ATILIM UNIVERSITY

GRADUATE SCHOOL OF SOCIAL SCIENCES

DEPARTMENT OF BUSINESS ADMINISTRATION

BUSINESS ADMINISTRATION MASTER'S PROGRAMME

A CONCEPTUAL ROADMAP FOR THE FOURTH INDUSTRIAL REVOLUTION (INDUSTRY 4.0) FOR SMALL AND MEDIUM-SIZED ENTERPRISES (SMES)

Master's Thesis

Ahmed Abdullatif Summak

Ankara - 2020

GCPS

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Ankara - 2020

ACCEPTENCE AND APPROVAL

This is to certify that this thesis titled "A Conceptual Roadmap for The Fourth Industrial Revolution (Industry 4.0) for Small and Medium-Sized Enterprises (SMEs)" and prepared by Ahmed Abdullatif Summak meets with the committee's approval unanimously as Master's Thesis in the field of School of Business Administration following the successful defense of the thesis conducted in 20/01/2020.

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ETHICS DECLARATION

I hereby declare that;

- I prepared this thesis in accordance with Atılım University Graduate School of Social Sciences Thesis Writing Directive,
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ÖZ

SUMMAK, Ahmed Abdullatif. Küçük ve Orta Boyutlu İşletmeler (KOBİ) için Dördüncü Endüstri Devrimi (Endüstri 4.0) için Kavramsal Yol, Yüksek Lisans Tezi, Ankara, 2020.

Bu çalışmanın amacı, Endüstri 4.0'ın mevcut olgunluk modellerini gözden geçirmektir, ve Küçük ve Orta Ölçekli İşletmelerin (KOBİ'ler) ihtiyaca uygunluklarını doğrulamak, ve daha sonra KOBİ'ler için Endüstri 4.0'ın uygulanması için kavramsal bir yol haritası önermekteyiz.

Bunu başarmak için, çalışma KOBİ'lerin özelliklerini ve Akıllı Üretimin (SM) doğru bir şekilde benimsenmesi için kapsanması gereken boşlukları göstermiştir.

Çalışmanın sonuçları olarak, KOBİ'ler için sadece birkaç çalışmanın uygun olduğu tespit edilmiştir.

Bu çalışmanın temel bulguları şunlardır:

- Her bir KOBİ için kaynaklarına ve durumuna göre benzersiz bir plan sunulmalıdır. Bu plan öz değerlendirme sonuçlarıyla bağlantılı olmalıdır.
- Gerçek durum vade düzeyinde tanımlanmalıdır, ve KOBİ'lerin çoğunda kaynak eksikliği nedeniyle, dolayısıyla (Level 0) bu yol haritasında verilmiştir. Ve bu seviyeden geçiş en zor aşama olacak.
- KOBİ'ler için öz değerlendirme araçlarının önemini bulduk, ve bu araçların anlaşılması kolay olmalı, böylece şirket durumunu periyodik olarak kontrol edebilir.

Bu çalışma, KOBİ'lerin amaçlarına ulaşmak için gerekli yol haritası ve stratejileri ile Endüstri 4.0'ın en uygun modelini geliştirmelerine yardımcı olduğundan, kültürdeki değişimi destekleyecektir.

Anahtar Kelimeler: Endüstri 4.0, Akıllı Üretim, Yol Haritası, Endüstriyel Nesnelerin İnterneti, Küçük ve Orta Ölçekli İşletmeler (KOBİ), Akıllı Fabrika.

ABSTRACT

SUMMAK, Ahmed Abdullatif. A Conceptual Roadmap for The Fourth Industrial Revolution (Industry 4.0) for Small and Medium-Sized Enterprises (SMEs), Master's Thesis, Ankara, 2020.

The aim of this study is to review existing maturity models of Industry 4.0, verify their suitability to the needs of Small and Medium-sized Enterprises (SMEs), and then propose a conceptual roadmap for implementation of Industry 4.0 for SMEs. To achieve that the study showed features of SMEs and determined gaps that need to be covered for the correct adoption of Smart Manufacturing (SM). As results of the study, it was discovered that only a few studies were appropriate for SMEs.

Key findings of this study include:

- A unique plan should be provided for each SME, based on its resources, and status. This plan should be connected with self-assessment results.
- The actual status should be defined in the maturity level, and because of lack in resources in most of SMEs, so the (Level 0) has been provided in this roadmap. And the transition from this level will be the hardest stage.
- We found the importance of the self-assessment tools for SMEs, and these tools should be easy to understand, so the company can check its status periodically.

This study helps SMEs to develop the most appropriate model of Industry 4.0 with required roadmap and strategies to achieve their goals, so it will support changing in culture.

Keywords: Industry 4.0, Smart Manufacturing, Roadmap, Industrial Internet of Things, Small and Medium sized Enterprises (SME), Smart Factory.

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Last but not the least, I owe sincerest thanks to my wife for her unflinching support and extended patience during the long and tedious years of my work. I dedicate this thesis to my Dad, Mom, wife, and daughter.

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LIST OF ACRONYMS

AMM: Adoption Maturity Model

AMTS: Advanced Manufacturing Technologies

ANP: Analytic Network Process

CVH: Campus Velbert/Heiligenhaus

ERP: Enterprise Resource Planning

HMI: Human Machine Interface

HR: Human Resources

ICT: Information and Communication Technology

IIOT: Industrial Internet of Things

IT: Information Technology

IOT: Internet of Things

ISA: International Automation Specifications

M2M: Machine-To-Machine

MCDM: Multi-Criteria Decision Making

MES: Manufacturing Execution Systems

MNES: Multinational Enterprise

MPS: Master Plan Schedule

OT: Operational Technology

PLC: Programmable Logic Controller

RFID: Radio frequency identification

SM: Smart Manufacturing

SME: Small and medium sized enterprises

SMSRA: Smart Manufacturing System Readiness Assessment

SPICE: Software Process Improvement and Capability Determination

CHAPTER 1

INTRODUCTION

Companies have to adapt to new changes in the market to stay competitive and the main direction of innovation focuses on Industry 4.0. According to (Schiersch, 2009), SMEs are backbones of many countries, and their impact on industry 4.0 is important. Challenges and barriers of large companies are different from SMEs.

In this study:

- Requirements of SMEs will be defined.
- A comprehensive review for currently maturity models of Industry 4.0.
- Check the fitting of these models with SMEs requirements.
- Define the research gaps of these models.
- Suggest a conceptual roadmap for implementation of Industry 4.0 for SMEs.

1.1.Industry 4.0 History

Industry 4.0 is the Fourth Industrial Revolution which focuses on data sharing and analysing, internet of things, and digitalization. It depends on the Third Industrial Revolution developments. Through its networks are responsible to achieve the "cyber-physical production systems" which inside its people , machines, and components are communicating. The key benefits of Industry 4.0 are increase the flexibility and productivity by using the automation, using the IOT in manufacturing, and increase the quality of products.

1.1.SMEs Requirements

The SMEs are defined according to the European Commission (EC, 2003).

Table 1.1. The Definition of SMEs According to European Commission, EC (2003)

Company type	The capital cycles (maximum)	Balance sheet (maximum)	Number of employees
Small	≤ € 10 million	≤ € 10 million	< 50
Medium	≤ € 50 million	≤ € 43 million	< 250

Wuest and Thoben, (2011) discussed the SMEs and the need of information management on them. Kennedy and Hyland, (2003) analysed 632 of SMEs and the result was that these companies are not interested in Advanced Manufacturing Technologies (AMTs). Dyerson et al., (2016) made a study for 117 small sized enterprises in United Kingdom, then collected them in groups according to their preparedness for IT. Terziovski, (2010) found out after studying 600 Australian SMEs, that these companies lack a culture of innovation. Vasudevan and Chawan, (2014) concluded his study about importance of knowledge management after numerous interviews with manufacturing consultants, CEOs, managers in Indian SMEs, that by attending global conferences, workshops and interaction between academia and industry are core activities that promote knowledge creation. Kumar et al., (2014) found out after completing a comparison study between SMEs in United Kingdom and Australia in quality management, that ISO 9000 certification, networking with academic and government institutions, as well as leadership are the success factors for SMEs. Müller and Voigt, (2017) made 68 interviews with experts (41 with CEOs) to required strategies in German SMEs. They concluded their study that the belief in digitization, personnel resources, standardization, and economical systems are unique restrictions for SMEs.

The similar SMEs requirements grouped in (cooperation, employees, economic systems, technological systems, specifications, and organizational culture).

Technological Systems are the most important features in Industry 4.0 and SM. Dangayach and Deshmukh, (2005) concluded that the quality, and Human Resources (HR) policies can be improved by adoption of AMTs. However, if the company is economically constrained, it means that access to technological systems is difficult. SMEs has lack in Information Technology (IT) integration and research and development comparing with MNEs.

Lee et al., (2010) showed that the survival of SMEs difficult compared to MNEs because of lack of awareness and resources.

Economic Systems are another important feature in any business. But most of SMEs are related to individual. In general, SMEs can be considered as economically constrained.

The organization behaviour and organizational structure have a critical impact on implementation and experimentation of new technologies, according to Van et al., (2009) study SMEs cannot invest in market researches and analysis like MNEs.

The opportunities and experiences of employees are different between SMEs and MNEs, Dombrowski et al., (2010) found that in SMEs employees can be less likely for development and increase their expertise in specific area because of daily work in multi areas. Conversely, with more expert in specific area and specialized for MNEs employees`. McAdam and Reid, (2001) concluded in his study SMEs employees can be more likely to lack in training and monitoring of experts.

Cooperation strategies are important for companies to increase their knowledge and experience in SMEs and because of the lack of alliances with research centers and universities, their experiences can be limited and focus in a specific area the opposite of MNEs. SMEs can have difficulty in interdisciplinary networking opportunities (national / international). So, they cannot update themselves and have alliances with research centers and universities.

Singh et al., (2007) found that due to the different size of cooperative networks in SMEs and MNEs, reliance on a limited number of suppliers / vendors in SMEs is increasing.

Trott, (2001) found that decisions of SMEs often come from manager or decision maker, but in MNEs decisions are made after studying and analysing the market and discussions in the Board of Investors and Advisors.

Singh et al., (2007) found that due to the different size of cooperative networks in SMEs and MNEs, reliance on a limited number of suppliers / vendors in SMEs is increasing.

Table 1.2 shows a general comparison between SMEs and Multinational Enterprise (MNEs). There may be cases where SMEs are more advanced like defense companies. However, the results of the study (Wuest et al., 2018) support our generalization. The comparison based on (Wuest and Thoben, 2011), (Dyerson et al., 2016), (Kennedy and Hyland, 2003), (Terziovski, 2010), (Kumar et al., 2014), (Vasudevan and Chawan, 2014), (Müller and Voigt, 2017).

