS AND HYGIENE PRODUCTS	SOUTHEAST
76	CZ831	SANITIZERS AND HYGIENE PRODUCTS	MIDWEST

77	DA904	BEVERAGE AND FOODS	SOUTH
78	DB905	BEVERAGE AND FOODS	NORTHEAST
79	DC906	SANITIZERS AND HYGIENE PRODUCTS	SOUTHEAST
80	DD907	SANITIZERS AND HYGIENE PRODUCTS	MIDWEST
81	DE908	WOOD	SOUTH
82	DF909	WOOD	SOUTH
83	DG910	WOOD	SOUTH
84	DH011	SANITIZERS AND HYGIENE PRODUCTS	MIDWEST
85	DI911	PACKAGING	MIDWEST
86	DJ864	FOODS	MIDWEST
87	DK258	FOODS	NORTH
88	DL124	WOOD	SOUTHEAST
89	DM587	PAPER, CELLULOSE	SOUTH
90	DN986	INDUSTRIAL EQUIPAMENT AND ENGINEERING	SOUTHEAST
91	DO782	PHARMACEUTICAL	MIDWEST
92	DP234	FOODS	MIDWEST
93	DS751	PACKAGING	SOUTH
94	DT753	PACKAGING	SOUTHEAST
95	DU794	PACKAGING	SOUTH
96	DV566	ANIMAL NUTRITION	MIDWEST
97	DW236	PHARMACEUTICAL	MIDWEST
98	DX413	PHARMACEUTICAL	NORTHEAST
99	DY179	COSMETICS AND NUTRITION	MIDWEST
100	DZ887	FOODS	SOUTHEAST

APPENDIX C – Presentation Letter for Empirical Research



Presentation Letter

Goiânia/GO, November, 3, 2023.

Hereby, we present **Mr. WAGNER SANTOS GUEDIN**, student of the Master's Program in Administration (MPA) duly enrolled at Centro Universitário Alves Faria - UNIALFA, who is carrying out research entitled “**Industry 4.0 scenario in Brazil: an empirical study to map the status of technological and non-technological elements**”.

We hereby request your authorization to carry out and collect data in your organization, informing you that the ethical nature of this research ensures the confidentiality of the information collected and also guarantees the preservation of the identity and privacy of the organization and the professional interviewed.

Regarding privacy and protection of personal data, the researcher undertakes to comply with the provisions of Brazilian Law 13,709/2018 (general personal data protection law) using data related to the natural person, which identifies or makes them identifiable (personal data) only for the processing necessary to carry out this research.

Thank you for your collaboration in the process of developing scientific research, and we are at your disposal through the following contacts:

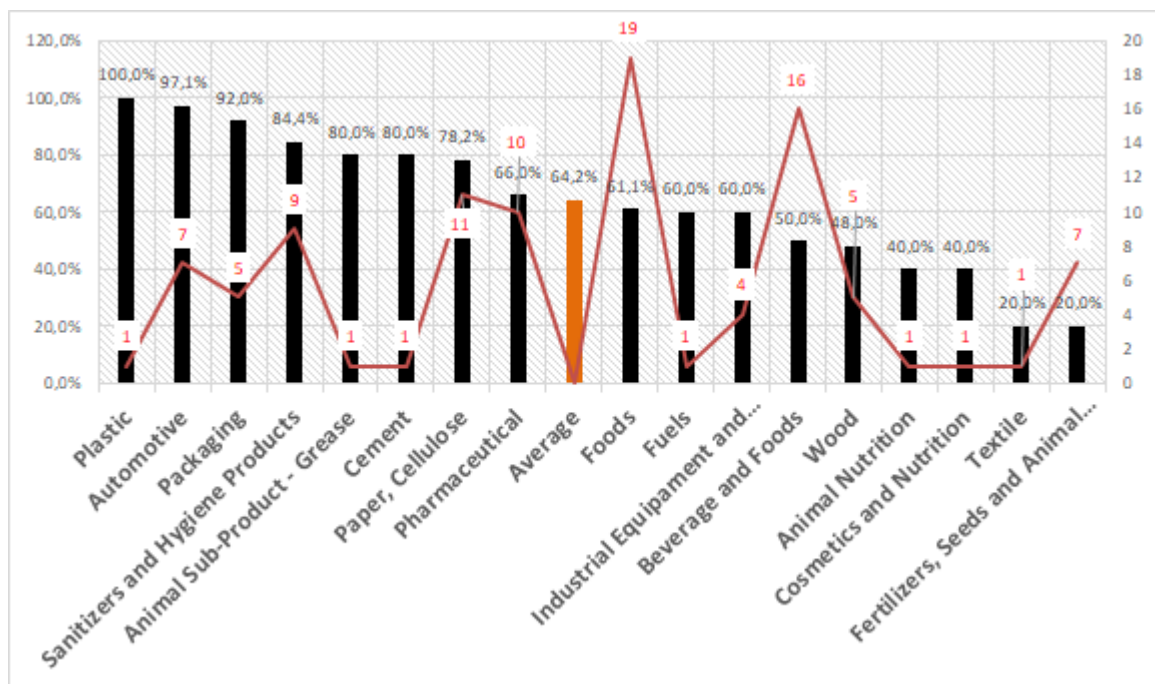
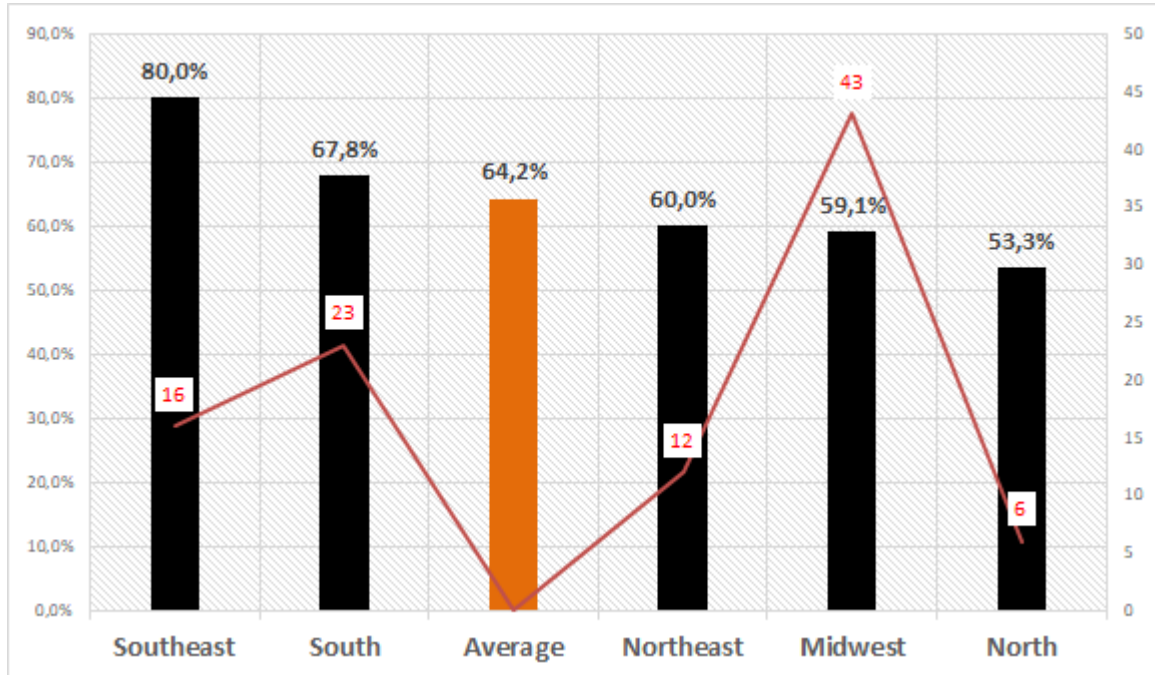
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APPENDIX D – Set of search results by question

Q1 Question Results Set

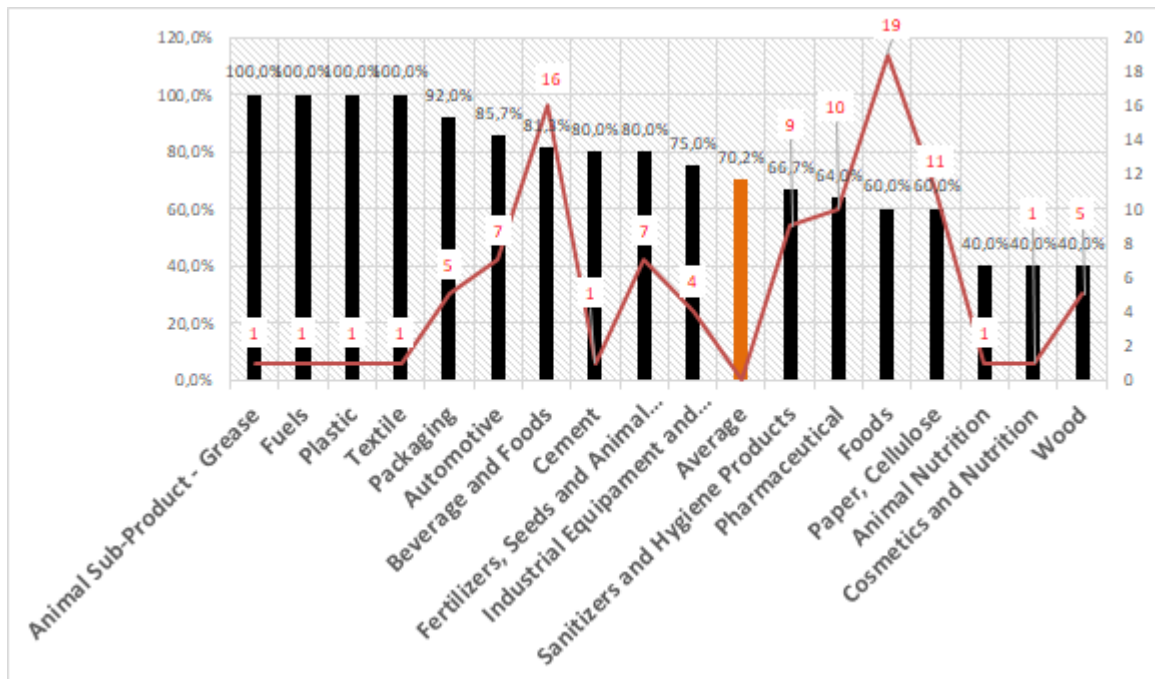
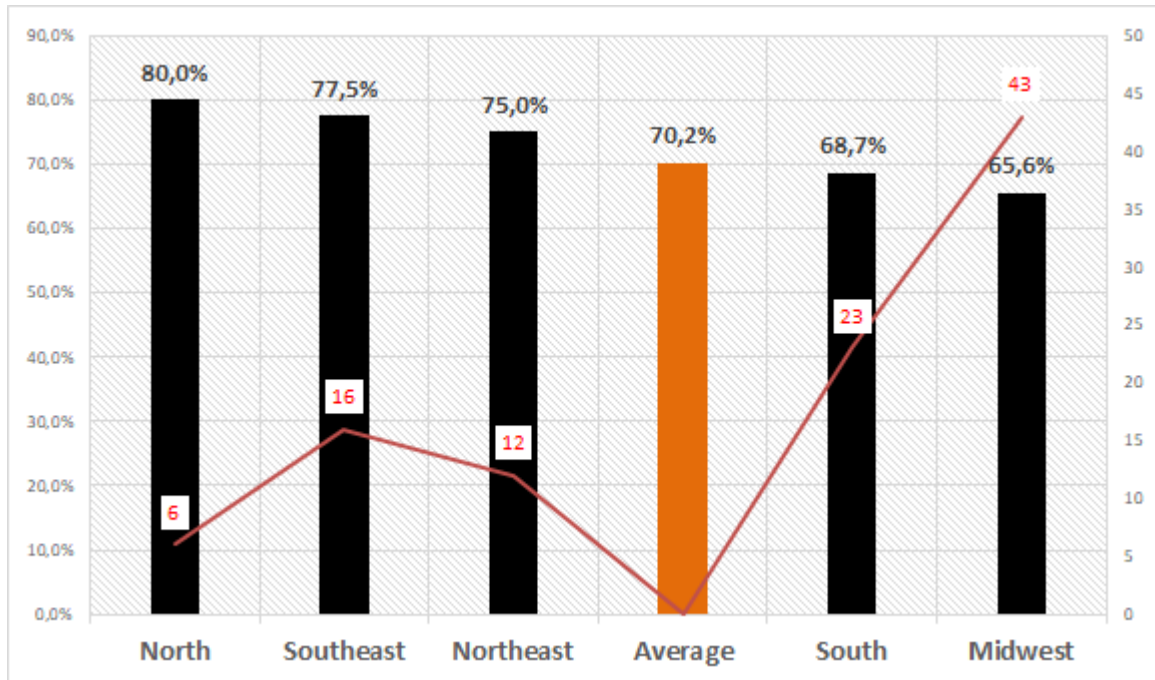
Q1	The company uses an ANDON-type system that informs about the generation of problems on the line.
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Source: Prepared by the author

