GESTÃO & PRODUÇÃO

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

ORIGINAL ARTICLE

Decision making in the process of choosing and deploying industry 4.0 technologies

Tomada de decisão no processo de escolha e implantação das tecnologias da indústria 4.0

Jocieli Francisco da Silva[1], Flávia Luana da Silva[1], Débora Oliveira da Silva[1], Luiz Alberto Oliveira Rocha[1], Ágata Maitê Ritter[1]

[1]Universidade do Vale do Rio dos Sinos – UNISINOS, São Leopoldo, RS, Brasil. E-mail: jocielifs@outlook.com; flavial_silva@hotmail.com; deboraoliveira@unisinos.br; luizor@unisinos.br; agataritter40@gmail.com

How to cite: Silva, J. F., Silva, F. L., Silva, D. O., Rocha, L. A. O., & Ritter, A. M. (2022). Decision making in the process of choosing and deploying industry 4.0 technologies. *Gestão & Produção*, 29, e163. https://doi.org/10.1590/1806-9649-2022v29e163

Abstract: Advances in the development and use of Industry 4.0 technology has resulted in it being applied in various industries. Industry 4.0 enables companies to develop their operations and improve their organizational efficiency. The process of implementing Industry 4.0 is very important, as it requires significant investment, skilled labor and state-of-the-art technology. The aim of this article is to identify the main criteria behind decision-making in choosing and implementing technology, that is part of the Industry 4.0 concept. The research method chosen for the study was a systematic literature review. The results show that the use of broad requirements tends to be predominant, using large groups of criteria that are intended to aggregate several different requirements. This review is relevant because few recent studies have been found, and therefore this article helps to identify what has been published so far on the subject of decision-making around choosing and implementing Industry 4.0 technology in organizations and what criteria and tools they base their decisions on. To date, the research has not encountered any similar work that aims to group all the information on decision-making around choosing and implementing Industry 4.0 technology.

Keywords: Industry 4.0; 4th Industrial Revolution; Decision making; Fuzzy front end.

Resumo: Os avanços no desenvolvimento e na utilização de tecnologias da indústria 4.0 vêm proporcionando sua aplicação em diversos setores. As tecnologias da indústria 4.0 proporcionam o desenvolvimento das operações e alavancam a eficiência das organizações. O processo de implantação das tecnologias da indústria 4.0 é muito importante, pois demanda altos investimentos, mão de obra qualificada e tecnologias de ponta. O objetivo deste trabalho é identificar os principais critérios que norteiam o processo de tomada de decisão para escolha e implantação das tecnologias dentro dos conceitos da indústria 4.0. O método de pesquisa selecionado para sustentar o estudo foi a revisão sistemática da literatura. Os resultados apontam para predominância de utilização de requisitos amplos, com a utilização de grandes grupos de critérios que se propõem a atender diversos requisitos de maneira agregada. Devido aos poucos estudos recentes encontrados, a revisão tornou-se relevante, uma vez que, o presente artigo traz contribuições apontando o que já foi publicado sobre o tema tomada de tomada de decisão na escolha e implantação de tecnologias da indústria 4.0 nas organizações

Received June 6, 2021 - Accepted July 15, 2021
Financial support: CAPES/Brazil (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior): 88887.342085/2019-00, 88887.342105/2019-00, 88887.150662/2017-00.

e quais os critérios e ferramentas utilizados para ancorar essa decisão. Até onde a pesquisa avançou não foram encontrados trabalhos que tenham realizado um estudo semelhante, com o objetivo de agrupar todas as informações sobre tomada de decisão na escolha e implantação das tecnologias da indústria 4.0.

Palavras-chave: Indústria 4.0; 4ª Revolução industrial; Tomada de decisão; *Fuzzy front end*.

1 Introduction

The fourth industrial revolution, commonly referred to as Industry 4.0, deals with the digital transformation of manufacturing, involving constant connectivity, through robotics, digitalization and automation (Muhuri et al., 2019). The term 'Industry 4.0' first appeared in 2011, at the Hanover Fair in Germany (Sanders et al., 2016), and refers to an intelligent system, integrated into the production system, which enables it to be flexible and self-managed, quickly and efficiently (Faller & Feldmüller, 2015). Industry 4.0 is considered to be the integration of technology and systems that enable manufacturing and management to be more agile and less uncertain, which has a positive effect on the organization (Arcidiacono & Pieroni, 2018).

Industry 4.0 enablers are based on information systems. According to Klingenberg et al. (2019) there are 111 digital technologies, which are used to create and capture data, send data, store and process data, as well as applications for the data, but only five of them are mentioned regularly in the literature: they are Cyber Physical Systems (CPS), the Internet of Things (IoT), Big Data, Big Data Analytics, and Cloud Computing. (Muhuri et al., 2019; Klingenberg et al., 2019).

Industry 4.0's digital technology led to the development of the global economy and operations, by improving the degree of industrialization, computerization and digitalization, which has led to greater efficiency, reliability and competitiveness (Xu et al., 2018). The reasons for integrating this technology are: to aid real-time decision making, to use resources and deliver products more efficiently and to have better control over the process (Kamble et al., 2018).

New technology affects companies' decision-making in both the short and long term, because these are changes that involve a high degree of associated uncertainty. Furthermore, a company's transition to Industry 4.0 requires a well-designed strategic plan that can make the most of the organization's competitive advantage (Ghobakhloo, 2018). As this subject is so important, there has been a growing demand for research into Industry 4.0, in order to provide new insights into the issues behind the challenges and solutions related to the design, implementation and management of Industry 4.0 (Xu et al., 2018).

According to Müller et al. (2018) there is a lot of interest in the subject of Industry 4.0 and the related technology and this subject has been examined from both academic and managerial perspectives on many occasions, but there has been little attention paid to the approach around organizational competitiveness. The implementation of Industry 4.0 raises a vast number of issues and opportunities, which could be looked at in detail and, on this subject, one of those that has not been fully examined is what issues and opportunities may arise in relation to the antecedents to companies implementing Industry 4.0.

Industry 4.0 develops the global economy and a company's operations by improving the degree of industrialization, computerization and digitalization, and provides a way to make organizations more efficient and competitive (Xu et al., 2018). On the other hand, companies are discouraged from implementing it due to the high cost, the need

for highly skilled labor, the lack of technology standards and because they cannot be certain what real benefits they will gain (Kipper et al., 2021).

This article intends to help fill this gap by identifying the main criteria used to inform the decision-making process when choosing and implementing technology as part of Industry 4.0. To achieve this objective, the method used was a systematic literature review. Systematic reviews improve the quality of the review process and the results by applying a transparent and reproducible procedure (Crossan & Apaydin, 2010). The documents identified during the systematic literature review were then analyzed, using the content analysis technique, to identify the main issues relating to the chosen research topic and the decision-making criteria used in the process of choosing and implementing Industry 4.0 technology.

The article was organized into four distinct sections: this introduction, which provides an overview of the topic and explains the objective of the article. Section 2 discusses the methodological aspects of the research. Section 3 discusses the results and the last section covers the conclusions and suggestions for future research.