Table 1.2. Comparison of SMEs and MNEs, (Wuest and Thoben, 2011), (Dyerson et al., 2016), (Kennedy and Hyland, 2003), (Terziovski, 2010), (Kumar et al., 2014), (Vasudevan and Chawan, 2014), (Müller and Voigt, 2017)

#	Features	SMEs	MNEs
1	Research	Weak	Strong
2	The using of Advanced Manufacturing Technologies (AMTs)	Weak	Strong
3	Leadership / Culture	Weak	Strong
4	Strategies	Based on business holder	Based on analysis
5	Economic Systems	Weak	Strong
6	Software	Weak	Strong
7	Employees improvement	Strong inside Industry / Weak outside Industry	Weak inside Industry / Strong outside Industry
8	Alliances	Weak	Strong
9	Experience	Specific	Wide
10	Participation	Wide	Specific
11	Important Activities	Outsourced	Internal
12	Outside connections	Strong	Weak
13	Specification consideration	Weak	Strong
14	Cooperation	Strong	Weak

Table 1.3. Small and Medium-Sized Enterprises Features

#	Features	SMEs Perspective on Features	Cluster
1	The Manufacturing Technologies (AMTs) using	Requested	Technological Systems
2	Research		
3	Software		
4	Economic Systems	Requested	Economic Systems
5	Strategies	Requested	Organizational Culture
6	Leadership / Culture		
7	Experience	Requested	Employees
8	Employees improvement		
9	Participation		
10	Specifications consideration	Requested	Specifications
11	Important Activities	Requested	Cooperation
12	Outside connections		
13	Cooperation		
14	Alliances		

1.2.Industry 4.0 in SMEs

The complexity is natural in modern manufacturing (Esmaeilian et al., 2016).

This study shows many of different studies which focused on how to deal with SMEs and this complexity.

Nieuwenhuize, (2016) made his study to identify strategies towards to shift to SM, after studied six different SMEs in Netherland from different sectors: (a) profile and tube cutting, (b) copper separation, (c) machine packaging, (d) sheet metal production, (e) steel processing, and (f) rail-road manufacturing. For that he classified SMEs to three sections: (1) dormant, (2) captives and (3) adopters, according to their level of adoption of SM practices. Because of fear from adopting inapt practices or investing in unknown or wrong technologies SMEs often cannot be classified as "early adopters". However, SMEs should be fast for learn about new digital practices and technologies to increase their chance of competing with MNEs (Faller and Feldmüller, 2015).

Under INSENT project for 159 Croatian companies and based on scale from 1 to 4 Veza et al., 2015 concluded their study about evaluation the Industry 4.0 Maturity Level, that the level of Croatian companies is “2.15” which means that Croatian companies did not start to adopt the Industry 4.0 and still in the second generation.

To focus on the needs of SMEs, above studies have been mentioned in the literature review. There is a research gap because of lack of numbers of studies about SMEs and their adoption for SM, although the huge numbers of studies about SM and proposed models for implementation, but most of studies focused on MNEs and tried to implement the same for SMEs. However, this can be considered a challenge, depending on the distinct differences and requirements of SMEs. Furthermore, most of studies shows that SMEs are working in operational and strategic decisions about the way of integrating the SM (Mittal et al., 2017) ; (Rüßmann et al., 2015). Table 1.4 based on (Mittal et al., 2017) study, shows a snapshot from the most common technologies of Industry 4.0. Eisert, 2014 report in WirtschaftsWoche magazine showed that more than 66.6% from more that thousand companies in Germany, Switzerland, and Austria which surveyed, they do not know basics of Industry 4.0

technologies and models. According to Sommer, 2015 a lot of SMEs in Germany do not know about linked trends with Industry 4.0 like automations and did not start to implement Industry 4.0. Table 1.4 showed the common definitions of SM Technologies (based on (Mittal et al., 2017).

Table 1.4. Industry 4.0 Definitions, (Mittal et al., 2017)

#	Technology	Definition	Reference(s)
1	Internet of Things (IoT)	The communicating and connecting over the internet between physical things.	(Wu et al., 2017)
2	Augmented Reality (AR) and Virtual Reality (VR)	Create a virtual environment through different technologies.	(Rüßmann et al., 2015) ; (Wu et al.,2013) ; (Tzong-Ming and Tu, 2009) ; (Kolberg and Zühlke, 2015)
3	(Big) Data Analytics	Because of big volume of data new analysis technologies and tools are required to transfer these data in efficient way.	(Lenz et al., 2018) ; (De Mauro et al., 2015) ; (Addo-Tenkorang and Helo, 2016) ; (Tao et al., 2018)
4	Cyber-Physical Systems	Collecting and sharing data online.	(Monostori, 2014) ; (Zhong and Nof, 2015)

1.3. Research Questions

The questions of this study are:

- RQ1:

  Are the existing models of industry 4.0 compatible with SMEs needs?
- RQ2:

  What are the gaps in the existing studies in Industry 4.0 that prevent SMEs from being supported?
- RQ3:

  How can maturity models be improved in Industry 4.0 to support the special requirements of SMEs?

1.4. Research Aims

The study aims are to answer above questions after a deep literally, and critically reviews. Then propose a conceptual roadmap for Industry 4.0 for SMEs.

As a result, this study shows an overview about challenges and opportunities of SMEs to adopt Industry 4.0 and implement its principles by maturity models.

According to Thoben et al., (2017) SM Initiatives are identified by many names according to various international specifications such as: “Industry 4.0”, “Smart Factory”, and “Smart Manufacturing (SM)”. Despite of different definitions, but these three terms demonstrate the fundamental objective to help companies to adopt new information, business, and operation technologies to increase revenue and efficiency. The used references present that the exists Industry 4.0 models of are more fit with MNEs requirements.

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CHAPTER 2

LITERATURE AND CRITICAL REVIEWS

This chapter shows the maturity models and provide the critical discussion on them. In the beginning and before start checking the selected 13 maturity models, discussion will be worthy for the previous literatures which compared between Industry 4.0 and SM and maturity models.

The previous literatures (Scremin et al., 2018), (De Carolis et al., 2017), (Akdil et al., 2018), (Gökalp et al., 2017) have below weakness points:

- They did not cover the topic in a comprehensive (in addition to other nine model).
- They did not include SMEs.

However, these papers may be important and for that in this study summary for them will be provided.

De Carolis et al., (2017) concluded their study after the completion of a series of workshops as: organization, staff ability, technology, and information connectivity are the main supporter to SM. In their workshops three models have been checked and compared from different viewpoints like objectives, and maturity levels but they did not study the SMEs.

Seven previous models have been studied and evaluated according to six different norms in Gökalp et al., (2017):

1. Granularity of dimensions.
2. Description of assessment method.
3. Fitness for purpose.
4. Objectivity of the assessment method.
5. Completeness of aspects.
6. Definition of measurement attributes.

And found that any of the studied models were fit to satisfy all norm. But their study is not fit for SMEs.

From industry scope, and maturity/readiness levels and dimensions Akdil et al., (2018) studied and compared four different maturity models, but in their comparison did not check the requirements of SMEs.

According to seven different criteria Scremin et al., (2018) compared seven maturity models (Geissbauer et al., 2016), (Beaudoin et al., 2016), (Jodlbauer and Schagerl, 2016), (Leyh et al., 2016), (Lichtblau et al., 2015), (Schumacher et al., 2016), the criteria are:

1. Method of measuring the target
2. The current stage
3. The number of stages
4. Where does the evaluation data come from?
5. How was the model designed?
6. What is the model used for?
7. Supported tools

But on this study below comments should be considered:

1. SMEs requirements did not consider in the study.
2. Two from the compared models were not written in English (Beaudoin et al., 2016) ; (Jodlbauer and Schagerl, 2016).
3. A pure model focusing of IT and software (Leyh et al., 2016) has been considered in the study.

As the result, the existing compared studies did not support the requirements of SMEs, but in this study many different of maturity models, and roadmaps were compared based on how these maturity studies met the SMEs requirements.

Limited numbers of studies which considered the Industry 4.0 or SM and their readiness assessments, frameworks, maturity models, and roadmaps to be fitted for SMEs requirements (Schumacher et al., 2016).

Below is a general definition of the following keywords “Readiness Assessments” “Roadmaps” “Frameworks” and “Maturity Models”:

- Readiness Assessments: According to Benedict et al., (2017) it is tool of evaluation and determination the degree of readiness, suitability, and resources availability on all system level`s to achieve the target
- Roadmaps: According to Garcia and Bray, (1997) they are specific plans to achieve short- or long-term goals through technical solutions.
- Frameworks: According to Storey, (2005) they are processes, procedures, and methods for designing the system.
- Maturity Models: According to Mettler, (2011) they are the models required to support optimization to higher levels by following a step-by-step process.

In this study thirteen different models of maturity will be discussed by critical review and through separated subsections, in every subsection a summary for each model will be provided regarding the scope, and methodology before checking the suitability with SMEs requirement. Then summary of the maturity models will be presented (how the thirteen models reflect the requirements of SMEs, an overview for the thirteen different maturity models and highlighting their fit with requirements).

2.1. The Existing Studies of Smart Manufacturing (SM) and Industry 4.0

2.1.1. First model: Towards industry 4.0: Gap analysis between current automotive MES and industry standards using model-based requirement engineering

Based on MESA International's "Manufacturing Execution Systems (MES) Product Survey" (CGI, 2015), Kannan et al., (2017) performed the gaps analysis between existing systems, and industry specifications. The study proposes that working in accordance with International Automation specifications (ISA), ISA-88 and ISA-95 will make the transition to SM easier.

This model has three stages:

1. Vendor selection: select the best vendors for products based on services provided by MES.
2. Modelling the requirement: determine and clarify the requirements of existing automotive MES.

3. Gaps analysis: provide a comparison analysis between provided services from vendors, and requirements of MES regarding automotive industry.

The above three stages cannot be implemented in profitable and meaningful way in SMEs because of:

1. SMEs have a limited number of vendors and suppliers.
2. They do not have a variety of products comparing with MNEs, so SMEs requirements can vary.
3. SMEs may not take into account in following ISA and other specifications.

As a result, this model is not reflecting requirements of SMEs.

2.1.2. Second model: An overview of a smart manufacturing system readiness assessment

(SMSRA) Smart Manufacturing System Readiness Assessment system has been presented by Jung et al., (2016).

This model consisted from four dimensions:

1. Information Connectivity maturity: to show evolution of used exchange information methodologies.
2. Organizational maturity: to show how manufacturers manage activities whether by automation or humans.
3. Information Technology maturity: to indicates presence of digital tools.
4. Performance maturity: to show the use degree of measure and monitor systems.

A statistical analysis has been done to present the positive connection between types of performances.

Because of lack in information technology, information connectivity, and AMTs as mentioned in Section 1.1, The lack of accessibility on this model dimensions by SMEs. Also, no valid evaluation system to check the readiness of the manufacturing system.

As result, this model can be evaluated as more suitable for MNEs.

2.1.3. Third model: Industry 4.0: Building the digital enterprise

With focus on "digitalization" as the main supporter a model has been suggested by Geissbauer et al., (2016) , the model have four stages:

1. Digital Novice.
2. Vertical Integrator.
3. Horizontal Collaborator.
4. Digital Champion.

Seven dimensions:

1. Digitizing product and service offerings.
2. Digitizing the way to reach customers.
3. Compliance security, legal and tax.
4. Flexible IT architecture.
5. Analytics and Data as core capability.
6. Digitizing and integrating the value chains horizontally and vertically.
7. Employees, Organization, and Digital culture.

In addition, for digital success the following points are recommended:

Define your strategy for Industry 4.0, create experimental projects, identify the required capabilities, improve your data analysis skills, transform into a digital institution.

Geissbauer et al., (2016) suppose there is a digital integrated supply chains need update in the real time, and because of economical constraints SMEs might not be able to apply the same.

Above dimensions need to implement the automation, digitalization, digital organization culture. These facilities may not be available for most of SMEs as mentioned in Section 1.1, so as result this model cannot be considered for SMEs.

2.1.4. Fourth model: Industrie 4.0 maturity index: Managing the digital transformation of companies

Based-on digitalization as main factor Schuh et al., (2017) proposed a model. This study included many case studies, workshops. The maturity model included four stages as follow:

- First stage: discussed many projects with consultants and experts.
- Second stage: formed group to review and follow-up the project progress.
- Third stage: in technology-based manufacturing companies, the feasibility of projects was checked.
- Fourth stage: checked results of above stages, by working in parallel with all other stages.

