VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHANICAL AND MATERIALS ENGINEERING

Özgür Özavcı

ASSESSING INDUSTRY 4.0 MATURITY: A MODEL FOR MANUFACTURING COMPANIES WITHIN THE METAL PRODUCTS INDUSTRY IN SWEDEN

PRAMONĖS 4.0 BRANDOS VERTINIMAS: MODELIS ŠVEDIJOS METALO PRODUKTŲ PRAMONĖS GAMYBOS ĮMONĖMS

BEDÖMNING AV INDUSTRI 4.0:S MOGNADSGRAD: EN MODELL FÖR TILLVERKANDE FÖRETAG INOM METALLPRODUKTINDUSTRIN I SVERIGE

Master‘s degree Thesis

Industrial engineering and innovation management, state code 6211EX056

Production and Manufacturing Engineering study field

Stockholm - Vilnius, 2023

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Özgür Özavcı

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Stockholm - Vilnius, 2023

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

INTERNATIONAL STUDIES CENTRE

DEPARTMENT OF MECHANICAL AND MATERIAL ENGINEERING

Production and Manufacturing Engineering study field	APPROVED BY
Industrial Engineering and Innovation Management study programme, state code 6211EX056	Head of Department
Industrial Engineering and Innovation Management specialisation	Ina Tetsmann
	2023-05-30

OBJECTIVES FOR MASTER THESIS

No. PIVfmuc21-4199

Vilnius

For student Ozgur Ozavci

Master Thesis title: Assessing Industry 4.0 Maturity: a model for manufacturing companies within the metal products industry in Sweden

Deadline for completion of the final work according to the planned study schedule.

THE OBJECTIVES:

Explanatory note:
The main goal is to develop an innovative model that evaluates the Industry 4.0 maturity level of manufacturing companies in the metal products industry in Sweden.
Objectives:
1. Analyse scientific literature to find out the challenges faced by enterprises, major factors and innovative solutions that can impact the successful implementation of Industry 4.0.
2. Conduct empirical research based on questionnaire and find out impact of different factors on Industry 4.0 implementation in manufacturing enterprises operating in Sweden.
3. Develop and propose a structured model that aims to determine the Industry 4.0 maturity level of manufacturing enterprises operating in the metal products industry in Sweden and assess the overall I4.0 maturity level of the industry.

Academic Supervisor Associated Professor Rūta Banelienė

Vilnius Gediminas Technical University	ISBN
Faculty of Mechanics	Copies No. ....
Department of Mechanical and Material Engineering	Date ..........-.....-.....

ISSN

Master Degree Studies **Industrial Engineering and Innovation Management** study programme Master Graduation Thesis 4	
Title	**Assessing Industry 4.0 Maturity: a model for manufacturing companies within the metal products industry in Sweden**
Author	**Ozgur Ozavci**
Academic supervisor	**Rūta Banelienė**

Thesis language: English

Annotation

The aim of this master's thesis is to develop an innovative model that evaluates the Industry 4.0 maturity level of manufacturing companies in the metal products industry in Sweden. The thesis structure consists of a comprehensive literature review, empirical research, and model development. A comprehensive scientific literature review is conducted to examine the challenges faced by enterprises, major factors and innovative solutions that may affect the successful implementation of Industry 4.0. Empirical research has been based on conducting questionnaires and aimed to determine the effective use of Industry 4.0 technologies, the importance of factors in the maturity model and the overall maturity level assessment. Industry 4.0 Maturity Model consists of 10 dimensions and 44 sub-dimensions with particular weights application. The developed model in this research is used to assess the Industry 4.0 maturity level of enterprises operating in the Metal Products Industry in Sweden.

The thesis consists of 7 parts: Introduction, Scientific Literature Review, Empirical Research, Model Development, Empirical Research Findings, Conclusions and Recommendations, and References.

The thesis consists of 78 pages of text without appendixes, 34 figures, 4 tables and 49 references. The appendixes are separately attached.

Keywords: Industry 4.0, manufacturing enterprises, metal products industry, model, maturity assessment, Sweden.

Vilniaus Gedimino technikos universitetas	ISBN	ISSN
Mechanikos fakultetas	Egz. sk.	
Mechanikos ir medžiagų inžinerijos katedra	Data ..........-.....-.....	

Antrosios pakopos studijų **Pramonės inžinerijos ir inovacijų vadybos** programos magistro baigiamasis darbas 4

Pavadinimas	**Pramonės 4.0 brandos vertinimas: modelis Švedijos metalo produktų pramonės gamybos įmonėms**
Autorius	**Ozgur Ozavci**
Vadovas	**Rūta Banelienė**

Kalba: anglų

Anotacija

Šio magistro darbo tikslas yra sukurti inovatyvų modelį, kuris įvertintų Pramonės 4.0 brandos lygį metalo produktų pramonės gamybos įmonėse Švedijoje. Darbo struktūrą sudaro išsami literatūros apžvalga, empirinis tyrimas ir modelio kūrimas. Išsami mokslinės literatūros apžvalga atliekama siekiant identifikuoti pagrindinius iššūkius, su kuriais susiduria įmonės, veiksnius ir inovatyvius sprendimus, kurie gali turėti įtakos sėkmingam Pramonės 4.0 įgyvendinimui. Empirinis tyrimas atliktas remiantis apklausomis ir jo tikslas buvo nustatyti Pramonės 4.0 technologijų efektyvų naudojimą, veiksnių svarbą brandos vertinimo modelyje ir bendrą brandos lygio vertinimą. Pramonės 4.0 brandos modelis susideda iš 10 dimensijų ir 44 subdimensijų su konkrečiomis svorių taikymo reikšmėmis. Šiame tyrime sukurtas modelis panaudotas Pramonės 4.0 brandos lygio Švedijos metalo produktų pramonės gamybos įmonėse vertinimui.

Darbas susideda iš 7 dalių: įvado, mokslinės literatūros apžvalgos, empirinio tyrimo, modelio kūrimo, empirinio tyrimo rezultatų, išvadų ir pasiūlymų, literatūros sąrašo.

Darbo apimtis: 78 puslapiai be priedų, 34 paveikslai, 4 lentelės ir 49 literatūros šaltiniai. Priedai yra pridedami atskirai.

Prasminiai žodžiai: Pramonė 4.0, gamybos įmonės, metalo produktų pramonė, modelis, brandos vertinimas, Švedija.