Q2 Question Results Set

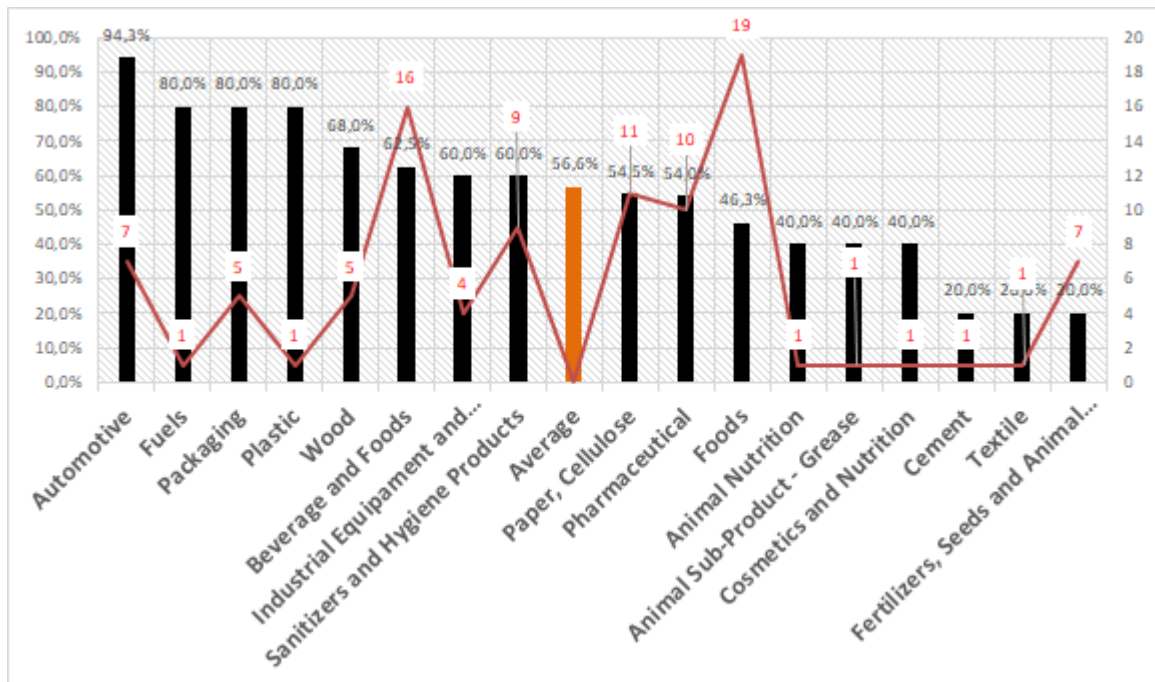
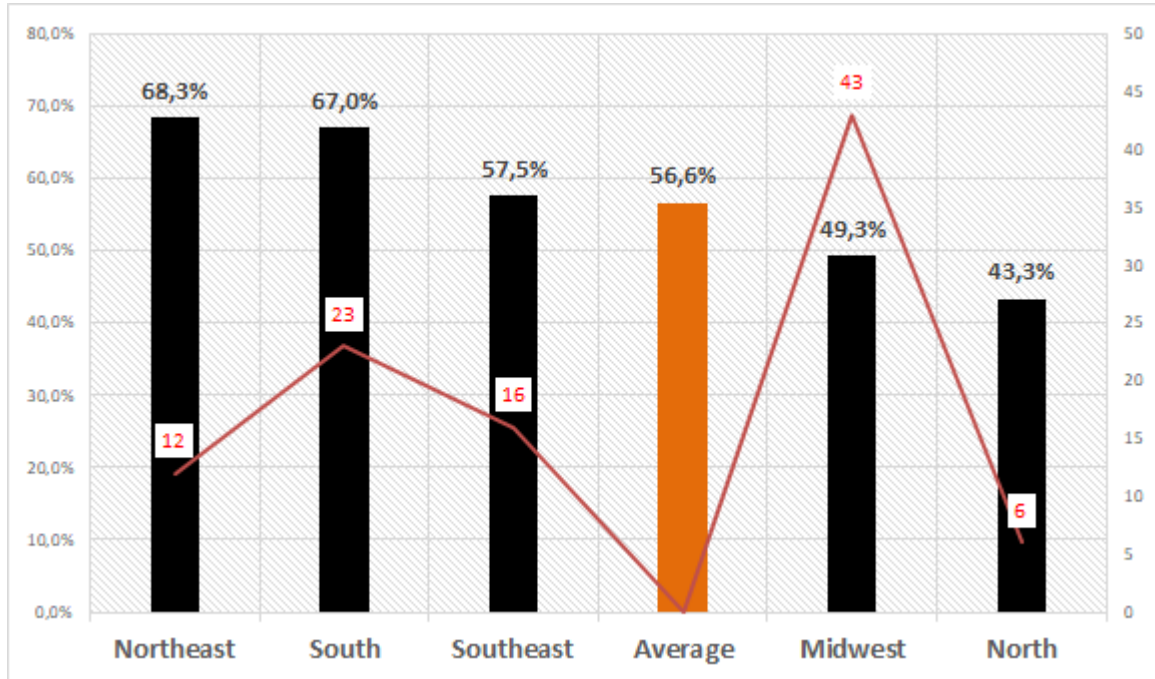
Q2	The company's Information Technology area has initiatives related to Big Data.
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Source: Prepared by the author

Q3 Question Results Set

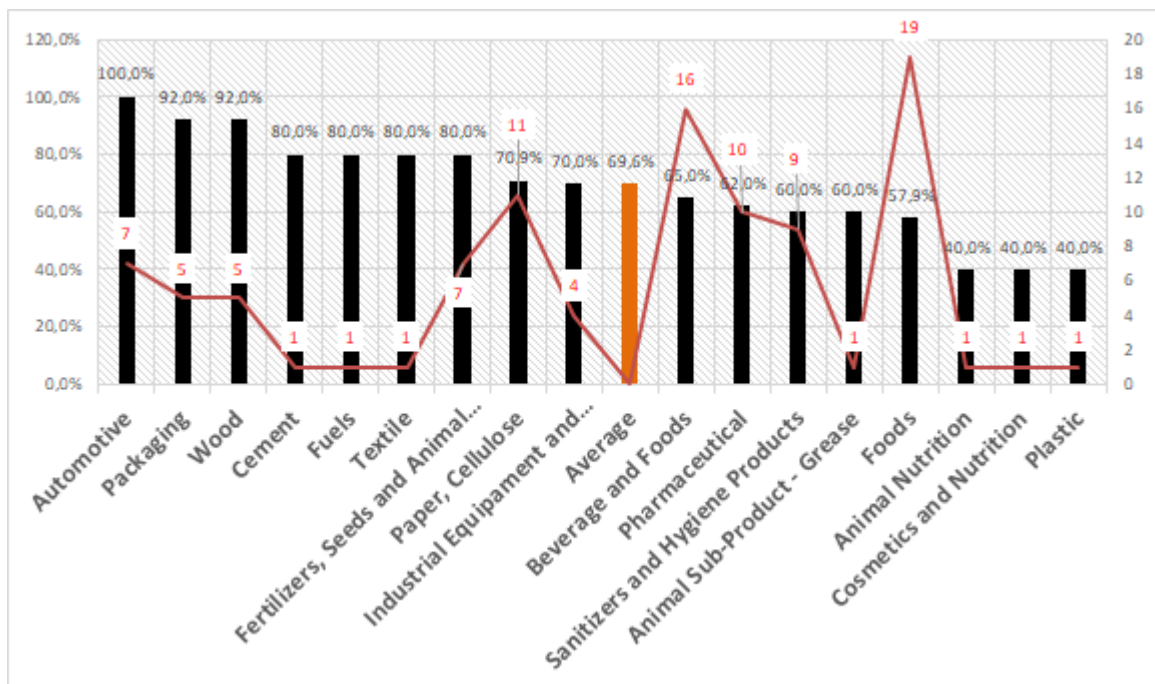
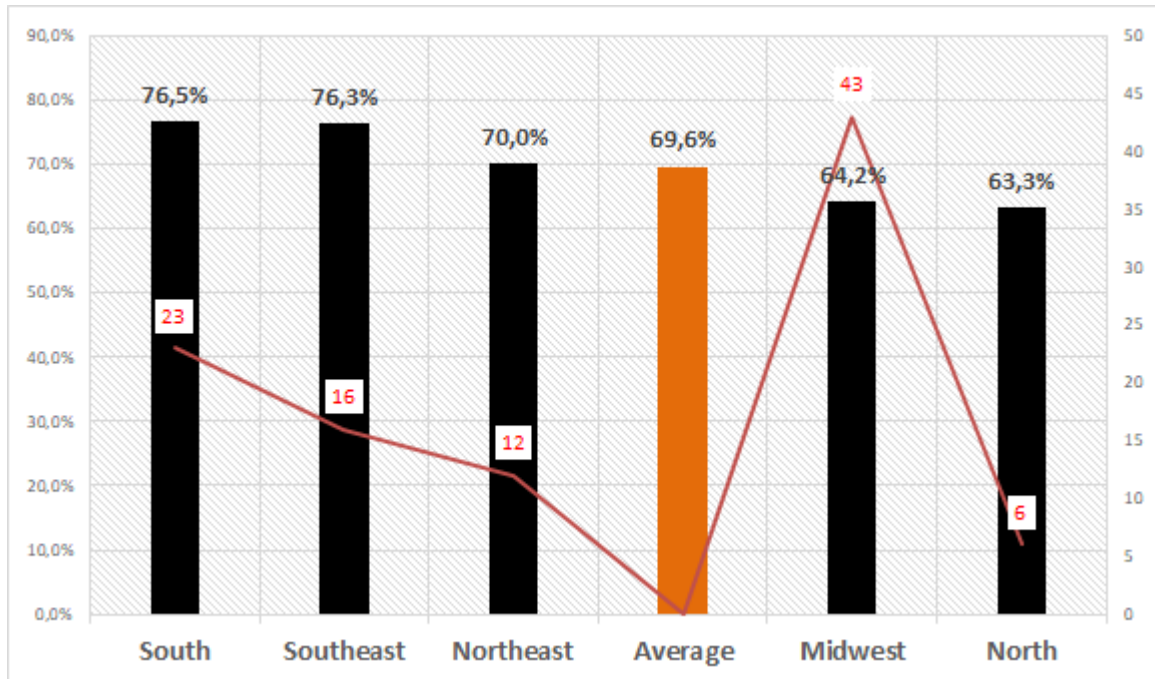
Q3	The company's Manufacturing areas have evolved with the use of Autonomous Robots.
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Source: Prepared by the author

