

# Technische Hochschule Ingolstadt

Faculty of Engineering and Management  
M. Eng. Automotive Production Engineering

## Master's thesis

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### **Evaluation of existing models for the assessment and selection of Digital Technologies in SMEs**

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Lesly Sánchez Solis

Student ID: 00102413  
les2673@thi.de

Supervised by:  
Prof. Dr.-Ing. Bernhard Axmann  
Prof. Dr.-Ing. Roland Meyer


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Lesly Sánchez Solís:  
Evaluation of existing models for the assessment and selection of Digital Technologies in  
SMEs  
Master thesis, Technische Hochschule Ingolstadt, 2021.

## Declaration

I hereby declare that this master thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

Stuttgart, 13.04.2021

A handwritten signature in black ink, consisting of a circular flourish with a diagonal line through it, and the name 'Lesly' written in cursive below it.

Lesly Sánchez Solis

## Preface

This thesis was conducted on the topic of "Evaluation of existing models for the assessment and selection of Digital Technologies in SMEs". It was submitted to the Technische Hochschule Ingolstadt, Department of Engineering and Management in Partial Fulfillment of the Requirements for the Degree of M. Eng. Automotive Production Engineering. It contains work done from November 2020 to the end of March 2021 in Stuttgart, Germany. This thesis was made under the supervision of Prof. Dr.-Ing. Bernhard Axmann, Program Director of the master's in Automotive Production Engineering and lecturer at the Technische Hochschule Ingolstadt. The author has solely made the thesis. However, all passages and ideas taken from other sources are cited accordingly.

## **Acknowledgements**

First and foremost, I thank my almighty God who never forsaken me, teaching me that everything has its time, and that in life every effort has a reward.

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I am extremely grateful to my parents, Silvia and Horacio, for their love, prayers, caring and sacrifices for educating and preparing me for my future. I owe and dedicate each and every one of my achievements to them.

I want to acknowledge the support of my whole family and friends. They kept me going on and this work would not have been possible without their input.

## **Abstract**

This research indicates that there are two models with a strong compatibility for SMEs. However, improvements are needed to ensure that they are efficient enough for SMEs. To do so, needs and characteristics of SMEs must be considered for a future model.

Small and Medium-sized Enterprises (SMEs) are an important key of the economic growth. In the recent years, the concepts Digitalization and Industry 4.0 have been addressed to these companies. These new approaches promise great potential and benefits to SMEs in terms of flexibility, productivity and resource efficiency. Thus, the introduction of Digital Technologies is a key factor for SMEs to remain competitive. SMEs experience challenges when trying to digitalize their business, these challenges involve the availability of evaluation models for Digital Technologies which are suitable for their needs. The goal of this research is to identify which models are currently available and to analyze if these existing models are suitable and efficient enough for SMEs. To reach our goal, 10 currently existing models were evaluated by means of a pairwise comparison. The evaluation criteria were defined through the analysis of the characteristics and needs of the SMEs. This research demonstrates that deciding on an appropriate technology is currently a struggling decision that many SMEs are currently facing, due to the lack of evaluation models for Digital Technologies customized and adapted for their needs. The study also indicates that complexity level and resources needed, as well as visual characteristics are important factors of the models. All these findings led to the proper analysis and evaluation of these ten models to define how efficient they are for SMEs.

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## Abbreviations

SME	Small and medium-sized enterprise
EU	European Union
EU-28	European Union (28 Countries)
NFBS	Non-financial business sector
CPS	Cyber-physical System
AHP	Analytic Hierarchy Process
QFD	Quality Function Deployment
IT	Information Technology
ICT	Information and Communication Technologies
DEA	Data envelopment analysis
MP	Mathematical Programming
CEO	Chief Executive Officer

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# Chapter 1 Introduction

The European Union defines a Small and Medium-sized Enterprise as an enterprise that has revenue of less than €50 M and no more than 250 employees. SMEs are an important key of the economic growth. The fourth industrial revolution has brought with it digital technologies that promise great potential and benefits for these companies in terms of flexibility, productivity and resource efficiency but introducing these digital technologies cause radical changes in the processes of the companies.

Due to the complexity of this process, SMEs experience challenges when trying to digitalize their business, these challenges involve the availability of evaluation models for Digital Technologies which are suitable for their needs. There are currently different evaluation models for the evaluation and selection of digital technologies, but SMEs still have difficulties to identify the right tool that suits their business needs.

Given the limitations associated with these models, this research investigates the specific requirements and needs of SMEs with respect to the tools that support their selection of digital technologies that introduce them to the world of Industry 4.0.

The aim of this thesis is to analyze which models are currently available and if these existing models for evaluation and selection of Digital Technologies are suitable and efficient enough for SMEs.

This thesis is divided into five chapters:

- Chapter 2 gives an overview about the Small and Medium Enterprises and introduces the general concept of Digital Technologies. Moreover, it introduces an explanation of what are the models for the identification and evaluation of Digital Technologies and its importance in the industry.
- Chapter 3 explains the research method applied in this thesis in means of how the data was gathered and analyzed. In addition, it gives the basic principles of the SWOT Analysis and Pairwise Comparison and explains how this comparison is conducted.
- Chapter 4, the result chapter, shows the current models for the identification and evaluation of Digital Technologies. Furthermore, it introduces the main

characteristics that makes a model efficient enough for a SMEs. It also explains the bases of the evaluation criteria for the Pairwise Comparison and shows the whole comparison process in order to score the currently available models for the evaluation and selection of Digital Technologies. A SWOT analysis is carried to define how efficient the best scored models are for SMEs. Moreover, there is a discussion of the results.

- Chapter 5 gives the conclusion of this thesis and explains the future work of this study and recommendations.

## Chapter 2 Evaluation and selection of Digital Technologies in SMEs

Before discussing the evaluation and selection of Digital Technologies in Small and Medium Enterprises (SMEs), basic concepts should be investigated in order to understand the whole context. This chapter discusses two main concepts which are Digital Technologies and SMEs. A general overview about models for the identification and evaluation of Digital Technologies that are currently available will be given.

### 2.1 Small and Medium-Sized Enterprises (SMEs)

An enterprise is considered to be any entity engaged in an economic activity, regardless of its legal form. This includes, in particular, self-employed persons and family businesses engaged in craft or other activities, as well as partnerships or associations that regularly carry out an economic activity (European Commission, 2012).

The literature offers a variety of definitions regarding SMEs. When it comes to a specific definition, each country shows very different approaches and factors to give the category of SME to a company. Germany's Federal Ministry for Economic Affairs and Energy defines SMEs as companies that have less than 500 employees or that generate up to 50 million euros in annual turnover (BMW, 2021).

Company category	Staff headcount	Turnover	Balance sheet total
Micro SME	< 10	≤ € 2 million	≤ € 2 million
Small SME	< 50	≤ € 10 million	≤ € 10 million
Medium SME	< 250	≤ € 50 million	≤ € 43 million

Table 1: SMEs definition (European Commission, 2012)

According to the European Commission, small and medium-sized enterprises are defined concerning the headcount and either turnover or balance sheet total. Table 1 summarizes the values of each characteristic. In order to classify a company as a SME, it should employ less than 250 people and furthermore, it needs to have an annual

turnover that does not exceed 50 Mio EUR and / or an annual balance sheet total of maximum 43 Mio EUR. This research work will follow this definition.

SMEs are the driving force of many manufacturing economies (Mittal, et al., 2018; Thrassou, et al., 2020). The annual report on European SMEs, gives an overview on the influence and importance of SMEs in the economy of Europe in a yearly basis. In 2018, the report showed that there were more than 25 million SMEs in the EU-28 and those represent the 99% of all businesses in the European Union. From 2013 to 2018, SMEs have created approximately 85% of the new jobs. (European Commission, 2019).

The European Commission considers SMEs to be one important key of the economic growth in the EU, but it is essential to take into consideration that these enterprises are constantly facing challenges and barriers which enterprises from other categories would not usually be facing, as limited resources and accessibility to information. In addition, the European Commission actively supports SMEs by providing direct financial support and indirect support to increase innovation.

## **2.2 Industry 4.0**

Throughout history, there have been four industrial revolutions, each of the four industrial revolutions was driven by a set of technologies that transformed the world at the time. The first one with the development of the steam engine by James Watt in England, and thus the introduction of mechanical production. This allowed products to be produced in greater quantities and quickly.

During the second industrial revolution, the key factors were electric power, division of labor and mass production. Workers could be more specialized due to the division of production lines into smaller processes and this in turn facilitated the reduction of production costs. The beginning of the third industrial revolution was marked by the introduction of the first programmable logic controllers (PLCs), electronics and information technologies, which made the individual steps of production smarter than in the past (Orzes, et al., 2020).

The fourth industrial revolution is based on the application of cyber-physical systems (CPS) and internet technologies in the manufacturing processes, leading to a convergence between the physical and the virtual world (Kagermann, et al., 2013).



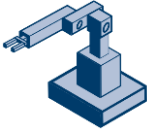

Industrial Revolutions			
First Industrial Revolution	Second Industrial Revolution	Third Industrial Revolution	Fourth Industrial Revolution
Introduction of mechanical production facilities with the help of water and steam power	Introduction of the division of labor and mass production with the help of electrical energy	Use of electronic and IT systems that further automate production	Use of cyber-physical systems
			

Figure 1: Industrial revolutions (Acatech, 2015)

The term “Industry 4.0” was presented for the first time in 2011 by a group of German scientists of the Deutsche Akademie der Technikwissenschaften (Acatech) in the Hannover Fair (Orzes, et al., 2020; Matt, et al., 2020). It was originated to denote the process of close integration of information and communication technologies (ICT) in manufacturing and logistics through the potential deployment of Cyber-Physical Systems (CPS), leading to a “fourth industrial revolution” (Acatech, 2015).

The convergence between the automation of industrial processes and information technologies makes it possible to improve operations, reduce costs and improve the quality of automation processes, providing them with flexibility and speed that have an impact on the productivity of the company (Peña Cabrera, et al., 2019). In short, everything in and around a manufacturing operation (suppliers, the plant, distributors, even the product itself) is digitally connected, providing a highly integrated value chain (European Commission, 2015).

According to a definition of the European Commission, Industry 4.0 consists of several new and innovative technologies, the so called “digital” technologies:

- Information and communication technology (ICT) digitizing information and integrating systems at all stages of product development, manufacture, and



utilization (including logistics and supply) within both, companies and across company borders.

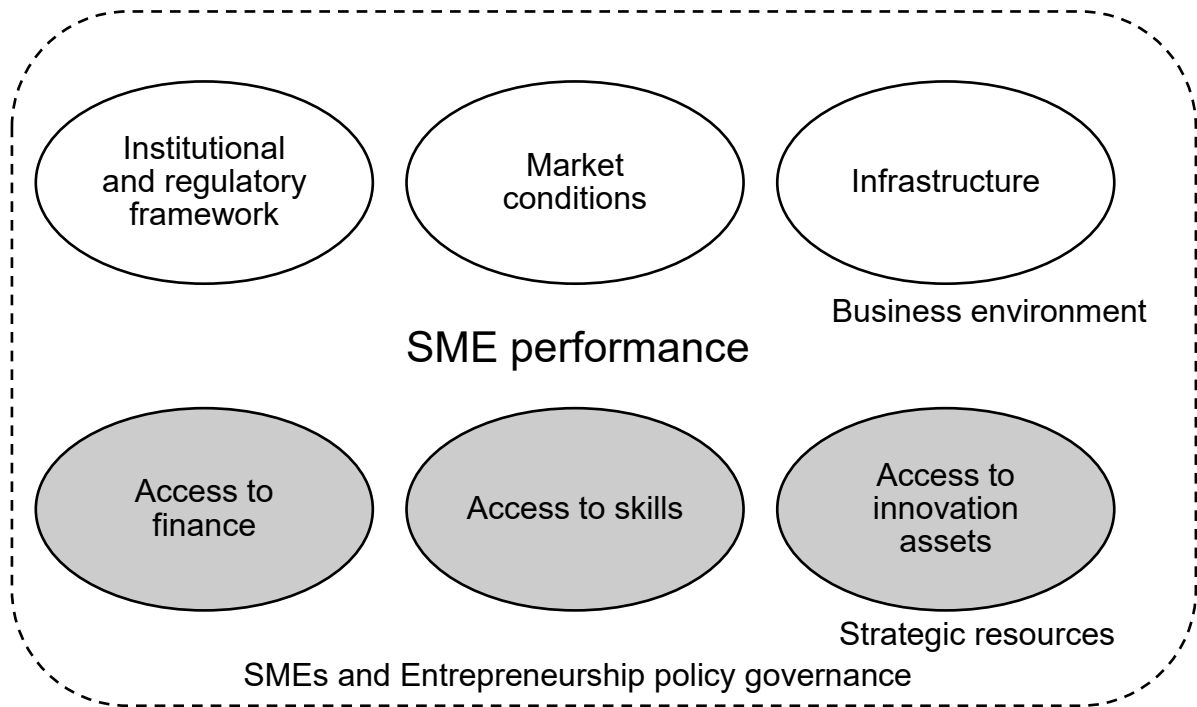
- Cyber-physical systems which use ICTs as mean to monitor and control physical processes and systems, involving embedded sensors, intelligent robots, or additive manufacturing (3D printing) devices.
- Network communications, which includes wireless and internet technologies that help to link machines, work products, systems and people, within the production plant, with suppliers and distributors.
- Simulation, modeling, virtualization in the design of products and the establishment of manufacturing processes.
- Big data collection, analysis and exploitation. Either immediately on the factory floor, or through cloud computing.
- Digital assistance systems for workers, including robots, augmented reality and intelligent aid systems (European Commission, 2015).

The use of digital technologies in companies is leading them to digitalization. *Digitalization is widely accepted as a principal technological strategy and is expected to vastly impact and transform industry, predominantly by a substantial improvement of the entire value chain* (Kilimis, et al., 2019).

Introducing these digital technologies cause radical changes in the processes of the companies. These changes come together with challenges which suggest a strong importance on the strategies followed by the company while digitalizing its businesses (Sarvari, et al., 2019).

### **2.3 Barriers and benefits of Digitalization in SMEs**

Most companies, especially SMEs, have not become aware of the industrial revolution we are going through. Technology is evolving much faster than we can assimilate, understand or assume. The concepts Digitalization and Industry 4.0 have been addressed to SMEs in the recent years (Matt, et al., 2020) because they alter the business conditions of the performance of SMEs (see Figure 2) and create new opportunities for them to overcome the innovation barriers related to its size, as well as on going global and growing by combining the Internet of Things (IoT), data analytics and cloud computing (OECD, 2021).



*Figure 2: The 6+1 pillars of SME performance (OECD, 2021)*

Globalization has had a great influence on SMEs. It has allowed them to compete not only locally, but also globally in changing market conditions since it makes them less culturally and physically constrained compared to traditional methods. Thanks to this, SMEs have paid more attention to competitiveness and efficiency, both have become a priority of SMEs. Thus, innovation and adoption of the latest technology is a key factor of a SME to remain competitive (Thrassou, et al., 2020).

Digitalization promises great potential to provide benefits to companies, such as fulfillment of individual customer requirements by shortening time to market, increased flexibility, as well as increased productivity and resource efficiency (Kagermann, et al., 2013; Gherghina, et al., 2020). Digitalization has also changed the conditions for access to finance. There is now a range of innovative financial services for this sector of companies. But it has also facilitated access to knowledge and skills through a variety of recruitment platforms or applications that have been created (OECD, 2021).

Unlike large companies that have already invested large amounts of resources in introducing digital technologies to their processes and other areas of their businesses, SMEs are in a very different situation; they lag in the digital transition (Seiter, et al., 2019; OECD, 2021), even though the implementation of digital technologies could be seen as a strategic weapon for SMEs to reach a bigger market and compete with the large enterprises (Thrassou, et al., 2020).