KTH Industrial Engineering and Management	Examensarbete TRITA-ITM-EX 2023:XXX **Bedömning av Industri 4.0:s mognadsgrad: En modell för tillverkande företag inom metallproduktindustrin i Sverige** Özgür Özavcı	
Godkänt 2023-06-01	Examinator Sofia Ritzén	Handledare Jenny Janhager Stier
	Uppdragsgivare	Kontaktperson

Sammanfattning

Syftet med denna masteruppsats är att utveckla en innovativ modell som utvärderar mognadsnivån på Industry 4.0 hos tillverkande företag inom metallproduktindustrin i Sverige. Uppsatsen består av en omfattande litteraturöversikt, empirisk forskning och modellutveckling. En omfattande vetenskaplig litteraturgenomgång genomfördes för att undersöka de utmaningar som företag står inför samt viktiga faktorer och innovativa lösningar som kan påverka en framgångsrik implementering av Industry 4.0. Den empiriska forskning en har baserats på genomförda frågeformulär som syftat till att fastställa den effektiva användningen av Industry 4.0-teknologier, betydelsen av faktorer i mognadsmodellen och den övergripande mognadsbedömningen. Industry 4.0:s mognadsmodell består av 10 dimensioner och 44 underdimensioner med speciell viktapplikation. Den utvecklade modellen i denna forskning används för att bedöma mognadsnivån på Industry 4.0 för företag som är verksamma inom metallproduktindustrin i Sverige.

Uppsatsen består av 7 delar: introduktion, vetenskaplig litteraturgranskning, empirisk forskning, modellutveckling, empiriska forskningsrön, slutsatser och rekommendationer samt referenser.

Uppsatsen består av 78 sidor text utan bilagor, 34 figurer, 4 tabeller och 49 referenser. Bilagorna bifogas separat.

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INTRODUCTION

The fourth industrial revolution, also known as digital transformation, is a global phenomenon that transforms the way companies operate and manage their businesses. Industry 4.0 involves the integration of advanced technologies such as big data analytics, Internet of Things (IoT), artificial intelligence into the production process, which provides increased productivity, efficiency, and flexibility (Peter et al., 2023). Enterprises that are willing to adopt these technologies are predicted to have a competitive advantage over others. The transformation of the manufacturing industry is an important priority for many countries, including Sweden, which has a strong manufacturing sector, particularly in the Metal products industry.

However, implementing Industry 4.0 is a complex process that presents several challenges for manufacturing enterprises and it requires overcoming various barriers and driving forces to successfully transition to Industry 4.0 (Bittencourt et al., 2021). Moreover, the Metal products industry is of strategic importance to the Swedish economy, with a long history of producing high-quality Metal products for domestic and international markets. Consequently, there is a need to understand the maturity levels of manufacturing enterprises operating in the Metal products sector in Sweden during the transition to Industry 4.0. While there are numerous studies on the implementation of Industry 4.0, no research has been identified on the readiness and maturity of manufacturing companies operating in the Metal products industry in Sweden.

The research problem. How to develop a comprehensive model to assess the Industry 4.0 maturity level of manufacturing enterprises in the Metal products industry in Sweden?

The aim of this thesis. The main goal is to develop an innovative model that evaluates the Industry 4.0 maturity level of manufacturing companies in the metal products industry in Sweden.

Objectives. In order to achieve the purpose of this research, the following will be covered in this work:

1. Analyse scientific literature to find out the challenges faced by enterprises, major factors and innovative solutions that can impact the successful implementation of Industry 4.0.
2. Conduct empirical research based on questionnaire and find out the impact of different factors on Industry 4.0 implementation in manufacturing enterprises operating in Sweden.

3. Develop and propose a structured model that aims to determine the Industry 4.0 maturity level of manufacturing enterprises operating in the metal products industry in Sweden and assess the overall I4.0 maturity level of the industry.

The methodology of investigation for this thesis involves a comprehensive literature review and the conduct of questionnaires. The literature review examines articles, journals, books, websites, etc., focusing on factors influencing successful adoption and innovative solutions related to the implementation of Industry 4.0 in the Metal products sector. The questionnaires targeted managers and employees in manufacturing companies in the sector. The collected data were analyzed using statistical techniques such as the Spearman correlation coefficient, using SPSS. Based on the findings from the literature review and existing models, an innovative model for assessing maturity levels was developed. The maturity dimensions and sub-dimensions in the developed model were determined from the literature and expert opinions. The overall maturity level of the Metal products sector in Sweden was assessed using the developed model and data obtained from the surveys.

This master's thesis is structured in six parts, as follows.

Table 1. Thesis structure

Section	Description
1. Introduction	An overview of the research problem and objectives, background to the study, and research questions.
2. Scientific Literature Review on I4.0	Examination of existing literature on Industry 4.0, including factors impacting successful implementation, challenges, existing maturity models.
3. Empirical Research	Explaining research approach, questionnaire preparation, data collection tools and methods, and data analysis processes.
4. Model Development	Description of the innovative model for determining the maturity of manufacturing enterprises in the Metal products sector.
5. Empirical Research Findings	Presentation of the findings of the surveys included in the empirical study, summaries

	of the data, the overall maturity level of the industry I4.0 using the developed model, and the main results.
6. Conclusions and Recommendations	Summary of main findings, recommendations for future research.

Source: prepared by author

The master's thesis begins with an Introduction, which offers an overview of the research problem and objectives. It provides background information on Industry 4.0, emphasizing its relevance and significance. The section also establishes the research questions that will guide the study. Following this, the Scientific Literature Review on I4.0 examines the existing body of literature on Industry 4.0. It encompasses factors influencing successful implementation, challenges faced, and available maturity models. This review synthesizes prior knowledge, establishing a solid theoretical foundation. The Empirical Research section (2. section) explains the research approach adopted, including questionnaire preparation, data collection tools and methods, and data analysis procedures. The subsequent section, Empirical Research Findings, presents the outcomes derived from the conducted questionnaires. It includes data summaries, overall industry maturity levels using the developed model, and key findings. The thesis further introduces the innovative model for determining the maturity of manufacturing enterprises in the Metal products sector in the Model Development section. Lastly, the Conclusions and Recommendations section summarizes the main findings and proposes future research directions. Collectively, these sections provide a comprehensive framework for the master's thesis, addressing the research problem, reviewing existing literature, presenting empirical findings, and offering recommendations for further study.