Q4 Question Results Set

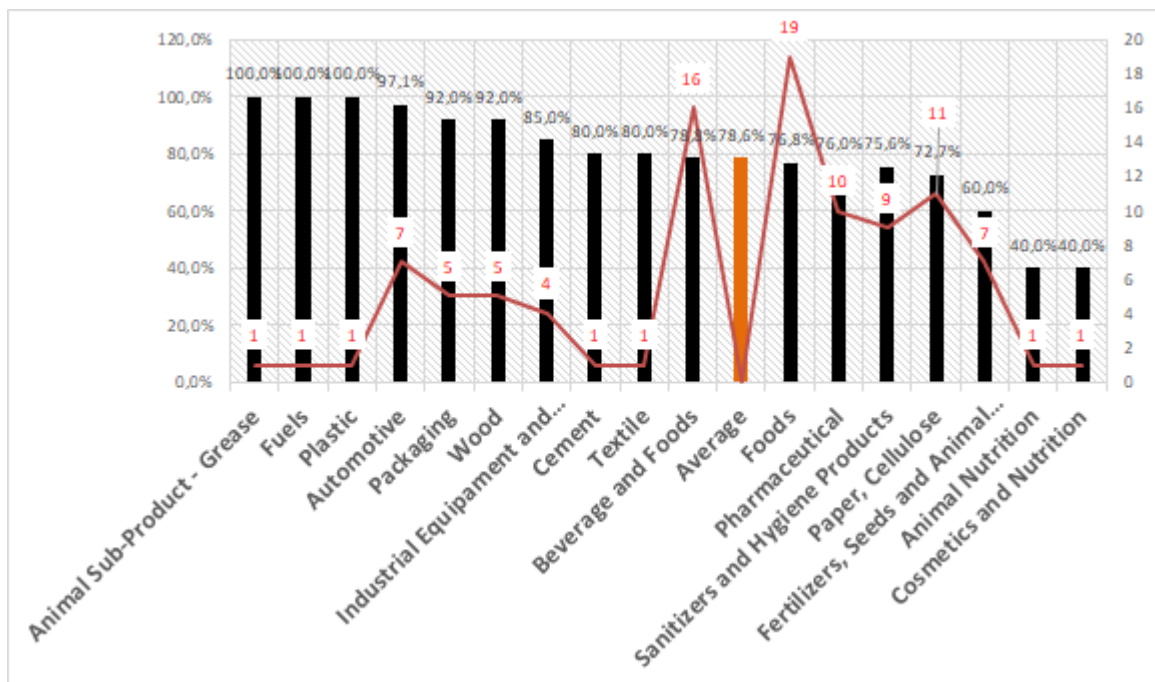
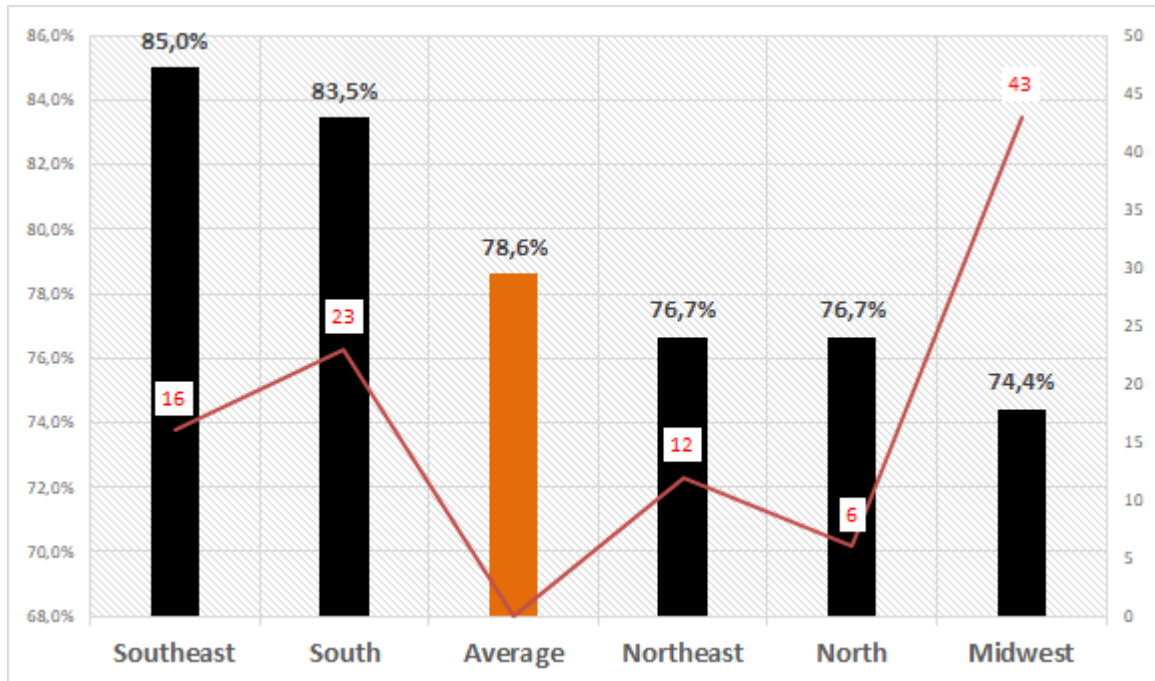
Q4	The company's Manufacturing areas have evolved with the use of the Internet of Things in the aspect of exchanging information between machines.
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Source: Prepared by the author

Q5 Question Results Set

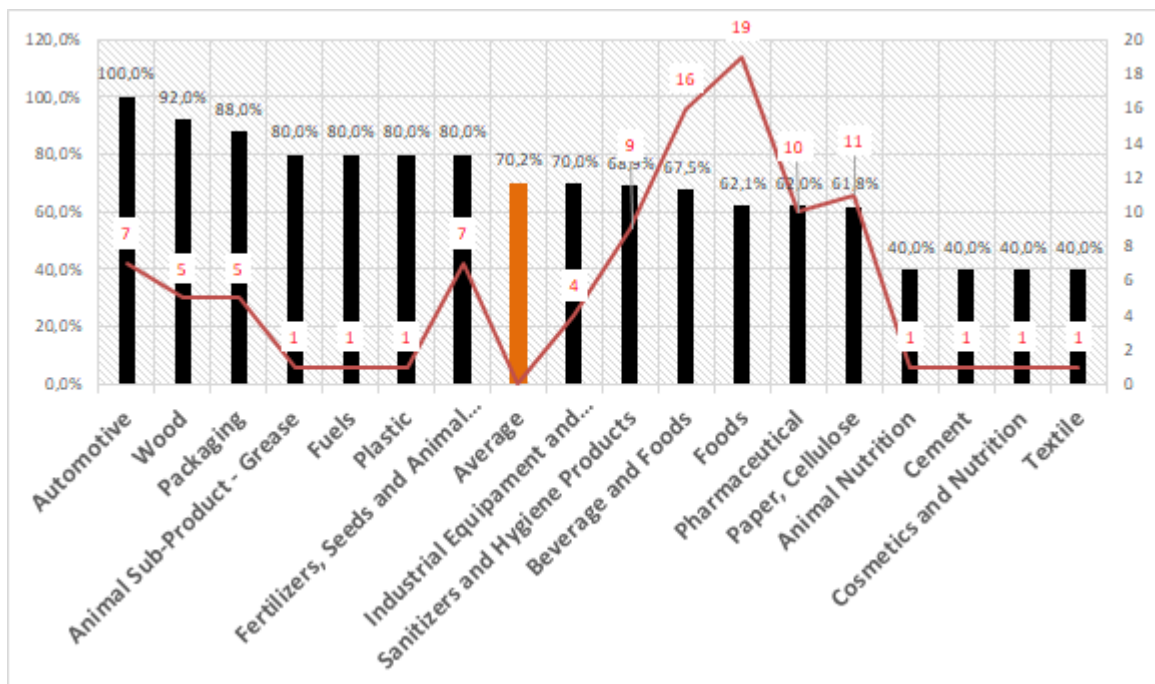
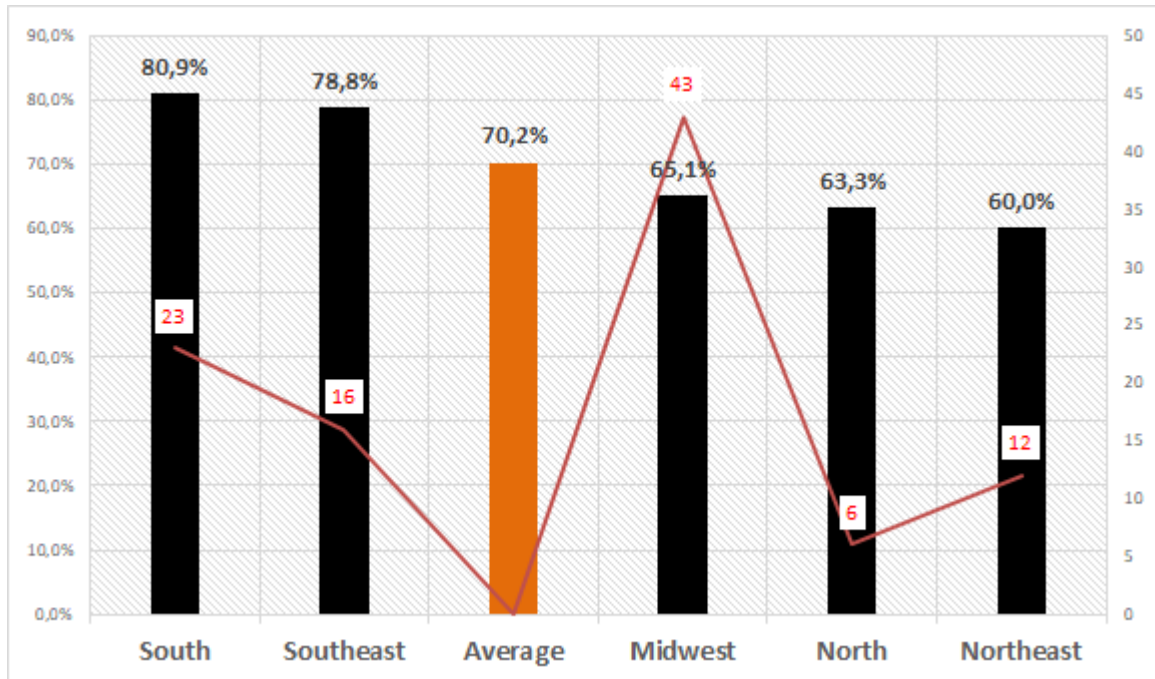
Q5	The company's Information Technology area has initiatives related to the topic of Cloud Computing.
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Source: Prepared by the author