SMEs experience challenges when trying to digitalize their business operations due to financial resources, limited time, managerial and human capital resources, which are the major barriers. Using the advantages of Industry 4.0 is not just about cost or complexity, it is a cultural issue. All change involves uncertainties and fears. For example, with automation, thousands of jobs were lost, but many more were created, as well as new skills and trades. This cultural change was not immediate, so it is not surprising to see that companies are still not venturing into the concepts of Industry 4.0 (Abel-Koch, et al., 2019).

Industry 4.0 represents a special challenge for SMEs in particular. Their readiness and knowledge to adapt Industry 4.0 technologies and concepts and their organization to meet this challenge is not fully developed. The size of the company is directly related to the ability to benefit from Industry 4.0, as the smaller the SME, the higher the risk of not achieving its benefits (Matt, et al., 2020).

SMEs face many barriers to industry 4.0. (Orzes, et al., 2020) classifies them into six categories:

- Economic/financial: high investments required, lack of monetary resources, lack of clearly defined economic benefits
- Cultural: lack of support by top management; preferred autonomy
- Competencies/resources: lack of skilled employees, lack of technical knowledge; complexity of the Industry 4.0 application both technical and practical, need to find suitable research partner
- Legal: data security concerns
- Technical: lack of standards, uncertainty about the reliability of the systems, weak IT infrastructure, difficult interoperability/compatibility, technology immaturity
- Implementation process: need for new business models, lack of methodical approach for implementation, high coordination effort.

Lack of digital skills has been a major concern among SMEs, including the lack of knowledge and expertise in the application of new technologies (Kilimis, et al., 2019). This opens up the need for further research and action plans to prepare SMEs in a technical and organizational direction. Therefore, special research and studies for the implementation of digital technologies in SMEs are needed. This companies will only

be updated to Industry 4.0 by following strategies and implementation approaches specifically customized and adapted for SMEs.

Furthermore, SMEs often fail to fully identify what are the results or consequences expected by implementing digital technologies for the organizational structures, operations and strategies (Thrassou, et al., 2020) and therefore, have difficulties to identify the right tool that suits their business needs.

In accordance with this identified gap, this research investigates the specific requirements and needs of SMEs with respect to the tools that support their selection of digital technologies that introduce them to the world of Industry 4.0.

## **2.4 Tools for the selection and evaluation of Digital Technologies**

The topic of digitalization in SMEs is new, however, the topic is well ahead in terms of large companies. Companies of this size have been developing through their experience different tools that have supported them on their way to digitalization, these are therefore adapted to the characteristics and resources of large companies.

In order to understand the categories of tools described below, it is necessary to define the following concepts according to the Cambridge Dictionary:

- Model: a description of a system or process that can be used in calculations or predictions of what might happen. A model is the application of strategies and methods as a system or process.
- Strategy: a way of doing something or dealing with something, a detailed plan for achieving success
- Method: a particular way of doing something (Cambridge).

Figure 3 illustrates the relationship between these three tools.

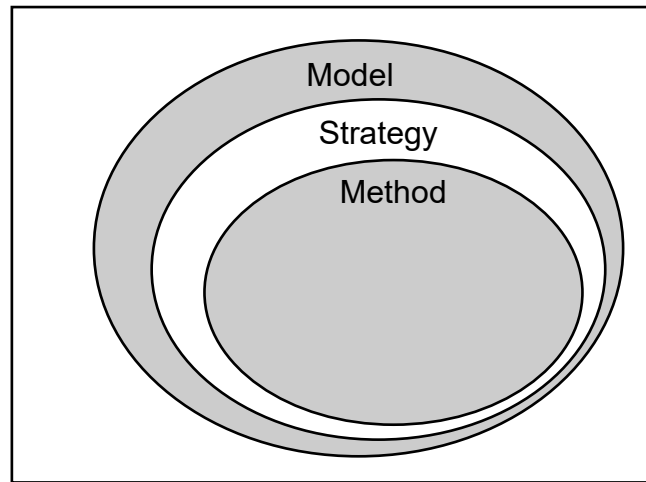


Figure 3: Relationship among Models, Strategies and Methods (own figure)

In the list of tools comes the Maturity Models, which assess the maturity level, defined as “state of being complete, perfect or ready”, of digital solutions and offers a small guidance about digitalization (Wiesner, et al., 2018). The main goal of maturity models is to provide guidance for assessing the maturity of a company to implement Industry 4.0 technologies and solutions. These models also help companies by identifying concrete actions to achieve a higher maturity level in order to increase the benefits.

In a study, where four different maturity level models developed specifically for SMEs were evaluated, it was observed that none of them could complete all the prerequisites to be compatible with an SME (Schuh, et al., 2017).

The maturity models are the base of the next category of tools called roadmaps, which are important to generate and deliver strategy and innovation in companies. The Industry 4.0 roadmaps give an overview of the current situation of the company and the expected situation in a time horizon. It helps and guides whoever in the industry to understand each step, the decisions that need to be done, who needs to make them and when (Sarvari, et al., 2019).

In other words, a roadmap is a strategy to identify and decide between different paths to follow to reach future success in terms of digitalization, exactly as a traditional city map guides the travelers to any destination. Sarvari, et al., gives the key benefits of technology roadmaps, which are the following:

- Establishing alignment of commercial and technical strategies
- Improving communication across teams and organizations

- Examining potential competitive strategies and ways to implement those strategies
- Efficient time management and planning
- Identifying the gaps between technology, market, and product intelligence
- Prioritizing the investments
- Setting competitive and rational targets
- Guiding and leading the project teams
- Visualizing outputs including goals, processes, and progresses (Sarvari, et al., 2019).

It is important to remark that although this tool supports companies in their transition to digitalization, it does not contain a specific method or model that describes the assessment of digital technologies from different perspectives. Rather, they focus on the company itself by "preparing the ground and the way" for implementation once the solution has been chosen.

The next category of tools are the Technology Selection methods which helps to identify the best technology from a group of possible alternatives. Most of these methods are focused on the characteristics of the technology, like contribution level, life cycle, etc., and the interaction between the technologies included in the group being evaluated (Hamzeh, et al., 2019). According to Hamzeh, et al., in a review from 1990 to 2017 of technology selection methods, the most common methods usually included in these models are:

- Analytic Hierarchy Process (AHP)
- Data envelopment analysis (DEA)
- Fuzzy Logic
- Mathematical Programming (MP)
- Hybrid Methods

In addition to these, there is also a wide variety of methods for technology assessment, which are not only limited to evaluation, but are also planning, analysis or forecasting tools. Table 2 shows a summary of these and their classifications according to type, time horizon and use (Hall, 2002).

Tool	Procedure			Phase		Type		Horizon	
	Forecast	Analysis	Evaluation	Exploration	Evaluation	Qualitative	Quantitative	Present	Future
Argument balance			X		X	X		X	
Benchmarking			X	X	X	X	X	X	
Evaluation matrix			X		X		X	X	
Conjoint analysis		X		X		X	X	X	X
Delphi method	X			X		X			X
Energy and material flow analysis		X		X		X	X	X	
Decision theory			X		X	X	X	X	
Cost-benefit analysis			X		X		X	X	
Cost-effectiveness analysis			X		X		X	X	
Morphological classification		X		X		X		X	
Utility analysis			X		X	X	X	X	
Patent analysis	X			X		X			X
Portfolio technique			X		X	X	X	X	
Product line analysis			X	X	X	X		X	X
Quality Function Deployment		X			X	X	X	X	X
Ranking method			X		X	X		X	
Sensitivity analysis		X			X		X	X	
Scenario technique	X			X		X			X
Target costing			X		X	X	X		X
Techno metric Indicators			X		X		X	X	
Trend Exploration	X			X			X		X
Interdependency matrix		X			X	X		X	
Value analysis			X		X	X		X	
Impact network		X		X	X	X		X	
Profitability analysis			X		X		X	X	

Table 2: Overview of common technology assessment tools and methods (Hall, 2002)

The last category is regarding the models of evaluation and selection of Digital Technologies in SMEs. These models are expected to contain one or more of the above-mentioned methods. But taking into consideration both, strategies and methods, that together create a process or system that allows companies to implement digital technologies correctly and successfully. However, the literature shows the gap that exists between the needs of SMEs and the tools, which are not compatible or adapted to them.

A study performed in 2020 presented the following statements from CEOs and managers of SMEs in which their concerns about the lack of a model for implementing Industry 4.0 for SMEs were externalized:

- “There are no methods and approaches for the correct introduction of Industry 4.0”
- “There are limited support resources and a lack of formalized, distilled information on how to implement industry 4.0”
- “Few Best-Practice-Examples.” (Orzes, et al., 2020)

Following the above challenges and issues, the aim of this research is to analyze which models are currently available and if these existing models for evaluation and selection of Digital Technologies are suitable and efficient for SMEs and the possible drawbacks that have to be taken into account when developing a new improved model for SMEs.



## Chapter 3 Methods

### 3.1 Research Method

To answer the main research questions, a seven-phase methodology was developed, which will be described in this section. Figure 4 represents a schematic overview of the research methodology.

The research was divided in two main topics which came from the two research questions. The first one is “Criteria for the evaluation of the models” and the second is “Models to be evaluated”.

Phase 1: The planning of the whole research work was made. In this phase, the main goal was to define the research questions, so the key search terms were also identified. As part of the planning phase, a review method for the models to be evaluated was defined which will be explained later in detail.

Phase 2: The research was conducted for both topics. Presented below is the full search string, used to identify the relevant literature for this research. It is important to consider all combinations of the search string words to obtain the best possible results.

Topic 1: Criteria for the evaluation of the models

Digitalization in SMEs; Industry 4.0 for SMEs; Strategies for Digital Transformation/Digitalization; Digital Transformation in SMEs; Best Practices Digitalization SMEs; Requirements for a successful digitalization in SMEs; Challenges of Digitalization in SMEs; Needs of SMEs in Digitalization
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Topic 2: Models to be evaluated

Digitalization Models; Implementation of Industry 4.0; Identification of digital solutions; Evaluation model of Digital Technologies; Industry Roadmap; Models for SMEs; Roadmap for SMEs; Selection of digital solutions in SMEs
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These keywords were searched in Google Scholar and Databases provided by the THI like EBSCOhost eBook Collection, as well as in the library catalogue.

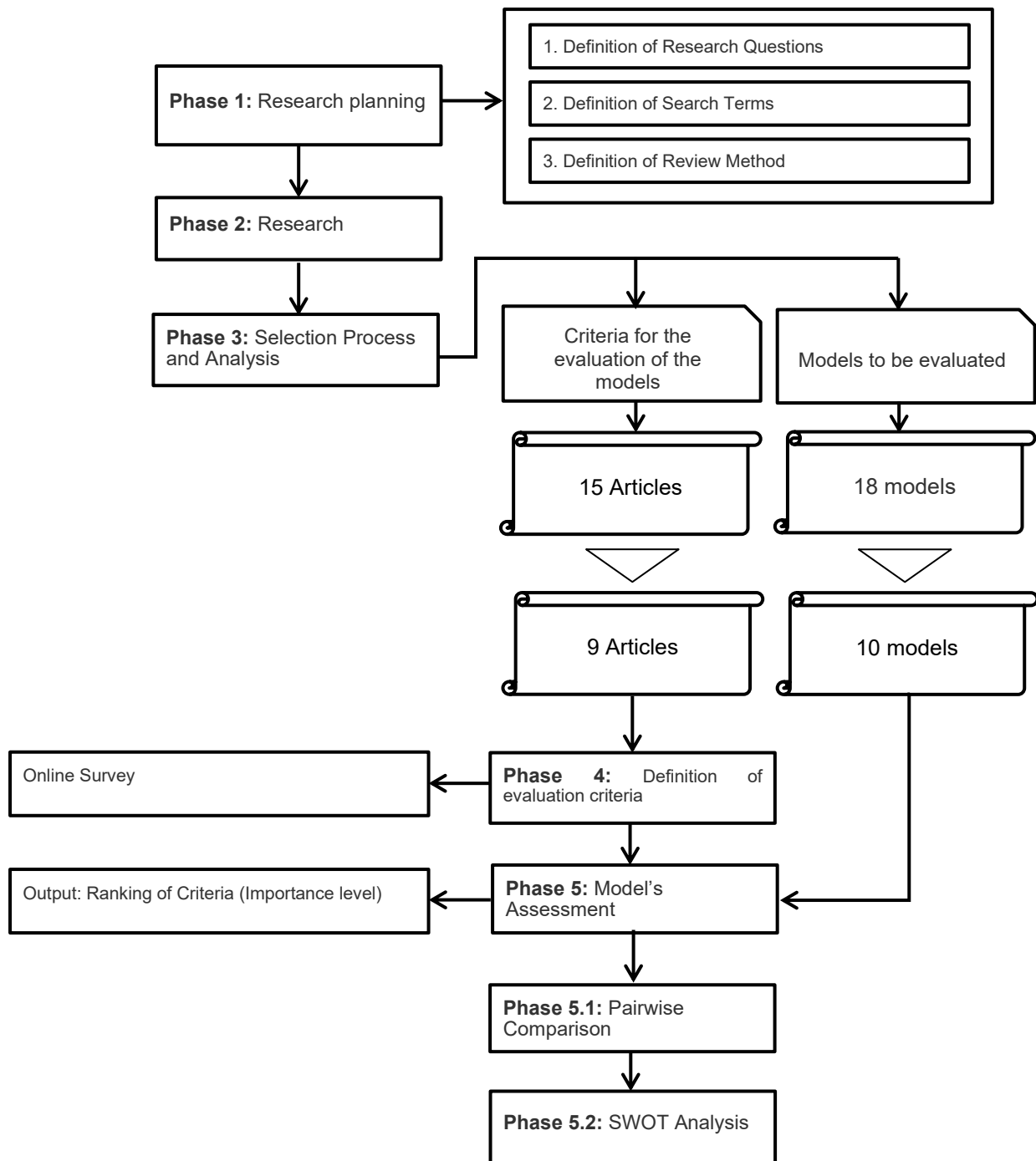


Figure 4: Research method (adapted from (Galster, et al., 2014))

Phase 3: For the topic: “criteria for the evaluation of the models”, after analyzing the titles and screening the resulting papers in the initial results of the research, in a first iteration, a total of 15 potential papers were identified. After that, a second iteration was performed, where the papers were read carefully and critically, as a result, only 9 papers resulted relevant for the purposes of this research work.

For the topic “models to be evaluated”, due to the limited number of relevant papers, each paper was checked deeply to see if it was actually a model for evaluation of digital technologies. Therefore, in the research approximately 90% of the resulted documents were about “maturity models” which are not on the scope of this work. In the first iteration of the research, 18 models/documents were identified. In the second iteration, during the review method, the classification between models for the “evaluation” of digital technologies (which is actually the desired result) and models for the “implementation” of digital technologies gave a result of only 10 models resulted relevant for the purposes of this work.

Phase 4: An online survey was conducted to define the final list of evaluation criteria for the models during the Pairwise Comparison. The methodology of the survey is described in section 3.2.

Phase 5, 5.1 and 5.2: A comparison between the evaluation criteria was performed to define the importance of each of them, and be able to perform adequately the phase 7, where the models are evaluated accordingly. The pairwise comparison is explained in section 3.4. The last step of this face was to conduct a SWOT analysis of the models with highest results to determine which are the opportunity areas or improvement areas of them to be “the best fit” for SMEs.

### **3.2 Online survey**

A survey is a tool used to gather information about characteristics, opinions or actions of a large group of people. Surveys can also be used to evaluate needs and demands, but also to find out the effect or impact of certain factors (Pinsonneault, et al., 1993).

For the purpose of this research, the online survey was conducted to examine the relationship between the proposed criteria. The collected data comes from people’s opinions and is therefore, subjective. The result of the survey showed the findings of a selected portion of the whole population and was later generalized to the total population.

The online survey was designed in Google Forms and was available from December 16<sup>th</sup>, 2020 to March 3<sup>rd</sup>, 2021. The survey was shared to the business community in the social network LinkedIn. This platform allows users to create professional profiles

and to learn more about their expertise areas. The necessary attribute of the sample population was that they had to be involved in the business sector, either as employees or entrepreneurs.