Schuh et al., (2017) proposed six different stages of developments:

1. Computerization: by using computers to support teams and achieve tasks.
2. Connectivity: by using Internet to support information and data sharing.
3. Visibility: by implementing an Enterprise Information Systems (EIS) to achieve visibility, manage the factory, and provide the required data for management.
4. Transparency: to support companies to solve events like problems and define the root causes.
5. Predictability: based-on understanding the Transparency stage, forecasting of future plans.
6. Adaptability: from all systems and machines according to their predictive capacity.

Industry 4.0 starts from third stage (Visibility), while the first two stage are related to the Industry 3.0 era.

In addition, four main areas, were evaluated at each stage of maturity with two sub-dimensions under each of them:

1. Organization Structure: dynamic collaboration and organic internal organization inside the value network.
2. Information Systems: Information system integration and self-learning information processing.
3. Resources: organized communication and digital capability.
4. Organization Culture: The desire for social cooperation and change.

The target of this study was to allow organizations to determine their current status and how can they improve it. Also, the model insisted on the idea of specific plan for each company.

The study assumes that high technology is available in SMEs, which is not correct as mentioned in Section 1.1.

So, though the model insisted on the idea of specific plan to company but required organizational and technical culture make this model is not suitable for SMEs.

Although this model provides the information required for companies to determine their current maturity level and how they can be improved, SMEs may hire a consultant to explain the survey questions.

As result, this model is not compatible with requirements of SMEs.

2.1.5. Fifth model: Development of an assessment model for industry 4.0: industry 4.0-MM

A model based on (SPICE) approach Software Process Improvement and Capability dEtermination has been proposed from Gökalp et al., (2017). The proposed model has five dimensions:

1. Application Management like information flow.
2. Organizational Alignment like human resource, and strategies management.
3. Asset Management like technologies of Industry 4.0.
4. Process Transformation like planning the main processes (sales, plan, production) with digital world.
5. Data Governance like decision making, and data gathering.

According to above dimensions and based on different side practices, six levels (0-5) of maturity were proposed Table 2.1:

1. Incomplete.
2. Preformed.
3. Managed.
4. Established.
5. Predictable.
6. Optimizing.

This model seems suitable for SMEs by support participation of employees and invest in employees by provide the required training related with Industry 4.0, but SMEs may not access to have the required technologies, and IT networks.

As result, this model is not compatible with SMEs requirements.

Table 2.1. Capability Dimensions and Levels of Industry 4.0 Maturity Model, (Gökalp et al., 2017)

Level	Generic Work Products	Generic aspect Practices
Incomplete	• Basic business operations are performed	• Not implemented
Performed	• Attempts to move is exist	• Implemented
Managed	• Physical elements are represented by a virtual action	• Install and operate the IT infrastructure independently
Established	• Develop a common language	• Vertical integration • Operations are standardized
Predictable	• Big Data Analytics	• Controlled operations • Horizontal integration
Optimizing	• Self-Improvement • Comprehensive digital integration of engineering	• Continuous adjustment • Innovative business processes

2.1.6. Sixth model: A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises

Model which may indicate the level of readiness to adopt SM technologies in SMEs has been proposed by Schumacher et al., (2016). The maturity model has been focused on the organizational sides during practice. Also, quantitative and qualitative

methods published to validate the model experimentally. The model depends on a survey from nine points:

1. Technology.
2. Operations.
3. Governance
4. People.
5. Leadership.
6. Culture.
7. Products.
8. Customers.
9. Strategy.

Table 2.2 shows the maturity model dimensions (based on organizational sides) with three different levels for each dimension.

Because of the wrong thinking about the high interaction between the company and customers or vendors in SMEs, so this model seems suitable. But as mentioned in Section 1.1 in SMEs, owner is responsible for strategies, so according to her/his understanding of SM Technique, the adoption and transition process will be performed. The points in the maturity model discuss many topics such as lack on training for employees, resist the adoption of new technologies and digitalization, do not work based on the protection of intellectual property rights, but did not recognize the requirements of SMEs, so this model is not suitable for SMEs.

Table 2.2. Dimensions and Their Explanation, (Schumacher et al., 2016)

#	Dimensions	Explanation
1	Technology	• Take advantage of machine-to-machine (M2M) communication. • Existence of modern information and communication technologies. • Use of mobile devices.
2	Operations	• Simulation and modelling. • Decentralization of operations. • Interdisciplinary and interdepartmental collaboration.
3	Governance	• Intellectual Property Protection. • Suitability of technological specifications. • Labour Regulations.

4	People	• Information and communication technology competence for employees. • Employees are open to new technology. • Employee independence.
5	Leadership	• Leaders' desire to embrace industry model 4.0. • Central coordination of industry strategy 4.0. • Competency management and methods (digital).
6	Culture	• Allow cooperation and innovation across the company. • Knowledge Sharing. • The information and communication technology (ICT) value.
7	Products	• Personalization of products. • Integrate the product into other systems. • Digitize products.
8	Customers	• Digitize services and sales. • Use client data. • Efficient digital media for the customer.
9	Strategy	• Applying of Industry Roadmap 4.0. • Adapting of work model. • Realizing the resources available for smart automation.

2.1.7. Seventh model: Towards a framework for assessing the maturity of manufacturing companies in industry 4.0 adoption

An Adoption Maturity Model (AMM) to support companies toward Industry 4.0 has been prepared by Scremin et al., (2018). by three main axes the thirty parts have been divided:

- Performance.
- Maturity.
- Strategy.

Eight indicators of maturity Table 2.3. By using a cross-sectional exploratory project which used for data collection a qualitative method, the model provided a specific requirement for each stage of its maturity stages Table 2.4. AMM was developed using the established methodology:

- Firstly, review of the current studies of models, and the enabling technologies of SM. Then propose a 30 of maturity items.
- Table 2.3. Then on eight maturity indicators, the maturity items have been distributed, and the interview questions were connected to maturity indicators.

- Secondly, for ten different companies (five from Italy, and five from Canada) the questions of the interview have been shared. The collected data supported the preparation of case studies on the companies understanding on different aspects regarding Industry 4.0. Then according to the collected data, the thresholds for each maturity item has been defined. The thresholds helped the validation of the model by using indicators. By helping from the individual cases, a cross-case comparative analysis has been provided.
- Finally, by analysing the individual maturity assessment and the comparison matrix, the formulate conclusions and archetypes of the Industry 4.0 have been identified.

The target of AMM was to provide the correct maturity stage only for each company that has been started the Industry 4.0 implementation process, so AMM will not be helpful for any company which did not start the adoption of Industry 4.0. Also, because of requirements of this model regarding the high technologies like Industrial Internet of Things (IIoT), etc AMM may not be suitable for SMEs. By using a comparison for eight models, the thirty maturity items have been developed (Leyh et al., 2016). The importance of software maturity model was not discussed in the manufacturing scenario either (Scremin et al., 2018).

Finally, for any company that do not have consultant will confuse because of lack in analysing for the thirty parts and the missing of the main features at each maturity level.

As result, the AMM practically is not suitable for SMEs.

Table 2.3 Industry 4.0 Maturity Assessment Framework, (Scremin et al., 2018)

Industry 4.0	Performance	Impact on Efficiency	• Reduce the time to make decisions • Order rate of fulfilment • Employee efficiency • Impact of inventory requirements • Cost, power consumption, lead time, reduce defect rate
		Benefits	• Economical • Environmental
	Maturity	Infrastructure for Industrial Internet of Things (IIoT)	• Protection systems • Equipment infrastructure • Supported technologies • IT systems
		Analytical Skills	• Using the big data for analysis • Self - assessment system • Reasons for using big data • Based on analytics the capability of change the real-time
		Absorptive Capacity	• Training system of employees • Awareness of the skills needed for the Industrial Internet of Things (IIoT) • Knowledge Management Systems
	Strategy	Technologies Strategy	• Cybersecurity issues • Platform selection and specifications
		Business Strategy	• Investments • Product Enhancements and develop of new products through IIoT • Roadmaps of IIoT
		Networking and Integration	• The availability of IIoT systems within organization • Horizontal integration of decision making • Vertical Integration of decision making

Table 2.4 Industry 4.0 Roadmaps Corresponding to a Particular Stage, (Scremin et al., 2018)

Stage	Roadmaps	Industry 4.0 in the company strategies
4	Exist with plan	Exist
3	Exist without long-term plan	Exist
2	Exist without plan	Exist
1	Not exist	Exist
0	Not exist	Not exist

2.1.8. Eighth model: Categorical framework of manufacturing for industry 4.0 and beyond

Existing roadmaps toward Industry 4.0 are not clear based on study of Qin et al., (2016), and does not commitment the transition period requirements a long-term commitment and recognition of key viewpoints: Customers, Business, Factory, and Processes.

Qin et al., (2016) provide five levels of maturity according to manufacturing system for transition to incorporation of new manufacturing capabilities is as follows:

- (L5) reconfigurable.
- (L4) computer-integrated.
- (L3) flexible.
- (L2) automated assembly system.
- (L1) single-station automated cells.

Figure **2.1** presents the research gap between the existing systems and SM, the Grey arrows represent the existing maturity level, the White arrows represent the gap toward the SM system. Qin et al., 2016 suggested to adopt the SM technologies to address these gaps, and advice companies to start creating the building blocks of the required integrated SM system (for example through using best technologies and practices).

The framework of this model considers three different levels for Automation and Intelligence.

Intelligence capabilities reflect on:

(z) Intelligence levels.

(y) Integration.

(x) Control.

Automation capabilities reflect on:

© Factory levels.

(b) Process.

(a) Machine.

The Industry 4.0 ready will be when Intelligence capabilities at: (z) Intelligence levels, and Automation capabilities at © Factory levels.

The study characteristics (like flexibility, customization), and levels (L1 to L5) have been done under AMTs principles.

This study is more suitable for MNEs than SMEs because of AMTs have not easily accessible in SMEs.

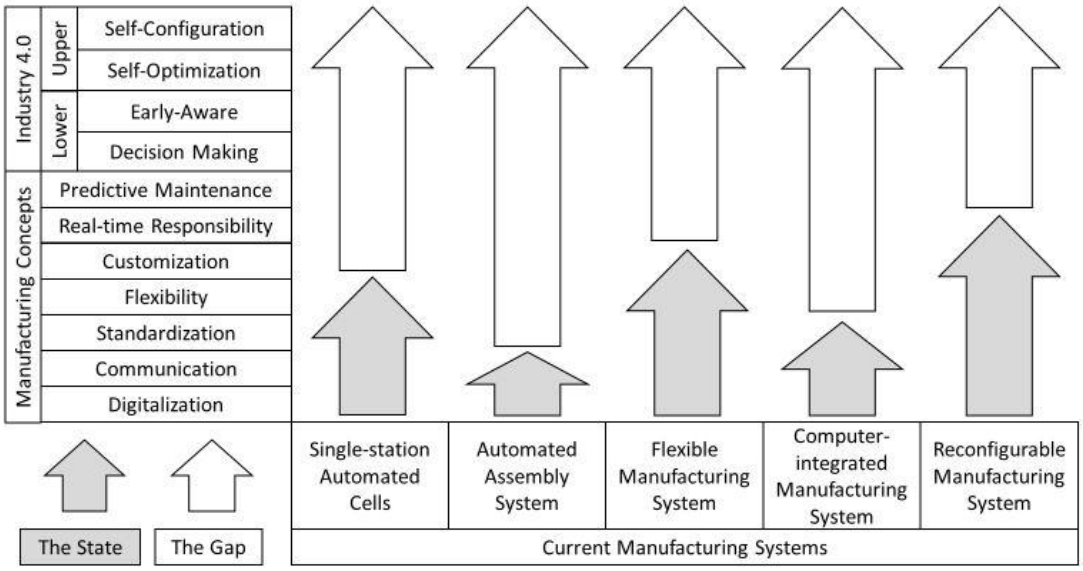

Figure 2.1. Research Gap between Current Manufacturing Systems and Industry 4.0, (Qin et al., 2016)

2.1.9. Ninth model: Maturity and readiness model for industry 4.0 strategy. in industry 4.0: Managing the digital transformation

Akdil et al., (2018) suggested in his study four level, and three dimensions, Table 2.5 presents the technologies and principles.