1. A SCIENTIFIC LITERATURE REVIEW ON INDUSTRY 4.0

1.1. General framework on industry 4.0

Industry 4.0 represents the fourth industrial revolution that symbolizes the digital transformation of various industries, including manufacturing and production. The three previous industrial revolutions were mass production, mechanical manufacturing, and finally the digital revolution. The adoption of automated control systems and new industrial technology has created wide opportunities to enhance production processes' efficiency through cloud computing (Dikhanbayeva et al., 2020). However, implementing Industry 4.0 has been challenging, primarily due to the lack of foundational understanding regarding its concepts, benefits, and advantages (Ejsmont et al., 2020). Companies aiming to undergo digital transformation must possess robust capabilities to bring about changes in their operations and processes (Da Silva et al., 2020; Westerman et al., 2014). To tackle this challenge, the design principles (DPs) of Industry 4.0 play a pivotal role in enterprises' and organizations' digital transformation. To evaluate business processes, maturity models (MMs) are widely employed tools that assess organizations' strengths and weaknesses from various perspectives critical for digital technology adoption. MMs may connect with the fundamental ideas of Industry 4.0 by concentrating on DPs, which acts as a sign of an in-depth MM. For an accurate evaluation, successful implementation of Industry 4.0 technology, and long-term growth of the business, these DPs must be implemented (Dikhanbayeva et al., 2020).

Dikhanbayeva et al. (2020) conducted a study to assess the effectiveness of different Industry 4.0 maturity models based on design principles. Their findings showed that the design principles should be aligned with Industry 4.0 concepts to ensure successful implementation. The study by Dikhanbayeva et al. (2020) aimed to assess the effectiveness of different Industry 4.0 maturity models based on design principles. The authors argued that successful implementation of Industry 4.0 requires a clear understanding of the key design principles that underlie the concept. Therefore, they evaluated four different Industry 4.0 maturity models using these design principles as a framework. The design principles assessed in the study were service orientation, virtualization, interoperability, modularity, decentralization, and real-time capability (Ruppert et al., 2022). The authors found that the effectiveness of the maturity models varied depending on how well they aligned with these design principles.

In their investigation into how Industry 4.0 ideas are being implemented in businesses, Da Silva et al. (2020) discovered that organizational elements including top management support, employee participation, and organizational culture are essential for the adoption of Industry 4.0 principles to be effective. The study by Da Silva et al. (2020) aimed to investigate the implementation of Industry 4.0 concepts in companies and identify the critical factors that contribute to successful implementation. The application of Industry 4.0 concepts was dependent on a number of organizational elements, which the authors discovered after conducting a literature study. One of the most important factors identified by the authors was top management support. The authors found that top management support was essential for the successful implementation of Industry 4.0 concepts because it provides the necessary resources and leadership to drive change throughout the organization.

Horváth & Szabó (2019) identified driving forces and barriers to Industry 4.0 adoption and implementation, finding that factors such as leadership, technological infrastructure, and employee skills were critical to the success of implementation. The goal of the Horváth and Szabó (2019) study was to determine the factors that encourage and inhibit the adoption of Industry 4.0 ideas. The authors reviewed the literature and examined the major elements affecting the adoption and use of Industry 4.0. The authors discovered that a number of factors were essential for the effective acceptance and use of Industry 4.0 principles. One of the most important driving forces was leadership, which included factors such as vision, strategic planning, and top management support. The authors argued that strong leadership is critical to driving change throughout the organization and creating a culture of innovation and continuous improvement.

Rauch et al. (2019) identified requirements and barriers to implementing smart manufacturing in SMEs. Their findings showed that factors such as data security, employee skills, and organizational culture were critical to successful implementation. The authors found that several requirements were critical to the successful implementation of smart manufacturing in SMEs. One of the most important requirements was data security. The authors argued that SMEs must implement robust data security measures to protect their sensitive information from cyber threats and data breaches. This is particularly important given the increasing frequency and sophistication of cyber-attacks targeting SMEs.

Akdil et al. (2018) proposed a maturity and readiness model for Industry 4.0 strategy. Their study identified key factors such as leadership, employee skills, and technological infrastructure as important to successful implementation. The authors proposed a maturity and readiness model that includes four levels of Industry 4.0 implementation: initiation, development, deployment, and sustainability. Each level includes specific criteria and indicators that organizations can use to assess their progress towards successful implementation. The authors argued that strong leadership is critical to driving change throughout the organization and creating a culture of innovation and continuous improvement.

Ghobakhloo (2018) cited key technologies as the Internet of Things, artificial intelligence, and big data analytics in his strategy roadmap as being necessary for Industry 4.0 adoption. The objective of the Ghobakhloo (2018) research was to create a strategic roadmap for Industry 4.0 deployment. The author reviewed the available literature and examined case studies of businesses that have adopted Industry 4.0 strategies.

Habib & Chimsom (2019) studied the impact of Industry 4.0 on sustainability and design principles. They discovered that taking sustainability and design principles into account at the outset of implementation is essential for the successful implementation of Industry 4.0 concepts. Habib & Chimsom (2019) conducted a study to investigate the impact of Industry 4.0 on sustainability and design principles. The authors investigated the connection between Industry 4.0 and sustainability, putting a focus on the necessity for businesses to take sustainability and design principles into account at the outset of implementation. According to the study , Industry 4.0 may support sustainable growth, but only if sustainability and design principles are taken into account at the beginning. In order to successfully execute Industry 4.0, the authors advised enterprises to use a comprehensive strategy that takes into account both technological and non-technological components of the initiative, such as social and environmental sustainability.

Ejsmont et al. (2020) conducted a literature review on the impact of Industry 4.0 on sustainability. Their findings showed that technologies such as green energy and circular economy could help to achieve sustainability goals while implementing Industry 4.0 principles. A literature review was carried out by Ejsmont et al. (2020) to investigate how Industry 4.0 would affect sustainability. With an emphasis on how Industry 4.0 technologies may aid in sustainable development, the research investigated the connection between Industry 4.0 and sustainability. The authors identified green energy and circular economy as key technologies that could help to achieve sustainability goals while implementing Industry 4.0 principles. They also emphasized the importance of addressing potential negative impacts, such as increased resource consumption and environmental degradation, through careful planning and management. According to the study, Industry 4.0 has the potential to help achieve sustainability goals, but both its advantages and disadvantages need to be carefully considered before adoption.

These studies highlight a number of variables and technological advancements that may affect how well Industry 4.0 principles are used. Successful implementation requires a comprehensive approach that considers organizational, technological, and sustainability factors.

1.2. Factors and technologies for successful industry 4.0 implementation

In the three industrial revolutions before the Industry 4.0 revolution, the process that started with primitive methods was tried to increase productivity in production with both mechanical and technical skills and finally information technology processes (Dikhanbayeva et al., 2020). In the first industrial revolution, people tried to increase productivity through the use of steam power and hydroelectricity, in the second industrial revolution, they increased productivity through mass production, and finally, in the third industrial revolution, an information technology-based production model was developed by discovering automation (Fragapane et al., 2022)

The term Industry 4.0, which is also called next generation automation, is a set of studies aimed at adding a new value to all organisation stages in the life cycle of the products produced, developing and integrating them into processes based on information Technologies (Stock & Seliger, 2016). This concept refers to a process that covers the time from the production idea of the product to the end user's use of the product as well as recycling (Gilchrist, 2016). As part of the Industry 4.0 revolution, which offers a new production model, internet-based technologies are integrated throughout the entire production system, the automation system causes significant changes, and the relationship among the virtual and physical worlds is strengthened (Fonseca et al., 2021).