2 Method

As the objective of this article was to systematically review the literature, the method proposed to support the study was a systematic literature review. For Morandi & Camargo (2015), a systematic literature review (RSL) is a method for extracting the information you want from a large volume. It is used to map, discover, consolidate and aggregate the results for a particular field, based on an explicit and planned method. In order to select the articles to form this review, a number of steps were taken to ensure that articles directly related to the subject were included and those that were not were excluded, in order to ensure that the searches were robust, checked and that the research could be replicated, as recommended by Morandi & Camargo (2015).

The criteria used for the design of the research include selecting the databases, keywords to be used, the period of time and the types of documents to be considered, as well as defining the inclusion and exclusion criteria for documents. In addition, there was a further stage which involved the analysis of the studies directly related to the topic, which is discussed subsequently.

The databases chosen to be searched were Web of Science and Scopus, as they are reliable platforms, with the most reputable and widely used journals (Muhuri et al., 2019). Afterwards, the Science Direct, Taylor and Francis and Emerald Insight platforms were also queried. The criteria for period and type of document used to select articles were: only full articles published in academic journals or conferences, in English or Portuguese, at the final stage of publication and from 2011 to 2021 (as the term ‘Industry 4.0’ appeared in the year of 2011 and because the last search of the databases was conducted on January 16, 2021). Finally, the keywords used for the search were: Industry 4.0, 4th Industrial Revolution, digital manufacturing, digital enterprise, advanced manufacturing, smart manufacturing, decision making and fuzzy front end. The search filter required that the words had to be present in the title, the abstract or the keywords of the article. The Boolean operator “and” was used to allow for combinations of keywords to be searched for and the operator “or” was used between the keywords ‘Industry 4.0’, ‘4th Industrial Revolution’, ‘digital manufacturing’, ‘digital enterprise’, ‘smart manufacturing decision making’ and ‘fuzzy front end’, since the words are synonymous and the objective was to identify all the papers that dealt

with the subject. The results obtained from this first search of the selected databases are presented in Table 1:

Table 1. Results of the Database Search.

Database	Search Terms	Search Field	Documents found
Scopus	(“Industry 4.0” OR “4th Industrial Revolution” OR “digital manufacturing” OR “digital enterprise” OR “smart manufacturing” OR “advanced manufacturing”) AND (“decision making” OR “fuzzy front end” OR “decision AND management”)	Title, abstract, keywords	1052
Web of Science	(“Industry 4.0” OR “4th Industrial Revolution” OR “digital manufacturing” OR “digital enterprise” OR “smart manufacturing” OR “advanced manufacturing”) AND (“decision making” OR “fuzzy front end” OR “decision AND management”)	Title, abstract, keywords	711
Science Direct	(“Industry 4.0” OR “4th Industrial Revolution” OR “digital manufacturing” OR “digital enterprise” OR “smart manufacturing” OR “advanced manufacturing”) AND (“decision making” OR “fuzzy front end” OR “decision AND management”)	Title, abstract, keywords	262
Taylor and Francis	(“Industry 4.0” OR “4th Industrial Revolution” OR “digital manufacturing” OR “digital enterprise” OR “smart manufacturing” OR “advanced manufacturing”) AND (“decision making” OR “fuzzy front end” OR “decision AND management”)	Anywhere	312
Emerald Insight	(“Industry 4.0” OR “4th Industrial Revolution” OR “digital manufacturing” OR “digital enterprise” OR “smart manufacturing” OR “advanced manufacturing”) AND (“decision making” OR “fuzzy front end” OR “decision AND management”)	Abstract	13

Source: Created by the authors (2021).

After running the search, the data were consolidated, so that they could be evaluated on the basis of a systematic literature review, according to predefined criteria for selecting articles. The selection criteria for the final group of the articles was: (I) repeated articles were excluded, (II) The titles were read: those titles and articles that dealt with decision-making, issues, opportunities, advantages or disadvantages in implementing Industry 4.0 were included and those that did not meet these criteria were excluded. (III) The abstracts were read: the abstracts of the articles selected in step II were read and all articles that did not cover the topic of decision making on the selection of digital technology for Industry 4.0 were excluded. After this filter, 14 articles remained to be read in their entirety. Figure 1 shows the sequence of steps described above and how the articles were grouped at each stage.

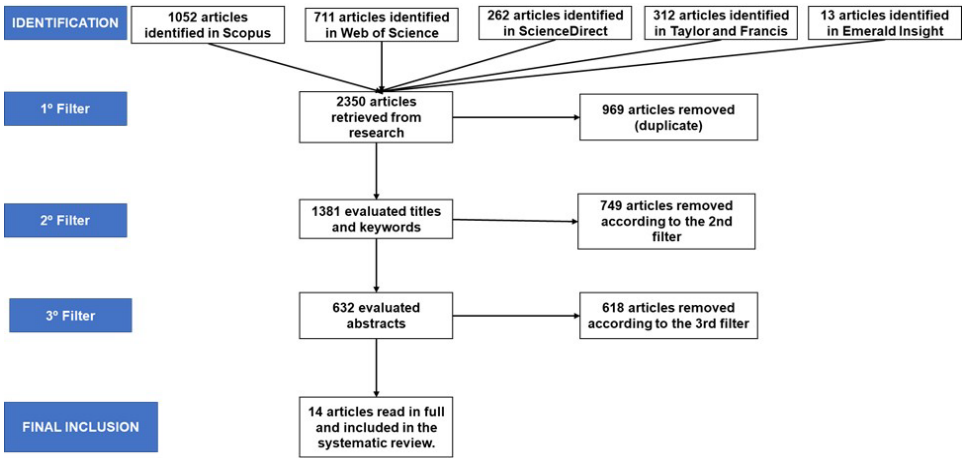


Figure 1. Article selection process. Source: Created by the authors (2021).

The 14 articles remaining by the end of the filtering were read in full and analyzed using the content analysis technique. Content analysis is a method used to identify the underlying meaning of the text by quantifying the meaning of the spoken or written language. This method provides a complete view of the text and its related context, so that the researcher can understand the phenomenon subjectively (Renz et al., 2018).

3 Analysis of the results

Chart 1 demonstrates the annual publication of articles on the topic. You can see that there has been a growth in the number of publications over the years, which confirms the interest of researchers in the topic and justifies the study of this subject. The first research is in 2014 and the most publications come in the year 2020, when almost 50% of the material was published. There are no publications listed for 2021 as the search was conducted before the start of the year.

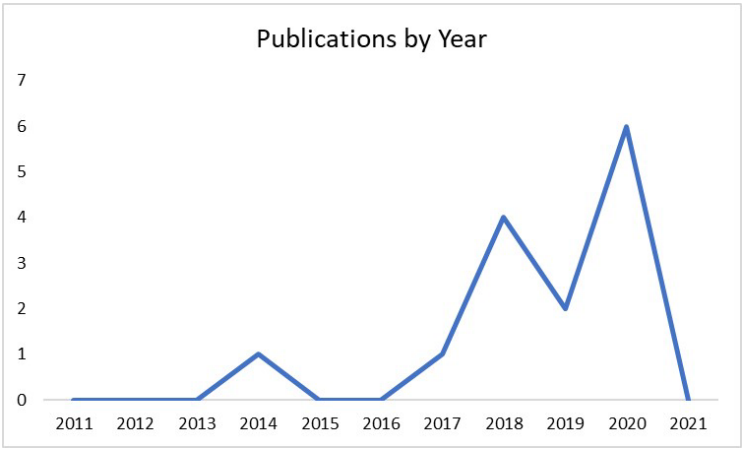


Chart 1. Number of Publications over time (2011-2021). Source: Created by the authors (2021).