Q6 Question Results Set

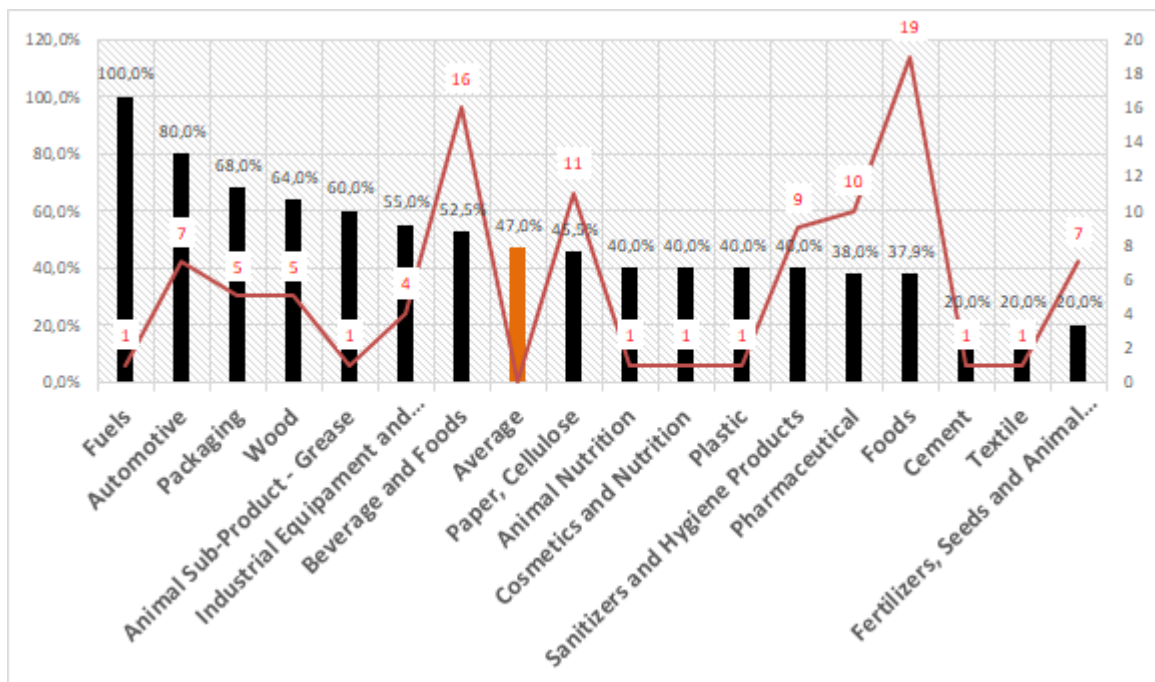
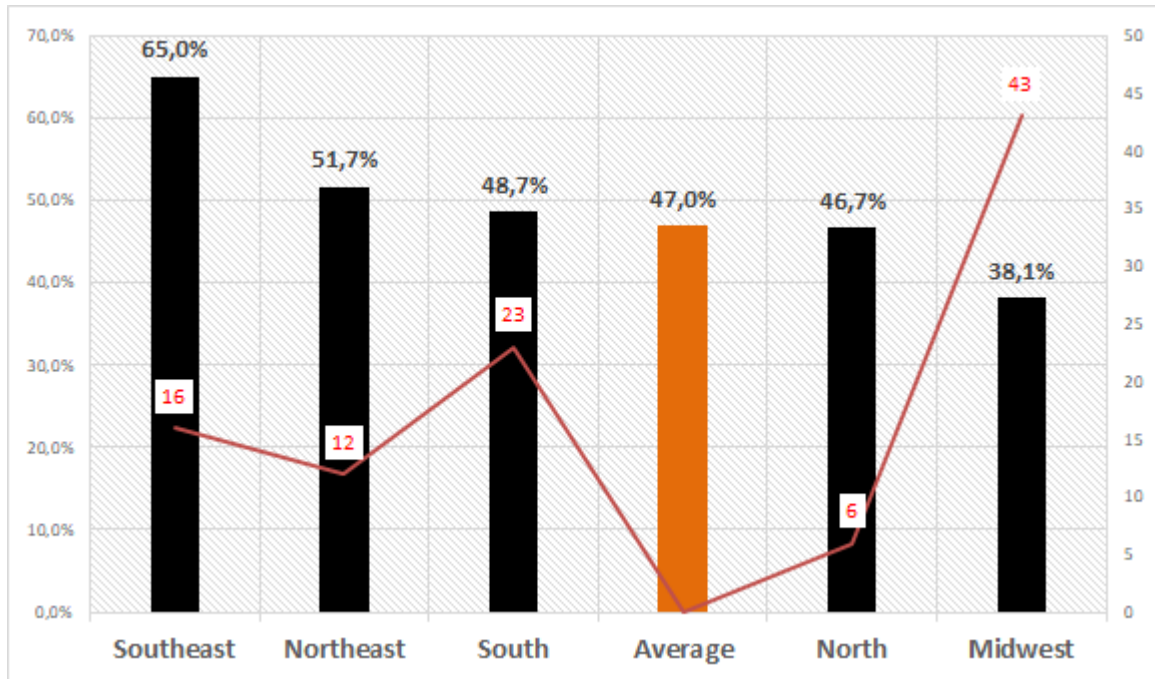
Q6	The company has a team of Information Technology specialists capable of meeting the demands of Industry 4.0.
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Source: Prepared by the author

Q7 Question Results Set

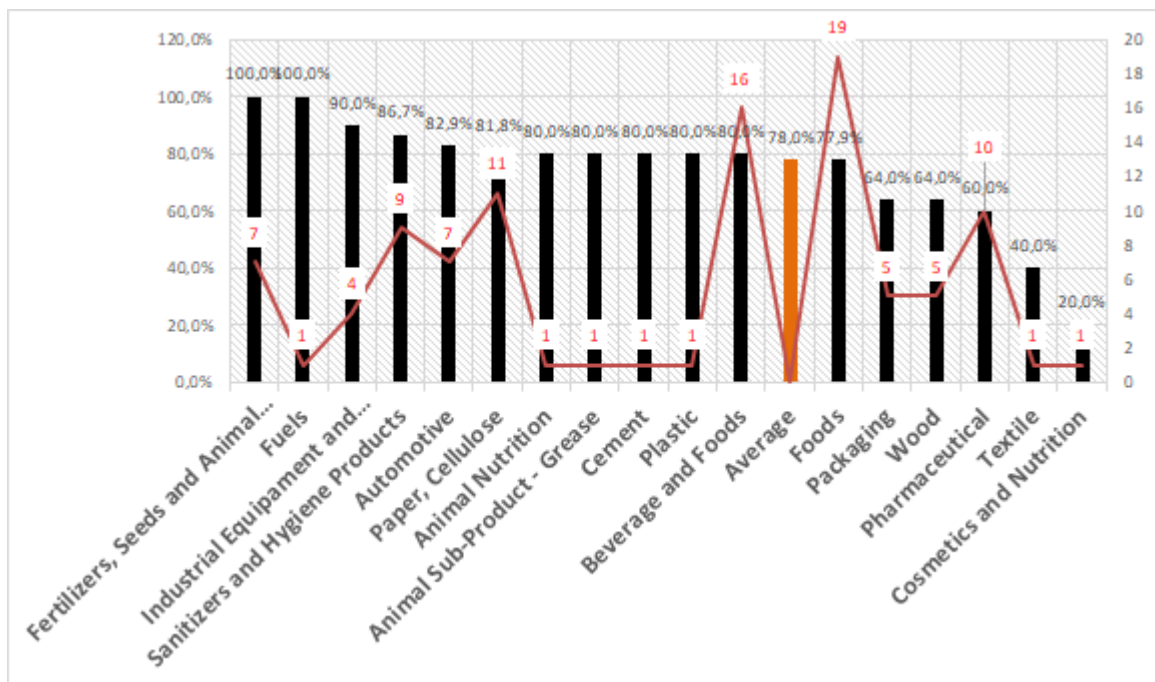
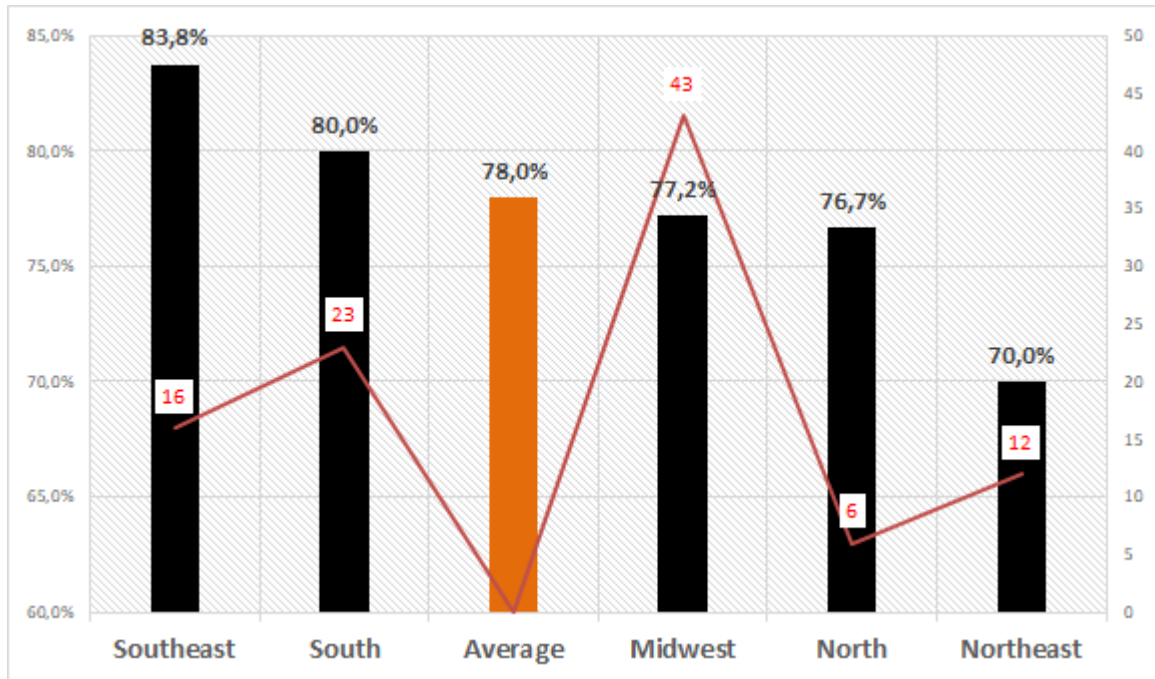
Q7	The company has initiatives to use Augmented Reality, that is, it uses technology that superimposes virtual elements on our vision of reality.
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Source: Prepared by the author

Q8 Question Results Set

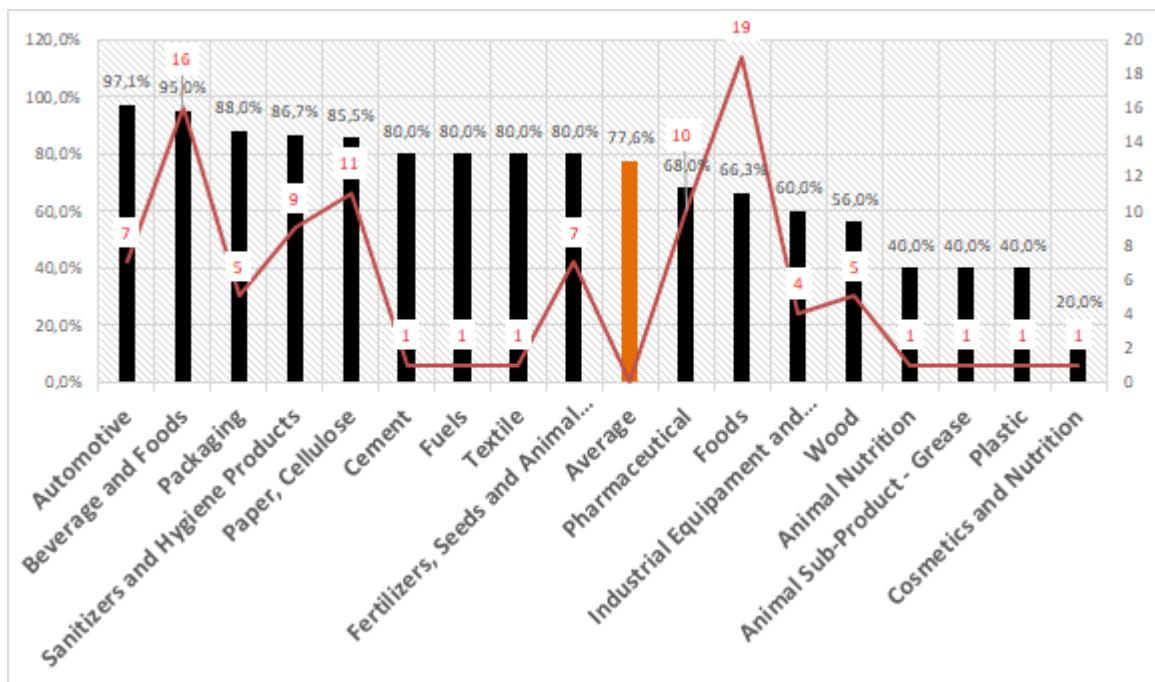
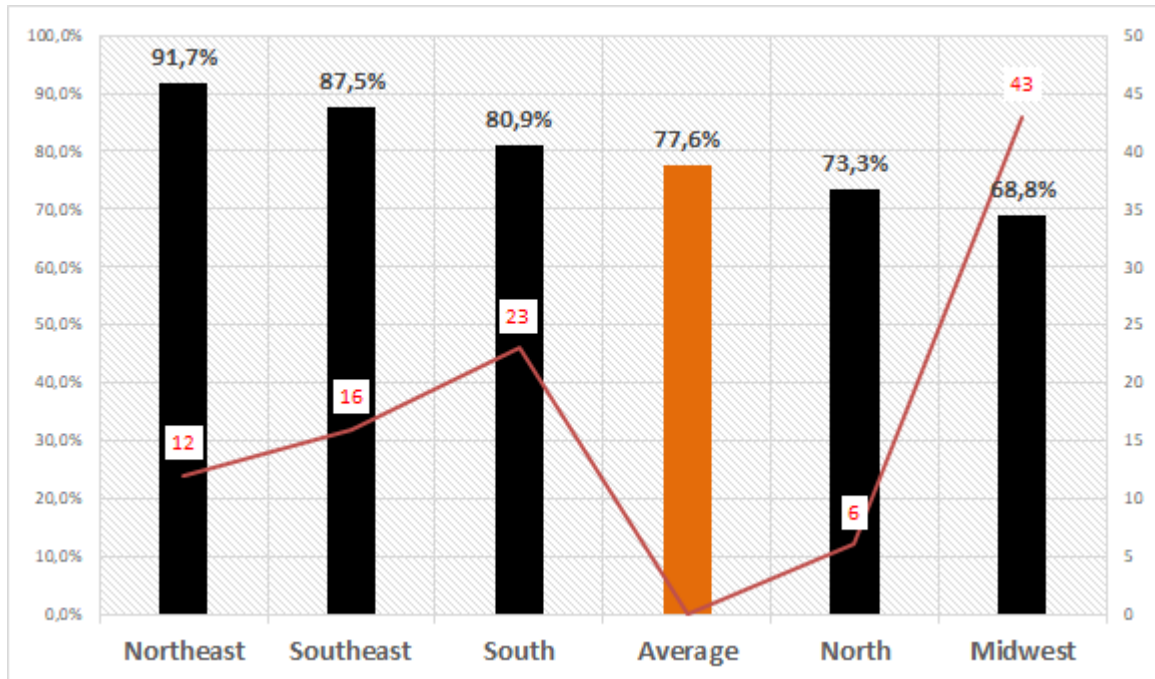
Q8	In the company, the Manufacturing areas can quickly coordinate production replanning when there is any problem or customer demand.
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Source: Prepared by the author