First, it will be important for companies to develop a comprehensive strategy for the introduction of Industrie 4.0 that takes into account both technological and organisational aspects. This includes, for example, training for employees, the integration of IT systems and the definition of clear responsibilities (Dikhanbayeva et al., 2020). Another important role is played by the available technologies that can be used for Industrie 4.0. These include, for example, artificial intelligence (AI), Internet of Things (IoT), Big Data and cloud computing. By using these technologies, companies can automate their processes, optimise them and make them more flexible. Another factor that will influence the success of Industrie 4.0 is the availability of skilled workers. Companies must be able to hire employees with the necessary skills and knowledge or train existing employees accordingly (Rauch et al., 2019).

The security of data and systems will also play an important role. As many processes and machines are interconnected, the risk of cyber attacks and data loss increases. Companies must therefore take appropriate measures to protect their systems and data. Finally, collaboration within supply chains and between companies will also play an important role. By working closely together, companies can better coordinate their processes and thus achieve greater efficiency and flexibility (Akdil et al., 2018). Overall, the success of Industrie 4.0 will depend on a combination of technology, strategy, skilled workers, security and collaboration. Companies that take these factors into account and act accordingly have a good chance of reaping the benefits of Industry 4.0 and increasing their competitiveness. The use of innovative technologies in numerous production processes defines the industrial revolution. These technologies include artificial intelligence, the Internet of Things (IoT), automation, big data analytics, and cloud computing. However, the successful implementation of Industry 4.0 principles can be impacted by several factors, including lack of skilled workforce (Horváth & Szabó, 2019).

A skilled workforce is essential for the successful implementation of Industry 4.0, which involves the integration of physical and digital systems, including the Internet of Things (IoT), artificial intelligence (AI), and robotics. However, there is a serious skills gap in the industrial sector, and there aren't enough skilled individuals to run and manage these advanced technologies (Dikhanbayeva et al., 2020). This shortage of skilled workers is a significant challenge for companies seeking to adopt Industry 4.0. There are several reasons for this lack of skilled labor in Industry 4.0. First of all, workers find it challenging to keep up with the most recent technological developments due to the rapid rate of change. Secondly, the required skillset for Industry 4.0 is more complex than traditional manufacturing, requiring a combination of technical, digital, and analytical skills. Finally, there is a widespread belief among younger generations that manufacturing is a low-skilled profession, which dissuades them from pursuing careers in this field (Da Silva et al., 2020).

To address the shortage of skilled workers in Industry 4.0, companies must take proactive steps to develop their workforce (Dikhanbayeva et al., 2020). This can include investing in training programs and upskilling current employees, partnering with educational institutions to develop programs that align with Industry 4.0 requirements, and developing apprenticeships and internships to attract and train new talent. Governments can also play a role in addressing the skills gap by investing in education, providing incentives for companies to invest in workforce development, and promoting careers in manufacturing and technology. Overall, addressing the shortage of skilled workers in Industry 4.0 is crucial for companies and economies to fully realize the potential of these advanced technologies (Horváth & Szabó, 2019).

The successful implementation of Industry 4.0 principles can be impacted by several factors, such as Cybersecurity Risks. Industry 4.0 involves the integration of physical and digital systems, which creates new opportunities for businesses to optimize their processes and increase efficiency. However, it also introduces new cybersecurity risks that need to be addressed (Ghobakhloo, 2018).

The proliferation of internet-connected devices in Industry 4.0 provides hackers with more potential entry points into a company's network. If these devices are not properly secured, they can be easily compromised, providing a gateway for cybercriminals to access sensitive data and systems. The use of advanced technologies in Industry 4.0 also increases the risk of malware and ransomware attacks (Dikhanbayeva et al., 2020). Attacks of this nature can seriously impair a company's operations, leading to downtime and financial losses. The integration of physical and digital systems in Industry 4.0 requires a high level of collaboration between different teams and departments. This increased collaboration also creates new opportunities for insider threats, such as employees with privileged access to critical systems who may be motivated by financial gain or other malicious intentions. Industry 4.0 involves complex supply chains that often rely on third-party suppliers and partners. These partners may not have the same level of cybersecurity measures in place, which can create vulnerabilities that can be exploited by cybercriminals (Rauch et al., 2019).

To mitigate these cybersecurity risks, companies must take a proactive approach to security. This can include implementing multi-layered cybersecurity measures, such as firewalls, intrusion detection systems, and encryption. Additionally, companies must educate their employees about the importance of cybersecurity and the potential risks associated with Industry 4.0. Companies should also regularly update and patch their systems and software, perform regular vulnerability assessments and penetration testing, and develop an incident response plan in case of a cyber attack (Shah & Mehtre, 2015).

Finally, companies should carefully vet their third-party suppliers and partners to ensure they have appropriate cybersecurity measures in place (Horváth & Szabó, 2019). In summary, while Industry 4.0 offers many benefits to businesses, it also introduces new cybersecurity risks that must be addressed through a multi-faceted and proactive approach to security. The integration of IoT devices and other advanced technologies into manufacturing processes can create vulnerabilities that can be exploited by hackers (Li et al., 2021). This can lead to cyber attacks, which can result in data breaches, operational disruptions, and financial losses. The implementation of Industry 4.0 requires the integration of various technologies and processes across different systems, which can be challenging. The integration of legacy systems with modern technology can lead to compatibility issues that can hinder the implementation process. Integrating physical and digital systems is a key component of Industry 4.0, which provides businesses with a number of integration issues. There are some of the key integration challenges in Industry 4.0:

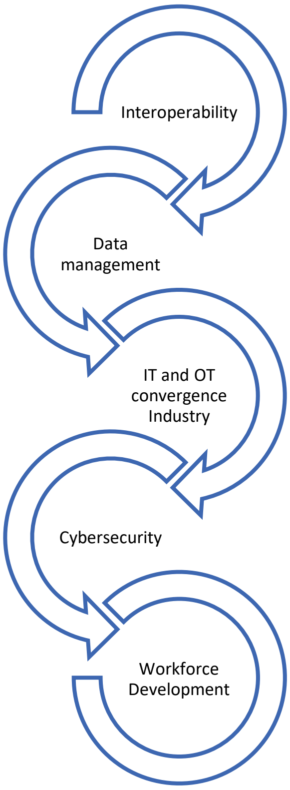


Fig. 1. The key integration challenges in industry 4.0

Source: prepared by author, based on Lu (2017)

Interoperability: Industry 4.0 involves the integration of various technologies and systems, which may not be designed to work together. This can create interoperability issues, where different systems cannot communicate or exchange data effectively (Dikhanbayeva et al., 2020).