Maturity levels from 0 to 3:

- Level 3 - Maturity: at high level, the digital technologies, automation, and integration are used in the company.
- Level 2 - Survived: at medium level, the digital technologies, automation, and integration are used in the company.
- Level 1 - Existence: at very low level, the digital technologies, automation, and integration are used in the company.
- Level 0 - Absence: Industry 4.0 requirements is not achieved.

The dimensions of this model:

1. Smart processes and business.
2. Smart services and products.
3. Smart organization and strategy.

The maturity levels have been defined by using a survey-based instrument, and a presentation for retail sector has been provided to support them to know how they can calculate their maturity level.

Calculating the readiness of Industry 4.0 has been supported by this model, but it provides the maturity path toward the MNEs instead of Industry 4.0. Also, the model dimensions appear no concern about the requirements of SMEs which mentioned in Section 1.1. The model has only two factors which concern towards SMEs, they are the readiness toward Industry 4.0 and the organization culture. The model dimensions also may not be suitable for SMEs, like processes should be semi- or fully- automated and products or services should be smart, also the lack in the required definition of maturity levels.

Table 2.5. SM Technologies / Principles, (Akdil et al., 2018)

Technologies	Principles
• Manufacturing • Embedded Systems • Robots • Actuators and Sensors • Simulation • Data analysis • Cyber security • Additive • Connections • Mobile Technologies • RTLS and RFID Technologies • Cloud • Virtualization	• Interoperability • Collect/process/analysis/Interference • Real-time data management • Decentralization • Integrated Business Processes • Virtualization • Service Oriented • Agility

2.1.10. Tenth model: Three stage maturity model in SME's toward industry 4.0

Ganzarain and Errasti, (2017) found that main factor for enable the Industry 4.0 is the diversification. In SMEs there are a lack in knowledge, awareness, and required processes for adopting the diversification strategies. According to Ansoff, 1957 the diversification works to show new or improved products. This model had three stages:

1. After analysing the available resources and capacities, SMEs develop the suitable plan.
2. Then the vision will be recognized by:
    a) Process, products, and networks of the company and market dimensions.
    b) The technologies.
3. Enact the project and establish related policies for risk management and training.

In stage 2 companies check the inputs from experts during the development stage of Vision 4.0.

During the development of Vision 4.0 in stage 2, companies check inputs of main partners and experts. This model integrates the diversification with maturity model of Industry 4.0 as explained in Table 2.6.

The model levels are:

1. Detailed: The business implemented the Industry 4.0.
2. Transform: Specific tasks for all required process to achieve the strategies.
3. Defined: Resources, value proposition, and customer segments of SMEs are determined.
4. Managed: The roadmap of vision of Industry 4.0 is exist.
5. Initial: The suitable vision of Industry 4.0 is not existing.

The study allows SMEs to analysis technology in their system, their economic situation, and the skills of their employees. Because of lack in experience in SMEs analyse their current capabilities and resources to develop their vision will not be an easy task. Also because of economic situation in SMEs hiring consultant may not be good option. Similarly, SMEs strategies should be changed to allow employees training.

As result, this model needs to be developed to be more suitable for SMEs.

Table 2.6. Maturity Model to the Industry 4.0 Revolution, (Ganzarain and Errasti, 2017)

Maturity	Actions	Business	Vision
	ENACT	ENABLE	ENVISION
5 MM	Projects Portfolio (Risk) Management	Future Industry 4.0 Enabled-Business Models	Future Challenges by the Industry 4.0
4 MM	Detailed Projects	Customer Expectation and Segments, Defined Resources	Industry 4.0 opportunity map defined
3 MM	Requirements defined	Customer Expectation and Segments, and Value Proposition Defined	Using specific resources, the Industry 4.0 has been understood
2 MM	Projects Portfolio without Prioritize	Customer Expectation and Segments Defined	Specific Vision of Industry 4.0
1 MM	No specific vision for Industry 4.0		

2.1.11. Eleventh model: A smartness assessment framework for smart factories using analytic network process

By using Analytic Network Process (ANP) method an analysis has been done for twenty Korean SMEs by Lee et al., (2017). The existing literature, and conceptual framework Table **2.7** were the main factors considered in the evaluation criteria. Then with the support of five industrial consultants these criteria have been divided to sub-criterions and then to assessment items Table 2.8.

The study worked according to the data collected, and according to processes of traditional value chain. SMEs were included in the study in three different categories:

1. Facility centred.
2. Purchase and inventory-centered.
3. All round groups.

Then after expert discussions assessment items have been weighed. Which classified SMEs in three groups by using ANP tool.

Lee et al., (2017) concluded their study by having five maturity levels for SM:

1. Autonomy.
2. Optimization.
3. Control.
4. Monitoring.
5. Checking.

The study cannot be used to support SMEs towards SM, due to the study does not provide the way toward SM while recognizing the included specifications.

Table 2.7. Conceptual Framework, (Lee et al., 2017)

<table>
<tr><th colspan="2">Management</th><th colspan="3">Operational</th></tr>
<tr><td colspan="2">Vision</td><td colspan="3">Strategies</td></tr>
<tr><td colspan="2">Goal</td><td colspan="3">Evaluation</td></tr>
<tr><td rowspan="4">Operations</td><td>Enterprise</td><td colspan="3">Information technologies</td></tr>
<tr><td rowspan="3">Company</td><td>Development</td><td>planning</td><td rowspan="3">Manufacturing Process</td></tr>
<tr><td>Procedures</td><td>Quality Control</td></tr>
<tr><td>Building</td><td>Logistics</td></tr>
<tr><td>Devices</td><td colspan="3">Automation</td></tr>
</table>

Table 2.8. The ANP Analysis, (Lee et al., 2017)

Criteria	Sub-Criteria	Assessment Items
Leadership	Strategies and Leadership	• Leadership • Intelligent plant capacity • KPI management • Strategy of adopt SM
Process	Development	• Product improvement • Technical information • Process design
	Production Planning	• Master Plan Schedule (MPS) • Sales and operation planning • Orders and demand planning • Production planning management
	Process Control	• Manage production progress • Develop a detailed schedule of work • Anomaly manufacturing management

Criteria	Sub-Criteria	Assessment Items
	Quality Control	• Manage machinery and equipment for quality control • Manage information for quality control • Test data management • Manage quality control specifications documents
	Facility Management	• Management of operating facilities • Spare parts management • Manage templates, and tools • Maintenance of facilities
	Logistics Management	• Tracking systems • Material demand management • Manage orders and lead time • Manage storage • Product delivery • Orders delivery systems
System and Automation	Information Technologies	• Use ERP and SCM • Use PLM • Use of MES • Information security management • Use FEMS
	Facility Automation	• Safety, Environment, and Energy Management • Automate the manufacturing facilities • Automate the assessment and testing facilities • Automate the logistics facilities • Automate the information network of enterprises
Evaluation	Evaluation Assessment	• Environment • Efficiency • Quality • Safety • Cost

2.1.12. Twelfth model: IMPULS-industrie 4.0-readiness

Report of Lichtblau et al., 2015 proposes a system to check the readiness of SMEs toward SM. This model has six level of readiness (outsider, beginner, learner, experienced, expert, and leader) and six main dimensions of study.

The model dimensions:

1. Smart Factory: By using high level of digitalization, automated environments, and IT systems.
2. Smart Products: By having automated, efficient, and flexible production management system.
3. Smart Operation: By having the integration of virtual and physical worlds in the company like IT security and cloud usage.
4. Organizational Strategy: By using the strategies of Industry 4.0.
5. Employees: The main support factor for digital transformation.
6. Data-driven Services: Which support the revenues streams, and new operational efficiencies.

In addition to above points this model provides an online assessment for SMEs to see their readiness level.

Lichtblau et al., (2015) considers that horizontal integration with providers, and clients is the main factor to support implementation SMEs. But like mentioned before SMEs will not obtain good results in the dimensions suggested above and may have a misjudgement of their readiness and may therefore be outside in industry 4.0.

2.1.13. Thirteenth model: Guideline industrie 4.0 - guiding principles for the implementation of industrie 4.0 in small and medium-sized businesses

By concentration on specific methods of Industry 4.0, and with help of a report provide guidance that takes into account the nature of German SMEs Anderl et al., (2015) has been proposed this model.

Model has five stages which provide an action plan for each company want to have its vision from Industry 4.0:

1. Implementation.
2. Evaluation.
3. Creativity.
4. Analysis.
5. Preparation.

In addition: Key facilitators in this model are the commitment of the multidisciplinary teams, managers, and key tools are the toolbox for Industry 4.0. The technologies of these toolboxes have been considered from point of views of process Table 2.9 and product Table 2.10. Anderl et al., (2015) provide a gradual plan has be used to support SMEs to achieve their vision by low-priced tools. However, the main challenges for SMEs will be how they can define their current level, which tools they need to.

As a result, although some points fit the requirements of SMEs, this model cannot be compatible with the requirements of SMEs.

Table 2.9. Technologies – Process, (Anderl et al., 2015)

Data Processing in Production	Automatic planning / control process	Evaluate the planning and control process	Analyse the data to monitor the process	Data storage for authentication	Lack of processing the data
Machine-to-Machine Communication (M2M)	Web Services (M2M Software)	The accessibility to internet for machines	Industrial Ethernet interfaces	Filed Bus Interfaces	Lack of communication
Company-wide Networking with the Production	Among the sections, the entire IT network solutions	Unified data formats and division-related data services	Incomplete formats and databases for data exchange	Share information via email / telecommunications	No production network with other business units
Information and Communication Technology (ICT)	Outside connection are involved	Automated information sharing	Internet-based portals with data sharing	Centralized data servers in production	Share information via email / telecommunications
Man-Machine Interfaces	Augmented Reality and Help	Using of mobile interfaces	Comprehensive production control	Using of local interfaces	Lack of information sharing between users and machines
Efficiency with Small Batches	Component-based normative production in value-added networks	Flexible production system in component level	Flexible production systems in product level	Flexible production systems and matching items	Rigid production systems

Table 2.10. Technologies - Product, (Anderl et al., 2015)

Integration of sensors / actuators	The product responds independently according to the acquired data	Data for analyses are evaluated by product	Sensor readings are processed by the product	Integrated sensors	Interest-free sensors
Communication / Connectivity	The accessibility of the product to the internet is available	The availability of Ethernet Interfaces	Availability of field bus interfaces in the product	The availability of sending and receiving I/O signals	There are no interfaces
Functionalities for Data Storage and Information Exchange	Exchanging data as an integral part	The availability of data storage in the product for independent information sharing	The availability of the passive data store in the product	Possibility of individual identification	Lack of functionality in the product
Monitoring	Independent control measures adopted	Diagnose its own functional condition	The availability of the recording of the operating status for diagnostic purposes	Failures detection	Lack of monitor by the product
Product-related IT Services	Full integration into IT infrastructure	Perform services independently	Implementation of the service directly across the product	Online services	Services not available
Business Models around the Product	Sell product functions	Additional sale of product-related services	Based on customer request	Consulting and sales	Standard Products

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CHAPTER 3

METHODOLOGY

A methodology from five step has been used to answer the study questions, See Figure 3.1.