Q9 Question Results Set

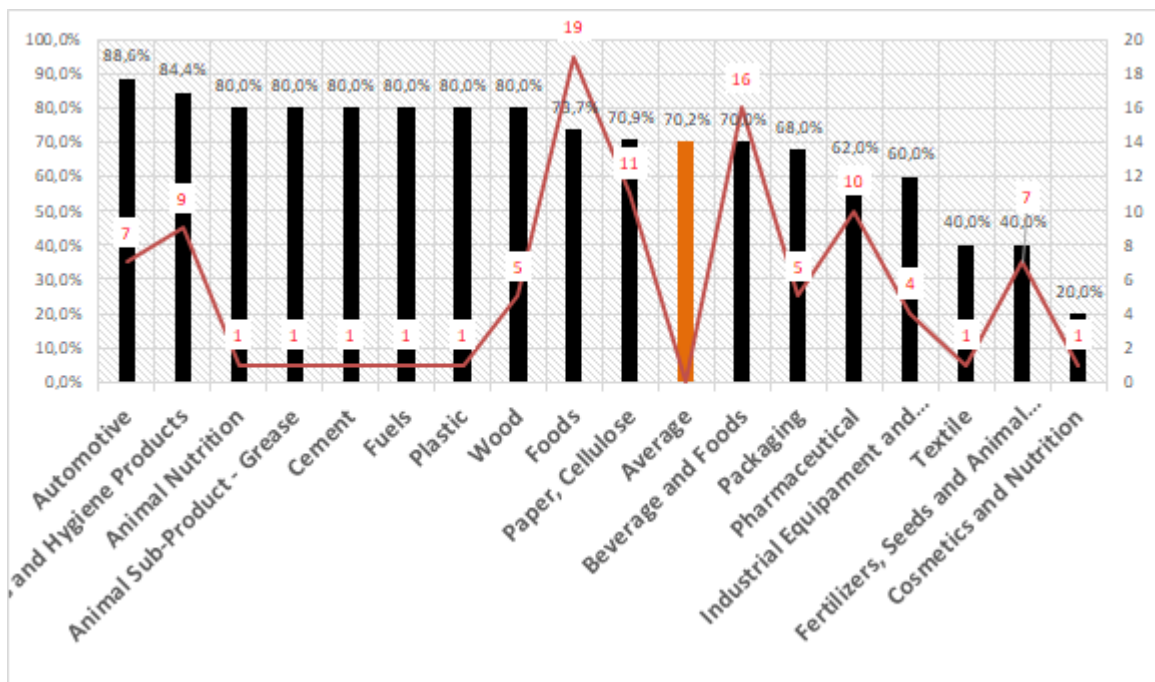
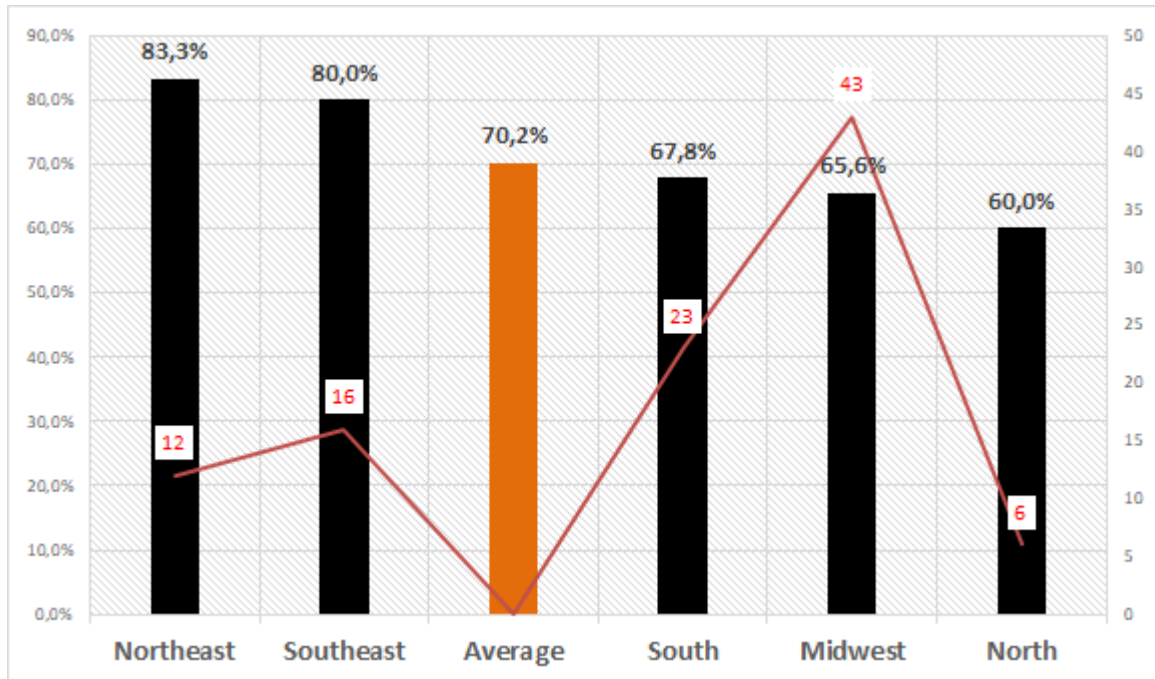
Q9	The company uses a management model based on operational excellence, such as Lean Manufacturing, TPM or WCM.
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Source: Prepared by the author

Q10 Question Results Set

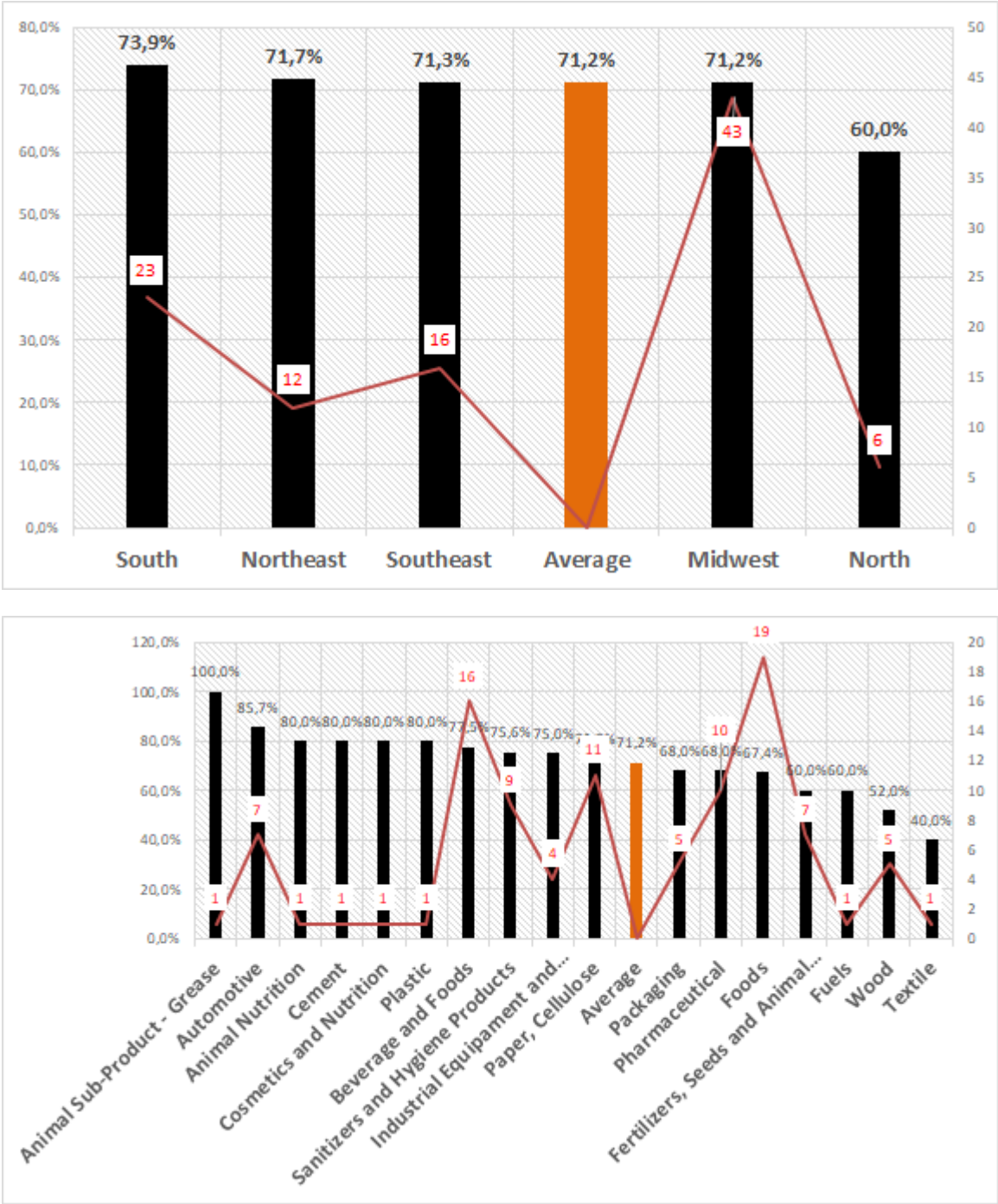
Q10	The company is prepared for a possible disruption in the process of acquiring inputs and raw materials.
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Source: Prepared by the author