One important aspect is to identify which terms are related to the others. For this, the keywords were grouped according to clusters, using the VOSviewer software. The networks of keywords were created from the literature used in this study, based on the number of significant terms taken from the body of the research article. The purpose of the networks was to identify the terms most commonly used in these publications and their frequency. As the number of documents was small, 1 citation only was considered sufficient. The most frequent terms were: Industry 4.0 (14 times), decision making (12 times) selection of technology and manufacturing technology (6 times each) and industrial management (4 times). Figure 2 shows the relationship between the keywords of the articles.

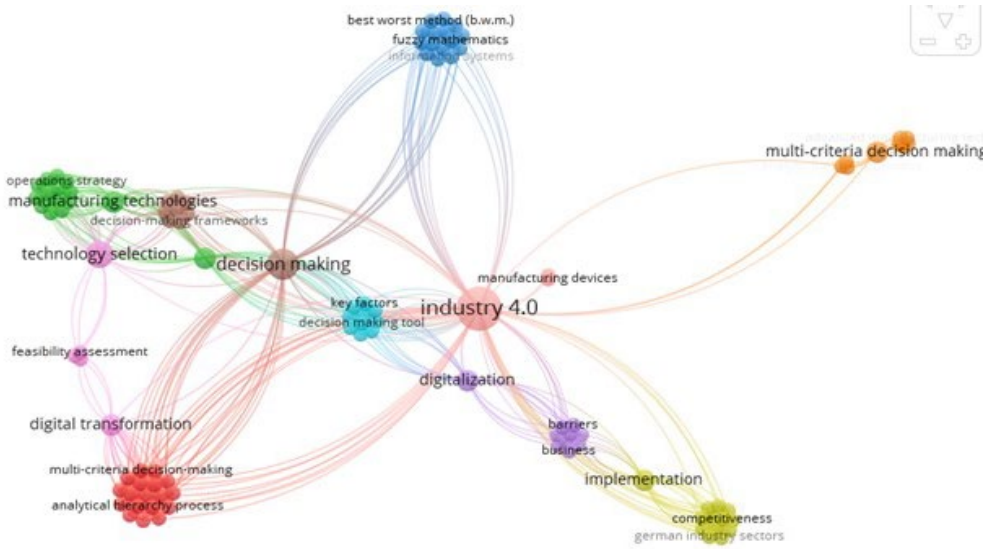


Figure 2. Incidence of Keywords. Source: Created by the authors (2021).

The three most important clusters are the red, blue and green ones. The red cluster is the largest, consisting of 18 terms and the most significant keywords in this cluster are: Analytic Hierarchy Process, decision making and multi-criteria decision making. Next comes the blue cluster, which consists of 15 terms and the keywords are: mathematical models, fuzzy models and information systems. The green cluster consists of 15 terms and the most significant keywords are: operational strategy, manufacturing technology and automation technology.

The results confirmed that, despite the growing interest in the subject of Industry 4.0 and its technology, there has been little discussion regarding decision-making in choosing and implementing digital technology, which confirms what has already been mentioned by Müller et al. (2018). Table 2 presents a synthesis of the 14 articles from the review on the subject of this paper.

Table 2. Synthesis of the Findings from the Systematic Review of the Literature.

Title	Method used in the article	Criteria//Phase	Tool Suggested by the Authors of the Article	Technology Mentioned	Context	Stages Described in the Article
A Strategic Approach for Automation Technology Initiatives Selection (Thomassen et al., 2014)	Research - action	Environmental and corporate policies	No tools adopted	Automation	Size of the organization not specified (small, medium or large)	Stage 1: technology strategy decisions.
		Process requirements			Manufacturing Companies.	Stage 2: process analysis.
		Technological maturity			Country studies: Norway.	Step 3: technology analysis.
		Economic feasibility				Stage 4: classification of the technology/process.
		Phase: Choice and Implementation				Step 5: investment and implementation.
Modelling Technical and Economic Parameters in Selection of Manufacturing Devices (Daneshjo et al. , 2017)	None specified	Technical parameters (level of automation, intelligence, machine model, etc.),	No tools adopted	No specific technology discussed	Manufacturing Companies Identified the size of the organization (small, medium or large).	No stages of a defined process;
		Economic parameters (costs involved and Return On Investment (ROI))			No type of industry specified	
		Environmental parameters (connection to the line, interaction between machines, etc.)			Country studied: not specified.	
		Phase: Choice and Implementation				
Analysis of the Difficulties of SMEs in Industry 4.0 Applications by Analytical Hierarchy Process and Analytical Network Process (Sevinç et al., 2018)	Literature Review and Case Studies	Innovation	Analytic Hierarchy (AHP) and Analytic Network Process (ANP)	No specific technology discussed	Small and medium-sized enterprises.	No stages of a defined process;
		Organization			No type of sector specified	
		Environment			Country studied: Turkey.	
		Cost				
		Phase: Choice and Implementation				
A Technology Selection Framework for Manufacturing Companies in the Context of Industry 4.0 (Hamzeh et al., 2018)	Literature Review	Cost choice, Lead Time, Quality, Flexibility, developing new products. Implementation:	No tools adopted	No specific technology discussed	Size of the organization not specified (small, medium or large)	Phase 1: Assessment of the current situation;
		(i) technical factors, including technology, complexity and interfaces, performance and quality; (II) project management, including finance, project dependencies, resources and pritization (sic); (III) organizational factors, including planning, control and communication; (IV) external factors, including suppliers, regulations, market and customers.			Manufacturing Companies.	Phase 2: Define the critical strategic factors for implementing Industry 4.0;

Table 2. Continued…

Title	Method used in the article	Criteria//Phase	Tool Suggested by the Authors of the Article	Technology Mentioned	Context	Stages Described in the Article
					Country studied: not specified.	Phase 3: establish the planning interval/time horizon;
						Phase 4: identify the technology to be implemented;
						Phase 5: Detailed assessment of the identified technology;
						Phase 6: Risk assessment of the technology to be used;
Selecting the best strategy for Industry 4.0 applications with a case study (Erdogan et al., 2018)	Literature Review and Case Studies	Leadership	Analytic Hierarchy (AHP) and VIKOR Fuzzy	No specific technology discussed	Size of the organization not specified (small, medium or large)	Stage 1: literature review;
		Customers			No specific industry.	Stage 2: Producing Questionnaires;
		Products			Country studied: not specified.	Stage 3: Applying AHP methods;
		Operations				Stage 4: Applying the Vikor method.
		Culture				
		People				
		governance				
		Technology				
		Quality				
		Organization				
		Phase: Choice and Implementation				
What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability (Müller et al., 2018)	Literature Review and Survey	Organizational strategy	No tools adopted	No specific technology discussed	Covers different sizes of organizations (small, medium and large).	No stages of a defined process;
					Companies in different sectors.	
		Operations			Country studied: Germany	
		Environment and people				
		Competitiveness and future viability				
		Organizational change				
		Qualifications and employee acceptance				
Drivers and Barriers in Using Industry 4.0: A Perspective of SMEs in Romania (Türkeș et al., 2019)	Survey	Customer requirements	No tools adopted	Big Data and Big Data Analytics, Autonomous Robots, Simulation, Horizontal and Vertical Integration, Internet of	Small and medium-sized enterprises.	No stages of a defined process;
		Competitors are already using the 4.0 model			Companies in different sectors.	
		Cost reduction			Country studied: Romania	