- Step 1: Study many of SMEs from many countries, define the main features, and then compare viewpoints of MNEs and SMEs with these features, and according to that the SMEs requirements will be identified.
- Step 2: Check the existing roadmaps, models, and frameworks of Industry 4.0. By searching the following main words, the literature review follows a gradual procedure for identifying related studies in this sector: "Smart Factory" or "Industry 4.0" or "Smart Manufacturing" and "Model" or "Framework" or "Roadmap".

Searching on keywords has been done in Web of science and Google Scholar databases and published date starting from 2015, after two steps of filtering 13 papers were selected for study. The limited number of studies shows the novelty of this subject.

From 13 selected papers 8 were academic papers, 1 was a chapter in book, and 4 were papers from consulting companies. These 4 papers have been defined as white papers. The white papers support the idea of implementation of maturity models although these papers may have a certain bias because of the publisher companies. Because of limited numbers of the available references the white papers have been included in the study.

- Step 3: Verify the suitability of the specific requirements for SMEs (identified in step 1) and existing maturity models (identified in step 2). By a critical discussion this discussion is the main contribute and novelty of this study. whereas most of the current maturity models have been improved according to MNEs requirements.
- Step 4: Explain the research gaps that retard SMEs from adopting Industry 4.0 by analysing suitability of current studies to SMEs requirements.

- Step 5: Suggest the required modifications on current maturity models to be suitable for SMEs and their requirements. Discuss how the model which has acknowledged the research gaps will work for SMEs.

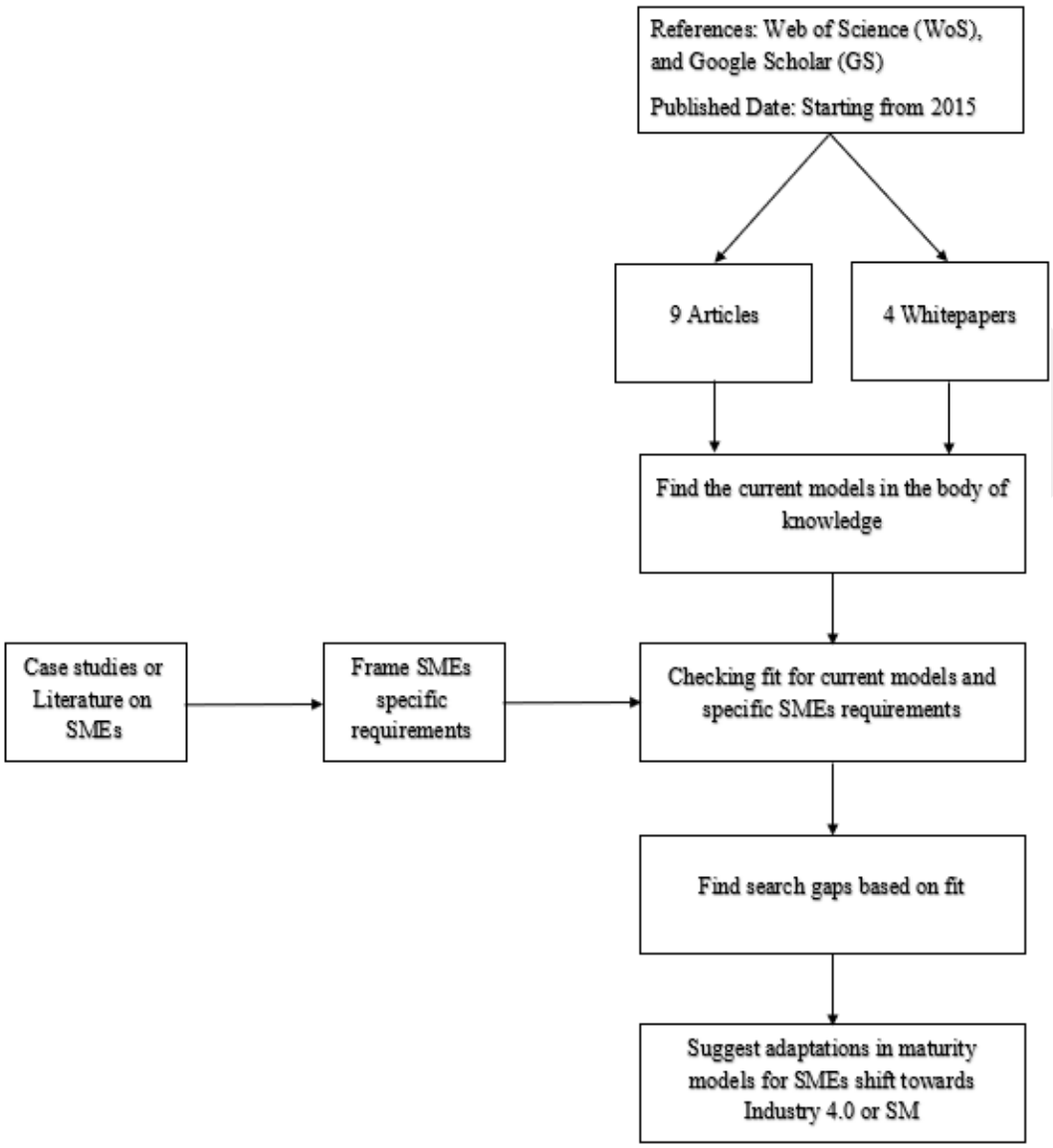

Figure 3.1. Schematic for Methodology Adopted in this study

3.1. Limitations

The first limitation of this study that it has been developed according to current models, readiness studies, and frameworks. Without collecting initial research data. As showed before most of these studies are focusing on MNEs and more advanced companies. Furthermore, no restrictions or cultural or site-based

influences were taken into account at this study. Because of the lack in knowledge in SMEs the importance of this problem may not be analysed. Although these points may have a high effect on them.

The second limitation of this study is that the proposed conceptual roadmap has not been tested with a sufficient number of companies, and with a sufficient number of experts.

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CHAPTER 4

THE RESEARCH ANALYSIS

An analysis for the thirteen studied models will be presented in Table 4.1. The main targets of this table are to highlight the supporting questions, and objectives that emerge from the thirteen discussed models that support SMEs in their adaptation process toward SM. The findings of this study can be used to find a better Maturity Model for SMEs. The methodology that has been applied in this study was mentioned. Table 4.1 shows the limited numbers of models that have worked for SMEs and their journey to adopt industry 4.0. It can be concluded that the subject is very modern, because of the thirteen models published between 2015 and 2018.

4.1. The Critical Review Summary

Different types of methodologies for discussing the company's journey toward Industry 4.0 have been followed in the thirteen models:

- Maturity model.
- Gap analysis.
- Framework.
- Readiness assessment.

To validate the maturity model, different types were used:

- Eight studies (Geissbauer et al., 2016), (Lee et al., 2017), (Schumacher et al., 2016), (Jung et al., 2017), (Akdil et al., 2018), (Ganzarain and Errasti, 2017), (Lichtblau et al., 2015) used pilot and survey studies.
- Two studies (Kannan et al., 2017), (Qin et al., 2016) provided gap analysis study.
- One study (Anderl et al., 2015) shared with managers a developed toolkit (methods, practice and tools) with the assistance of a workshop.
- One study (Scremin et al., 2018) used survey study.
- One study (Akdil et al., 2018) validated the results with case study.
- One study (Schuh et al., 2017) started by survey study and workshops, and with help of an industrial case the results have been validated.

Another finding in the study is the different understanding of dimensions between researchers:

- Three studies (Anderl et al., 2015), (Scremin et al., 2018), (Lee et al., 2017) discussed about main requirements of SM in the form of technologies.
- One study (Lichtblau et al., 2015) considered two dimensions the people and strategy and organization.
- One study (Ganzarain and Errasti, 2017) focused on the specific vision on Industry 4.0 idea.
- One study (Jung et al., 2017) considered one dimension the organizational maturity.
- One study (Geissbauer et al., 2016) considered two dimensions the digital culture, and organization employees.
- One study (Schumacher et al., 2016) considered three dimensions the strategy, people, leadership, governance, and culture.
- One study (Schuh et al., 2017) considered three dimensions the organization culture, organization structure, resources, and information systems.
- One study (Lichtblau et al., 2015) focused on the idea named "outsider" for companies which do not work to adopt Industry 4.0, and do not have any information about it.

Another observation finding in this study that some models determined the journey to implement Industry 4.0 according to companies' awareness in SM.

1. One study (Geissbauer et al., 2016) mentioned that digitization is empowerment, because the essence of this publisher's work is information technology, and digitization.

As general this study determined many of gaps for the thirteen discussed models which are not support requirement of SMEs. As example four studies (Qin et al., 2016), (Anderl et al., 2015), (Lee et al., 2017), (Ganzarain and Errasti, 2017) only worked in Industry 4.0 from SMEs perspective. And some of them (Lichtblau et al., 2015), (Geissbauer et al., 2016), (Jung et al., 2017), (Akdil et al., 2018), (Scremin et al., 2018), (Schumacher et al., 2016) worked on the readiness assessment toward SM.

And some of them (Qin et al., 2016), (Kannan et al., 2017), (Ganzarain and Errasti, 2017) worked on the required steps toward SM.

Table 4.1. The Critical Review Summary

Number	Name	Focusing Area	Weakness Points	Author(s)
First Model	Towards Industry 4.0: Gap Analysis between Current Automotive MES and Industry Standards Using Model-Based Requirement Engineering	• In automotive sector: Highlighting the importance of standardization to adopt the 4.0 industry.	• Missing the main requirements of Industry 4.0. • Uncompleted study because does not include other sectors.	(Kannan et al., 2017)

Second Model	An Overview of a Smart Manufacturing System Readiness Assessment	• Four dimensions. • Smart Manufacturing Readiness Index (SM) assessment for small and MNEs.	• Missing steps to introduce SM readiness.	(Jung et al., 2017)
Third Model	Industry 4.0: Building the digital enterprise	• Seven dimensions. • Industry Readiness Assessment Form 4.0 was conducted.	• Missing steps to introduce SM readiness. • SMEs are not listed.	(Geissbauer et al., 2016)

Fourth Model	Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies	• Consider both evaluation and steps towards Industry 4.0. • Demonstrates the state of dissemination of the methodology. • Six maturity levels.	• SMEs are not listed.	(Schuh et al., 2017)
Fifth Model	Development of an Assessment Model for Industry 4.0: Industry 4.0-MM	• Consider improvement for Industry Vision 4.0. • Five-aspect dimensions. • Six maturity levels.	• SMEs are not listed. • Missing steps to introduce SM readiness.	(Gökalp et al., 2017)

Sixth Model	A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	• Perform a calculation for the proposed maturity index. • Nine dimensions.	• The maturity model for Industry 4.0 is missed. • SMEs are not listed.	(Schumacher et al., 2016)
Seventh Model	Towards a Framework for Assessing the Maturity of Manufacturing Companies in Industry 4.0 Adoption	• Model with 30 items divided three axes: 1. Performance. 2. Maturity. 3. Strategy. • Developing the readiness index of Industry 4.0 is considered. • Five maturity levels. • Interview methodology has been followed with the help of ten companies' cases.	• SMEs are not listed. • Implementation stages are missed. • The maturity items are not defined.	(Scremin et al., 2018)