Data management: Industry 4.0 generates large volumes of data from sensors, machines, and other sources. Managing this data and ensuring its quality, security, and accessibility can be challenging, especially when data is collected from multiple sources and systems (Horváth & Szabó, 2019).

IT and OT convergence: Industry 4.0 requires the convergence of information technology (IT) and operational technology (OT) systems, which have traditionally been managed separately. This convergence requires changes in organizational structures, processes, and culture, which can be challenging to implement (Horváth & Szabó, 2019).

Cybersecurity: As Industry 4.0 involves the integration of digital systems, cybersecurity risks also increase. Ensuring the security of data, systems, and networks is critical but can be challenging due to the complexity of Industry 4.0 environments. The integration of digital systems in Industry 4.0 introduces new cybersecurity risks that can compromise the security and confidentiality of data, systems, and networks (Horváth & Szabó, 2019). There are some of the key cybersecurity risks associated with Industry 4.0. Hackers and other cybercriminals can leak Industry 4.0 systems and networks without authorization using a variety of approaches, including exploiting holes in software and hardware, obtaining login information, and social engineering. Industry 4.0 generates large volumes of data from sensors, machines, and other sources. Sensitive information, including business secrets, patents, and personal information, can be made available to unauthorized people or institutions through a data breach (Abomhara & KøIen, 2015). Malicious software such as malware and ransomware can attack Industry 4.0 systems and seriously harm them. Malware can disrupt operations, steal data, or provide unauthorized access to systems, while ransomware can encrypt data and demand payment for its release. Industry 4.0 involves the integration of multiple suppliers and vendors, which can increase the risk of supply chain attacks. These attacks involve compromising the security of a supplier or vendor and using their access to gain unauthorized access to the target system or network. Human error, such as accidental data deletion, misconfiguration of systems, or falling for phishing scams, can also compromise the security of Industry 4.0 systems (Da Silva et al., 2020).

To address these cybersecurity risks, companies should implement a comprehensive cybersecurity strategy that includes the following elements (Horváth & Szabó, 2019). In general, maintaining the cybersecurity of Industry 4.0 networks and systems is essential to the accomplishment and viability of Industry 4.0 activities. To safeguard their data, systems, and networks from online attacks, businesses should invest in cybersecurity solutions.

Implementing Industry 4.0 requires a skilled workforce with the knowledge and expertise to manage and operate these systems. However, there is currently a shortage of skilled workers in this field, which can create challenges in finding and training the necessary personnel (Fahim et al., 2019; Schwab, 2017).

Workforce Development: Workforce development in Industry 4.0 refers to the various strategies and initiatives undertaken by companies and organizations to prepare their employees and other stakeholders for the new and emerging technological advancements and changes associated with Industry 4.0. This can involve a range of activities, such as providing training and development opportunities for workers to acquire new skills and knowledge, reorganizing work processes and structures to accommodate new technologies, and investing in new technologies to support workforce development and productivity (Li et al., 2021).

To overcome these integration challenges, companies must take a systematic and strategic approach to implementation (Pessl, 2017). This may involve conducting a thorough analysis of the existing systems, processes, and infrastructure, identifying integration opportunities, and developing a roadmap for implementation. To enable the successful integration of many technologies, businesses must also invest in the appropriate infrastructure, such as sensors, interaction and data analytics tools. Additionally, companies should focus on developing a skilled workforce that can manage and operate these systems and ensure cybersecurity measures are in place to protect data and systems. Overall, addressing integration challenges is crucial for companies to successfully implement Industry 4.0 and reap the benefits of increased efficiency, productivity, and innovation (Bhatia & Kumar, 2020).

A large investment in infrastructure and technology is needed to achieve Industry 4.0. For small and medium-sized enterprises (SMEs), the cost of implementing Industry 4.0 can be a barrier to adoption. The cost of implementing Industry 4.0 varies depending on the size of the company, the scope of the implementation, and the technologies and processes involved. Implementing Industry 4.0 involves the integration of various technologies, such as IoT devices, sensors, cloud computing, and big data analytics. These technologies require investments in hardware, software, and networking infrastructure (Fragapane et al., 2022)

Implementing Industry 4.0 requires a skilled workforce with the knowledge and expertise to manage and operate these systems. Companies may need to invest in training programs, recruitment efforts, and competitive compensation packages to attract and retain the necessary personnel. Industry 4.0 generates large volumes of data that need to be managed effectively (Li et al., 2021). This may require investments in data storage, security, and analytics tools to ensure the quality, security, and accessibility of the data. As Industry 4.0 involves the integration of digital systems, cybersecurity risks also increase. To safeguard data and systems from cyber attacks, businesses may need to make investments in cybersecurity solutions like firewalls, intrusion detection systems, and encryption. Implementing Industry 4.0 may require changes in organizational structures, processes, and culture to support the integration of different systems and the use of data and analytics in decision-making. These changes may require investments in change management and organizational development initiatives (Akdil et al., 2018).

Overall, implementing Industry 4.0 can involve significant upfront costs, but these costs may be offset by the potential benefits of increased efficiency, productivity, and innovation. To decide on the extent and pace of Industry 4.0 deployment, businesses should perform a detailed study of the costs and advantages. (Gilschrist, 2016).

The usage of data in Industry 4.0 raises questions about data security and privacy. To avoid facing legal and financial repercussions, manufacturers must abide by several data protection and privacy laws. Industry 4.0 uses data produced by sensors, equipment, and other sources, which poses questions about data security and privacy.

The absence of standardized protocols and frameworks in Industry 4.0 technologies can give rise to challenges in interoperability, impeding seamless communication between disparate systems. Manufacturers may be locked into specific vendors or technologies due to the lack of interoperability between different systems. This can limit their ability to switch to other vendors or technologies in the future. The lack of standardization can increase the complexity of Industry 4.0 environments, requiring manufacturers to develop custom solutions to integrate different systems. Custom integration solutions can be costly to develop and maintain, increasing the overall cost of Industry 4.0 initiatives (Li et al., 2021).

By adopting these standards and protocols, manufacturers can ensure interoperability between different systems and reduce the complexity and cost of Industry 4.0 initiatives. It's crucial to remember that these standards and protocols are currently being developed and might not be able to handle all interoperability issues in Industry 4.0. Therefore, manufacturers should stay up to date with the latest standards and protocols and work with their vendors to ensure interoperability between different systems (Wang et al., 2018).