Table 2. Continued…

Title	Method used in the article	Criteria//Phase	Tool Suggested by the Authors of the Article	Technology Mentioned	Context	Stages Described in the Article
		Improved time to market		Things (IoT), Cyber-security, 3D Printing, Augmented Reality, Cloud Computing, Artificial Intelligence, Radio Frequency Identification (RFID) and Real Time Location Systems (RTLS)		
		Due to legal requirements/changing legislation				
		Phase: Choice and Implementation				
An Assessment Model for Organizational Adoption of Industry 4.0 Based on Multi-criteria Decision Techniques (Keskin et al., 2018)	Literature Review and Case Studies	Products and services (degree of product customization, digital features for products augmented with intelligent services, etc.) Manufacturing and operations (data collection, systems integration, etc.)	Analytic Hierarchy (AHP) and Topsis	No specific technology discussed	Size of the organization not specified (small, medium or large)	Stage 1 - Criteria selected by a Working Group;
		Strategy and organization (level of innovation management, investment analysis of the 4.0 sector (financial, cost/benefit)			Clothing Companies.	Stage 2 - Weighting assigned to the relevant main and sub-criteria;
		Supply chain integration (use of intelligent inventory control, customer focus, etc.)			Country studied: Turkey.	Stage 3 - The level of organization was assessed and given an assessment score;
		Business model (automated and real-time programming, aligning strategies to customer needs, etc.)				
		Legal considerations (data sharing and data protection, protection of intellectual property etc.)				
		Phase: Choice and Implementation				
Technology Selection for Digital Transformation: A Mixed Decision-Making Model of AHP and QFD (Erbay & Yıldırım, 2018)	Literature Review and Case Studies	Improved process efficiency	Analytic Hierarchy (AHP) and Quality Function Deployment (QFD)	RFID, Big Data, Robotics, MES, ERP, Data Analytics, 3D Printing, Virtual Reality, Augmented Reality, Image Processing	Size of the organization not specified (small, medium or large)	Phase 1: Identifying I 4.0 technology;
		Improved quality performance			Automotive Companies.	Phase 2: Comparing technology using AHP;
		Improved delivery time			Country studied: Turkey.	Phase 3: Comparing technology using QFD;
		Efficient and robust production planning				
		Specialization				
		Reducing Stock				
		Increased productivity				
		Reduced Labor				

Table 2. Continued…

Title	Method used in the article	Criteria//Phase	Tool Suggested by the Authors of the Article	Technology Mentioned	Context	Stages Described in the Article
		Improved Maintenance				
		Phase: Choice and Implementation				
Industry 4.0 on Demand A Value Driven Methodology to Implement Industry 4.0 (Leone & Barni, 2020)	Case Study	Acquisition costs of Hardware and Software;	Analytic Hierarchy (AHP) and Design thinking	No specific technology discussed	Size of the organization not specified (small, medium or large)	Phase 1: Maturity assessment of Industry 4.0;
		Project Implementation Costs			Pharmaceutical Company	Phase 2: Analysis of the process
		Improving the Overall Equipment Effectiveness (OEE)			Country studied: not specified.	
		Improving Quality				Phase 3: Design the Industry 4.0 Roadmap.
		Reduced wastage				
		Reducing Total Costs				
		Expanding the project to other companies in the industry.				
A Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing A Case Study from Automotive Supplier Industry (Beyaz & Yıldırım, 2020)	Case Study	Financial feasibility; Organizational feasibility;	TOPSIS	Augmented Reality,	Large business	Stage 1: Identifying existing issues.
		Technology feasibility;		(smart glasses), 3D Printing, GPS, RFID, RTLS,	Component suppliers to the automotive industry.	Phase 2: Financial, operational and technology feasibility study;
		Legal feasibility.			Country studied: Turkey.	Phase 3: Using the TOPSIS method. Select the most appropriate technology;
Creating a roadmap for Industry 4.0 by using an integrated fuzzy multicriteria decision-making methodology (Kaya et al., 2020)	Literature review	Leadership, Customer, Product, Operation, Culture, People, Governance, Technology, Quality, Organization and Others.	Analytic Hierarchy (AHP), TOPSIS and Interval-valued intuitionistic fuzzy sets (IVIFSs)	No specific technology discussed	Size of the organization not specified (small, medium or large)	Stage 1: Decide the criteria;
					No specific industry	Stage 2: Create criteria matrix;
					Country studied: not specified.	Stage 3: Analyze the matrix for consistency;
						Stage 4: Calculate the matrix of evaluation scores;
						Phase 5: Multiply the matrices;
						Phase 6: Decide the priority vectors;
						Phase 7: Create matrices based on degree of possibility;
						Phase 8: Standardize the weighting of the criteria.
An integrated model of fuzzy multi-criteria decision making and stochastic programming for the	Not specified	Economic (Payback Return investment, Discounted cash flow (NPW, IRR)) and Strategic (Technical importance, Business objectives, Competitive	Linear Programming and triangular fuzzy numbers.	No specific technology discussed	Size of the organization not specified (small, medium or large)	Stage 1: Integrated decision making;
					No specific industry	Phase 2: Establishing the

Table 2. Continued…

Title	Method used in the article	Criteria//Phase	Tool Suggested by the Authors of the Article	Technology Mentioned	Context	Stages Described in the Article
evaluating and ranking of advanced manufacturing technologies (Olfati et al., 2020)		advantage, Research and development)				strategic and economic criteria;
					Country studied: not specified.	Phase 3: Establishing weighting for the criteria;
						Phase 4: Deciding the better technology options;
						Phase 5: Classifying each of the technology options and selecting the best investment.
Evaluating strategies for implementing industry	Literature Review and Survey	Leadership	Best Worst Model and TODIM-IVIF	No specific technology discussed	Size of the organization not specified (small, medium or large)	Stage 1: literature review;
4.0: a hybrid expert oriented approach of BWM		Client			No specific industry	Stage 2: determining the requirements;
and interval valued intuitionistic fuzzy TODIM (Mahdiraji et al., 2020)		Product			Country studied: not specified.	Stage 3: Consulting the specialists;
		Operation				Stage 4: Applying the BWG (sic) method;
		Culture				Stage 5: Applying the TODIM-IVIF method.
		Teams				
		Technology				
		Organization				
		Quality				

Source: Created by the authors (2021).

The following sections discuss the results of the studies presented in Table 2. These articles were read in full in an attempt to find similarities and differences between the selected articles and to identify which criteria were being used in decision making when it comes to an organization choosing and implementing Industry 4.0 technology. For the content analysis, seven categories were chosen to help define the articles: the project's subject area (project selection and implementation), the identified criteria, the tools used, the technology mentioned, the context in which the research took place, the methodology used to carry out the research (use of a theoretical or practical approach) and the stages that the research was broken down into. Next, these stages are analyzed one by one.

3.1 Selecting and implementing projects

Ten of the fourteen articles selected for the literature review were about the decision-making process in relation to selecting technology (Daneshjo et al., 2017; Sevinç et al., 2018; Hamzeh et al. 2018; Müller et al., 2018; Keskin et al., 2018; Erbay

& Yıldırım, 2018), while nine dealt with implementation (Thomassen et al., 2014; Sevinç et al., 2018; Hamzeh et al., 2018; Erdogan et al., 2018; Müller et al., 2018; Türkeș et al., 2019; Keskin et al., 2018; Erbay & Yıldırım, 2018; Leone & Barni, 2020; Beyaz & Yıldırım, 2020; Kaya et al., 2020; Mahdiraji et al., 2020; Olfati et al., 2020).