In order to obtain important information about the participants, the first section of the survey was composed of three initial questions regarding size of the company, experience level and industry sector of their current job. These are the most important characteristics for our analysis. Unclear instructions were avoided by presenting a simulated situation to put the participant in context, as follows:

You work in a SMALL COMPANY and are assigned as a project manager for the introduction of a new digital technology to optimize the production area. As you are a fan of digital technologies, you know that there are many models that can help you in the process of selecting the appropriate digital technology. You have made great research on all the models that exist nowadays, and you have chosen 5 that are more aligned with the needs of your company.

Followed by the description and image of five different models. Each in a monochromatic format, same font and same information shown as key points as seen in Appendix 1. All this in order to not influence the attractiveness of the models with colors or other factors and to be able to carry out a survey without any bias or inclination.

The survey then continued with two multiple choice questions (allowing only one answer) to define the model that most appealed to the user and the one that they perceived could give the most optimal result. Then, using the Likert scale, the participants had to indicate on what extent they would be willing to use each model for the simulated situation described at the beginning. In order to assess the opinions about each model, the answer was a five-point scale, going from Strongly Disagree to Strongly Agree (Bhandari, 2020).

To define the predominant characteristic of each model, a matrix question was added. Finally, the survey ended with a last multiple-choice question (allowing several options), regarding the popularity of the model. The results of this online survey will be described and discussed in section 4.2.3.1.

### 3.3 SWOT Analysis

The SWOT or “Strengths, Weaknesses, Opportunities and Threats” analysis is commonly used to develop business strategies, but it is also used to assess new solutions to different problems related to any kind of topic. To do so, it is necessary to list the good and bad, internal and external issues or facts that are closely related to the study object; and use de idea of system analysis to review the various factors, such as to draw a series of corresponding decision-making conclusions (Helms, et al., 2010) (s. Table 3).

This analysis helps to understand how to minimize the weakness and even avoid the threats, to know how the strengths can be used to take advantage of the opportunities or to avoid potential threats and to find a way to use the opportunities to deal with the weaknesses. (Charantimath, 2012)

	Internal		
Positive	Strengths	Weaknesses	Negative
	Opportunities	Threats	
	External		

Table 3: SWOT sample layout (own graphic)

A SWOT analysis is usually created during a period that allows enough hours to have good brainstorming and inquiry of the topic of interest. The best results come when the process is collaborative and inclusive.

In order to conduct a good SWOT analysis, five steps must be followed:

1. Decide on the objective of your SWOT analysis.
2. Research your business, industry, and market.

3. List your business' strengths, weaknesses, opportunities, and potential threats.
4. Establish priorities from the SWOT.
5. Develop a strategy to address issues in the SWOT (Queensland, 2017).

Once the SWOT analysis has been finished, a real insight about the topic is done. The resulting information should be used to have a deep overview of the point of interest of any research.

### 3.4 Pairwise Comparison

Pairwise Comparison is a method to evaluate and compare alternatives in preparation of a decision-making process. It gathers one complex decision into many small packages on which is then decided singularly (Schnurr, 2019). The aim is to judge which alternative is preferred or has more of a property. It also shows when a pair of alternatives are identical or the opposite (Ramík, 2020).

This method can be applied in four steps:

1. Problem definition and determination of the type of knowledge being sought.
2. Give structure to the hierarchy. It is suggested that the first level should stand for the goal of the decision and the last levels represent alternatives to it.
3. Construction of the matrices, where each alternative of an upper level is compared to the level immediately below.
4. Using the priorities gathered from the comparison to weigh the priorities in the lower level (Saaty, 2008).

To start with the pairwise comparison and to determine the importance of each alternative, a numbers scale is needed. (s. Table 4 Table 4: Scale of absolute numbers ).

Importance	Description
0	The alternative in the horizontal (row) is <i>less important than</i> the alternative in the vertical (column)
1	The alternative in the horizontal (row) is <i>just as important as</i> the alternative in the vertical (column)
2	The alternative in the horizontal (row) is <i>more important than</i> the alternative in the vertical (column)

Table 4: Scale of absolute numbers (Sonntag, et al., 2015)

Regarding the construction of the matrix, the alternatives are listed in the first row and the first column respectively. Then three columns will be added: sum of rating, percentage and ranking (s. Table 5). Once the matrix is created, each pair of alternatives (row – column) will be evaluated with the scale given in Table 4.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10	Sum of rating	%	Ranking
Alternative 1													
Alternative 2													
Alternative 3													
Alternative 4													
Alternative 5													
Alternative 6													
Alternative 7													
Alternative 8													
Alternative 9													
Alternative 10													
Total													

Table 5: Schematic table for pairwise comparison matrix (own graphic)

After the evaluation, the rating of each row will be summed up in the corresponding column. In order to obtain then the rating in percentage, the sum of rating of each alternative will be divided by the total points which were given in the matrix (Sonntag, et al., 2015). Lastly, the ranking is given in a scale of 1 to n, where n is the total number of alternatives in the matrix, according to the following logic: the alternative with the highest percentage will be ranked as the 1 – most important and the one with the lowest percent as n – the least important.

It is important to keep in mind that the pairwise comparison method is commonly based on a subjective assessment. For this application, the selection of the importance number is based on a research explained on the research method and discussed on Chapter 4.

For the purpose of this work, the result of the pairwise comparison will help to evaluate the models by multiplying the relative result (percentage) with the given score (1 to 10, where ten is the best, and one is the worst score) of each model in the specific criteria.



## Chapter 4 Results

### 4.1 Existing models for the identification and evaluation of Digital Technologies

Following the research method described in chapter 3, in total ten different models of evaluation of digital technologies were found. The final list is as follows:

- (A) Selection and Prioritization Model for Industry 4.0-Use Cases in Logistics
- (B) Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty
- (C) Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics
- (D) Technology selection for digital transformation: A mixed decision-making model of AHP and QFD
- (E) 5D ASSESSMENT CYCLE
- (F) A Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing
- (G) Digital Compass
- (H) Tech Radar 2020
- (I) Capgemini "Trend Technologies"
- (J) Gartner Hype Cycle

Each of the methods found uses one or more evaluation methods in order to give as a result the suggestion of digital technology to be used. Table 6 shows specifically for each of the cases.

Models Evaluation methods	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
Analytical Hierarchy Process				X						
Benefit Analysis					X					
Break Point Analysis			X							
Cost-Benefit Analysis	X		X		X	X				
Expert Interviews				X		X	X	X	X	
Feasibility Analysis						X				X
Funnel Method	X									

Evaluation methods	Models										
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	
Fuzzy Set Theory		X									
Life Cycle Costing			X								
Maturity Assessment (company)		X			X						
Morphological Box			X								
Net Present Value		X				X					
Quality Function Deployment				X							
Risk Analysis		X									
Sensitivity Analysis		X									
Stochastic Model		X									
Technology Ranking	X								X		
Technology Readiness Level					X		X	X	X	X	
Top-down Approach	X										
TOPSIS						X					
Usability Check					X				X		

*Table 6: Overview of evaluation methods included in the models (own table)*

In the following sections a general description of each model will be provided with the aim of giving a better understanding on each of them. Then, in the section 4.4, the models will be analyzed deeply and evaluated accordingly.

## Selection and Prioritization Model for Industry 4.0-Use Cases in Logistics

The model was developed with a strong focus on the logistics and was published in the Logistics Journal in 2019. It presents a model which is based on the funnel model, which is used in the development of a product or process. As the funnel model, this model starts with a broad number of inputs and gradually reduces them by selection. (University of Cambridge, 2016).

The aim of this model is to determine relevant Industry 4.0 use cases from logistics for a specific case in the company at the end of the “filtering” top-down approach process. Figure 5 shows the four-stage selection and prioritization model. And the stages are as follow:

- First stage: Cross-industry identification
- Second stage: Filtering by relevance
- Third stage: Evaluation and prioritization, then ranking
- Fourth stage: Cost-benefit analysis (Kohl, et al., 2019)

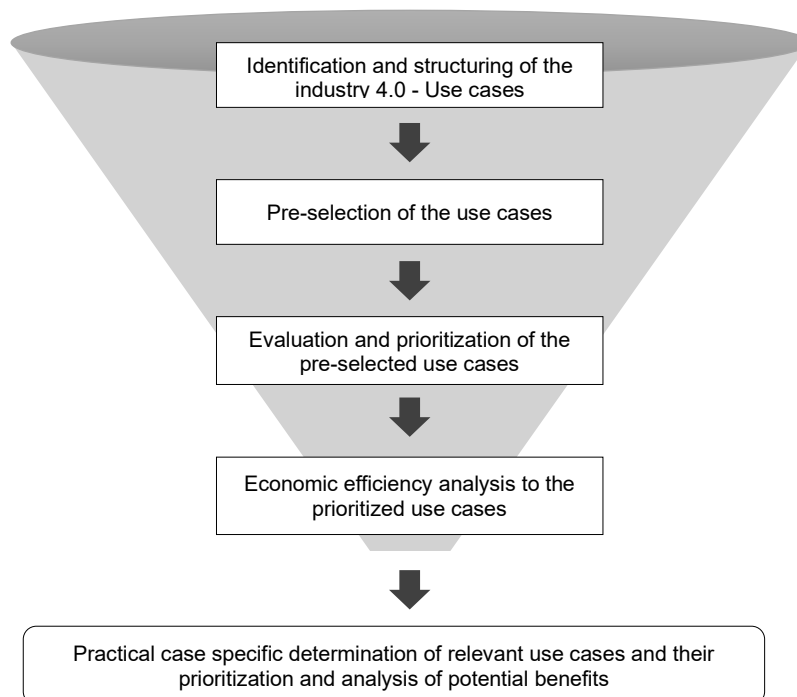


Figure 5: Selection and Prioritization Model for Industry 4.0-Use Cases in Logistics (Kohl, et al., 2019)

## Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty

The model presented was the result of a research which showed that the current models available were not focused on Industry 4.0 solutions for manufacturing. As a result, a model with a five-step evaluation method was developed, which includes uncertainty via fuzzy set theory and stochastic models.

As shown in the Figure 6, the first step is to define the evaluation scope, which means, the evaluation object, the time span and the alternatives. In this step, a maturity analysis of the company is also recommended. Then, the monetary and non-monetary criteria are selected based on the strategy of the business, followed by the data collection by using predefined and standardized templates.

The third step is the definition of the mathematical model, followed by the fourth step which is the execution of the model. As this model is specialized on Cyber-physical manufacturing systems, the recommended model is a Monte-Carlo Simulation to obtain a probability distribution of the net present value (NPV). At the end, the results are analyzed by means of a sensitivity or risk analysis in a so-called evaluation portfolio. (Liebrecht, et al., 2017)

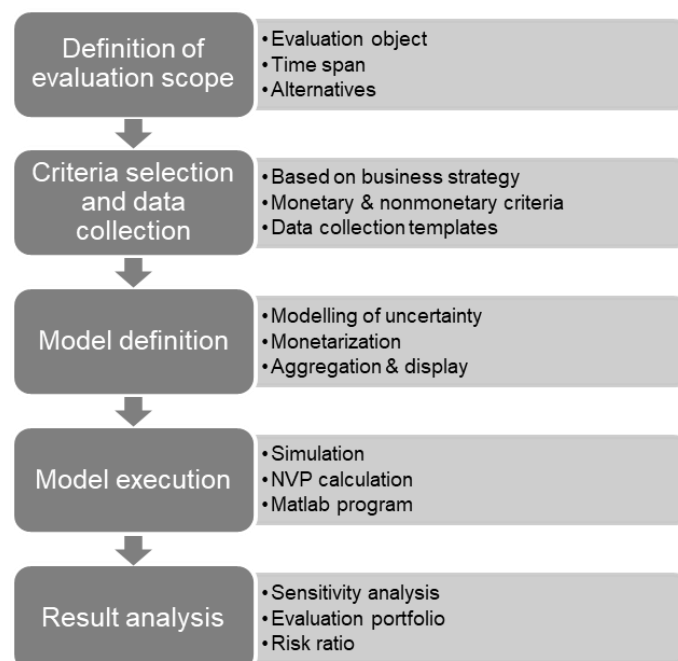


Figure 6: Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty (Liebrecht, et al., 2017)

## **Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics**

This model is focused on CPS in Intralogistics and it was then translated into a software demonstrator and is adapted to the SMEs requirements which allows them to reduce costs and save time.

The model starts with the use of the morphological box for the classification of the CPS technologies. Then, a benefit analysis of this technologies is conducted by means of a predictive performance measurement tool. The next step is to determine the cost with an advanced Life Cycle Costing. The model shows which technologies can actually be used in which areas of intralogistics. In addition, the tool allows a brief but meaningful comparison between the different technologies on the market and the consequent associated costs.

As a result of this research an Excel-Tool was developed with the aim of helping SMEs to choose the right technology. The use of the model starts with the user guide, followed by the selection of the application areas for the CPS project by the user. After that, the tool shows a catalogue of suggested technologies which are suitable for that specific area and then the user decides on a technology.

The next step is the costing, the tool allows two ways. In both ways the key data of the project must be provided and then, the first way is entering data manually in case of having quotations or information from other sources. The second option is that the tool sends a quotation request to one supplier, then the supplier sends back an offer, the costs are taken automatically and entered on the tool. To complete the cost analysis, financing options can be chosen (Seiter, et al., 2019). The result then, is a graphical representation of the cost comparison (see Figure 7).

Projektname: Beispielprojekt 1	Mit CPS Technologie: SSI Schärer FTS 2 Pick	Ohne CPS	CPS-Kalkulation speichern
Auswertungen:			Andere CPS-Kalkulation laden
Nutzungsdauer (Jahr)	2,25	2,25	CPS-Kalkulation entfernen
Konzept & Designphase	97.076,72 €	60.240,6536 €	
Beschaffungs & Implementierungsphase	90.023,10 €	48.370,0289 €	
Betriebsphase	414.854,08 €	224.286,0578 €	
Summe Lebenszyklus	601.953,90 €	332.896,7403 €	
Delta Mit CPS und Ohne CPS	-269.057,1584 €		
Diskontierungszinssatz	0,04	Zinssatz ändern	

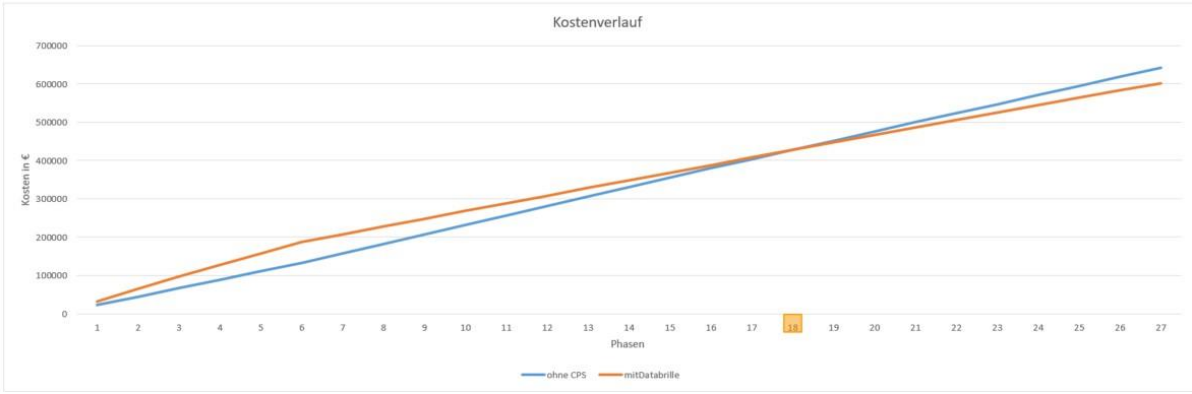


Figure 7: Graphical representation of the cost comparison (Seiter, et al., 2019)

### Technology selection for digital transformation: A mixed decision-making model of AHP and QFD

The proposed model covers technological issues and managerial pillars. It is based on a multi-criteria decision named Analytic Hierarchy Process (AHP) and a need analysis by means of a Quality Function Deployment (QFD) (see Figure 8). This model can be described in three steps. In the first one, a research in literature but also with experts' interviews is done to identify the pillars of the I4.0. These pillars are then ranked via AHP and the importance of each one is set via surveys. Lastly, the ranking with QFD is applied. In this ranking, the benefits, elements and challenges of these pillars are evaluated.