Eighth Model	Categorical Framework of Manufacturing for Industry 4.0 and Beyond	• Automation and intelligence capabilities are enablers for Industry 4.0 or SM. • Technologies which may help SMEs implement the Industry 4.0.	• The analysis of gap does not determine the current level of maturity for SMEs and how to lead them towards industry model 4.0. • SMEs are not listed.	(Qin et al., 2016)
Ninth Model	Maturity and Readiness Model for Industry 4.0 Strategy. In Industry 4.0: Managing the Digital Transformation	• Consider developing Readiness Index. • Demonstrates a retail case deploying the methodology. • Three dimensions. • Four maturity levels.	• SMEs are not listed. • Missing steps to introduce SM readiness.	(Akdil et al., 2018)

Tenth Model	Three Stage Maturity Model in SME's toward Industry 4.0	• Specific vision for SMEs. • Three stages. • Five maturity levels.	• Diversification is the main enable. • Missing the main requirements of SM. • Missing steps to introduce SM readiness.	(Ganzarain and Errasti, 2017)
Eleventh Model	A Smartness Assessment Framework for Smart Factories Using Analytic Network Process	• Arrange smart factories for Korean SMEs. • The dimensions of multi-criteria decision-making are considered. • Five maturity levels.	• Missing steps to introduce SM readiness.	(Lee et al., 2017)

Twelfth Model	IMPULS-Industrie 4.0-Readiness.	• The readiness assessment is available. • Six level of readiness. • Six dimensions.	• SMEs are not listed. • Missing steps to introduce SM readiness.	(Lichtblau et al., 2015)
Thirteenth Model	Guideline Industrie 4.0-Guiding Principles for the Implementation of Industrie 4.0 in Small and Medium Sized Businesses	• Implementation plan with five stages. • Consider development of Industry 4.0 Vision for SMEs.	• Missing steps to introduce SM readiness.	(Anderl et al., 2015)

4.2. Answer of The First Question: Verification The Fit of The Current Models with Specific Manufacturing Small and Medium-Sized Enterprises (SMEs) Requirements

Table 4.2 describes the comparison between the thirteen models of Industry 4.0 which have been explained above, regarding the requirement of SMEs that explained in Section 1.1. (√) denotes that the model is enhances the SMEs requirement. (-) denotes that the model is not compatibles with SMEs requirements.

In below is discussed the requirement of SMEs which mentioned in Section 1.1 and the thirteen model which have been described.

4.2.1. Technological systems

All models except Kannan et al., (2017) supported the technology as main factor toward adoption of Industry 4.0, but for SMEs and because they are more focusing to manufacture the specialized products or services, so may not want to have the high technologies. Only the models (Anderl et al., 2015), (Ganzarain and Errasti, 2017) asserted SM's vision and believed that companies could accept techniques that support their own vision. Model (Schuh et al., 2017) asserted of specific vision of SM, but this vision is not suitable for SMEs requirement because of it is more focused on digitalization.

4.2.2. Economic systems

Only models (Ganzarain and Errasti, 2017) ; (Schuh et al., 2017) ; (Anderl et al., 2015) recognize the existence of the specific vision of SM, and so their idea may be suitable for SMEs. The specific vision idea takes into account the unique requirements of companies; hence, a better understanding of the economical constraints of SMEs.

4.2.3. Organization culture

Eight models have discussed the organizational culture (Akdil et al., 2018), (Schumacher et al., 2016), (Gökalp et al., 2017), (Lichtblau et al., 2015), (Geissbauer et al., 2016), (Lee et al., 2017), (Jung et al., 2017), (Schuh et al., 2017), but only in model (Akdil et al., 2018) the perspective of SMEs has been highlighted, their model

also believes that the availability of organizational culture is first required step toward to industry 4.0.

4.2.4. Employees

Eight models (Ganzarain and Errasti, 2017), (Lichtblau et al., 2015), (Geissbauer et al., 2016), (Gökalp et al., 2017), (Schumacher et al., 2016), (Anderl et al., 2015), (Lee et al., 2017) discussed the importance of employees, but only four models (Scremin et al., 2018), (Gökalp et al., 2017), (Ganzarain and Errasti, 2017), (Anderl et al., 2015) considered the employees from the perspective of SMEs, since these four models believed that provide the required training for employees and good explanation of Industry 4.0 are main factors for companies to support their journey toward Industry 4.0.

4.2.5. Specifications

The models (Kannan et al., 2017), (Schumacher et al., 2016) showed importance of the of maintaining specifications. But from SME's perspective none of them can have a positive impact on them. And for SMEs that do not have a consultant who can help study and provide the required and clear information regarding the industry specifications, it will be a difficult process of implementing and tracking specifications.

4.2.6. Cooperation

Although the high level of cooperation between SMEs and their vendors and customers, but only five models (Kannan et al., 2017), (Lee et al., 2017), (Geissbauer et al., 2016), (Schuh et al., 2017) discussed this point, and none of them considered from the SME's perspective because they assumed that the project is digitalized and the updated information can be reached at real-time from vendors and customers. None of these models proposed the correct cooperation network. Also, the alliances with research/academic institutes and attending the seminar will help employees of SMEs to increase their knowledge and exchange their viewpoints with other participants.

According to above discussion, none of the discussed models cover all the SMEs requirements and answer the first question in this study. So thorough model is required that can be compatible with SMEs requirements.

For some of SMEs one from the above discussed models can be used if it covers its requirement. Like SMEs with lack in employees, technological systems, and economic systems it can adopt the proposed maturity model by (Anderl et al., 2015). But the target of this study is to improve a thorough and general model that can be compatible with all points.

Table 4.2: Summary of Comparison The Current Studies with SMEs Requirements

Model	Author(s)	Technological Systems	Economic Systems	Organizational Culture	Employees	Specifications	Cooperation
First Model	(Kannan et al., 2017)					-	-
Second Model	(Jung et al., 2017)	-		-			
Third Model	(Geissbauer et al., 2016)	-		-	-		-
Fourth Model	(Schuh et al., 2017)	-	-	-			-
Fifth Model	(Gökalp et al., 2017)	-		-	√		
Sixth Model	(Schumacher et al., 2016)	-		-	-	-	
Seventh Model	(Scremin et al., 2018)	-			√		
Eighth Model	(Qin et al., 2016)	-					
Ninth Model	(Akdil et al., 2018)	-		√			
Tenth Model	(Ganzarain and Errasti, 2017)	√	√		√		
Eleventh Model	(Lee et al., 2017)	-		-	-		-
Twelfth Model	(Lichtblau et al., 2015)	-		-	-		
Thirteenth Model	(Anderl et al., 2015)	√	√		√		

4.3. Answer of The Second Question: Gaps Identification

Many of gaps will be defined in this section. By solving these gaps correctly, the requirement of SMEs regarding Industry 4.0 can be covered.

Firstly, most of the discussed models have been done to cover requirement of MNEs, since they assumed that MNEs have the accessibility for necessary resources like automated machines, and IT systems. So, they supposed that most of MNEs started their journey toward SM. But for SMEs and because of lack in resources they supposed that most of them faced difficulties in their journey towards SM.

One possible challenge situation is the following: The initiation level regarding the journey toward Industry 4.0 of large organizations is (Level 1): means the company accept the challenge to adopt SM ", but for SMEs the initiation level is (Level 0): means the company do not aware about SM".

But before that, this generalization cannot be correct all the time, because some of SMEs companies, which work in high technologies can be used as references for Industry 4.0 implementation process.

However, in general, from the studies from many authors like (Buonanno et al., 2005) ; (Arendt, 2008) ; (Wielicki and Arendt, 2010) ; (Mutula, 2010) ; (Lenny and Simpson, 2005) ; (Quinton and Simkin, 2016) and practical experience indicate that this generalization is suitable to be use as base for this study.

The challenges which SMEs will face in the transition stage from (Level 0) to (Level 1) will be more heavy comparing with transmission stage from (Level 1) to (Level 2), because of SMEs should work to educate and upgrade workers, built the required infrastructure and mind-set. So, because of the different challenges which face SMEs regarding its the journey toward Industry 4.0 the required roadmap of MNEs cannot be considered suitable for SMEs. Secondly the Industry 4.0 or SM has many different meanings and implementation ways according to the applying area, the same should be considered for SMEs. Thirdly, there is a need for a special process that allows to integrate of self-assessment methods to assess the current level of industry readiness 4.0. Based on this indicator, characteristics, techniques, and enablers factors and / or building blocks (Mittal et al., 2017) to direct the individual manufacturing system to SM are still missing. In this literature review three gaps related to SMEs have been determined:

4.3.1. Research gap 1

The different between SMEs and MNEs regarding start conditions in their journey toward Industry 4.0 or SM consider that most of the current models, frameworks, or roadmaps are suitable for the MNEs not SMEs. According to that, the base level which has been used in the thirteen discussed models is an advanced level that include some form OT/IT integration, IT systems, and sensors. Also, they did not consider the SMEs economic situation. In addition, most of the thirteen discussed models suppose that the employee skills and organizational culture of Industry 4.0 are available in SMEs, which is not real.

Because in many SMEs, these start conditions are not achievable, so the same should be reflected in the maturity model to achieve the required target for SMEs towards adopting Industry 4.0. In addition to above there is a new question that need to be solved:

Can compared the requested effort in transition stage from (Level 0) (which is currently missing) to (Level 1) with requested effort in other transition stage?

4.3.2. Research gap 2

The dysconnectivity between self-assessment readiness tools and maturity models.

According to Table 4.1, not all models which support the adopting toward SM include a readiness assessment tool. The smooth transition and ease of use between the maturity model and self-assessment tools are among the most needed benefits for SMEs.

4.3.3. Research gap 3

After assessed the maturity and readiness stages, in the next stage the required support is needed. SMEs comparing with large companies have a lack in the dedicated Industry 4.0 strategic resources because in the large companies there is a group or department which can work with inputs from maturity and readiness stages. However, according to the results of readiness assessment and the processes of the model SMEs may need to have their plan from SM.

4.4. Answer of The Third Question: The Requirement of The New Models

The research gaps will be deeply analysed in this section with details to adapt the current studies to support SMEs journey toward SM. The aim is based on primary data to lay a solid foundation for specific studies, such as surveys. In this stage and based on the experience of the authors and available literature the discussion and answers will be framed.

4.4.1. The difference between MNEs and SMEs in start terms

In Section 0 found that most of the discussed models, frameworks, and roadmaps are mainly focus on MNEs requirements and resources. So, the start points for most of SMEs is a separate from the average level of smartness. For example, SMEs cannot think about sensors and IT, and they do not have a Wi-Fi in their shop floor. As result, putting SMEs in the (Level 1) in the current maturity models will harm them strategically. But if SMEs know their level at (Level 0) which reflect the real stage of maturity, they may invest according to their available economic and technological systems to improve their employees.

In (Akdil et al., 2018) ; (Gökalp et al., 2017) they mentioned (Level 0) as absence or incomplete stage, and in (Lichtblau et al., 2015) suggested the "outsider" stage, but none of them mentioned this level requirements. (Level 0) can be determined as the stage which companies did not know the Industry 4.0 and did not start their journey toward it. For example, many of SMEs depends on labours and do not have the required experience and resources to implement the SM technologies. SMEs may not have internet, like a small family business produce a hand-made product, so defining the (Level 0) will be important to know the start point and to improve their position along long- and short-terms.