To overcome these challenges, manufacturers must adopt strategies that include employee training programs, implementation of robust cybersecurity measures, investing in compatible technologies, partnering with technology providers, and complying with relevant regulations. Industry 4.0 requires a holistic approach that combines people, processes, and technology to achieve a successful implementation (Da Silva et al., 2020).

In conclusion, the successful implementation of Industry 4.0 principles requires a careful consideration of a wide range of factors and technologies. Companies can improve their operations, boost productivity, and maintain competitiveness in an increasingly digital and connected world by being aware of these issues and deploying the right technology (Li et al., 2021).

1.3. Industry 4.0 awareness of manufacturers

In general, larger manufacturers with more resources and exposure to global markets are more aware of Industry 4.0 than smaller ones. Many manufacturers recognize the potential benefits of Industry 4.0, such as increased productivity, improved quality control, and reduced costs (Fonseca et al., 2021; Fahim et al., 2019).

However, because of the alleged high costs and ambiguity regarding the return on investment, some people could be reluctant to invest in the essential technology and infrastructure. Governments and industry associations in some countries have launched initiatives and campaigns to raise awareness of Industry 4.0 among manufacturers and provide support for their digital transformation (Butt, 2020). This includes providing training and funding programs to help manufacturers adopt advanced technologies and improve their competitiveness in the global market. Overall, it is expected that the level of awareness and acceptance of Industry 4.0 among manufacturers will increase in the coming years as more businesses realize the benefits of digital transformation and the importance of maintaining competitiveness in the rapidly changing global economy. Additional information on manufacturers' knowledge of Industry 4.0 is available (Ejsmont et al., 2020; Ghobakhloo, 2018).

In order to enhance their operations and competitiveness, SMEs may also profit from digital transformation and use cutting-edge technology (Li et al., 2021). However, SMEs may face additional challenges such as lack of resources and technical expertise, which can limit their adoption of Industry 4.0. The level of Industry 4.0 awareness also varies by industry sector. For example, manufacturers in the automotive, aerospace, and electronics industries have been early adopters of advanced technologies due to their high-tech nature and the need for precision and efficiency. Other sectors, such as construction and food manufacturing, may be slower to adopt Industry 4.0 due to their traditional and labor-intensive nature. The COVID-19 pandemic has boosted manufacturers' adoption of Industry 4.0, as companies seek to automate processes and reduce their reliance on human labor to maintain social distancing and ensure business continuity. This has led to an increased interest in robotics, AI, and other advanced technologies (Da Silva et al., 2020; Zeng et al., 2020).

Industry 4.0 calls for a change in corporate culture and thinking in addition to technology. Manufacturers need to adopt a data-driven approach and embrace innovation and continuous improvement to fully realize the benefits of digital transformation. This requires leadership commitment, employee training, and a willingness to experiment and learn from failures. The increase of Industry 4.0 awareness and acceptance among manufacturers may be greatly aided by governments and academic organizations. This includes providing education and training programs, funding research and development, and creating supportive policy frameworks to incentivize investment in advanced Technologies (Schwab, 2017; Kuo et al., 2019).

In conclusion, the awareness of Industry 4.0 among manufacturers is growing, but there is still a long way to go to fully realize the potential of digital transformation. Companies that embrace innovation and adopt advanced technologies are likely to be more competitive and resilient in the global market (Horváth & Szabó, 2019).

1.4. Innovations for manufacturers in industry 4.0

"Innovations for manufacturers in Industry 4.0" refers to new and advanced technologies that are transforming the manufacturing industry by improving productivity, efficiency, and quality. The driving factor behind these advancements is the fourth industrial revolution, which is characterized by the integration of cutting-edge technologies like the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, and Cloud Computing into the manufacturing process. Here are some examples of innovations that are transforming the manufacturing industry in the context of Industry 4.0: (Wang et al., 2018).

Industrial IoT (IoT): To enhance manufacturing processes, raise product quality, and decrease downtime, the IoT is a network of interconnected devices and sensors that can interact with one another and the cloud (Wójcicki et al., 2022). IoT can enable real-time monitoring, predictive maintenance, and remote control of machines, among other benefits. The Internet of Things (IoT) is a network of interconnected sensors and equipment that may communicate with one another and the cloud to improve product quality, speed up production processes, and reduce downtime. IoT can enable real-time monitoring, predictive maintenance, and remote control of machines, among other benefits. By using IoT, manufacturers can gather data from machines and sensors, analyze that data in real-time, and use insights to make data-driven decisions. For example, IoT can be used to predict when a machine is likely to fail, allowing maintenance to be scheduled before the machine breaks down and causes production downtime (Fahim et al., 2019; Schwab, 2017).

Artificial Intelligence (AI): AI can be used in manufacturing to automate and optimize production processes, identify patterns and anomalies in data, and enhance product quality. Illustratively, quality control systems empowered by artificial intelligence have the capability to identify defects and anomalies in products that would pose challenges for human detection. Artificial intelligence (AI) can be applied to manufacturing to improve product quality, find patterns and anomalies in data, and automate and optimize production processes. AI may be used, for instance, to evaluate production data to find patterns and trends that can point to inefficiencies or quality problems. By anticipating the best settings for machines and equipment, AI may also be used to streamline manufacturing processes. This can increase productivity and cut down on waste. Furthermore, AI-driven quality control systems are able to find product flaws and abnormalities that would be challenging for humans to notice (Dikhanbayeva et al., 2020).

Augmented Reality (AR): AR can be used to enhance the efficiency and accuracy of manufacturing processes by overlaying digital information onto the physical environment. For example, AR can be used to provide real-time instructions to workers or to enable remote collaboration and training (Ejsmont et al., 2020). AR can be used to enhance the efficiency and accuracy of manufacturing processes by overlaying digital information onto the physical environment. For example, AR can be used to provide real-time instructions to workers or to enable remote collaboration and training. AR can also be used to simulate and optimize production processes, allowing manufacturers to identify potential issues and inefficiencies before they occur (Fahim et al., 2019; Schwab, 2017).

As a result, these technologies are reshaping the industrial sector in the framework of Industry 4.0 and enabling firms to boost their efficiency, become more competitive, and raise the caliber of their output. Manufacturers can acquire a competitive edge in a market that is rapidly changing by implementing these technologies (Dikhanbayeva et al., 2020).

1.5. Challenges, obstacles and driving forces in the metal products industry

The metal products industry is one of the oldest and largest industries in the world, and it is facing significant challenges in implementing Industry 4.0. Here are some of the challenges, obstacles, and driving forces faced by companies in the Metal products industry in implementing Industry 4.0: (Wang et al., 2018).