As a result, a Top 3 of each (Benefits, Tools and Challenges) is shown and that chart helps companies to decide regarding the tool to be used or applied in the company to introduce Industry 4.0 solutions into their businesses. (Erbay, et al., 2019)



## 5D ASSESSMENT CYCLE

The Five Dimension Assessment Cycle as stated on its own name, involves a method of analysis in five dimensions of the company and it is developed with focus on the needs and challenges of SMEs. This model takes into account the need of SMEs to focus on intangible benefits, so in its first step "benefits" the company's priorities are established.

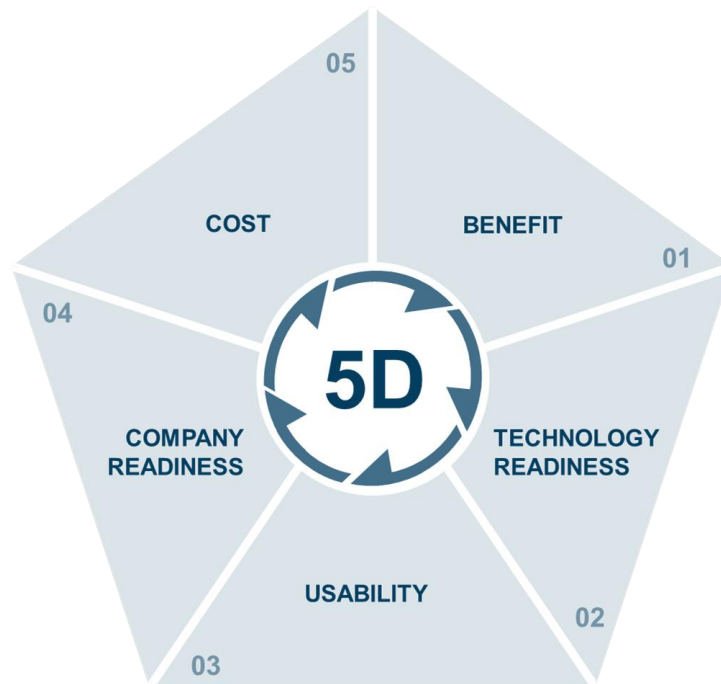


Figure 9: 5D ASSESSMENT CYCLE (Axmann, et al., 2021)

Then, in the second step "technology readiness", depending on the benefits sought, the maturity of the technologies that could be used is determined. In its web tool, within the technical assessment, it allows users to choose the importance of the maturity level of the software. Once the user chooses the level of importance, the suggested software is adapted to this requirement since the model is complemented with the Gartner Hype Cycle as a tool to help SMEs assess whether a new technology is already established and ready for adoption (Axmann, et al., 2021).

The next step is "usability" where the main criteria used are understandability, ease of learning, usability and attractiveness. And the results are evaluated according to the following logic: The better the comprehensibility of a new technology, the lower the cost impact. Where the result goes from 1 to 4, where level 1 would be the one that SMEs should avoid and level 4 would be the best for use in SMEs.



In the fourth step, an analysis of the company's readiness is carried out, in which the company's internal resources available for the introduction of the new technology are analyzed. In its web tool, the criteria are as follows: Restructuring of data for the introduction of the new software, Adaptability to company processes, Effort for qualification of personnel and Adaptability to other software.

Finally, the "cost" dimension is the last one, as a strategy for SMEs to give more importance to other aspects of technologies. For this section, the evaluation is made according to investment costs and running costs. Once the assessment is completed, the result shown is the software (digital solution) that adapts to the requirements and needs of the company (Axmann, et al., 2021).

### **A Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing**

This model was developed by using process measurement data of lean companies and expert opinions in order to assess the feasibility of the digital solutions for process improvement. It is important to mention that this model used the Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) during its process.

In this model, a list of problems and potential Industry 4.0 technology solutions is created by means of several Value stream mapping and technology audits. Then, a feasibility analysis of each technology is done with a scoring model which includes three dimensions: financial, organizational, and technological (see Figure 10).

The financial analysis includes a Net Present Value, Return of Investment and acquisition costs with different approaches including estimations. In the technological analysis, expert opinions were used. Once the scores are assigned, TOPSIS method helps to combine these scores and give the ideal solution as a result (Beyaz, et al., 2020).

<b>Significance level (1-10)</b>	<b>Technological feasibility</b>	<b>Technology scoring (1-10)</b>
	To be able to respond to the need	
	Increase in labor efficiency	
	Increase in energy efficiency	
	Control and maintenance cost	
	Impact on capacity utilization rate	
<b>Significance level (1-10)</b>	<b>Organizational feasibility</b>	<b>Technology scoring (1-10)</b>
	Impact on factory design and layout	
	Impact on production integration	
	Time needed for adaptation	
	To be able to be used in the long run	
	Impact on physical crowdedness	
<b>Significance level (1-10)</b>	<b>Financial feasibility</b>	<b>Technology scoring (1-10)</b>
	Acquisition cost	
	Orientation cost	
	Increase in labor efficiency	
	Increase in energy efficiency	
	Rate of return	
	Net present value	

*Figure 10: Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing (Beyaz, et al., 2020)*

## Digital Compass

This model was constructed based on client projects of the McKinsey company with the aim of helping companies to identify the best digital solution, allowing them to have the information that they need and to give a “direction” of which task should be prioritized.

The model combines experience, knowledge and insights gathered from its own benchmark database. In the model (see Figure 11), starting from the inner ring, a variety of areas of the company, followed by the second wing which shows the suggested technologies which should be applied on each case and finally a note where the user can actually see the benefit in percentage based on McKinsey’s customer projects (McKinsey, 2016)

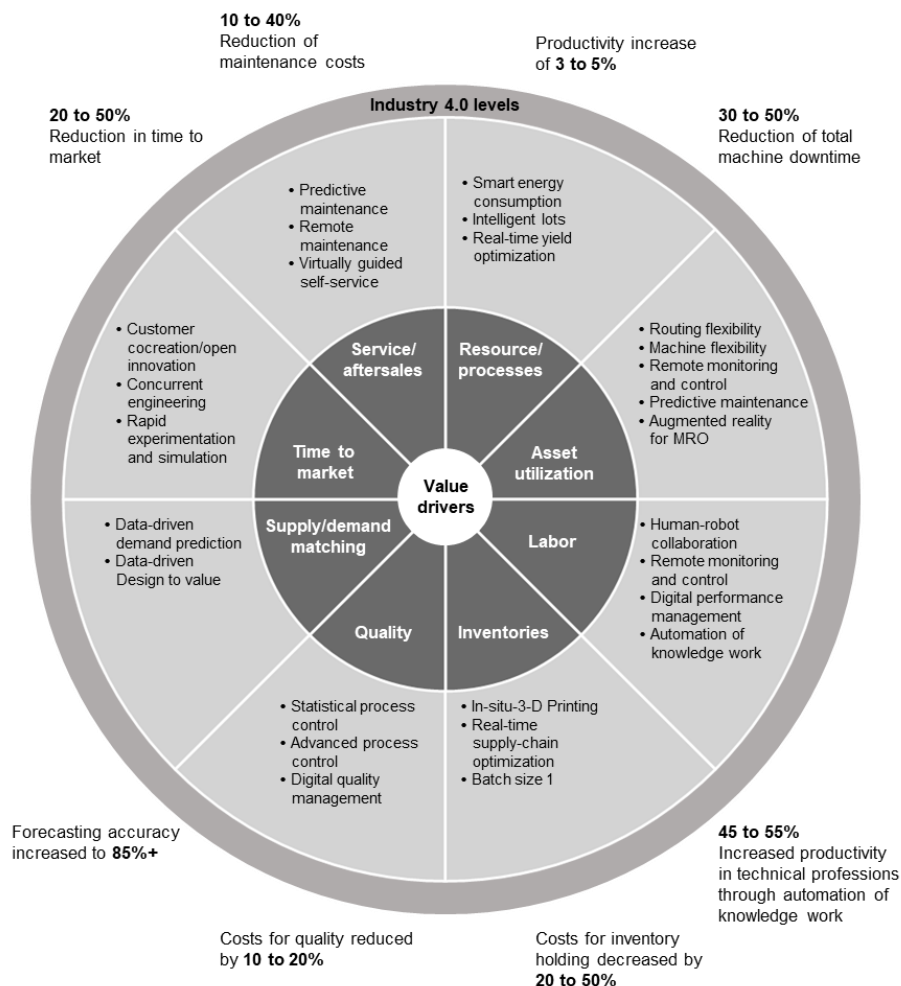


Figure 11: Digital Compass (McKinsey, 2016)

## Tech Radar 2020

The Tech Radar is a model focused on SMEs with the purpose of helping these companies to recognize available and trend technologies that could be applied in different areas of the company. It is mostly focused on the idea of helping SMEs know-how to make the right decision. As mentioned on the website “it is about providing a condensed overview of emerging technologies, pointing out concrete applications and ultimately inspiring and setting impulses for one's own innovation activities” (Mittelstand 4.0, 2018).

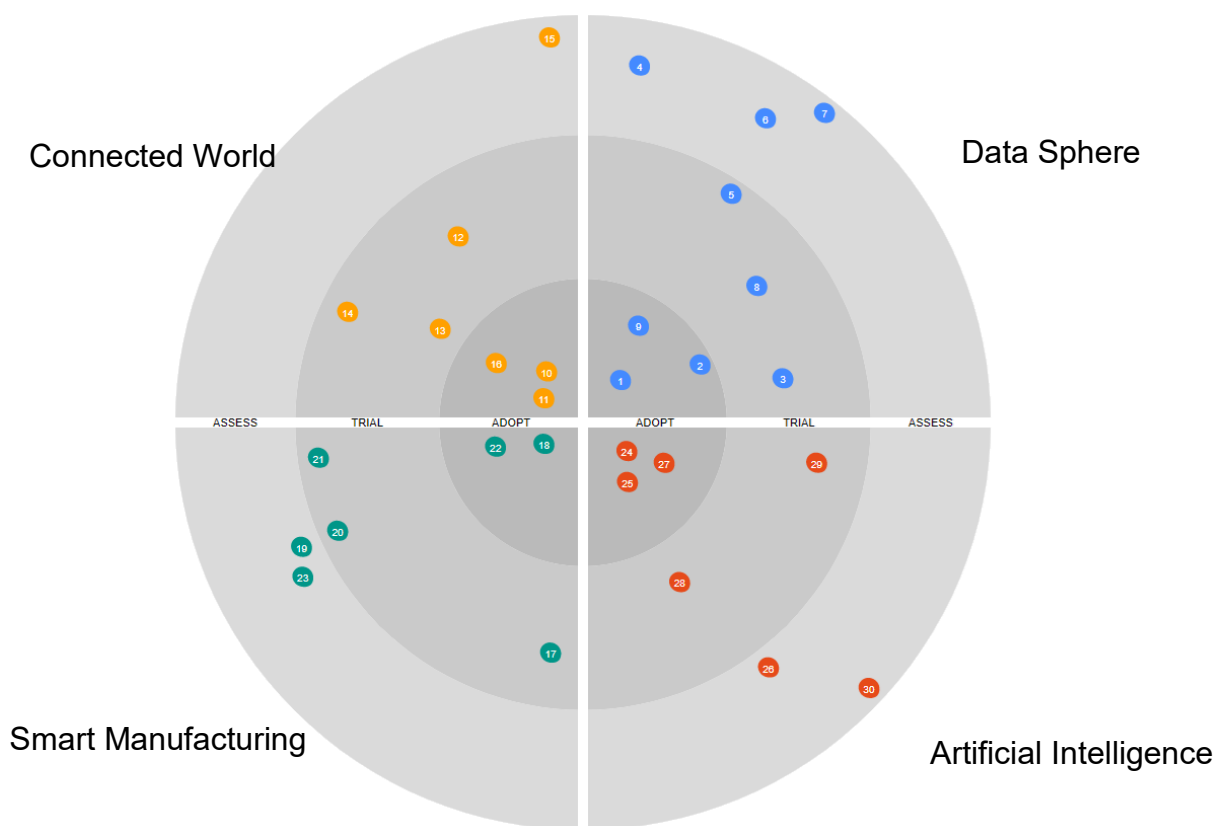


Figure 12: Tech Radar 2020 (Mittelstand 4.0, 2018)

This model provides an overview of the current technologies and the degree of maturity of each of them depending on the ring where they are placed. It is also divided in four quadrants (see Figure 12), which represent the technology areas: Data Sphere, Connected World, Smart Manufacturing and Artificial Intelligence.

## Capgemini "Trend Technologies"

Capgemini publishes each year an IT trend study with the aim of helping companies to see what technologies are more applied in the industry, the importance of each one, as well as the readiness level. The study also gives insights regarding the rising technologies in the year, as well as the technologies with declining trends. At the end of the yearly published document, the Trend radar (see Figure 13) is given as a summary together with a diagram that shows the percentage of participants using or currently implementing the respective technology. (Roth, et al., 2021)

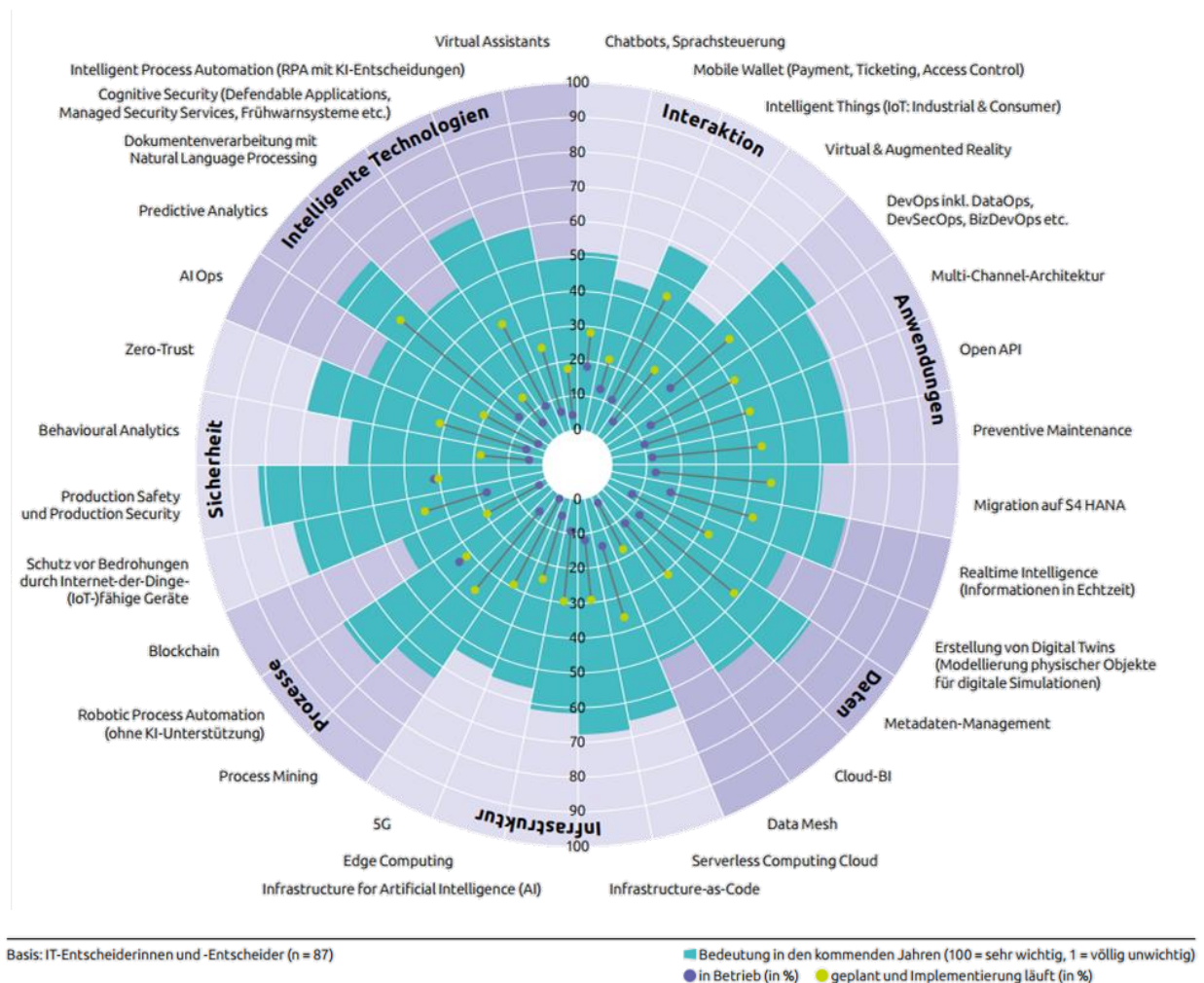


Figure 13: Capgemini "Trend Technologies" (Roth, et al., 2021)

## Gartner Hype Cycle

This model offers a graphic representation (see Figure 14) of the maturity level of technologies and applications, as well as the potential of each technology of helping to solve problems in the company. It helps companies to see emerging technologies but also mature technologies, then the decision should be made by the company.