The only article that addressed selection only was by Daneshjo et al. (2017), who had developed an algorithm to select digital devices for production machinery and equipment, based on an analysis of the technical, environmental and economic parameters. This tool was able to select the best machine for a set situation, out of an existing catalogue. Erdogan et al. (2018) and Türkeș et al. (2019) addressed the issues of organizations who were transitioning to Industry 4.0 and their studies aimed to provide methods on how to implement technology. Sevinç et al. (2018) and Müller et al. (2018) addressed the same gap, but their work was designed to improve two processes: the selection of technology and its implementation.

3.2 The criteria identified

Some authors define the criteria quite broadly and there were criteria used for grouping and sub-criteria within these. For example, Daneshjo et al. (2017) stated that one of the criterion for developing the algorithm was the technical parameters, within this there were sub-criteria that needed to be met, such as: the degree of machine automation, the machine intelligence required, the machine model, the integration of the machine into the system etc. The same occurs in the articles by Thomassen et al. (2014), Sevinç et al. (2018), Erdogan et al. (2018), Müller et al. (2018), Keskin et al. (2018), Leone & Barni (2020), Kaya et al. (2020), Mahdiraji et al. (2020) and Olfati et al. (2020). Türkeș et al. (2019) only listed five criteria as determining factors: customer requirements, cost reduction, competing with those that already use Industry 4.0 technology, improving the time to market and meeting legal requirements/changing legislation.

The results show that the only factors that managers consider relevant are reducing costs, improving the time to market and complying with new legislation/legal requirements. Erbay & Yıldırım (2018) followed the same logic. They listed the criteria as opportunities to improve process efficiency, quality performance, delivery time, having efficient and robust production planning, reducing stock etc. The results show that the greatest benefits from implementing technology are improving process efficiency, improving quality performance and reducing costs. Beyaz & Yıldırım (2020) stated that financial feasibility, operational feasibility, technological feasibility and legal feasibility were criteria, but only financial feasibility, operational feasibility and technological feasibility were relevant when using the method, as legal issues could not be included for legal reasons.

Hamzeh et al. (2018) proposed a conceptual framework to help with choosing and implementing digital technology in manufacturing companies. This was the only article that divided the criteria into project evaluation and implementation. The project evaluation criteria consisted of: cost, lead time, quality, flexibility and developing new products. For the implementation phase, the following were mentioned: (I) technical factors, including technology, complexity and interfaces, performance and quality; (II) project management, including finance, project dependencies, resources and prioritization; (III) organizational factors, including planning, control and communications; (IV) external factors, including suppliers, regulations, the market and customers.

We can see that all of the studies included those criteria which relate to economic feasibility, technological maturity and process/environment feasibility. In Table 2 there is a summary of the criteria listed by the authors in their studies.

3.3 Tools

In relation to the tools mentioned in the articles, the most cited tool was the Analytic Hierarchy Process (AHP) and in most cases it was combined with other methods to achieve more significant results.

Sevinç et al. (2018) tried to ascertain the transition factors that help with implementing Industry 4.0, by using the Analytic Hierarchy (AHP) and the Analytic Network (ANP) processes. Erdogan et al. (2018) used the Analytic Hierarchy (AHP) method, together with the VIKOR Fuzzy method, to identify the best decision-making strategy for implementing digital technology in their study.

Keskin et al. (2018) also used the AHP method, alongside the Topsis method, to try to develop a method to help companies clarify the requirements for digital technology. Erbay & Yıldırım (2018) also used the AHP method, but in their study they linked it to the QFD method (Quality Function Deployment) in order to list and prioritize the criteria for implementing technology in the automotive industry.

Leone & Barni (2020) used the AHP method together with design thinking to define a roadmap for implementing digital technology. Kaya et al. (2020) used the Analytic Hierarchy (AHP), TOPSIS and Interval-valued intuitionistic fuzzy sets (IVIFSs) methods to achieve the same objective as Leone & Barni (2020) and develop a roadmap for choosing digital technology.

Thomassen et al. (2014), Hamzeh et al., (2018), Müller et al. (2018) and Türkeș et al. (2019) did not use any decision making tool for the criteria when choosing and prioritizing. Müller, et al. (2018) and Türkeș et al. (2019) used the Partial Least Squares-Path Modeling (PLS-SEM) and IBM SPSS Statistics software, respectively, to support their analysis of the responses to their surveys. Olfati et al. (2020) combined the Linear Programming and triangular fuzzy numbers methods to identify and select the most appropriate digital technology. Beyaz & Yıldırım (2020) used the TOPSIS method to identify the most appropriate digital technology for a supplier in the automotive industry. Daneshjo et al., 2017 used heuristic methods and computational techniques to develop an algorithm to select digital devices for machines and equipment and Mahdiraji et al. (2020) used the BWM and TODIM-IVIF methods to classify the most important criteria when implementing Industry 4.0.

3.4 Technology mentioned

Ten of the fourteen studies did not mention specific technology and only discussed selection and implementation in general. Only the studies conducted by Thomassen et al. (2014), Türkeș et al. (2019), Erbay & Yıldırım (2018) and Beyaz & Yıldırım (2020) mentioned specific technology.

Erbay & Yıldırım (2018) investigated the selection and implementation of RFID, Big Data, Robotics, MES, ERP, Data Analytics, 3D Printing, Virtual Reality, Augmented Reality and Image Processing. The results of their study was that the most relevant technology was data analysis, intelligent sensors to gather data and production management software.

Türkeș et al. (2019) examined the implementation of Big Data or Big Data Analytics, Autonomous Robots, Simulation, Horizontal and Vertical Integration, the Internet of Things (IoT), Cyber-security, Additive Manufacturing, Augmented Reality, Cloud Computing, Artificial Intelligence, Radio Frequency Identification (RFID) and Real-Time Location Systems (RTLS). Based on the results, the most important of these to implement were: Autonomous robots (35.2%), horizontal and vertical integration (27.8%), Big Data and Big Data Analytics (21.6%), the Internet of Things (IoT) (21.6%) and Cyber-security (17.6%).

For Beyaz & Yıldırım (2020) the most important digital technology that would improve the processes of the company they were studying were: Smart Cameras, Automated Guided Vehicles (AGV), Augmented Reality (Smart Glasses), 3D Laser Scanning, a GPS System, Radio Frequency Identification (RFID) and Real Time Location Systems (RTLS). In the particular case studied, AGV provided the greatest benefits, but the authors pointed out that the most appropriate technology for a company may differ depending on the resources needed and the company's operations.

Thomassen et al. (2014) investigated the selection of digital technology for automation. They stated that this should be carried out in five steps: i) Step 1: Strategic definition of the technology; ii) Stage2: Analyze the process affected; iii) Stage 3: Decide on the technology to be implemented; iv) Stage 4: Verify the relationship between technology and process and v) Stage 5: Planning investment and implementation;

3.5 Method used in the article (theoretical or empirical study)

One of the areas we chose to examine was the method used by the authors for their research. The method chosen for any study is fundamental, as it supports the entire research and ensures it can be viewed as reliable (Dresch et al., 2015). A literature review was the method chosen by most of the authors.