Challenges:

Metal products companies face a number of challenges when implementing Industry 4.0 technologies. One of the major challenges is legacy equipment and infrastructure (García et al., 2022). Many of these companies have aging equipment and infrastructure that is not compatible with modern technologies such as IoT, AI, and Big Data. This can make it difficult to integrate new technologies and create a seamless digital ecosystem. Another challenge is the complexity of production processes. Metal production involves complex and highly interdependent processes, which can make it difficult to implement new technologies without disrupting the entire production process. Additionally, the complexity of these processes makes it challenging to gather and analyze data from different parts of the production process. A third challenge is cybersecurity concerns. Metal products companies are highly vulnerable to cyber-attacks due to the sensitive nature of their operations and the critical infrastructure they operate. As such, implementing new technologies without robust cybersecurity measures can pose a significant risk to the company's operations and reputation (Ejsmont et al., 2020).

Obstacles:

Lack of skilled workforce: Implementing Industry 4.0 technologies requires a highly skilled workforce, which is often in short supply in the Metal products industry. Finding and training workers with the necessary skills to operate and maintain new technologies can be a significant obstacle (Majumdar et al., 2021).

Resistance to change: Many workers and managers in the Metal products industry are accustomed to traditional methods and may be resistant to change. Implementing new technologies requires a cultural shift, which can be difficult to achieve.

Cost: Implementing Industry 4.0 technologies can be expensive, particularly for companies with aging infrastructure. The cost of upgrading equipment and infrastructure, as well as training workers, can be a significant obstacle (Dikhanbayeva et al., 2020).

Driving Forces:

Industry 4.0 technology adoption in the metal products industry has been driven by a number of factors. First off, the market is fiercely competitive, and businesses that resist adopting new technology run the danger of falling behind their rivals. Companies may improve productivity and save costs by embracing Industry 4.0 technology, providing them a competitive edge in the global market. Second, clients are expecting speedy delivery of personalized, high-quality goods. Industry 4.0 technology can help firms satisfy these goals more successfully and efficiently. Finally, the Metal products industry is a significant contributor to environmental concerns, such as greenhouse gas emissions. Industry 4.0 technologies can assist companies in reducing their environmental impact by optimizing production processes and minimizing waste. Despite the challenges and obstacles involved in implementing Industry 4.0 technologies, it is critical for Metal products companies to adapt and leverage the benefits of these technologies to improve efficiency, reduce costs, and stay competitive in the global marketplace (Horváth & Szabó, 2019).

1.6. Innovative solutions against these challenges and obstacles

There have been several innovative solutions developed and implemented to address the challenges and obstacles faced by companies in the Metal products industry in implementing Industry 4.0 technologies:

Legacy equipment and infrastructure: To address the challenge of integrating new technologies with outdated equipment, some companies have developed solutions that allow for retrofitted IoT sensors to be added to existing machines. This approach avoids the need for expensive equipment upgrades and allows companies to collect and analyze data from legacy equipment. One solution is to use IoT sensors that can be retrofitted onto existing machines to collect data, monitor performance, and optimize maintenance. Another solution is to use edge computing that can be deployed at the machine level to process data locally and reduce the need for expensive infrastructure upgrades (Wang et al., 2018).

Complexity of production processes: To address the complexity of production processes, some companies have developed digital twin technologies that simulate the production process. These digital models enable companies to test and optimize new technologies without disrupting the actual production process. Additionally, some companies have implemented advanced analytics and AI to improve process optimization and decision-making. Digital twins can be developed to simulate the production process, allowing for testing and optimization of new technologies without disrupting the actual production process. Advanced analytics and machine learning algorithms may also be used to find and fix manufacturing process bottlenecks and inefficiencies (Ejsmont et al., 2020).

Cybersecurity concerns: In order to mitigate cybersecurity risks, organizations have implemented a diverse array of security measures, such as firewalls and event management (SIEM) systems. Additionally, some companies have implemented blockchain technology to secure data and transactions. Blockchain technology may be used to protect data and transactions, as well as secure data storage and sharing protocols. Additionally, security-by-design practices can be implemented to embed security in every step of the technology development process (Horváth & Szabó, 2019).

Lack of skilled workforce: To address the shortage of skilled workers, some companies have developed training programs to upskill their existing workforce. Additionally, some companies have partnered with educational institutions to develop specialized training programs for Industry 4.0 technologies (Li, 2022). Some companies have also implemented collaborative robots or "cobots" to help address the labor shortage. Training programs can be developed to upskill existing workers and educate them on new technologies. Collaborative robots, or cobots, can be introduced to assist workers with repetitive or dangerous tasks and free up time for higher-value work (Horváth & Szabó, 2019).

Resistance to change: Change management programs can be developed to prepare employees for the transition to Industry 4.0. These programs can include training, communication, and incentives to encourage employees to embrace new technologies. To address resistance to change, some companies have developed change management programs to prepare their employees for the transition to Industry 4.0. These programs can include training, communication, and incentives to encourage employees to embrace new technologies (Dikhanbayeva et al., 2020).

Cost: Shared service models can be implemented where companies collaborate with each other to share the cost of implementing new technologies (Da Silva et al., 2020; Han & Trimi, 2022).

Additionally, pilot projects can be used to test and optimize new technologies before scaling up to reduce costs and risks. To address the cost of implementing new technologies, some companies have implemented phased approaches, where they start with small pilot projects to test and optimize new technologies before scaling up. Additionally, some companies have implemented shared service models where they collaborate with other companies to share the cost of implementing new technologies (Ejsmont et al., 2020).

These studies demonstrate the breadth of innovative solutions being developed and implemented to address a wide range of challenges and obstacles. By continuing to explore and invest in these solutions, we can work towards creating a more sustainable, equitable, and just society (Da Silva et al., 2020; Morrar & Arman, 2017).

In conclusion, these solutions include retrofitting legacy equipment, digital twins, cybersecurity measures, upskilling programs, change management programs, and phased approaches. By adopting these innovative solutions, companies can overcome the challenges and obstacles and reap the benefits of Industry 4.0 technologies.

1.7. Examination of previously developed maturity models

To implement Industry 4.0 successfully, examining previously developed models is crucial as it allows companies to avoid duplicating efforts and learn from others' experiences. Smart factory models, such as the Reference Architecture Model Industrie 4.0 (RAMI 4.0) and the Industrial Internet Reference Architecture (IIRA), offer a framework for integrating different systems and technologies in a smart factory environment. On the other hand, digital twin models provide virtual representations of physical objects, systems, or processes to simulate and analyze their performance. A digital twin model has three components, namely, the physical object or system, the virtual model, and the data that connects them. Digital twins are used to enhance product design, optimize manufacturing processes, and predict maintenance needs. By utilizing these previously developed models, companies can efficiently and effectively implement Industry 4.0 technologies in their operations (Fahim et al., 2019; Schwab, 2017; Dikhanbayeva et al., 2020; Horváth & Szabó, 2019).