The user can decide, for example, to go for an early adoption of the technology, the other option would be to wait until an analysis is done (moderate approach) or simply wait until the technology is completely in the maturity zone. So the main goal of this model is to reduce the risk of the company's technology investment decisions (Fenn, et al., 2018).

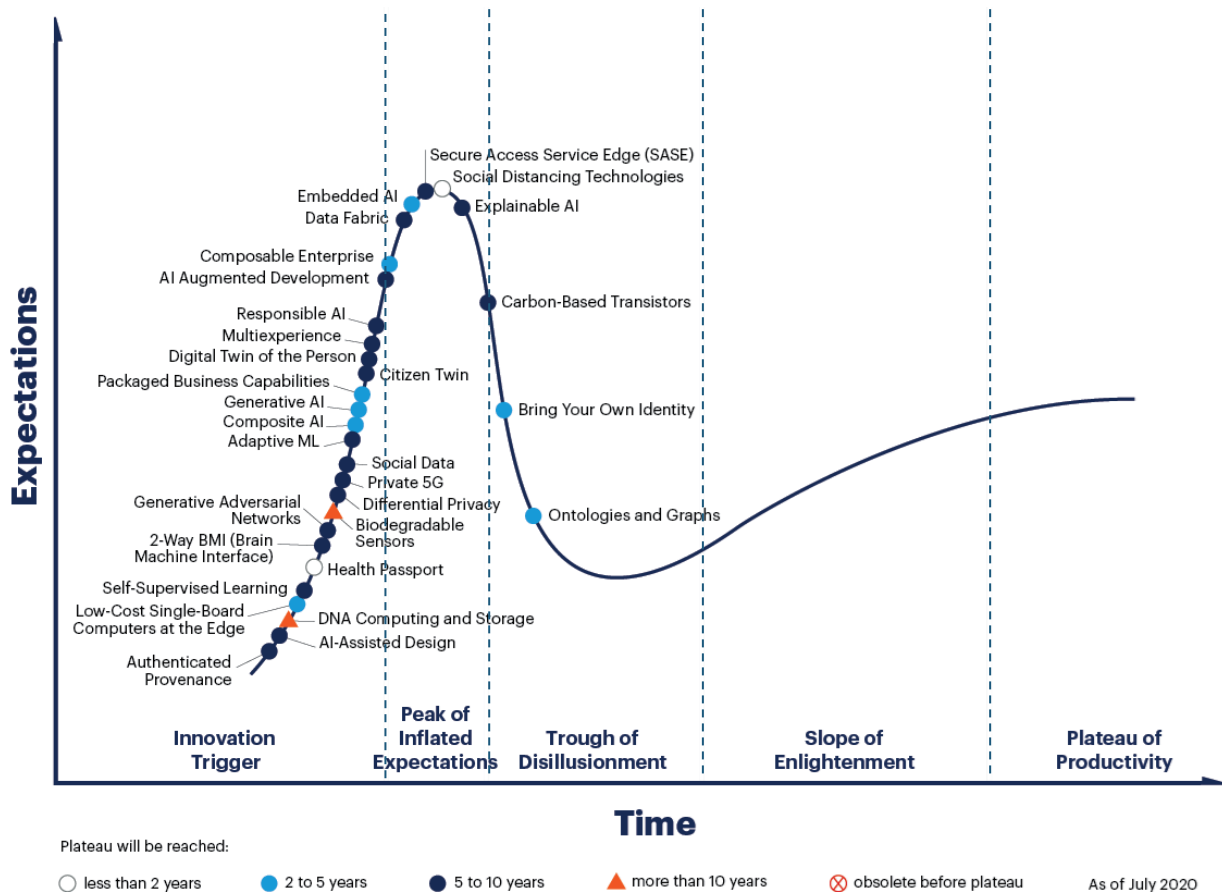


Figure 14: Gartner Hype Cycle (Fenn, et al., 2018)

## **4.2 Regarding Digital Technologies, when is an evaluation model efficient enough for SMEs?**

As shown in chapter 2, SMEs face a lot of challenges regarding the introduction of Industry 4.0. These challenges involve the availability of evaluation models which are suitable for their characteristics to be completely compatible with how a SME operates and thinks.

Deciding on an appropriate technology is currently a struggling decision that many SMEs are currently facing, due to the lack of standards and lack of understanding of the strategic importance of Industry 4.0 (Mirela Catalina, et al., 2019), this companies face the challenge of applying multi-dimensioned decision-making tools in order to evaluate their needs (Beyaz, et al., 2020). The lack of standards shows the importance to understand which characteristics are vital for a model to be well-known or used in the SMEs.

The first research iteration ended with a total of 15 articles of which only 9 were considered after the second iteration of the research. The number of resulted articles gives a hint on the novelty of the application or standardization of these models in the SMEs. For this reason, most of the information showed the needs of SMEs regarding the expected effects of the digital solutions in its processes as well as the success factors of the implementation of digital solutions.

### **4.2.1 Needs and characteristics of Models in SMEs**

In a critical review of maturity models for digitalization in SMEs, some key characteristics and needs are described as follows. SMEs depend on the availability of financial resources and are affected by financing difficulties (Abel-Koch, et al., 2019). This companies are usually owned by an individual and there are several risk factors in small businesses, so SMEs are financially challenged and fear an unfavorable cost-benefit ratio because they initially see the costs without having confidence in the economic outcome and are confronted by the matter where to start with a proper and useful solution (Hoellthaler, et al., 2018).

Financial resources usually form a barrier for the introduction of digital technologies for these companies, since it is one of the main resources needed for any change in

an organization. Therefore it is possible that many resources are not available, due to financial obstacles which leads them to not having the necessary budget for the implementation followed by lack of workforce, infrastructure and facilities (Alkhoraif, et al., 2019).

There is a strong need of SMEs to have access to shared knowledge. This access is part of collaboration strategies, which are completely important for a company to reach success. SMEs face a lack of alliances with institutions that support SMEs, innovation laboratories, universities and other research institutes so they are forced to only have access to their own results and experiences (Mittal, et al., 2018).

To carry out the digital transformation, it can be useful to consult with companies that have experience and expertise in this topic and obtain consulting services to provide personalized guidance on today's trends and, above all, to explain the importance and possible results by showing success stories in other companies (Ulas, 2019).

Another important characteristic is that in order to integrate new technologies into a company, specific skills and expertise are key in the success of an Industry 4.0 project and are therefore needed (Alkhoraif, et al., 2019; Moeuf, et al., 2020).

According to the European SME Survey, SMEs have larger skill and knowledge gaps than large companies and training efforts in SMEs are, on average, significantly weaker per employee than in large companies resulting in uncertainty regarding benefits and outcomes (Wiesner, et al., 2018).

Experts highlight that SMEs are lacking internal competency enabling the exploitation of Industry 4.0 technologies which is a common factor for these companies independently of the economic and cultural environment (Moeuf, et al., 2020; Matt, et al., 2020). Thus it is essential for SMEs to create an inventory of required abilities and skills and to detect gaps; in this way they can expand the skill sets and competencies of existing workers, and be able to outsource when investing in new technology (Ulas, 2019).

There is a strong need to recruit and retain highly skilled personnel with digital knowledge and expertise (Abel-Koch, et al., 2019; Matt, et al., 2020). As the need to have highly trained personnel conflicts also with the characteristic of not having such



a large budget for the project. Simplifying Industry 4.0 tools is proposed as a solution, so that their implementation will have a better promotion among SMEs.

The simplicity and accessibility of Industry 4.0 tools would favor the implementation of this concept (Moeuf, et al., 2020). A suitable model should not be too complicated to be understood, it should be able to explain digitalization and its related concepts, but above all, it should be able to clarify uncertainties rather than create new ones. This also includes ease of application (Wiesner, et al., 2018).

Other important fact is that SMEs need solutions that help them react appropriately to the requirements of today's changing and challenging markets as well as to have solutions that help a specific situation depending on the area to be improved with digital technology (Hoellthaler, et al., 2018; Vogelsang, et al., 2018).

SMEs expect from any tool flexibility, simplicity, and ease of understanding. In addition, as a result of the implementation of Industry 4.0 solutions they expect their processes and supply chain to be optimized, costs to be reduced, employee qualification to be increased and, most of all, their revenue and profit to rise (Ulas, 2019).

The European SME Survey also showed that one concern shared by SMEs regarding the implementation of digital solutions is IT security. (Abel-Koch, et al., 2019; Vogelsang, et al., 2018). They have the need to keep their assets and information safe, therefore Industry 4.0 brings many opportunities but also a significant requirement: data security (Matt, et al., 2020).

The tools used for the selection of digital technologies must have a high level of overall adaptability to the organizational structure of SMEs. As well as promoting support for an agile enterprise, permitting fast decision-making processes. But also, being a notorious change, it must take into consideration the inclusion of processes that facilitate the adaptation of the entire company and its areas to this new technology.

It should provide SMEs with information on how to reach a higher level of maturity in their specific field and continue in the right direction with their business strategy. It should provide them with the ability to position their business against external trends and give them a guideline for selecting the right technology (Wiesner, et al., 2018).

All of the above characteristics and needs, as a result of the literature research, are the general requirements of today's SMEs. The different authors describe these needs in different ways and with specific cases, but each of them provides a different perspective on their importance within the decision-making process of an SME.

In order to analyze these concepts in a more adequate and simpler way, a summary table was created to show which concepts are mentioned in each of the documents. As shown in Table 7, a total of 13 characteristics and needs were identified.

Needs / characteristics	Articles								
	(Mittal, et al., 2018)	(Alkhoraif, et al., 2019)	(Abel-Koch, et al., 2019)	(Vogelsang, et al., 2018)	(Moeuf, et al., 2020)	(Hoellthaler, et al., 2018)	(Ulas, 2019)	(Wiesner, et al., 2018)	(Matt, et al., 2020)
Simplicity				X	X			X	
Ease of understanding				X	X			X	
Adaptability to the company			X	X		X		X	
Flexibility				X		X			
Low cost	X	X	X		X	X			X
Quick response / result				X		X		X	
Cost-benefit ratio						X			
Few resources	X	X	X		X	X	X		X
Application in different areas				X		X			
Knowledge needed	X	X	X		X			X	X
Provided guidance								X	
Privacy and security			X	X			X		X
Alliances and collaboration	X								

Table 7: Needs and characteristics of SMEs (own table)

These needs and characteristics show only what SMEs expect from a model, and how a model can be adapted to the needs of the company. Therefore, the list must be translated into criteria. These criteria are then the answer to the research question: "When is an evaluation model efficient enough for SMEs?"

#### 4.2.2 Conversion of requirements to evaluation criteria

The above-mentioned characteristics and needs can be strategically grouped to optimize the evaluation criteria to be obtained. A company's need for simple solutions that are easy to understand and flexible, as well as its concern for the level of knowledge needed to implement them and the need for guidance in doing so are, in fact, characteristics and needs that are related to complexity. Therefore, the criterion obtained is the level of complexity of the model. The ability to adapt to the needs of the company and the application in its different departments or processes, can be grouped in the areas of application of the model.

When talking about the need for SMEs to invest the least amount of money and resources, like workforce, infrastructure, etc., possible and to obtain a balance between cost and benefit. As well as the need to form alliances or collaborations with other companies in order to reduce the resources invested, it speaks of the importance of resources in general for SMEs. Consequently, the next criterion is the resources needed for their use/application. The model should be resource efficient.

The response time or time to obtain results is one of the important characteristics. The need for SMEs is that they are obtained quickly, but at the same time that they are secure and do not affect the privacy of the company. These characteristics are directly related to the results expected from the use or application of the model.

Thus, from the 13 characteristics mentioned in the previous section, 4 important criteria were obtained for the evaluation of the models. The criteria are then shown in Table 8.

<b>Criteria</b>	<b>Needs / Characteristics</b>
Complexity	Simplicity
	Ease of understanding
	Flexibility
	Knowledge needed
	Provided guidance
Application Areas	Adaptability to the company
	Application in different areas
Resources needed	Low cost
	Alliances and collaboration
	Cost-benefit ratio

	Few resources
Expected results	Quick response / result
	Privacy and security

*Table 8: Translation from needs/characteristics into criteria (own table)*

Now that the first four criteria could be obtained by understanding the needs of SMEs and translating them into specific criteria to define how efficient a model of evaluation and selection of digital technologies in SMEs is, the next step is to focus on another perspective to have the whole context.

### **4.2.3 Criteria based on visual elements**

The most important question is: How or with which criteria SMEs decide on which model should be used? To complement the four criteria listed on Table 8, the decision-making process of SMEs will be used as basis. In the conditions of an environment with a high degree of uncertainty (as the external environment is generally perceived by SMEs), managers act in an inspired manner (Ogarcă, 2010).

A study performed with the purpose of identifying different types of entrepreneurial decision-makers with a total of 646 participants, showed that: “About three quarters of the entrepreneurs indicated they made their decision after consulting other persons” (Jong, et al., 2006). It would then mean that the influence of what other SMEs are using are very high, so the popularity of the model would become the next criterion for the purpose of this research.

Supporting the “popularity” of the model as part of the evaluation criteria, two important concepts need to be considered: Isomorphism and the Neo-Institutional theory. Both refer to the similarity of organizations in a field but also the perspective to understand organizational behavior influenced by other organizations (Lounsbury, et al., 2018).

From the management fashion perspective, there are some key criteria regarding the Name/Title and Design of the model which are very important in the decision-making, where the manager selects the model to be used or applied in the company.

The next criterion is then, Name/Title of the model. Regarding fashion potential, in a research about management concepts and ideas, several characteristics, which are considered success criteria, were identified as key factors that give a concept or model greater potential for popularity (Røvik, 2002).

One of the most important characteristics of a model to influence management decisions is the use of a “catchy label” as a name. Popular management ideas are typically labelled using an acronym, and usually this acronym can be then frequently used as a verb (e.g. SWOT – SWOTing) (Madsen, 2016).

Visual elements may be designed so that people can absorb information in the environment more easily and more quickly to change it into information in the head (Tezel, et al., 2009). That is why the design of the evaluation models form a very important part in influencing the decision making of a manager or an SME. Therefore, the last evaluation criterion for the models will be the design (attractiveness) of the models.

#### ***4.2.3.1 Testing the importance of visual criteria on the models***

With the purpose of evaluating the influence of the design, the popularity and the title/name of the models, an online survey was conducted as described in Chapter 3. The results of the survey will be described and analyzed below, and the complete results can be consulted in Appendix 1.

A total of 108 answers were received, 69.4% of the survey participants are currently working in a company qualified as an SME according to the European Commission, the rest are currently working in large companies and most of the participants have entry level experience.