Faller and Feldmüller, (2015) discussed three cases of SMEs that started in the Campus Velbert/Heiligenhaus (CVH) a “learning factories” to show the Industry 4.0. These companies used many technologies like Programmable Logic Controller (PLC), and Human-Machine Interface (HMI). But this study recognized that some SMEs has a lack in resources to be suitable with technologies of Industry 4.0, so it believed about the importance of having the (Level 0) to segregate this type of SMEs from the others.

Companies at (Level 1) the ability to accelerate the upgrading their Industry 4.0 toward (Level 2), the same can be done between other levels. But for SMEs at (Level 0) the process will be harder because the company has the lack on basic requirements like technology. For SMEs at (Level 0) should invest more on required technology, organization culture, and employees. Working on above points are very important but the most important point in (Level 0) which can be a big challenge is to have the desire to change. For instance, the moving to digital records is harder and need more resources from transition between different types of digital records like mobile applications. Some of SMEs may keeping the manual records, and from their viewpoint especially when taking into account the "thinking group" the moving from between other levels is less need than moving from (Level 0) to (Level 1).

4.4.2. Dysconnectivity between self- assessment tools and maturity models

Most of discussed models, frameworks, and roadmaps do not have the required readiness assessment tool which can support SMEs to define the current position. Researchers want to provide the required strategy to direct the digital transition, but these maturity models did not have self-assessment tool. (Schuh et al., 2017) proposed a self-assessment tool with the model but not for SMEs. (Anderl et al., 2015) provided a toolbox to support companies journey`s toward Industry 4.0 but without support to define the current position for company. Therefore, the connectivity and integration are needed.

SMEs have a lack in economic systems and because of that may not be able to hire consultant unlike of MNEs. As a result, the required model should be easy to understand, easy to apply from the SMEs managers and include the readiness assessment and maturity model. The importance of readiness assessment tool is to keep SMEs up to date about their position in Industry 4.0.

4.4.3. Specific plan for each SMEs is needed

Only two papers, (Erol et al., 2016), (Schumacher et al., 2016) from the thirteen discussed models focus on specific plan for companies and the needed roadmap to achieve it, but none of them supported their models with examples from SMEs. Presenting a methodology to implement Industry 4.0 or SM may motivate

other SMEs to work to have their plan of Industry 4.0. Because of each SMEs has its special requirements and needs, so the specific plan of Industry 4.0 is needed, and allows SMEs to invest on technical or non- technological systems according to their needs. On the other hand, readiness assessment will support SMEs to know their capabilities. Awareness about Industry 4.0 is an important factor. Seminars about SM with research institutes and universities will support to keep SMEs up to date about technologies, and specifications like ISOs, these seminars and workshops will increase SMEs awareness to improve their plan about Industry 4.0. Section 1.1 mentioned that SMEs have a high dependent on their collaborators, Specific Industry 4.0 plan may support SMEs to define their requirements and reduce the dependence on collaborators. The workshops may allow SMEs to explain to their suppliers how to meet in the best way the industry specifications and improve their relationship with collaborators. With the help of reports from different consultants, SMEs can foster organizational culture towards SMEs. Different cases may guide the SMEs about work culture have been included in these reports.

Because SMEs usually specialize in specific areas, so document and evaluate of their lessons and success stories will be important to highlight the successful stories.

Also, confidence in SMEs, since SMEs trust their peers a lot comparing with services providers whom may have their self-interest or agenda from SMEs viewpoint.

From the identified gaps, we found that although many sites support businesses to determine its current situation, but without allowing them to make an independent evaluation. Identifying / allocating elements within dimensions is somewhat limited. Only (Schumacher et al., 2016) discussed elements such as decentralization of processes, client data, etc. And (Lichtblau et al., 2015) discussed data analysis, employee skills, etc. However, (Schumacher et al., 2016) ; (Lichtblau et al., 2015) did not contain a corporate self-assessment tool. The transparent characteristics for the readiness assessment of SM are not determined in most of readiness assessment tools (for example (Jung et al., 2017) ; (Geissbauer et al., 2016) ; (Veza et al., 2015). There are many of toolkits which claim that they can support

companies to adopt the SM. SMEs may ignore some of the installed technologies, may be confusing in their work, and may have additional operational and strategic difficulties because there are incomplete toolkits.

4.5. Summary of Discussion

In this section of the thirteen models discussed, three main gaps were identified and discussed. The suitability of these models to SMEs requirements has also been verified. According to the results, the current models cannot address these gaps in enough ways. Table 4.3 illustrates how the gaps that have been identified address the requirements of SMEs previously presented.

Table 4.3. The Research Gaps with SMEs Requirements

#	Recommendations for New Model	Economic Systems	Technological Systems	Specifications	Organizational Culture	Employees	Cooperation
First	The difference between MNEs and SMEs in start terms.	√	√		√	√	
Second	Dysconnectivity between self- assessment tools and Maturity Models.	√					
Third	Specific plan for each SMEs is needed.	√	√	√	√	√	√

It may be interesting to think about why focusing solely on specific plan of SM for SMEs may not be enough for the future maturity model. Although the specific plan of Industry 4.0 or SM will support all SMEs requirements, but it will not allow SMEs to assessment their strength and weakness points, therefore, the readiness assessment tools must be performed before carrying out the specific plan for SMEs in Industry 4.0 or SMEs. The transition stage from (Level 0) to (Level 1), and existence of (Level 0) are very important, and need an investment in many resources like human resources, economic, IT systems, etc. So, SMEs should focus on these points deeply. Also, the existence of the self-assessment model has been

highlighted, but it does not recognize the integration of the readiness tool with the maturity model (which can be understood differently). For example, SMEs need to assess their current position over time, so they need the readiness tool. Therefore, the desire for a maturity model will firmly uphold the recognition of all identified research gaps and convincing compliance with SMEs requirements.

From the above discussion, it can be concluded that new model focusing on SMEs requirements are needed. Firstly, this model should include the assessment tools. Then support SMEs to have their specific plan. Which will help to find the required tools (Mittal et al., 2018) that can enhance the organizational dimensions of SMEs (Mittal et al., 2018) of SMEs, and thus direct them towards SMEs. For example, SMEs at (Level 0) may save their data in spreadsheets, which may be sufficient at this stage, but if company want to adopt the Industry 4.0 or SM the saved data should be in more accessible and reliable data storage system (Mittal et al., 2018).

4.6. The Conceptual Roadmap

Figure 4.1 will cover the research gaps which have been defined in this chapter.

4.6.1. First part: The maturity model should be created to fit with SMEs

The proposed conceptual roadmap should support SMEs to know their existing level by readiness tools. SMEs will invest according to their available economic and technological systems to improve their employees, and organizational culture towards Industry 4.0 if SMEs know their weakness points and if the maturity model provide clear plan. The basic motivation for SM is the integration between manufacturing systems to increase efficiency. Proposed roadmap provides the conceptual study of Industry 4.0 to fit with SMEs requirements. The trends of SM are to provide the smart products and production lines which focus on full automation instead of human works.

The smart product has three main parts:

1. Hard parts: which include the mechanical parts.

2. Intelligent parts: which include the sensors, etc.

3. Connection parts: which include the communication devices and software's.

First a course about Industry 4.0 concepts, technologies, advantages, and challenges will be provided to help the related persons to answers correctly on the self-assessment readiness tools and to do in efficient way the implementation plan.

The maturity levels will be defined as five levels:

(Level 0) which should be the most important level because of this level can reflect the real level of most of SMEs. (Level 0) can be defined as the stage which companies did not know the Industry 4.0 and did not start their journey toward it. Also, the moving from one level to the above level need from SMEs to invest more on required technology, organization culture, and employees. The hardest period will be the moving period from Level 0 to Level 1.

Generally, the model should be easy to understand, and apply from the SMEs managers.

4.6.2. Second part: Self-assessment readiness tools

The proposed roadmap should have its readiness tools which should focus on main dimensions that presented in the Section 1.1. The main dimensions will have sub-items to simplify the study and make it more easily to implement without need for outsourcing consultants.

The readiness tools will be used many times during the implementation periods to know the real maturity level, to know the efficiency of the implementation plan, and to recheck the investment plan on SMEs resources.

The importance of readiness assessment tool is to keep SMEs up to date about their position in Industry 4.0, by using questionnaire inside the company, the result will be provided after implementing the weighting factor according to special requirements and situation of each SME that want to use this model.

4.6.3. Third part: Specific roadmap for implementing the maturity model

The roadmap is a complex short-term and long-term planning tool that allows for the identification of strategic targets, Because of each SMEs has its special

requirements and needs, so the specific plan of Industry 4.0 is needed and should be defined to fit with the requirements of each SME which will use it.

The roadmap that is enabling anyone in the implementation team to know the next step, what are the advantages of it, when should be done, who should do it, and simplify these decisions. In the project plan all these procedures are described. The roadmap will be updated according to results of readiness tools because the desire for transferring from the present situation to the required level need a clear steps and correct prioritization.

The roadmap will provide the path of the transition period after a clear study of the SMEs requirements, weakness points, the required level of maturity, the implementation period, and the investigation plan of the SMEs resources.

The roadmap of implementing the Industry 4.0 or SM will support all SMEs requirements, but it will not allow SMEs to assessment their strength and weakness points, so the specific plan of Industry 4.0 or SM for SMEs should be done after assessing their readiness.

The main advantages of the roadmap:

- Provide the specific implementation plan after deep study on the requirement of each SME that will use this model.
- Leading the project implementation team.
- Provide the priorities on the investment on the resources.
- Define the strategic targets, and the way of implementing them.
- Study and define all required actions during the project implementation period.
- Visualize the outputs like targets, and processes.
- Schedule of checking the readiness level.
- The maturity levels which should be determined to be suitable for SMEs.

The challenges of implementation of the Industry 4.0:

- Difficulties in knowing the current level.
- Lack about Industry 4.0 knowledge and its advantages.

- The lack on human and economic systems.
- Difficulties about defining the priorities in the implementation plan.