Q11 Question Results Set

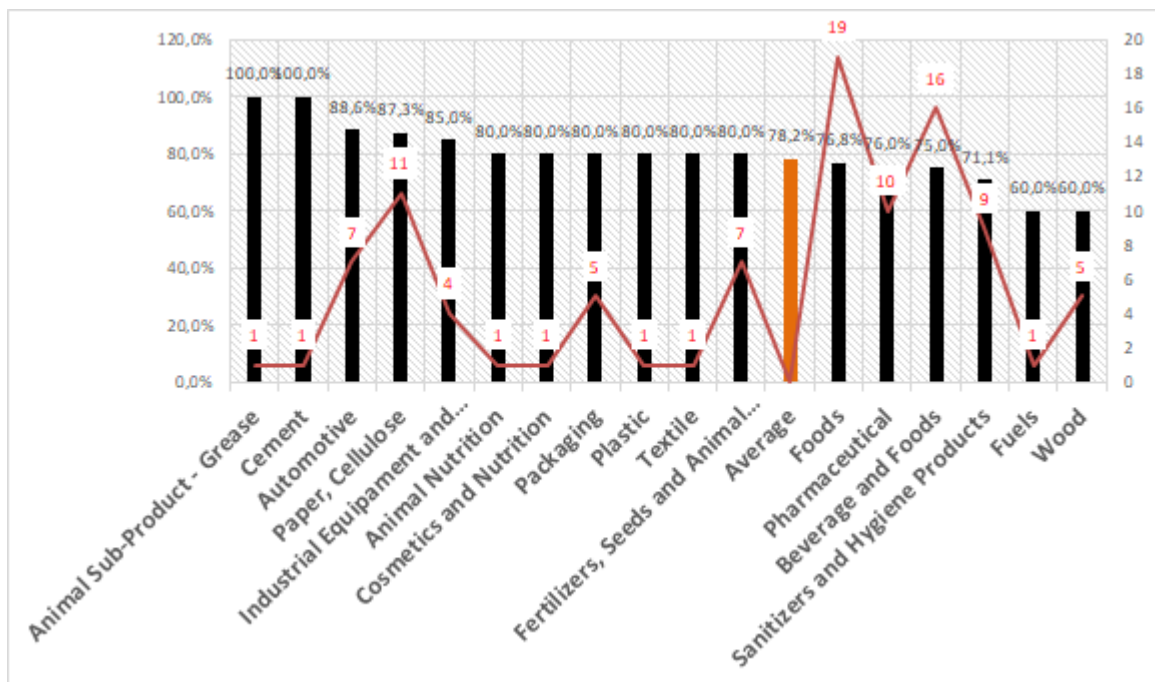
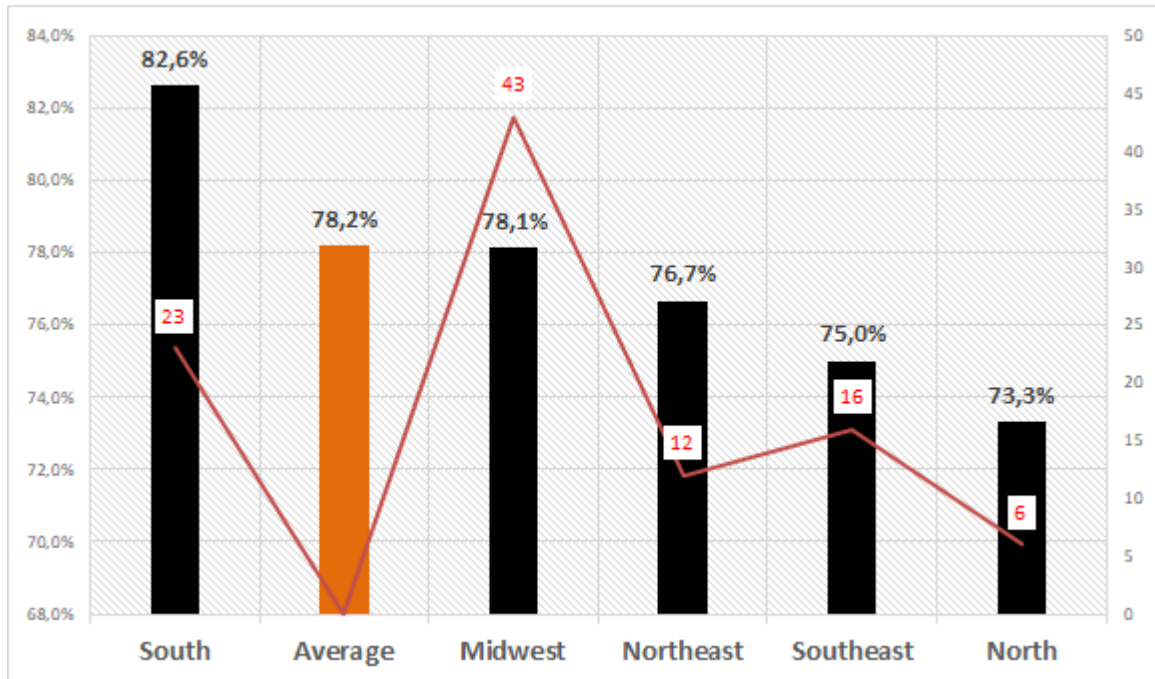
Q11	I have knowledge of public policies for the development of industrial innovation.
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Source: Prepared by the author

Q12 Question Results Set

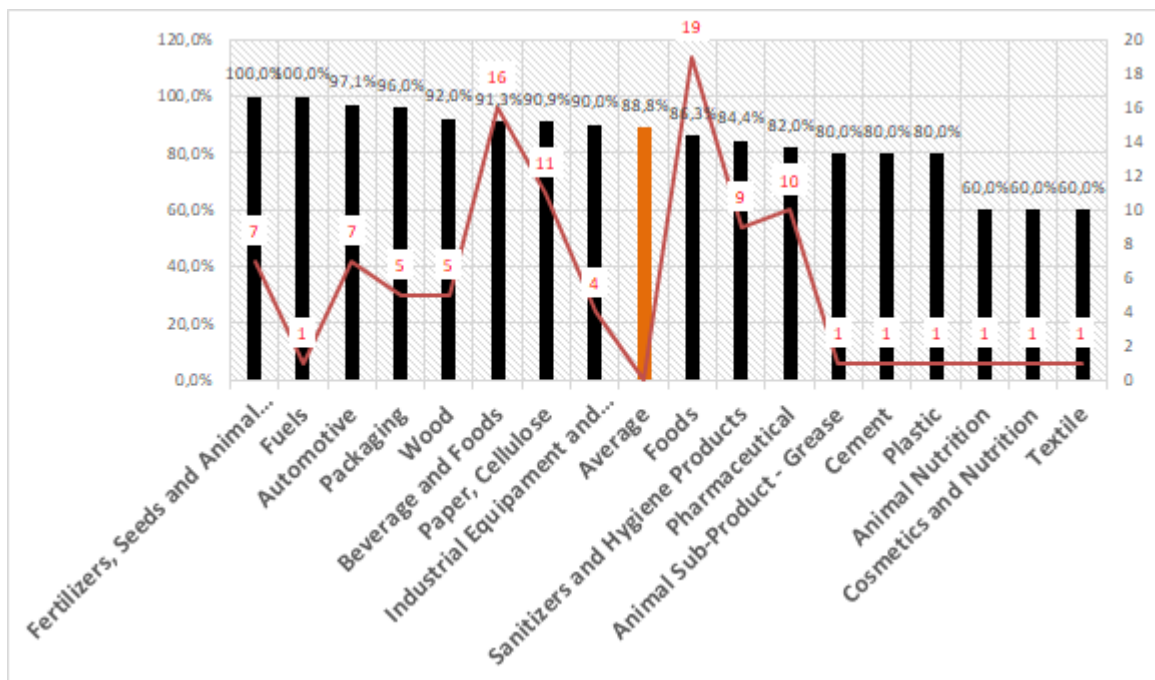
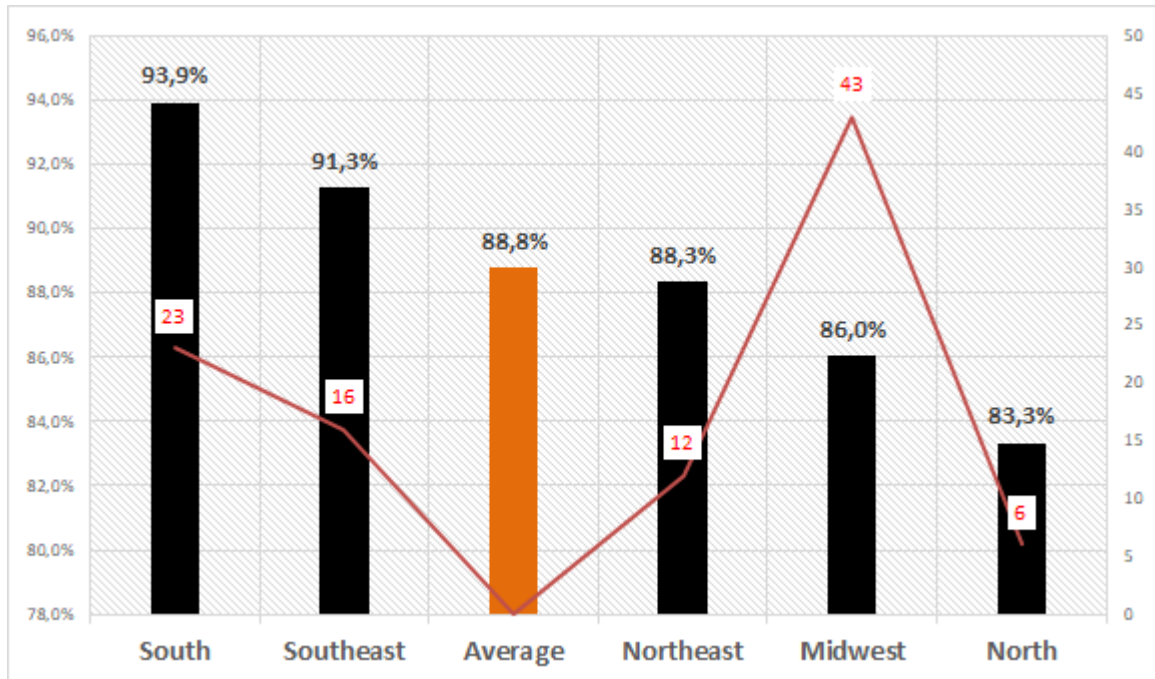
Q12 I consider that I have knowledge about the concepts of Industry 4.0.