The predominant industrial sector is the automotive sector, followed by the industrial products sector, the energy sector, financial services and the healthcare industry. As explained in section 3.2, four models were used in this survey and the SWOT analysis model was included as a test of the influence of popularity on participants' choice. In order to understand the effect of the visual characteristics, it is necessary to study the results of each model one by one.

As seen on Figure 15 and Figure 16, for the first model "Digital Compass", two important data could be observed. This model was the one rated as the most attractive and with a high rating in terms of the number of people who would use it. On the other hand, it had the highest rating for being complex and the lowest rating for effectiveness.

The “Technology selection for digital transformation: A mixed decision-making model of AHP and QFD” was the worst rated in terms of the number of people who would use it. It also obtained a low evaluation in terms of its attractiveness and was rated as complex but promising.

The “Selection and Prioritization Model for Industry 4.0” was the best evaluated in terms of effectiveness, received the most votes regarding its use and gave the impression of being the model with which results could be obtained most quickly.

The "5D Digital Technology Assessment Cycle" was rated as easy to understand and user-friendly, which made it attractive and effective in the eyes of the participants, even though the model is in the last places in terms of popularity.

The "SWOT Analysis" was the most popular model, but at the same time it obtained low evaluations in terms of attractiveness, effectiveness and the number of people who would use it for this simulation.

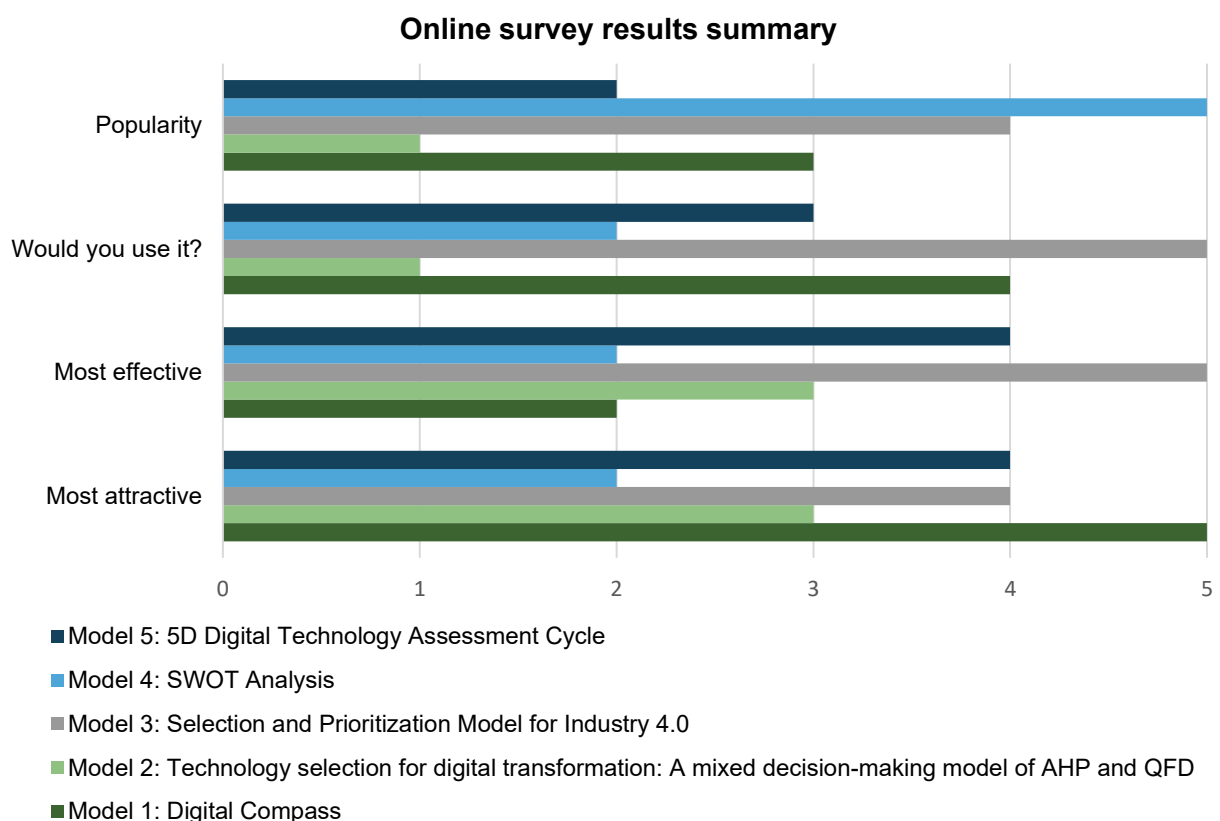
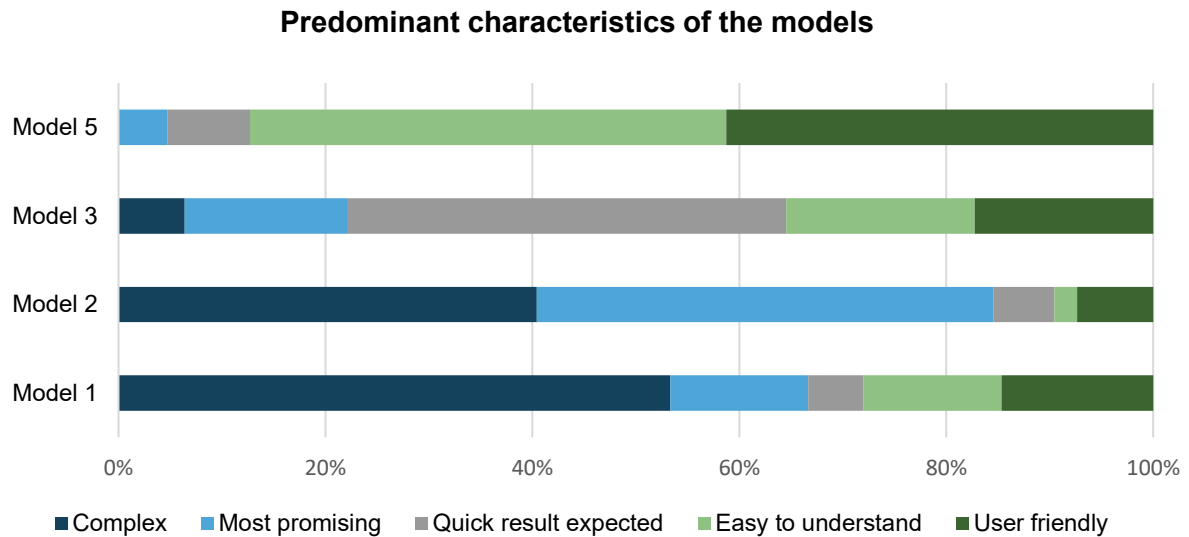


Figure 15: Online survey results summary (own figure)



*Figure 16: Predominant characteristics of the models (own figure)*

The results confirmed the importance and the influence of the visual-based criteria on the models. They also showed that there is a direct relationship between the attractiveness and the use of the models, where the higher the attractiveness, the more users prefer that model and vice versa. The design (attractiveness) of the model also influences the way the complexity of the model is evaluated.

In this specific case, the popularity criterion had a negative influence on the choice of the SWOT model for the solution of the proposed context. The SWOT model was the most familiar to the participants of the survey. It was precisely the popularity of the model that led users to decide that it was not the best model for choosing a digital technology, as the SWOT analysis is usually applied to assess an organizations' current position before deciding on any new strategy.

#### **4.2.3.2 Final Evaluation Criteria**

As result of the research on this section, the final criteria are: Title / Name, Design, Complexity, Popularity, Resources needed, Application areas and Expected results. The explanation of how the models will be evaluated on each criterion will be described in the following section.

### **4.3 Pairwise Comparison of existing models for the assessment and selection of Digital Technologies in SMEs**

To be able to determine which are the most important criteria in existing models for the assessment and selection of Digital Technologies in SMEs, the qualitative analysis tool of pairwise comparison can be used. The goal is to obtain information about which potential each model carries.

As a preparation step to apply the pairwise comparison, it is necessary to define the hierarchy of the evaluation criteria. In terms of existing models for the assessment and selection of Digital Technologies in SMEs, the following criteria occur:

- Title / Name
- Design
- Complexity
- Popularity
- Resources needed
- Application areas
- Expected results

To get a better understanding of what the given terms are referred to, a short explanation is given in the following line:

- "Title / Name" is the initial factor seen on a model, it has the power to attract the user and to give a first impression.
- The next criterion "Design" is closely linked to the first term "Title / Name" because it is as well a visual criterion. The Design can influence the way the user perceives the model in terms of its complexity or its effectiveness, that is why this criterion is so important.
- The third criterion is the "Complexity" of the model, in which the best scenery would be that the model is easy to understand and perform, either because the model is relatively simple and the call to action is clear, or the interaction pattern is familiar (Rohrer, et al., 2016).
- The next criterion is "Popularity" which was evaluated in terms of the number of search results, citations, etc., on search engines like: Google, Google Scholar and THI Online Library.



- “Resources needed” is a criterion focused on all the different resources in a company, financial, intellectual, human, and physical resources which are needed for the use or application of a model in the company.
- The next term, “Application areas”, refers to the ability of a model of being applied across different company processes or functions (e.g. production, logistics, etc.).
- The last criterion, “expected results”, is mostly about the clarity of the model regarding the results which can be obtained by applying the model in the company, either described or proven by application examples.

As second step, the matrix for the pairwise comparison is set up and filled. The ranking of the different criteria occurs as in the definition given in Table 4. As a reminder a short summary is given:

- **0** – The horizontal is **less** important than the vertical
- **1** – Horizontal and vertical are **just as** important
- **2** – The Horizontal is **more** important the vertical

Table 9 shows the matrix of the pairwise comparison to define the hierarchy of the evaluation criteria. It is clearly shown that, above all, the complexity of the models for the selection of Digital Technologies in SMEs is the most important criterion. During the research phase, this criterion was shown in all the articles as one of the biggest barriers for digitalization in SMEs.

The criteria Resources needed and Application areas received an equal rating. According to the literature, SMEs need to have tools and solutions that require minimal investment, not only in financial resources, but also in resources such as intellectual capital, infrastructure and collaborations. Therefore, the criterion “Resources needed” is assigned to the second place in the ranking. “Application areas” stays in third place. For SMEs, it is important that the model can be applied in any part of their processes, but also that this model can be adapted to the company.

The visual criteria come next with the same rating. Its position in the ranking was assigned according to the following logic. The results of the online survey showed that there is a direct relationship between the attractiveness and the use of the models, where the higher the attractiveness, the more users prefer that model and vice versa.

The design (attractiveness) of the model also influences the way the complexity of the model is evaluated.

The foregoing information supports the confirmation that the attractiveness of a model is a key factor in the SME's decision-making process when choosing a model. Considering that the main direct contact with the user is the name assigned to the model, the access to it should therefore start with a "catchy label" as mentioned in the fashion management concept, that is the reason why "Title/Name" owns the fourth position in the ranking followed by the "Design" of the model which takes the fifth place.

*"About three quarters of the entrepreneurs indicated they made their decision after consulting other persons"* (Jong, et al., 2006) then, popularity is the next decision factor in the ranking. The last criterion in the ranking is "Expected results", due to the novelty of the models for selection of digital technologies, there is very little freely available information on the results obtained through the use of the models. On the other hand, the expected results can be influenced by different factors, which do not depend on the selection model.

	Title / Name	Design	Complexity	Popularity	Resources needed	Application areas	Expected results	Sum of rating	%	Ranking
Title / Name		1	0	1	0	0	2	4	9.5%	<b>4</b>
Design	1		0	1	0	0	2	4	9.5%	<b>5</b>
Complexity	2	2		2	1	1	2	10	23.8%	<b>1</b>
Popularity	1	1	0		0	0	2	4	9.5%	<b>6</b>
Resources needed	2	2	1	2		0	2	9	21.4%	<b>2</b>
Application areas	2	2	1	2	2		0	9	21.4%	<b>3</b>
Expected results	0	0	0	0	0	2		2	4.8%	<b>7</b>
							<b>Total</b>	42	100%	

Table 9: Pairwise comparison - hierarchy of evaluation criteria (own table)

To be able to calculate the result and find the best option of models for the assessment and selection of digital technologies in SMEs, a ranking of the different models according to the criteria in Table 9 is needed. As a reminder, the models are:

- (A)** Selection and Prioritization Model for Industry 4.0-Use Cases in Logistics
- (B)** Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty
- (C)** Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics
- (D)** Technology selection for digital transformation: A mixed decision-making model of AHP and QFD
- (E)** 5D ASSESSMENT CYCLE
- (F)** A Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing
- (G)** Digital Compass
- (H)** Tech Radar 2020
- (I)** Capegmini "Trend Technologies"
- (J)** Gartner Hype Cycle

The score is numbered according to the following logic. The higher the scored number, the more positive impact the criterion has on the method which means that ten is the best score, and one is the worst. Using the results from Table 9 each score is multiplied with the rates of each criterion and the final result is then given by the sum of the single results of the different methods. To determine the best method the highest sum is the best result which is then decreasing to the least good option.

		Title / Name	Design	Complexity	Popularity	Resources needed	Application areas	Expected results	Sum
Rating in %		9.50%	9.50%	23.80%	9.50%	21.40%	21.40%	4.80%	
(A)	Score	1	10	10	3	9	8	3	7.49
	Result	0.095	0.95	2.38	0.285	1.926	1.712	0.144	
(B)	Score	1	1	3	3	4	8	2	3.85
	Result	0.095	0.095	0.714	0.285	0.856	1.712	0.096	
(C)	Score	1	10	10	4	10	7	10	7.92
	Result	0.095	0.95	2.38	0.38	2.14	1.498	0.48	
(D)	Score	1	2	5	4	5	8	5	4.88
	Result	0.095	0.19	1.19	0.38	1.07	1.712	0.24	
(E)	Score	10	10	10	1	10	10	8	9.04
	Result	0.95	0.95	2.38	0.095	2.14	2.14	0.384	
(F)	Score	1	1	2	2	3	8	8	3.59
	Result	0.095	0.095	0.476	0.19	0.642	1.712	0.384	
(G)	Score	10	10	10	6	1	10	1	7.25
	Result	0.95	0.95	2.38	0.57	0.214	2.14	0.048	
(H)	Score	10	10	10	7	1	10	1	7.35
	Result	0.95	0.95	2.38	0.665	0.214	2.14	0.048	
(I)	Score	5	9	8	10	1	10	1	6.59
	Result	0.475	0.855	1.904	0.95	0.214	2.14	0.048	
(J)	Score	10	10	8	10	1	10	1	7.16
	Result	0.95	0.95	1.904	0.95	0.214	2.14	0.048	

Table 10: Evaluation of models (own table)

An explanation of the evaluation of each model showed in Table 10 is provided below.

**(A)** The Selection and Prioritization Model for Industry 4.0-Use Cases in Logistics had a poor rating because its name is firstly, very long, secondly, there are no acronyms included and it is a very general name, which can be used for any other model, the name does not add value or uniqueness.

In design, it obtained the highest rating because it visually shows the concept of the model, which is a top-down approach but also the design of this model has a very interesting feature. It shows similarity to one of its base concepts, the funnel model, which is highly used for innovation issues, so it captures the user's attention quickly due to the popularity of the topic. The design of this model becomes familiar to users because of this concept.

As for the complexity of the model, it scored very high due to two important points, it is easy to understand and carry out because the process becomes familiar to the funnel model, so the steps become simpler to understand. The description of the indications and the steps to follow, as well as the exemplification of the tools to use along each phase of the process are really specific and it guides the user through the whole process.

It is important to emphasize that this connection with the funnel model does not influence the popularity of the model; only five results about this model were found in the search engines used and the original document was subsequently cited only two times, none of the articles besides the original one show the implementation of this model.

In terms of the resources needed for the use of this model, it is not defined in the description of the model, but throughout the process. It can be assumed that a multidisciplinary team is needed to evaluate the processes according to costs, effects on the processes, modeling simulations, etc. However, the authors emphasize the importance of reducing uncertainty. In the early stages of the concept, which are characterized by a high degree of uncertainty, qualitative methods are the most appropriate. As the model progresses and the information situation becomes more concrete, quantitative tools are also used (Kohl, et al., 2019), this is their strategy for minimizing the resources required.