In most studies, it was used to conduct a survey of the criteria for choosing and implementing technology. Authors such as Sevinç et al. (2018), Erdogan et al. (2018), Keskin et al. (2018), Erbay & Yıldırım (2018) used a literature review to survey the criteria cited in the literature and then used case studies to test the results in real situations. Hamzeh et al. (2018) used a literature review on its own as the basis for their conceptual framework, which was intended to help decision makers in choosing and implementing Industry 4.0 technology. The authors explain that the proposed framework needed to be validated in a real environment, in order to test its performance. Kaya et al. (2020) also used a literature review to identify the criteria used to choose technology and developed a roadmap to use in assessing digital technology. Mahdiraji et al. (2020) also used a literature review method in their study.

The method chosen by Müller et al. (2018), Türkeș et al. (2019) was to conduct a survey. Surveys are assessments where data is gathered on specific variables in order to evaluate our understanding of an area, so that conclusions can be drawn about individuals or the relevant environment (Cauchick et al., 2018). Daneshjo et al. (2017) did not specify the methodology used in their work.

The authors proposed an algorithm that would be able to select digital devices for production machinery and equipment from an existing catalogue, but they did not test the algorithm in a real-life situation to analyze how it would perform. The authors carried out a survey of the technical parameters (level of automation, intelligence, model of

machinery, etc.), the economic parameters (costs involved and Return On Investment (ROI)) and the environmental parameters (connection to the production line, interaction between machines, etc.), but it is not clear where the information was taken from. This is the same case in the article by Olfati et al. (2020), which proposed a method to select the most appropriate technology, based on economic and technical criteria, but they did not explain the methodology used to support this and did not validate the model in a real-life situation.

Thomassen et al. (2014) used the Action Research methodology. Action Research is an empirically-based research method, where the researcher or researchers work closely with a particular action or with an attempt to resolve a given problem. The findings from the research help to create a specific case study (Cauchick et al., 2018). The studies by Sevinç et al. (2018), Erdogan et al. (2018), Keskin et al. (2018), Erbay & Yıldırım (2018), Beyaz & Yıldırım (2020) and Leone & Barni (2020) used the methodology of a case study.

The purpose of the case studies examined by the authors is to test the results they have acquired in a real-life situation, for example Keskin et al. (2018) tested their results on a clothing company and Erbay & Yıldırım (2018) on an automotive company. Beyaz & Yıldırım (2020) used an automotive components supplier and Leone & Barni (2020) used a pharmaceutical company. Sevinç et al. (2018) did not implement their findings, but they did use a case study to validate them with experts.

3.6 Context

In regards to context, the objective was to identify the nature of the organizations that were mentioned in the studies, in terms of size, industry and country.

Thomassen et al. (2014), Daneshjo et al. (2017), Hamzeh et al. (2018), Erdogan et al. (2018), Keskin et al. (2018), Erbay & Yıldırım (2018), Leone & Barni (2020), Kaya et al. (2020), Mahdiraji et al. (2020) and Olfati et al. (2020) did not identify the size of the organization they were studying, unlike Sevinç et al. (2018) and Türkeş et al. (2019) who clearly mentioned throughout their work that their studies were aimed at small and medium-sized companies. Müller et al. (2018)'s proposal was for organizations of all sizes (small, medium and large) and the study by Beyaz & Yıldırım (2020) was only related to one large company.

In relation to a particular industry, Thomassen et al. (2014)'s proposal was tested on two manufacturing companies: a shipping equipment supplier and a plastic piping supplier. The conceptual framework produced by Hamzeh et al. (2018) was not tested, but the authors do mention that it was developed for manufacturing companies, without referring to size. The method proposed by Beyaz & Yıldırım (2020) was produced with an automotive components company.

The results from the studies by Müller et al. (2018) and Türkeş et al. (2019) relate to organizations from various industries, including: automotive, pharmaceutical, industrial, IT, oil and gas, chemicals, electronics, consultancy, insurance and healthcare, mechanical, electrical and agricultural engineering, plastics manufacturers and the steel industry. Keskin et al. (2018) only looked at the clothing industry; Erbay & Yıldırım (2018), car manufacturers and Leone & Barni (2020), pharmaceutical companies. Meanwhile Daneshjo et al. (2017), Erdogan et al. (2018), Sevinç et al. (2018), Kaya et al. (2020) and Olfati et al. (2020) did not specify any particular industry.

The studies were conducted in different countries. Four of them were from Turkey (Sevinç, et al., 2018; Keskin et al., 2018; Erbay & Yıldırım (2018); Beyaz & Yıldırım,

2020), one from Germany (Müller et al., 2018), one from Romania (Türkeș et al., 2019) and one from Norway (Thomassen et al., 2014). As Müller et al. (2018) mention, it is important to treat the country as a knowledge gap, because the sample may limit the results from being applied generally, since the results can be affected by cultural origins, international approaches to Industry 4.0 and political support, as well as the industrial infrastructure.

3.7 Stages of the process

The last identified category was referred to as 'stages'. It aimed to identify whether the studies established specific stages that needed to be followed when replicating them. In the case studies described by Sevinç et al. (2018), Müller et al. (2018) and Türkeș et al. (2019) the authors did not explain if they took any specific steps when conducting the studies, they only described how the study was carried out. However, those described by Thomassen et al. (2014), Keskin et al. (2018), Erdogan et al. (2018), Erbay & Yıldırım (2018), Leone & Barni (2020), Beyaz & Yıldırım (2020), Kaya et al. (2020), Mahdiraji et al. (2020) and Olfati et al. (2020) did identify a series of steps for the decision-making process in their articles.

Hamzeh et al. (2018) developed a conceptual framework for choosing and implementing Industry 4.0 technology and Daneshjo et al. (2017) proposed an algorithm to select the digital devices for the production machinery and equipment. As part of this they recommended a series of steps, which were represented by a diagram that formed part of their model. These diagrams are in Appendices A and B of this article.

4 Conclusion

These results confirm the findings of the authors Müller et al. (2018), who stated that Industry 4.0 has often been looked at academically, but there has been little discussion about the process of choosing and implementing technology. The small number of articles that relate directly to this subject corroborates the authors' statement.

From the results of this study, we could see that the literature does not yet provide a dominant model on how to select and implement technology as part of Industry 4.0. The requirements for the selection and implementation of this technology differ from one organization to another, but there are some that appear frequently, such as technological maturity and economic feasibility.

From our analysis of the articles, we can confirm that the subject of this article, decision-making on choosing and implementing digital technology for Industry 4.0, has become more common in recent years, but this does not compare to the reported use of this technology in organizations. It is impossible to identify how this process takes place, based on the studies we have, both in terms of a dominant model or based on empirical case studies, which suggests that there is a need for more research in this area.

This article contributes to the research by identifying what has already been published on the subject of decision making in choosing and implementing Industry 4.0 technology in organizations, although the amount of studies carried out is few. From the results of the research, there was a conceptual framework proposed by the authors

Hamzeh et al. (2018) to support the choosing and implementing of Industry 4.0 technology and an algorithm created by Daneshjo et al. (2017) to select the best technology, but neither of these tools was validated in a real environment to test their performance, which is therefore an option for a future study. Another identified gap has to do with the context of the studies. As Müller et al. (2018) pointed out, the context of a study is very important, as the sample may limit the results, as there will be cultural, economic and structural influences that without doubt vary from one country to another. Therefore, another opportunity for further investigation is understanding how the different context can influence a companies' decision-making in relation to initiating digital transformation. In addition, companies that are beginning a digitalization process could be investigated and tested with the criteria that were identified from this study.