Source: Prepared by the author

Q13 Question Results Set

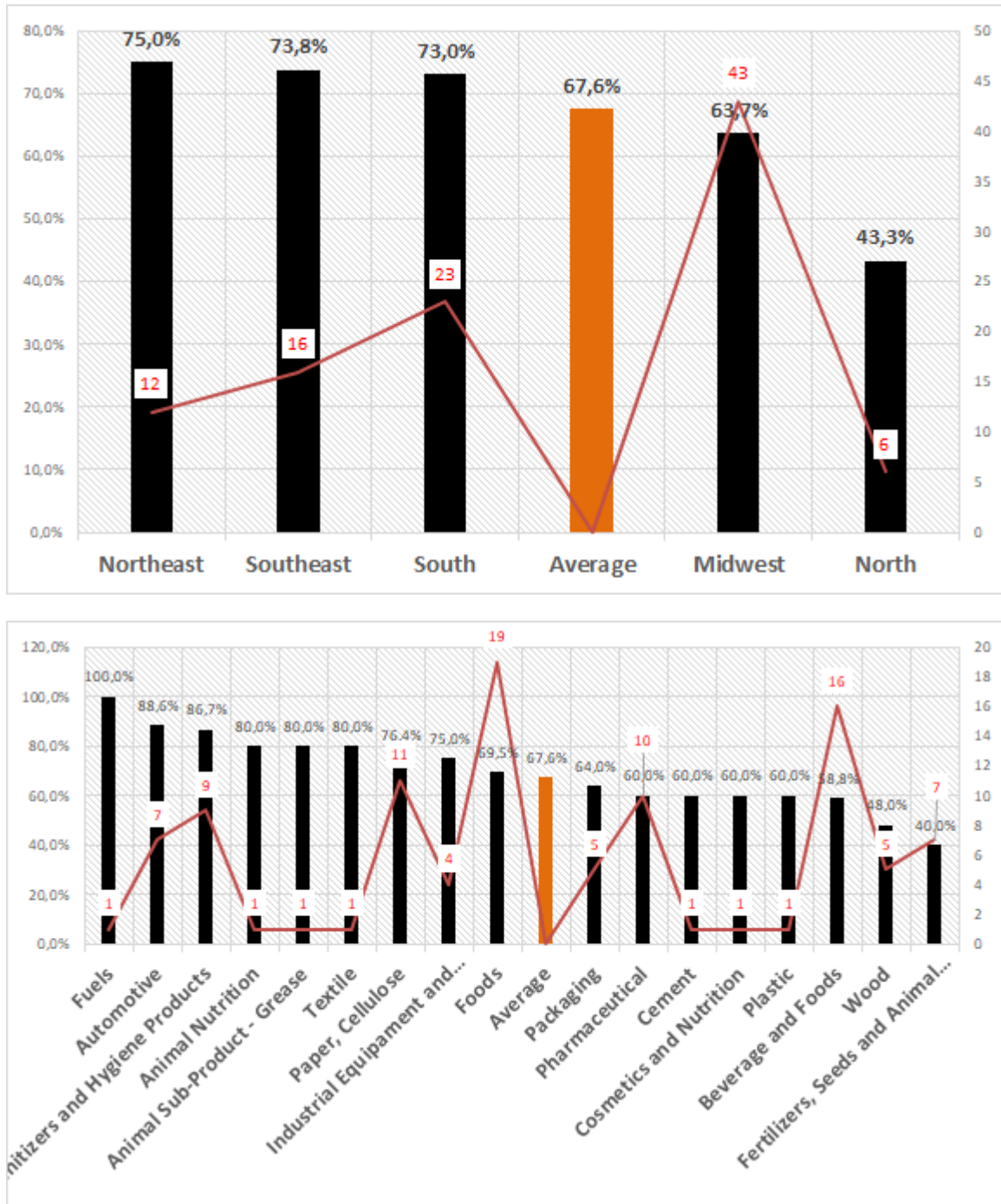
Q13	How often does the company control the product phases, from development, manufacturing, delivery and recycling?
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Source: Prepared by the author

Q14 Question Results Set

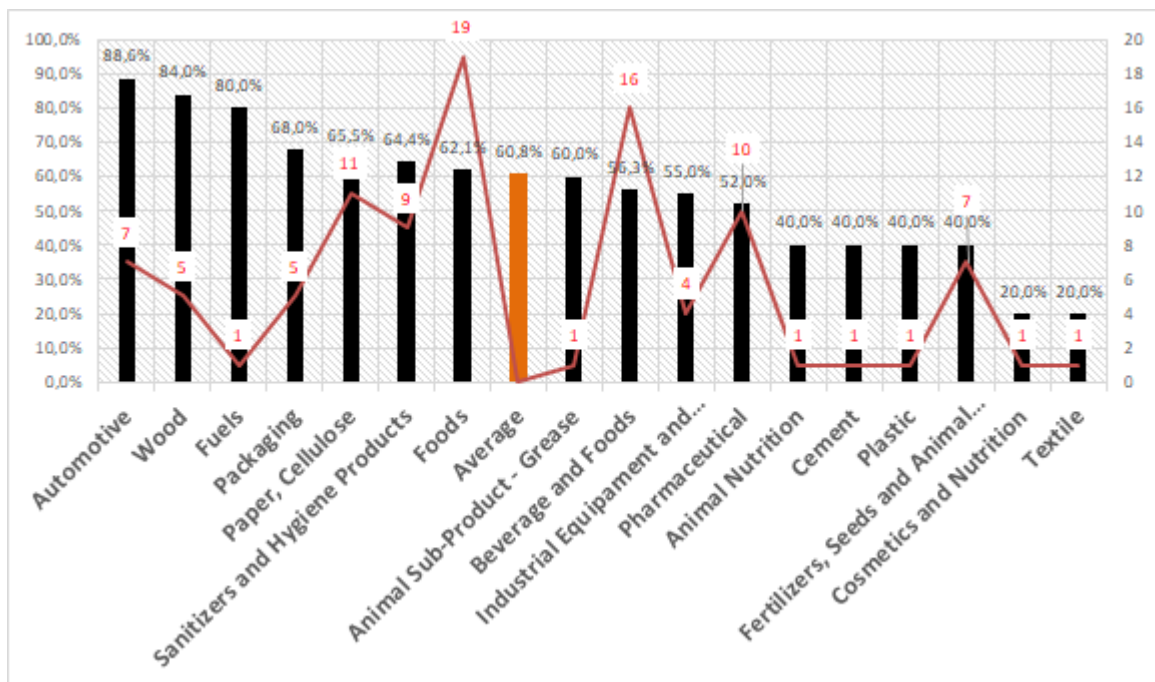
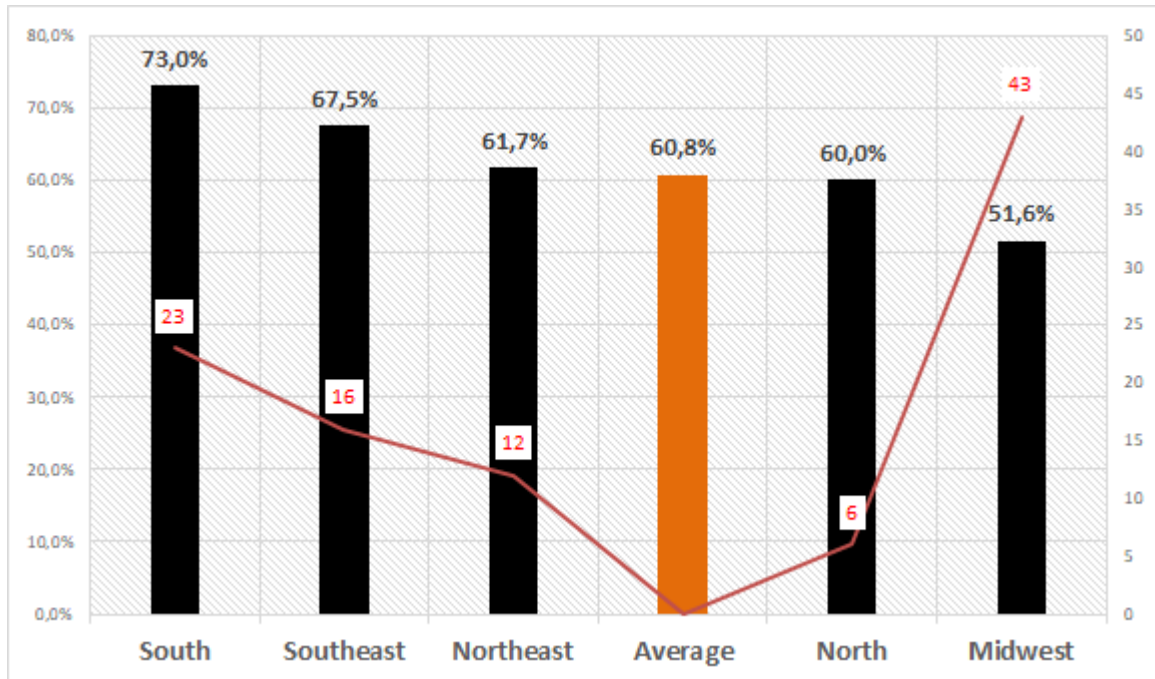
Q14 How often do customers actively participate in new product development?



Source: Prepared by the author

Q15 Question Results Set

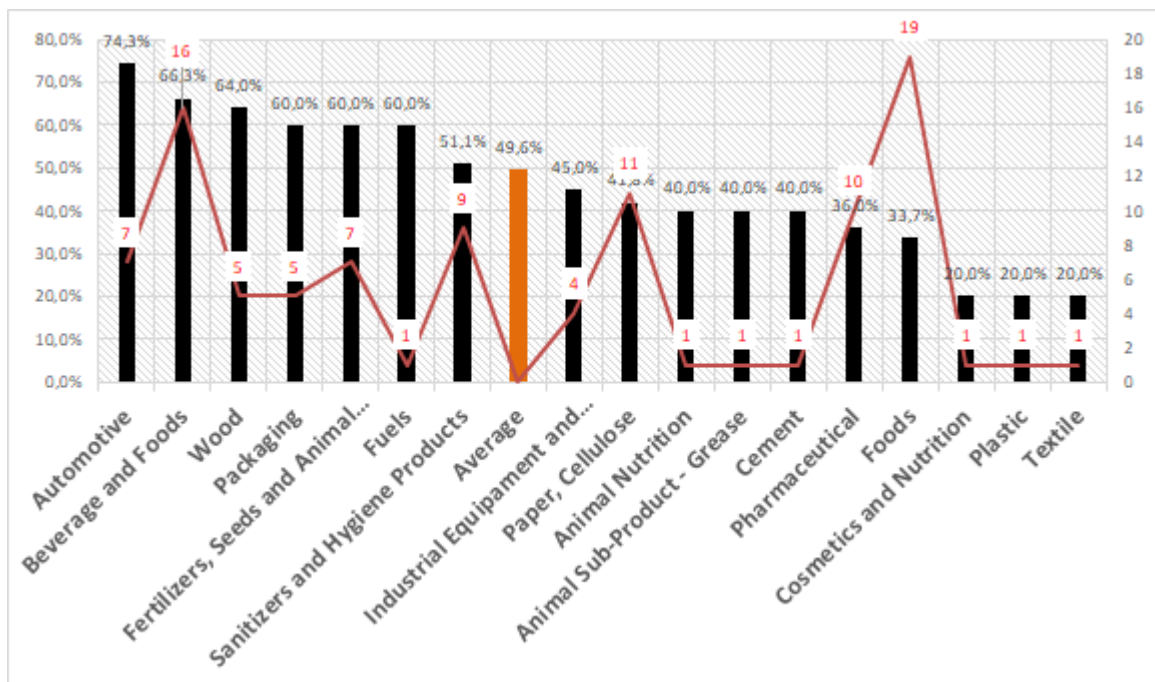
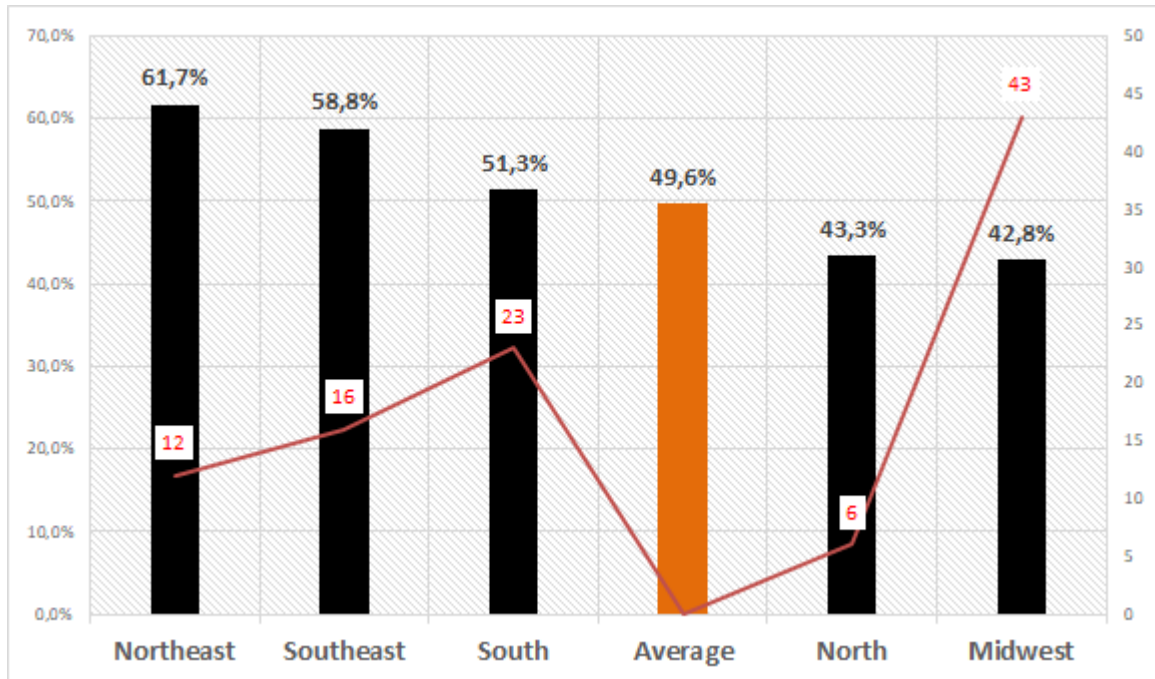
Q15	How often does the company use artificial intelligence for process management? E.g.: intelligent surveillance systems (CCTV), route applications, virtual reality glasses, etc...
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Source: Prepared by the author