A disadvantage of this model is that from its name it can be inferred that it is focused on the logistics area of a company, however, the method and its entire procedure could be used in any area of the company. The article actually takes logistics as a basis for the exemplification of the model, not as an exclusivity to the area.

In terms of results, the description of the model mentions that it enables companies to anticipate the effects of different digital solutions in logistics both in non-monetary and monetary terms. It also helps to increase the rationality of decisions with reference to digitalization and thus to use limited operational resources in a targeted way for potentially profitable digitalization projects, existing obstacles can be removed, the potential benefits of Industry 4.0 applications increases and the competitiveness as well (Kohl, et al., 2019). In the application example it was possible to achieve a filtering of 117 digital solutions, to only 3, which were prioritized for application in logistics centers. Therefore, the expected results can be inferred but are described only qualitatively.

**(B)** The model “Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty” has a long name and contains different concepts, which increases its complexity and generality since the term Multi-Criteria Evaluation is used repeatedly in different areas of study. The model lacks a special design, within its source article it is visually represented as a default diagram of the Microsoft Office suite.

The level of complexity of the model is high due to the fact that it requires the application of methods such as Fuzzy Set Theory, Monte Carlo Simulation in MATLAB, NPV calculations and Risk Ratio. Therefore, the required resources are also high in terms of knowledge, personnel and software licenses for its application.

The model description mentions that a software should be available to support the modeling of fuzzy set theory, as well as the random drawing of specific probability distributions. In terms of popularity, this model yielded 6 overall results and 20 articles citing this model. But none of the articles besides the original one shows the implementation of it.

As for the next criterion "areas of application", the model is specifically focused on the manufacturing systems of companies. Although it does not preclude its application in other areas, the model is completely focused on manufacturing areas in terms of the methods used and the guidance given to the user throughout the process, is also focused on manufacturing. However, the authors mention in each section that the methods used can be adapted to the needs and strategy of the company.

The expected results obtained a low evaluation because the model is tested in the laboratory of an institution, not in a company, and certain characteristics may influence the results in a different way when applied in the industry. On the other hand, the results of this model are evaluated in comparison with an objective value, which makes the choice of the digital solution more rational.

**(C)** Once again, the model "Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics" has a long name that contains several concepts. As for the visual representation of this model, there is not a specific one because the model is a software specially designed to facilitate its use. This software includes videos and application specifications. This directly influences its complexity, although the whole process as such is complex due to the number of processes and methods involved, it is completely user friendly and easy to understand since the software serves as a guide, it is only necessary to add the data. It facilitates the process so much that it even makes the request of quotations to third parties and upon receiving a response. The software automatically includes the costs of the project.

The resources required are low as there is no need for additional software since it is based on the Microsoft Excel platform. The processes are simplified and therefore, the necessary equipment (personnel) is not numerous. Even though this project has been presented since its inception in different platforms, the model as such has not been so popular, when searching for this model in different search engines only five results related to this model were found. None of them talk about its application, but only seek to describe the model.

A disadvantage of this model is that it is available only for use in intralogistics and the software is designed only for the calculation of the factors of these

areas, as well as specific digital solutions for this purpose in its initial morphological box. As the article describes, this model enables SMEs to evaluate investments in CPS technologies. This enables companies to make coordinated technology investments transparently.

The articles found show only non-real examples of its application, so it is difficult for the potential user to have a clear idea of the benefits of its use from a real case. However, the model is completely customized to the data of the company in which the new technology is to be implemented. By having the possibilities defined 100% from the beginning with the morphological box, the precision and accuracy of the results is quite high since no assumptions are made, but an evaluation is formed with real and specific data and this ensures a reliable result.

**(D)** This specific model, Technology selection for digital transformation: A mixed decision-making model of AHP and QFD, helped to demonstrate the influence of the design on the perception of potential users, where the design of this model directly influenced the perceived level of complexity, which was very high but also made it unattractive to users. The name of the model adds arguments to the perceived complexity, as there are other methods within the title in the form of an acronym, AHP and QFD, which could make it difficult to understand.

The level of complexity is neutral, because even though the design suggests complexity, the process is quite simple, consists of three steps and is subject to the perceptions of subject matter experts. This model allows to obtain a general result that is not specific to the case of the company's need but shows the prioritization of the benefits and challenges in terms of digitalization and also shows which tool or digital solution is recommended with reference to these challenges and benefits. This is a model that can be taken as a reference for general consultation or guidance, but not for a specific consultation that is tailored to the needs of the company. As for the popularity of this model, its search yielded eight related results and its main article was cited in six different papers.

Due to the general nature of this model, its area of application within any company is quite extensive, and the resources required for its application are low since it does not require a deep mathematical analysis but only prioritization



matrices. A group of experts is needed to carry out this model, which could be a barrier to its use for SMEs.

**(E)** The 5D ASSESMENT CYCLE has an attractive name and is composed of an acronym "5D: Five Dimensions", which makes it attractive for use and implementation as well as easy to remember for the user. Its design shows the five dimensions of which the model is composed and shows the flow of the assessment cycle. The model is presented on a web page, which serves as a tool for the practical execution of the general assessment, the technical assessment, and the result output.

The process of this model has a very low level of complexity because the tool guides the user through their evaluations with key questions that lead to the result that best suits their needs and expectations. The resources required to implement this model are very low, as it is designed for specific use in SMEs. However, being focused on measuring the readiness of the company and the digital technology to be deployed, leaves the assessment of costs as an additional activity that the SME can undertake.

Currently, due to the newness of this model (2021), the popularity is very low. Within the online survey it could be observed that the people who were familiar with this model are people who have had direct contact with the authors of this model. This model is the first one that emphasizes its application in all areas of the company such as: production, marketing, logistics and supply chain, distribution, human resources, quality, construction and design, finance, etc.

The model gives priority to the evaluation of the benefits, so that the result is directly focused on the needs of the SME. The result of this assessment not only gives the hint of which technology to apply, it also gives a recommended software which will match with the requirements, although currently this result is delimited to 33 software.

**(F)** The Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing is very complete because it takes into consideration three main factors of a company. By starting with an analysis of the current state of the company and linking the problems it faces with the possible digital technologies

that can attack that problem, the results obtained are specific to the company, and are really focused on its needs.

However, the use of a method such as TOPSIS, which is usually programmed in Python, makes it complicated and as preparation for the TOPSIS, the expertise of a group of workers is required, in order to collaborate for the qualification and evaluation of the different digital technologies, so this resource is the most important to carry out this method.

The design of this model consists of a series of evaluation and decision matrices that are directly linked to the TOPSIS-based method. Therefore, it is not attractive. Its name is general, where it includes words that are constantly used in other models. The model can be applied in any area of the company, although the title suggests its use in productive areas. The popularity of this model is the one with the lowest level, the search engines returned only four results, all of which referred to the same article in this model.

**(G)** The Digital Compass has a very catchy name, followed by a great design which is user-friendly. As explained in section 4.1, the model combines experience, knowledge and insights gathered from its own benchmark database. It shows the suggested technologies which should be applied on each case and finally a note where the user can actually see the benefit in percentage based on McKinsey's customer projects (McKinsey, 2016). For this reason, the model only serves as a reference when looking for possible digital solutions but is not linked to the specific characteristics of the company or its needs.

As its name suggests, it can be taken as a compass that can give direction to a company on which path to take in its journey towards digitalization. Even if only a guide, more steps are still needed to reach the choice of a suitable digital solution, so not being described within this model, the company needs to invest more additional resources for the use of another model that does give "customized" direction to the company. In search engines, this model was found in 594 results, which reflects the popularity of the model.

**(H)** A similar evaluation is given to the Tech Radar 2020. This model has a digital platform that allows interaction with the different digital technologies evaluated

in this model. This increases the attractiveness of the model and captures the attention of companies because the model reflects the trends of digital technologies in the industry, which also reflects the popularity it has, since search engines display around 33,900 results referring to this model.

- (I) The model included in the Capgemini "Trend Technologies" report has a name that, although short, is generally used. The model attempts to provide as much information as possible about the areas of use, the technologies in trend, but also their importance in the coming years, their percentage of operation or application in companies today and also their planned or ongoing implementation. So much information in a single diagram is difficult to show visually without increasing complexity. This model is quite popular, with about 478,000 results but once again, the model only serves as a reference and is not designed to fit the needs of the particular company, so more resources will have to be expended. The generality of the model provides a wide range of application areas.
  
- (J) The Gartner Hype Cycle is focused on providing insight into emerging digital technologies and their state of maturity. Thus, the main objective of this model is to reduce the risk of the company's technology investment decisions (Fenn, et al., 2018). Although the model is easy to understand, it does not explain in which areas the technologies shown can be applied, nor does it provide specific guidance for selection.

According to the score obtained during the evaluation of the models, the ranking of the models, where 1 is the best rated and 10 is the worst rated, would be as follows:

1. (E) 5D ASSESSMENT CYCLE
2. (C) Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics
3. (A) Selection and Prioritization Model for Industry 4.0-Use Cases in Logistics
4. (H) Tech Radar 2020
5. (G) Digital Compass
6. (J) Gartner Hype Cycle
7. (I) Capgemini "Trend Technologies"

8. (D) Technology selection for digital transformation: A mixed decision-making model of AHP and QFD
9. (B) Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty
- 10.(F) A Multi-criteria Decision-Making Model for Digital Transformation in Manufacturing

Nevertheless, two groups according to the type of model and differences between them could also be found through their evaluation and analysis. The first type of models is the one that serves as a reference, the study of digital technologies is done in a general way and results in the trends of these technologies and their level of maturity. On the other hand, the second type of models is the one that puts a particular focus on the company and its needs and through this, develops the model using information from the company, which provides a customized solution. This groups are the following:

- Models Type 1: G, H, I, J
- Models Type 2: A, B, C, D, E, F

As described in section 4.2.1. a model efficient enough for SMEs needs to meet its needs, which some of them are adaptability to the company and provided guidance (Wiesner, et al., 2018). The models grouped in Type 1 do not fulfill these needs. This is the main reason for its impact, both in terms of expected results and resources required.

As mentioned in the individual evaluation of each model, Tech Radar 2020, Digital Compass, Gartner Hype Cycle and Capgemini Trend Technologies serve as a digitalization guide for the industry in general, where current trends, emerging technologies and the maturity of such technologies are exposed in these models.

These models are intended to allow the company to choose to be selectively aggressive and move forward early with potentially beneficial innovations and let others learn the hard lessons of less impactful innovations, delaying adoption until the innovation is more mature (Fenn, et al., 2018). This is in fact a luxury that an SME cannot afford.

To better understand the difference, most Type 2 models integrate into their process the preselection or search for digital technologies that are potential solutions to their

needs, usually requiring the collaboration of experts to obtain these options in order to carry out the following steps of the models. So, the Type 1 models could be of great support for this step since in these models guide, it is possible to obtain information of which technology could be used in which area and what level of maturity this technology has. As is the case with the 5D ASSESSMENT CYCLE, which includes the Gartner Hype Cycle in its Technology Readiness assessment.

With the Pairwise comparison, it was possible to obtain the ranking of the existing models for the assessment and selection of digital technologies in SMEs. In which we can see that the model with the highest score was the 5D ASSESSMENT CYCLE followed by the Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics.

However, none of them reached the highest rating (10), therefore, it is important to know what problems or areas of opportunity or improvement these models have, in order to be truly efficient models for SMEs. For this reason, these two models will be analyzed in the following section through a SWOT analysis.

#### **4.4 Are the existing models for the assessment and selection of digital technologies efficient enough for SMEs?**

To define whether a model is sufficiently efficient for an SME, the SWOT tool was used, which was shared for both models. The blue factors are exclusive to the 5D ASSESSMENT CYCLE and the green factors are exclusive to the Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics model, the black factors are shared for both models (see Table 11).

It is evident that both models have a greater number of strengths, since they are the best evaluated existing models in the Pairwise Comparison in the previous section. Among their strengths it was found that both models are developed with a direct focus on SMEs. This led both models to make a detailed analysis of the characteristics of this type of companies, but above all, of their needs so that the model could be adapted to them so both models take into consideration the business strategy.

		Internal			
Positive	Strengths	<ul style="list-style-type: none"> <li>- Focus on SMEs</li> <li>- Available - Developed Tool (eye-catching)</li> <li>- Adaptability to the company on every category</li> <li>- Few resources needed</li> <li>- Cost-saving approaches</li> <li>- Guidance provided – low complexity level</li> <li>- User-friendly methods included in the model</li> <li>- Application areas</li> </ul>	Weaknesses	<ul style="list-style-type: none"> <li>- Delimited results</li> <li>- Robustness of the Tool</li> <li>- Cost guidance</li> <li>- IT Security</li> <li>- Software release</li> <li>- Focus on Logistics</li> <li>- Popularity</li> </ul>	Negative
	Opportunities	<ul style="list-style-type: none"> <li>- Novelty of the model</li> <li>- Success in area-specific solutions</li> <li>- Promotion of the model</li> </ul>	Threats	<ul style="list-style-type: none"> <li>- Obtaining false information from suppliers</li> <li>- Technical problems with the software</li> <li>- Development of new models</li> </ul>	
		External			

Table 11: SWOT Analysis of models (E) and (C) (own table)

Both models developed a user-friendly tool that involves as little effort as possible, as well as the investment of as few resources as possible (included expertise). In addition, the tool provides the necessary guidance to adequately complete the assessment and obtain the expected results.

The decision through the Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics model is focused mainly on the cost-analysis, but it also includes the matching of digital solutions to the company needs. On the other hand, the strengths by the 5D ASSESSMENT CYCLE are shown. This model includes an assessment that incorporate a broad analysis of both, the company and the technology, including methods such as: benefit analysis, usability check, cost-benefit analysis, company readiness and technology readiness.

Regarding the technology readiness, the inclusion of the Gartner Hype Cycle tool helps the user to make appropriate decisions with the recommendation of established technologies ready to be adopted (Axmann, et al., 2021). The use of this model can be seen as a strategy, since instead of evaluating technologies with the support of

experts in the field and spending resources, a model is used that has already done the previous and necessary research to be able to reliably show the state of maturity of current digital technologies.

From the Pairwise Comparison results, the most penalized factor for both models was popularity, which suggests a weakness, as stated in section 4.2.3, “About three quarters of the entrepreneurs indicated they made their decision after consulting other persons” (Jong, et al., 2006). Promotion of the model should be an important factor; the more SMEs try it out and share their experiences, the more companies would want to use it as a tool on their way to digitalization.

As shown in the literature research, few results were found, which showed the novelty of the subject in terms of models for the evaluation of digital technologies for SMEs, this is a great opportunity for these models because they have the ability to improve as new models emerge, having a competitive advantage against the threat of the emergence of new models in the future.

Speaking of this improvement opportunity, it could also decrease the weaknesses of the models if the authors perform a constant increase and update in software solutions presented by the 5D ASSESSMENT CYCLE. And in turn, for the case of the Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics model, the authors could extend the focus of intralogistics to different areas of the company.

In the technical part of the models, important weaknesses and threats were found. In the case of the Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics model, the model itself offers the option to automatically send a request for quotation to suppliers, and upon their response, the collection of data for use in cost analysis. Sharing information and having that direct link with suppliers can be a threat to the security of the company's data (Matt, et al., 2020). For the developed software to enter the data automatically, the supplier must always send the quotation in the same format required for the macro to work. There is a risk that the supplier sends the quotation in a different format or does not want to share all the requested information and that would directly influence the result.

In the case of the 5D ASSESMENT CYCLE, the general assessment allows the entry of free-format answers. The problem is that, for example, the size based on annual revenue could be answered with SME as well as with a specific number of euros. The openness in these types of questions gives a sense of informality to the model. Even though it is mandatory to answer each of the requested questions, the model is not protected against answers that do not provide what the question is really looking for. This weakness is not present in the technical assessment, where the answers are completely limited and designed to provide the software that best suits the needs and characteristics of the company.