This article has limitations, one of them is the keywords chosen. This research could be expanded by adding additional search terms that are synonymous with those used and searching the databases further, such as: selection, choice, adoption, criteria, and various combinations. Another limitation is the language and the types of documents. Only English and Portuguese documents were included in this research. As Industry 4.0 emerged initially in Germany it is possible that there are relevant documents in German, which were not included in this study. In addition, this review only considered articles and conference papers, as they are peer-reviewed documents, so there may be some significant results from books that have been missed by this study.

Authors contribution:

Jocieli Francisco da Silva and Flávia Luana da Silva worked on the conceptualization and theoretical-methodological approach. The theoretical review was conducted by Jocieli Francisco da Silva and Ágata Maitê Ritter. Data collection was coordinated by pela Jocieli Francisco da Silva and Luiz Alberto Oliveira Rocha. Data analysis included Jocieli Francisco da Silva and Débora Oliveira da Silva. All authors worked together in the writing and final revision of the manuscript.

Acknowledgements

This research was conducted with financial support from CAPES/Brazil (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior).

References

Arcidiacono, G., & Pieroni, A. (2018). The revolution lean six sigma 4.0. *International Journal on Advanced Science, Engineering and Information Technology*, 8(1), 141-149. http://dx.doi.org/10.18517/ijaseit.8.1.4593.

Beyaz, H. F., & Yıldırım, N. (2020). A multi-criteria decision-making model for digital transformation in manufacturing: a case study from automotive supplier industry. In *Proceedings of the International Symposium for Production Research 2019* (pp. 217-232). Cham: Springer.

Cauchick, P., Morabito, R., & Pureza, V. (2018). *Metodologia de pesquisa em engenharia de produção.* Rio de Janeiro: Elsevier.

Crossan, M. M., & Apaydin, M. (2010). A multi-dimensional framework of organizational innovation: a systematic review of the literature. *Journal of Management Studies*, 47(6), 1154-1191. http://dx.doi.org/10.1111/j.1467-6486.2009.00880.x.

Daneshjo, N., Majerník, M., Krivosudska, J., & Danishjoo, E. (2017). Modelling technical and economic parameters in selection of manufacturing devices. *TEM Journal*, 6(4), 738.

Dresch, A., Lacerda, D. P., & Antunes, J. A. V., Jr. (2015). *Design science research: a method for science and technology advancement*. Cham: Springer. http://dx.doi.org/10.1007/978-3-319-07374-3.

Erbay, H., & Yıldırım, N. (2018). Technology selection for digital transformation: a mixed decision making model of AHP and QFD. In *The International Symposium for Production Research* (pp. 480-493). Cham: Springer.

Erdogan, M., Ozkan, B., Karasan, A., & Kaya, I. (2018). Selecting the best strategy for Industry 4.0 applications with a case study. In F. Calisir & H. Camgoz Akdag (Eds.), *Industrial engineering in the industry 4.0 era* (pp. 109-119). Cham: Springer. http://dx.doi.org/10.1007/978-3-319-71225-3_10.

Faller, C., & Feldmüller, D. (2015). Industry 4.0 learning factory for regional SMEs. *Procedia Cirp*, 32, 88-91. http://dx.doi.org/10.1016/j.procir.2015.02.117.

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, 29(6), 910-936. http://dx.doi.org/10.1108/JMTM-02-2018-0057.

Hamzeh, R., Zhong, R., Xu, X. W., Kajáti, E., & Zolotova, I. (2018, August). A technology selection framework for manufacturing companies in the context of Industry 4.0. In *2018 World Symposium on Digital Intelligence for Systems and Machines (DISA)* (pp. 267-276). New York: IEEE.

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2018). Sustainable Industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, 117, 408-425. http://dx.doi.org/10.1016/j.psep.2018.05.009.

Kaya, I., Erdogan, M., Karasan, A., & Ozkan, B. (2020). Creating a road map for Industry 4.0 by using an integrated fuzzy multicriteria decision-making methodology. *Soft Computing*, 24(23), 17931-17956. http://dx.doi.org/10.1007/s00500-020-05041-0.

Keskin, F. D., Kabasakal, İ., Kaymaz, Y., & Soyuer, H. (2018). An assessment model for organizational adoption of industry 4.0 based on multi-criteria decision techniques. In *The International Symposium for Production Research* (pp. 85-100). Cham: Springer.

Kipper, L. M., Furstenau, L. B., Hoppe, D., Frozza, R., & Iepsen, S. (2021). Scopus scientific mapping production in Industry 4.0 (2011-2018): a bibliometric analysis. *International Journal of Production Research*, 15(18), 129-147.

Klingenberg, C. O., Borges, M. A. V., & Antunes, J. A. V., Jr. (2019). Industry 4.0 as a data-driven paradigm: a systematic literature review on technologies. *Journal of Manufacturing Technology Management*, 32(3), 570-592. http://dx.doi.org/10.1108/JMTM-09-2018-0325.

Leone, D., & Barni, A. (2020). Industry 4.0 on demand: a value driven methodology to implement Industry 4.0. In *IFIP International Conference on Advances in Production Management Systems* (pp. 99-106). Cham: Springer.

Mahdiraji, H. A., Zavadskas, E. K., Skare, M., Kafshgar, F. Z. R., & Arab, A. (2020). Evaluating strategies for implementing Industry 4.0: a hybrid expert oriented approach of BWM and interval valued intuitionistic fuzzy TODIM. *Economic Research-Ekonomska Istraživanja*, 33(1), 1600-1620. http://dx.doi.org/10.1080/1331677X.2020.1753090.

Morandi, M. I. W. M., & Camargo, L. F. R. (2015). Systematic literature review. In A. Dresch, D. P. Lacerda & J. A. V. Antunes Jr. (Eds.), *Design science research: a method for science and technology advancement* (pp. 141-175). Cham: Springer.

Muhuri, P. K., Shukla, A. K., & Abraham, A. (2019). Industry 4.0: a bibliometric analysis and detailed overview. *Engineering Applications of Artificial Intelligence*, 78, 218-235. http://dx.doi.org/10.1016/j.engappai.2018.11.007.

Müller, J. M., Kiel, D., & Voigt, K. I. (2018). What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, 10(1), 247. http://dx.doi.org/10.3390/su10010247.

Olfati, M., Yuan, W., & Nasseri, S. H. (2020). An integrated model of fuzzy multi-criteria decision making and stochastic programming for the evaluating and ranking of advanced manufacturing technologies. *Iranian Journal of Fuzzy Systems*, 17(5), 183-196.

Renz, S. M., Carrington, J. M., & Badger, T. A. (2018). Two strategies for qualitative content analysis: An intramethod approach to triangulation. *Qualitative health research*, 28(5), 824-831.

Sanders, A., Elangeswaran, C., & Wulfsberg, J. P. (2016). Industry 4.0 implies lean manufacturing: research activities in Industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management*, 9(3), 811-833. http://dx.doi.org/10.3926/jiem.1940.