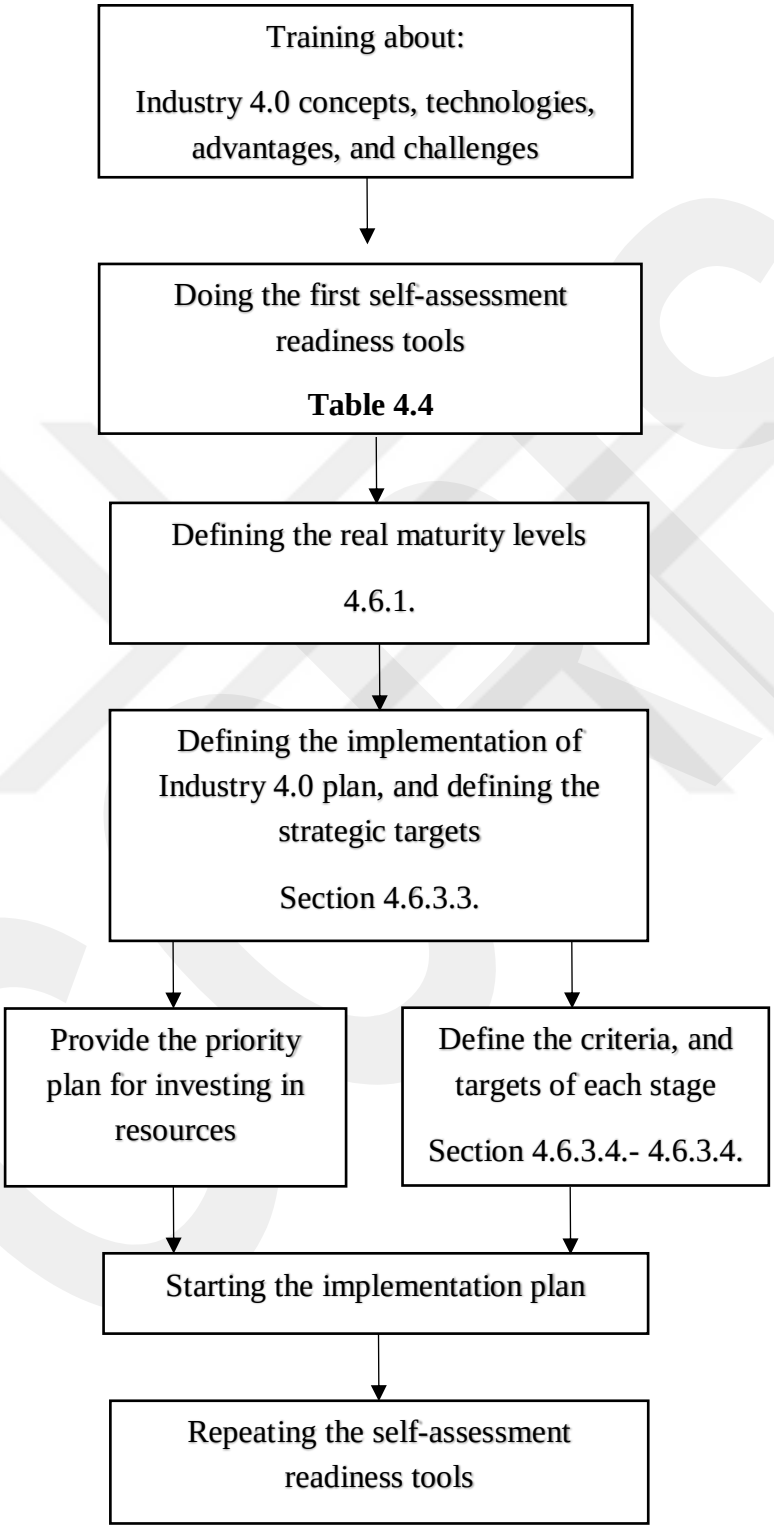

Figure 4.1. A Conceptual Roadmap for Implementation Plan of Industry 4.0

Table 4.4. Sample of the self-assessment readiness tools

Dimensions	Samples of questions
Technological Systems	What technologies do you use in the company?
	What is the ERP system used in the company?
	What is the level of using the technologies inside the company departments`?
Economic Systems	What is the availability of economic systems?
	In which department the company has been invested in the last two years?
	What are the plans for investing in the future?
Organizational Culture	How is the company dealing with success and failure?
	What is the level of work independently inside the company?
	What is the strategy of the company to improve its employees experience?
Employees	The employees' level of experience in technologies?
	Digital transformation ideas are encouraged by employees?
	Digital tools are used to manage knowledge and improve skills?
Specifications	What is the priority of the required specifications?
	To which level the required specifications are followed in the company?
	What are the used procedures in the company to ensure that the specifications are followed?

Cooperation	What is the level of cooperation between departments inside the company?
	What is the strategy of the company to encourage cooperation?
	What are the used methods inside the company to improve the discussion between the teams?
	What are the requirements of the alliances?
	What were the previous alliances between the company and research institutes for the last two years?
	What priority areas for alliances does the company need?

4.6.3.1. Weighted sum model

Studying the alternatives and choosing them based on values is the decision making. The weighted sum model is the simplest method to evaluate many alternatives in accordance to different criteria, from Multi-Criteria Decision Making (MCDM) methods. The aim of weighted sum model is to determine according to the existing status of the company the list of prioritize the roadmap. The Weighted sum model provides the easy way to use to achieve the multi-goal optimization. The weighted sum model is a tool which provides the system of selection. By determining the most important criteria, assigning the weight for each criterion, and developing a model for scoring (Triantaphyllou, 2000). The weighted sum model is the general model that used for many different applications like processing data. According to (Fishburn, 1967) the weighted sum model is the most common model for single dimensional problems.

After discussion with six experts from the academic and business sectors, we found that not all dimensions have the same importance in the improvement stage of the model, for example availability of technological systems and specifications. Therefore, the experts rating has been used to revaluate the six dimensions Table 4.5, and the questions of each dimension

Table **4.7** to find the contribution and the practical impact of each dimension. This study is weighted on 100-point-scale.

By using the below formula, the first step to find the actual maturity level for each dimension:

Result of dimension (X_i): $((Z_{i1} * A_{i1}) + (Z_{i2} * A_{i2}) + (Z_{i3} * A_{i3}))$

Then define the overall maturity level by using the below formula:

Overall result: $\sum_{i=1}^{n}(X_i * Y_i)$

Since the self-assessment tool fail if it is too complex, this study tried to present the questions in simple way, so the companies can use it and do the self-assessment and know their actual maturity level for Industry 4.0.

Table 4.5. The Weighted Sum of Main Dimensions

The Main Dimensions	Weighted Sum
Technological Systems	19%
Economic Systems	21%
Organizational Culture	15%
Employees	15%
Specifications	8%
Cooperation	22%

4.6.3.2. Readiness levels criteria

After discussion with six experts from the academic and business sectors, and checking the previous studies, we defined all levels according to Table 4.6.presents the used criteria to identify the readiness level of each dimension.

Table 4.6. Readiness Levels Criteria by Percentage (Y)

The Main Dimensions	Criteria (%)
Level 4	$90 < X \leq 100$
Level 3	$75 < X \leq 90$
Level 2	$60 < X \leq 75$
Level 1	$45 < X \leq 60$
Level 0	$0 < X \leq 45$

4.6.3.3. Defining the implementation of Industry 4.0 plan, and defining the strategic targets

After finalizing the previous stage, the below steps will be defined to start the implementation plan:

- A deep study and analysis of the results of the previous stage will be required to define the real level of maturity.
- Providing the report for management to explain weakness points and the required preventive and corrective actions.
- Increase the spirit of teamwork and effective leadership and identify ways of communication.
- Specifying the steps of work for each person in the implementation team, by dividing the work into phases to simplify them to the team and management.
- Defining the schedule of this stage.
- Defining the targets of this stage, with a simplified explanation for the team.
- Defining the priorities of investment at this stage, with a simplified explanation of management.
- Defining the required training about Industry 4.0 after analysing the results of the previous stage.

4.6.3.4. Define the criteria, and targets of each stage

Since most SMEs have a lack of economic and technological systems, so they will be for most of the selected dimensions in the (Level 0).

In this section, the transition plan from (Level 0) to (Level 1) will be studied for three dimensions:

Technological Systems:

Upgrading the automation level for the shop floor, the connectivity between machines, equipment, and used systems, and the ability of the Information Technology (IT) and Operational Technology (OT) systems will allow company to increase the productivity, by analysing a large amount of data, the early detecting for deviations, and predict potential failures in future.

For SMEs at (Level 0) the first step should be to provide the Wi-Fi internet in the shop floor, to start the next stage of Internet of Things (IoT).

Employees:

Developing the employees' experiences, skills, and capabilities will support companies to achieve their targets, and change the work culture. As example for engineers the normal engineering capabilities need to be developed with new digital skills like systems integration, software development, and data analytics. For other employees the need for adapting the new types interactions between machines and human.

For SMEs at (Level 0) the first step should be to prepare the basic training program which should be structured and implemented on an ongoing basis for employees. Which will allow employees to have the opportunities for continuous learning and learn new skills.

This program should be compatible with work needs and able to be developed based on feedback from employees.

For example, in (Level 0) the training should be about teamwork skills, time management and Microsoft Applications.

Organizational Culture:

Leadership Competency means the ability of the management to take advantage from the latest technologies and concepts to guarantee the continued and competitiveness of the company. As the transformation period will take many years

and will be developed and adopted over time, so the strong leadership with right knowledge and capabilities, clear plan, and commitment will be needed. The company should build systems, and processes to have the knowledge about the latest concepts and trends.

Strategy relates with design and execute the work plan to achieve the required long-terms targets, design the roadmaps, and identify the priorities, and develop a system from rules and processes to transform the plan to real value for the business.

For SMEs at (Level 0) the first steps should be:

- Start to define the plan, and end-outcomes.
- Change the decision-making mentality and start to create the brainstorming committees.
- Develop the organizational structure by putting the basic rules, responsibilities, and roles for the team members.

4.6.4. Case-study small enterprise

In this study one small enterprise has been studied, total number of workers: 25, and total income 0.1 million dollar. To guarantee the accuracy of results, we selected company which want to implement the Industry 4.0.

From results of the main dimensions, the organization in the (Level 1) in the employees, and the Cooperation.

Table 4.7 Example for One Small Sized Enterprise

The Main Dimensions	Weighted sum for each dimension (Z)	Answer	Result (A)	Result of dimension (X)	Weighted Sum (Y)	Level of dimension
Technological Systems	30%	Computers	30%	23%	19%	Level 0
	50%	Excel files	20%			
	20%	Normal	20%			
Economic Systems	50%	Normal	45%	44%	21%	Level 0
	20%	Planning Department	45%			
	30%	Technical Department	40%			
Organizational Culture	30%	Learn and adapt	50%	44%	15%	Level 0
	30%	Common	30%			
	40%	Internal training	50%			
Employees	35%	Middle level	50%	50%	15%	Level 1
	35%	Often	50%			
	30%	Often	50%			

Specifications	40%	Medium	53%	44%	8%	Level 0
	30%	Medium	47%			
	30%	Low	30%			
Cooperation	17%	Medium	55%	51%	22%	Level 1
	20%	Communication	35%			
	13%	Weekly meeting	43%			
	17%	High	80%			
	13%	Discussion with experts	40%			
	20%	Technical side	50%			

Over all result: 42.56% so the overall level is Level 0.

The most required area to be developed is the technological systems.

Validation of the study: The validity of the study was confirmed on the basis of reference studies.

CHAPTER 5

CONCLUSIONS, LIMITATIONS AND FUTURE WORK

5.1. Findings

The main results of this study are:

- A unique plan should be provided for each SME, based on its resources, and status. This plan should be connected with self-assessment results.
- The actual status should be defined in the maturity level, and because of lack in resources in most of SMEs, so the (Level 0) has been provided in this roadmap. And the transition from this level will be the hardest stage.
- We found the importance of the self-assessment tools for SMEs, and these tools should be easy to understand, so the company can check its status periodically.

5.2. Conclusions

The workflow of this study began with the identification of SMEs requirements, then a deep study for the current models of SM, finally according to study results we proposed a conceptual roadmap for implementing the Industry 4.0 for SMEs. From these models three research gaps have been defined that have been answered by a comprehensive critical review. It has been noticed from the results of the thirteen discussed models, that these models mainly considered the MNEs requirements and challenges. The research gaps have been recognized from SMEs requirement that were not met. As result, this study defined gaps which should be solved to help SMEs in their implementation plan for SM. Then after a comprehensive critical review the study answered on these gaps according to the available literature and proposed a conceptual roadmap to adopt the Industry 4.0 for SMEs. The industrial experience provided authors with a real value for the digital transformation of SMEs towards SM by supporting the future model and the development of tools to respond to the defined gaps in this study. Then the way in which defined gaps respond to SMEs requirement was discussed.

5.3. Future Work

By answering of the defined research gaps and propose a conceptual roadmap for Industry 4.0 in this study, this study can be used as solid foundation for future maturity models of Industry 4.0 or SM according of SMEs requirement. By using the needs specified and following the proposed roadmap in this study, a maturity model more suited to SMEs requirements can be developed soon.

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Yayın

Alıntıları çıkart	Kapat	Eşleşmeleri çıkar	Kapat
Bibliyografyayı Çıkart	Kapat		

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