Q16 Question Results Set

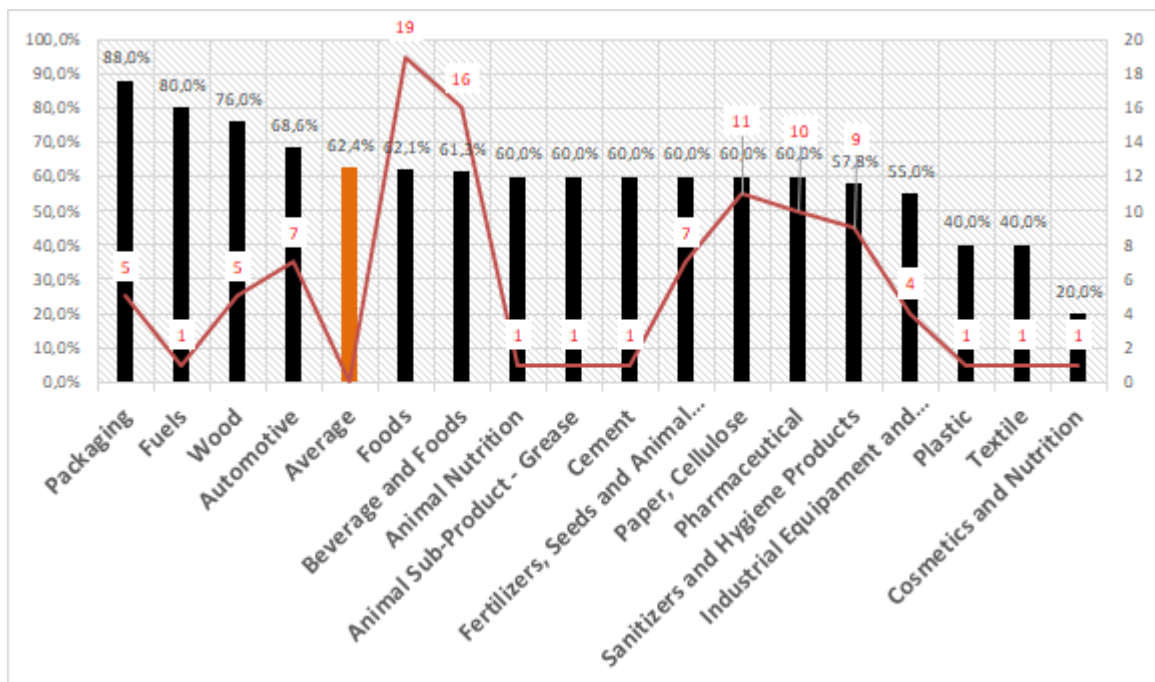
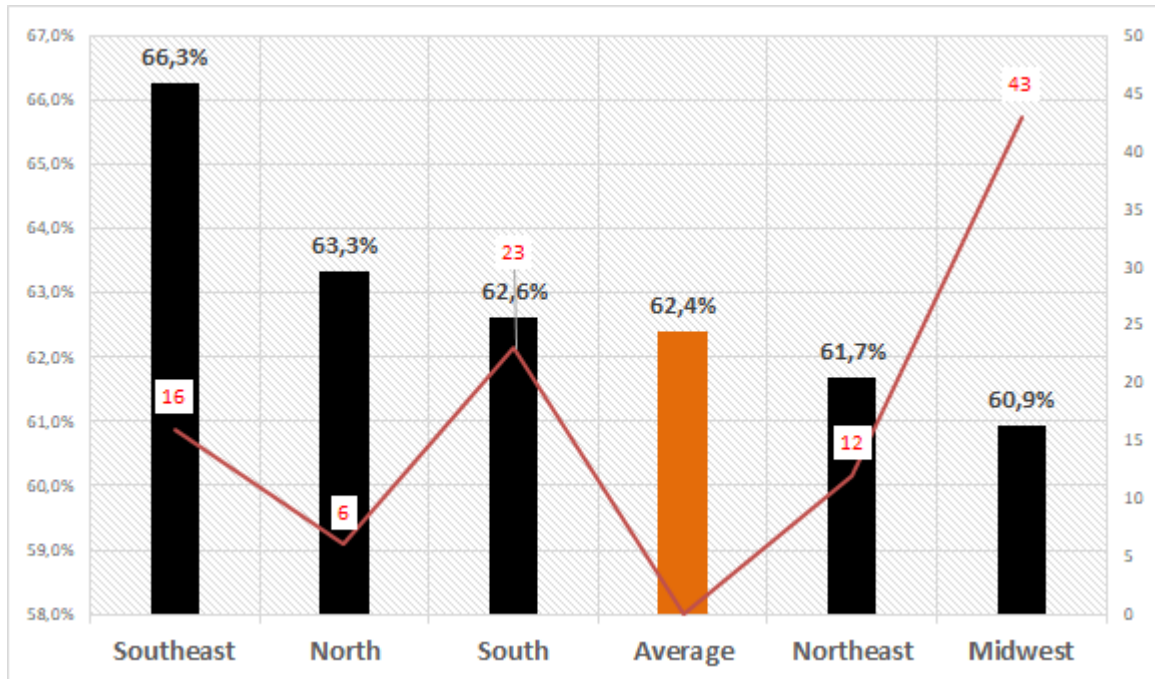
Q16	How often does the company have initiatives to use Additive Manufacturing, that is, does it use 3D Printing technology, for example?
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Source: Prepared by the author

Q17 Question Results Set

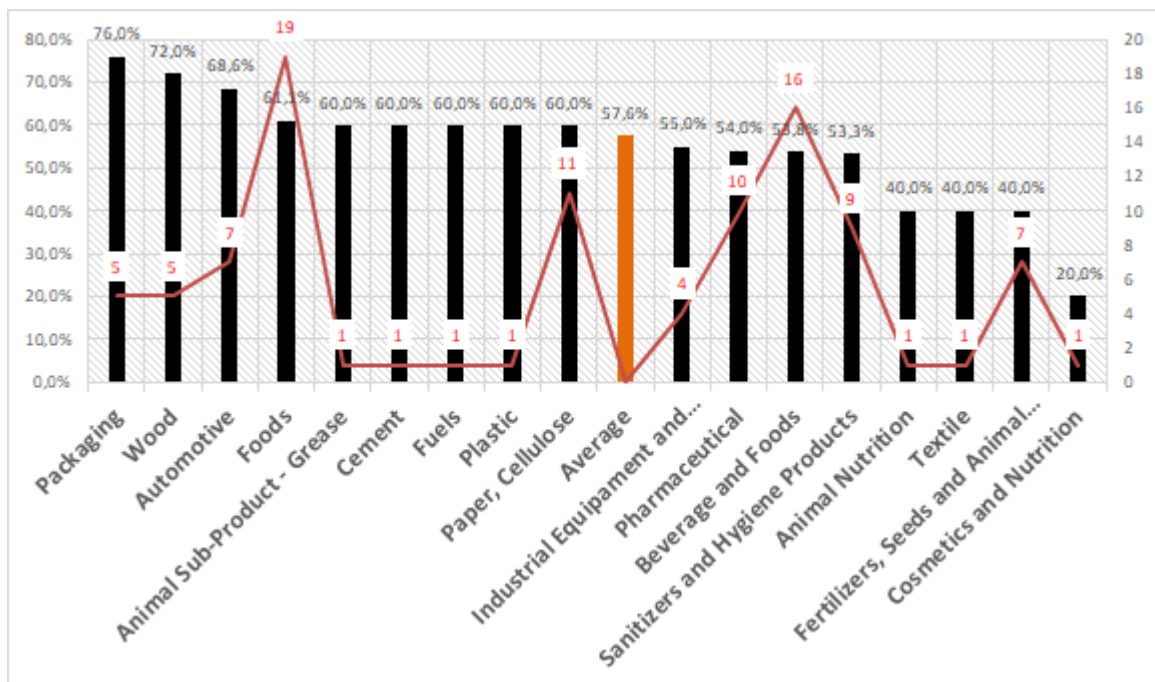
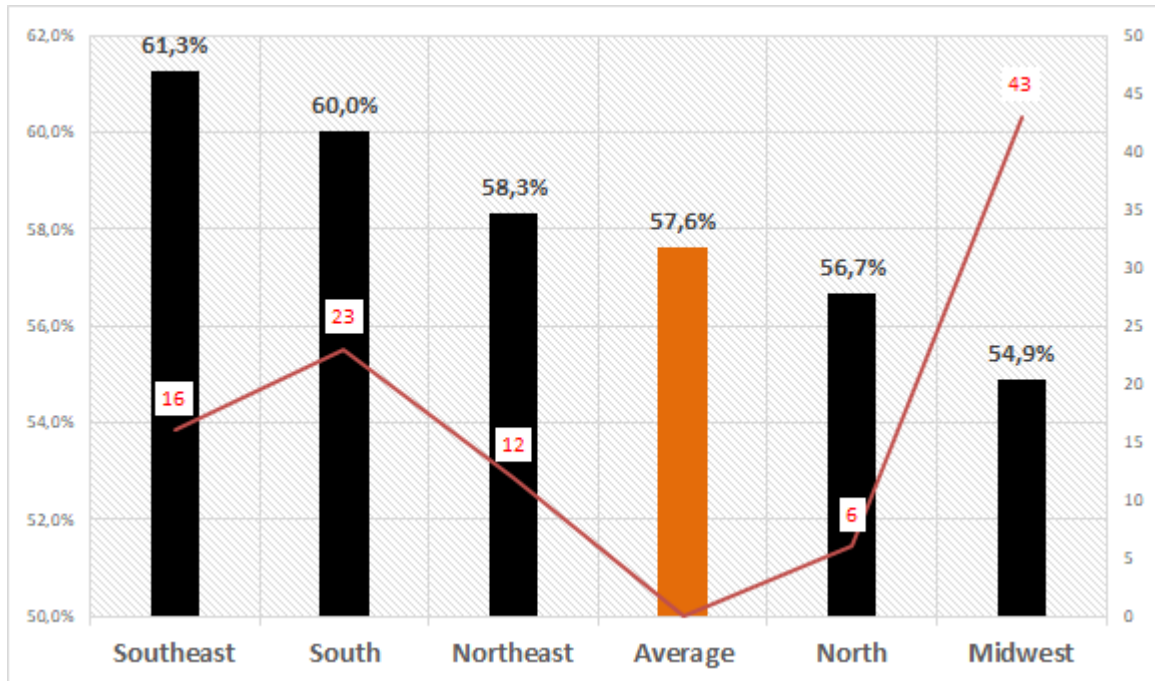
Q17	In the company, the development of cognitive and procedural skills necessary for the Industry 4.0 digitalization process is...
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Source: Prepared by the author

Q18 Question Results Set

Q18	In the company, actions that minimize employees' difficulties regarding the Industry 4.0 digitalization process are...
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Source: Prepared by the author