The strengths, weaknesses, opportunities and threats found in the models with the highest scores in the pairwise comparison, show that there is a great compatibility for SMEs. However, there are still some issues and opportunity areas in which the models must work and optimize to be able to say that they are completely efficient for SMEs.



## Chapter 5 Conclusion

SMEs are undoubtedly a fundamental part of the economy. However, models that help in decision making for digitalization have not paid attention to this group of companies. The research and analysis carried out with respect to the evaluation and selection models of digital technologies in SMEs showed the great importance of these models for this group of companies due to their development potential. However, very few models designed specifically for SMEs have emerged.

The overall results indicate that there are two models with a strong compatibility for SMEs. However, there are still issues and opportunity areas in which the models must work and optimize to be able to say that they are efficient enough for SMEs. To do so, needs and characteristics of SMEs must be considered for a future model.

As digitalization is the key to the competitiveness and success of SMEs, it is necessary to provide the necessary tools or model so that they can correctly choose the digital technology that best suits their needs and requirements. Therefore, this research aimed to identify the available models for the evaluation and selection of digital technologies in SMEs and to evaluate them to define if these models are suitable and efficient enough for SMEs.

This research has presented a comprehensive review of the literature on the needs and characteristics of these companies. These factors were analyzed and categorized. The results indicated that the basic criteria that a model must meet to be compatible and efficient for SMEs are as follows: Title / Name, Design, Complexity, Popularity, Resources needed, Application areas and Expected results.

These criteria were evaluated as the first part of a pairwise comparison to define their level of importance. This was the bridge that led to the next part of the process, which was the evaluation of the ten models according to these criteria to define the level of efficiency they have with SMEs.

The results of the pairwise comparison showed that the 5D Assessment Cycle and the Life Cycle Costing and Performance Quantification of Cyber-physical Systems in Intralogistics Model were the nearest appropriate models for the assessment and selection of digital technologies in SMEs because they both have a direct focus on SMEs, they created a user-friendly tool as part of their method, which provides

simplicity and guidance throughout the process. However, none of them achieved the highest rating or compatibility, therefore a SWOT analysis of these two models was carried out.

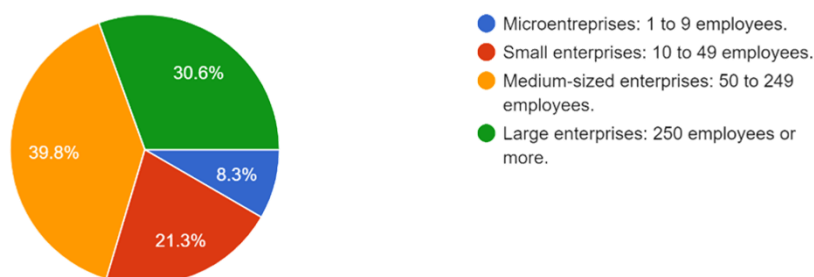
This analysis showed that both models have weaknesses in terms of robustness and the limitations on the results. As well as opportunity areas due to the novelty of the topic of these models, such as the opportunity to take advantage of the stage of development in which the models are in order to strengthen their tools and above all, to make them well-known within the industry.

# Appendix

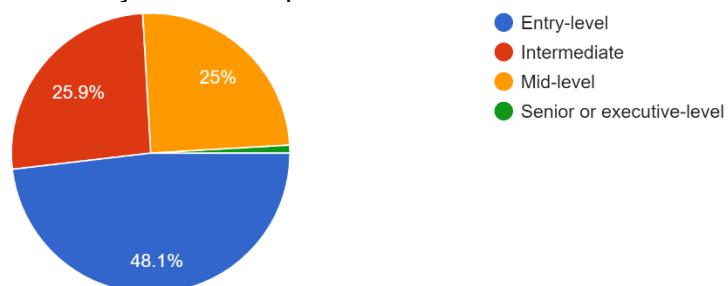
## Appendix 1: Online Survey results

### Section 1

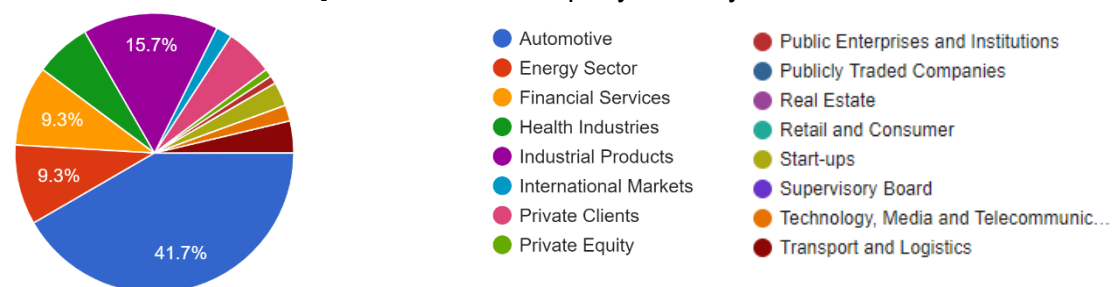
Please select the size of the company where you are working right now



Which is your work experience level?



Please select the industry sector of the company where you work



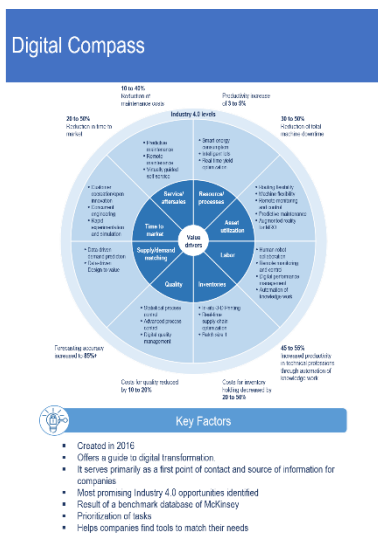
## Section 2: Context description

You work in a SMALL COMPANY and are assigned as a project manager for the introduction of a new digital technology to optimize the production area.

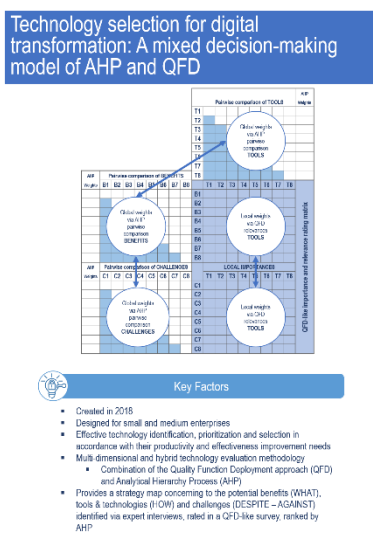
As you are a fan of digital technologies, you know that there are many models that can help you in the process of selecting the appropriate digital technology.

You have made great research on all the models that exist nowadays, and you have chosen 3 that are more aligned with the needs of your company.

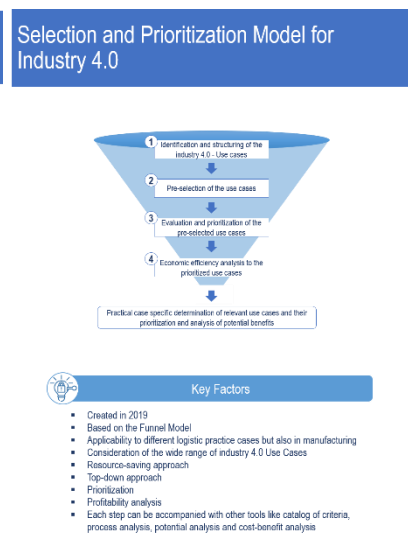
Model 1



Model 2



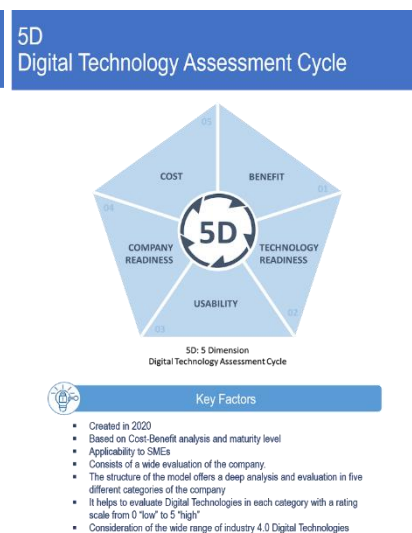
Model 3



Model 4



Model 5



After observing each model and knowing its key factors, please answer the following questions: (Please consider the context)

Which model are you most attracted to?



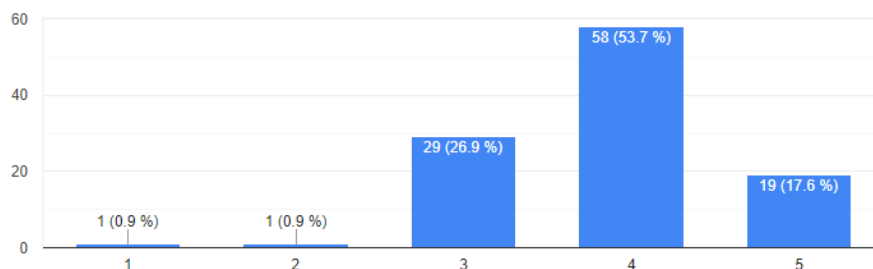
Which model do you think will give you the optimal result?



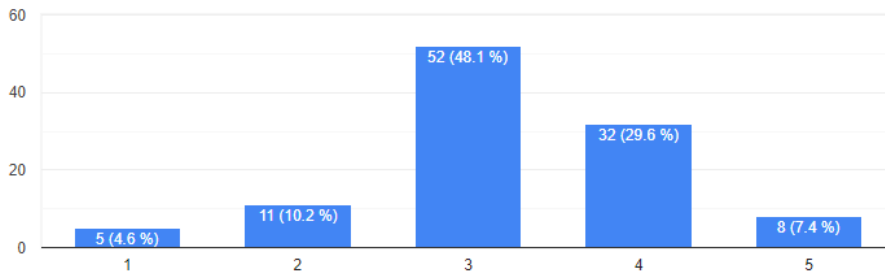
Would you agree to use this model to choose the new digital technology in your company?



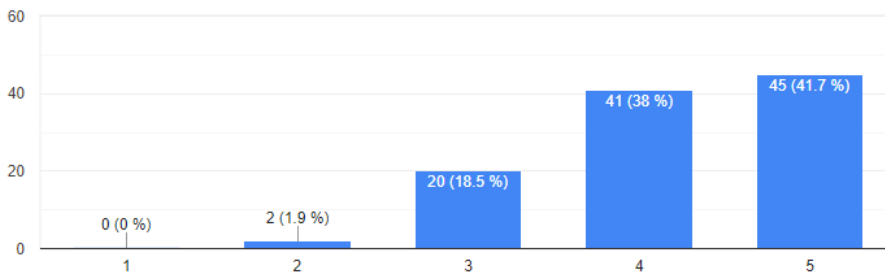
### 1. Model 1: Digital Compass



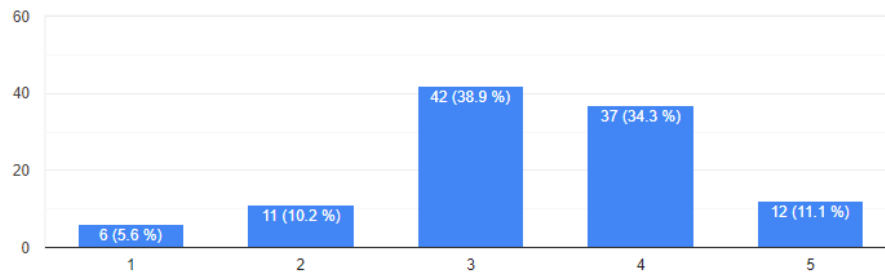
2. Model 2: Technology selection for digital transformation: A mixed decision-making model of AHP and QFD



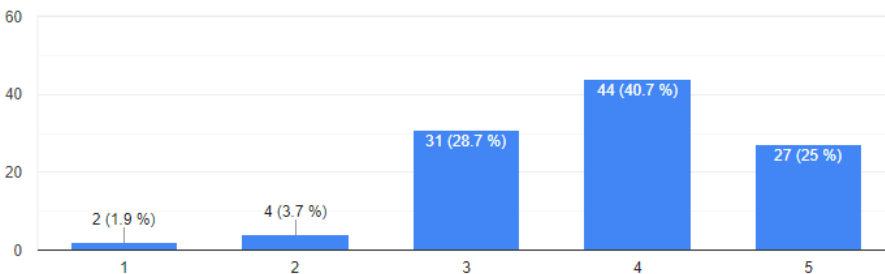
3. Model 3: Selection and Prioritization Model for Industry 4.0



4. Model 4: SWOT Analysis

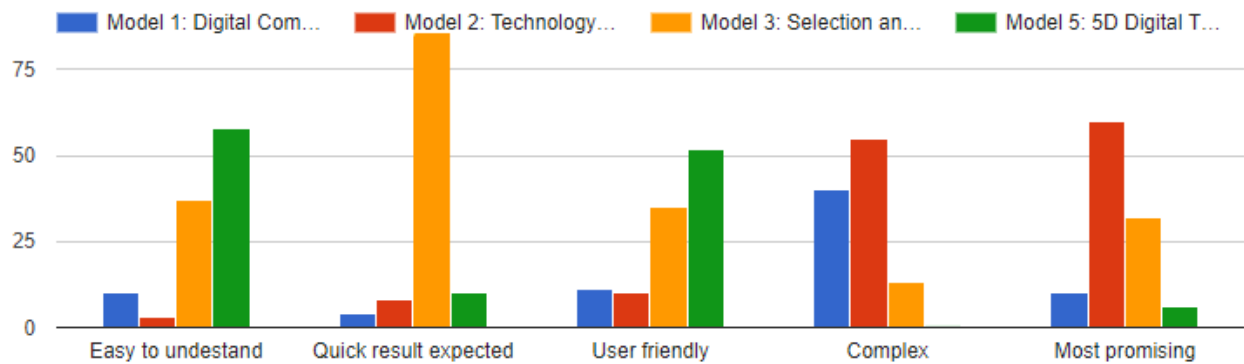


5. Model 5: 5D Digital Technology Assessment Cycle

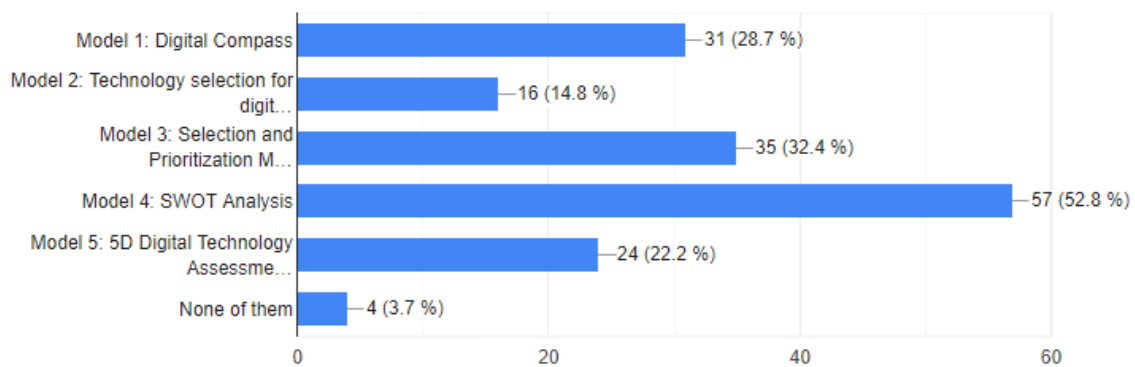


Please select the model that is closest to each characteristic

	Model 1: Digital Compass	Model 2: Technology selection for digital transformation: A mixed decision-making model of AHP and QFD	Model 3: Selection and Prioritization Model for Industry 4.0	Model 5: 5D Digital Technology Assessment Cycle
Easy to understand	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quick result expected	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
User friendly	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Complex	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Most promising	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



Which model have you used or seen before?



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