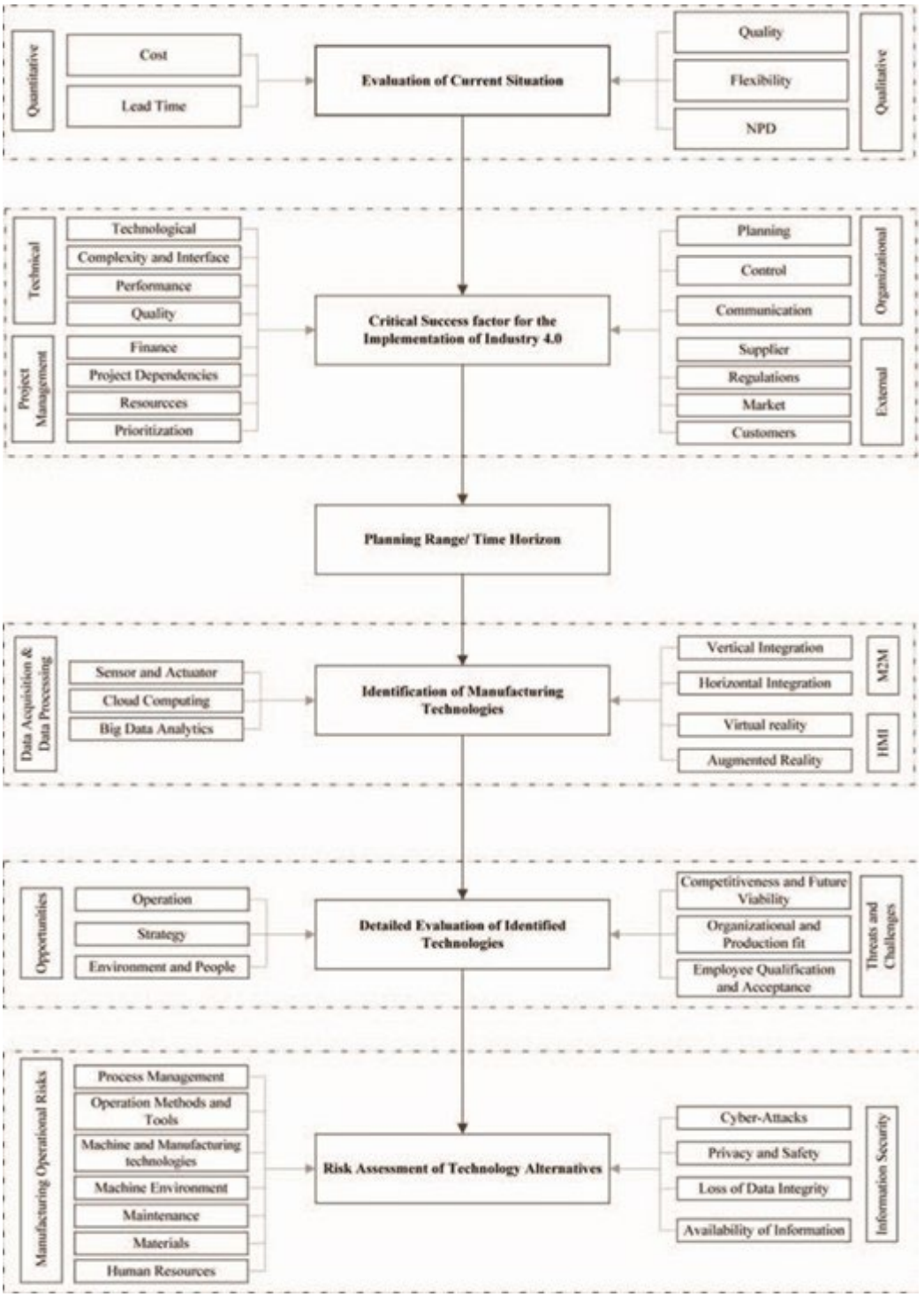
Sevinç, A., Gür, Ş., & Eren, T. (2018). Analysis of the difficulties of SMEs in Industry 4.0 applications by analytical hierarchy process and analytical network process. *Processes*, 6(12), 264. http://dx.doi.org/10.3390/pr6120264.

Thomassen, M. K., Sjøbakk, B., & Alfnes, E. (2014). A strategic approach for automation technology initiatives selection. In *IFIP International Conference on Advances in Production Management Systems* (pp. 288-295). Heidelberg: Springer. http://dx.doi.org/10.1007/978-3-662-44733-8_36.

Türkeș, M. C., Oncioiu, I., Aslam, H. D., Marin-Pantelescu, A., Topor, D. I., & Căpușneanu, S. (2019). Drivers and barriers in using Industry 4.0: a perspective of SMEs in Romania. *Processes*, 7(3), 153. http://dx.doi.org/10.3390/pr7030153.

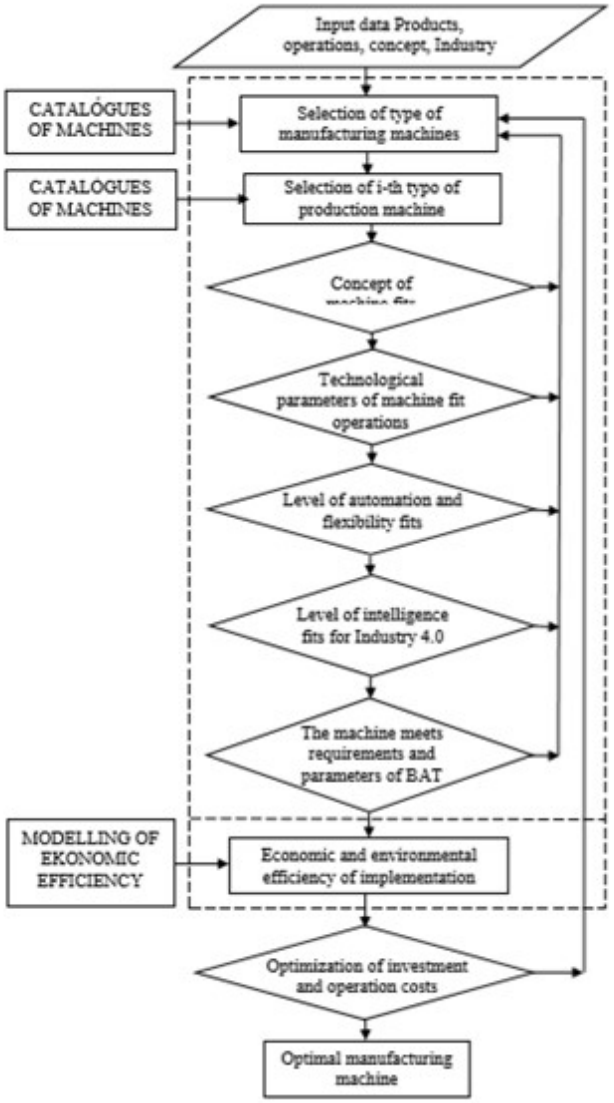
Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. *International Journal of Production Research*, 56(8), 2941-2962. http://dx.doi.org/10.1080/00207543.2018.1444806.

Appendix A. Stages of the Process for Choosing and Implementing Technology.



Source: Hamzeh et al. (2018).

Appendix B. Algorithm for Selecting Technology.



Source: Daneshjo et al. (2017).