There are several examples of digital twin models that have been developed for Industry 4.0 applications. Cloud computing models have been developed to enable secure and efficient data storage and processing. Examples of cloud computing models include Amazon Web Services (AWS), Microsoft Azure, and Google Cloud. AR and VR models have been developed for various applications, including worker training, remote collaboration, and virtual product design (Eswaran & Bahubalendruni, 2022). Some examples of AR and VR models include Microsoft HoloLens, Oculus Quest, and Unity (Dikhanbayeva et al., 2020). Cybersecurity models have been developed to address the security challenges associated with Industry 4.0 technologies. Examples of cybersecurity models include the NIST Cybersecurity Framework, ISO/IEC 27001, and the IEC 62443 series. By examining these previously developed models, companies can gain insights into best practices, potential pitfalls, and lessons learned from real-world implementations. This can help companies avoid common mistakes and accelerate their own implementation of Industry 4.0 technologies (Horváth & Szabó, 2019).

The study conducted by Gajdzik (2022) aimed to develop a maturity model framework for Industry 4.0 and assess the maturity levels of steel enterprises in Poland. The study found that there are several maturity models available in the literature, but none of them were fully applicable to the steel industry. Therefore, the author proposed a new maturity model framework that consists of six domains: strategy, organization and culture, processes, products and services, human resources, and technology. The framework was applied to 20 steel enterprises in Poland, and their maturity levels were assessed based on the proposed domains. The results showed that the overall maturity level of the steel industry in Poland is still low, with the highest maturity level being in the technology domain. The study also identified several challenges and obstacles that hinder the implementation of Industry 4.0 in the steel industry, including the lack of awareness and knowledge, inadequate financial resources, and the shortage of skilled workforce. The study indicates the need of creating industry-specific maturity models to measure organizations' preparation for Industry 4.0 and offers useful insights into the maturity of the Polish steel sector in terms of sector 4.0 implementation. The study's conclusions can assist Polish steel companies and those in comparable nations in identifying their implementation of Industry 4.0 strengths and shortcomings and in developing plans to raise their degrees of maturity in this area.

Rafael et al. (2020) present an Industry 4.0 maturity model for machine tool firms in their study. From Level 1, which is characterized by a low level of automation and digitalization, to Level 5, which represents full integration and optimization of all processes and technologies, the model consists of five maturity levels that represent the degree of implementation of Industry 4.0 practices and technologies in a company. The study uses a case study approach to apply the maturity model to four machine tool companies in Spain. The findings indicate that the model is beneficial for measuring organizations' level of Industry 4.0 maturity and suggesting opportunities for development. The study finds that the companies have different levels of maturity, with some being more advanced than others. The study also identifies some common challenges faced by the companies, such as the need for better data management and analysis, the development of new skills and competencies among employees, and the integration of different systems and technologies. Overall, the study suggests that the Industry 4.0 maturity model can be a useful tool for machine tool companies to assess their current level of Industry 4.0 implementation and to develop a roadmap for future improvements. The model can also help companies to identify best practices and benchmark their performance against other companies in the industry.

The article by Schumacher et al. (2016) titled "Industry 4.0 Maturity Assessment of Manufacturing Enterprises" discusses the development of this comprehensive maturity model and its associated tool. The authors propose the development of a maturity model to assess the readiness and maturity of manufacturing enterprises in the field of discrete manufacturing for Industry 4.0. The model consists of nine dimensions and 62 items, focusing on technological and organizational aspects. These dimensions include "Products," "Customers," "Operations," "Technology," "Strategy," "Leadership," "Governance," "Culture," and "People." The model was created through expert workshops, literature reviews, and case studies. It desires to assist manufacturers in assessing their present Industry 4.0 capabilities and developing strategies and action plans in accordance. Each dimension's maturity level is determined by taking the weighted average of all of its elements. The authors used a three-step process, including a questionnaire-based self-assessment tool, to measure, determine, and represent the maturity levels of each enterprise. They also conducted case studies in industrial enterprises to evaluate the model's content and structure and test the usability of the assessment tool. A software tool was developed to facilitate its practical application by manufacturing companies.

Canetta et al. (2018) released a study on the construction of a factory digitalization maturity model. In order to measure the degree of digitalization in industrial organizations and to give them a path for enhancing their digital capabilities, experts set out to develop a framework. The process, technology, organization, and strategy are the four primary elements that the researchers discovered after conducting an extensive literature analysis on digitalization in manufacturing. They also defined several maturity levels for each dimension. The maturity model was then tested on a sample of manufacturing companies in Switzerland, and the results showed that the model was effective in identifying the level of digitalization in the companies and highlighting areas for improvement. The researchers also found that companies with higher levels of digitalization tended to have better performance in terms of productivity and innovation. Overall, the study provides a useful tool for manufacturing companies to assess their digitalization capabilities and to identify areas for improvement.

The study published by Gökalp and Martinez (2022) aims to develop and implement a digital transformation capability maturity model. To achieve this goal, the researchers defined the definition of digital transformation capability and identified its areas and sub-areas. These areas of competence include human resources, technological infrastructure, business processes, and strategic management. The researchers identified 36 different sub-areas of competence and defined criteria for each one to create the model. The model covers a four-stage process that includes identifying the sub-areas of competence, identifying the criteria, determining the levels of competence, and evaluating the process. The model was applied in various manufacturing companies in Turkey, and the results helped evaluate the digital transformation capability of these companies. The findings showed that human resources and technological infrastructure were the most critical areas for companies in the digital transformation process. This study can be used as a tool to assess the capabilities of companies in the digital transformation process and can provide useful guidance to companies wishing to manage this process.

2. EMPIRICAL RESEARCH FOR MANUFACTURERS IN INDUSTRY 4.0

The aim of this master's thesis is to develop an innovative model that evaluates the Industry 4.0 maturity level of manufacturing companies in the Metal products industry in Sweden and to assess their maturity level by the developed model.

Research Questions

The research questions for this study are:

- How to assess the effective use of Industry 4.0 technologies according to the enterprise size and production type of the manufacturers operating in the Metal Products Sector in Sweden?
- How to develop a comprehensive model to assess the Industry 4.0 maturity level of manufacturing enterprises in the Metal products industry in Sweden?
- How to assess the overall Industry 4.0 Maturity Level of manufacturing enterprises operating in the Metal Products Industry in Sweden?

2.1. Research approach

The methodology part of the study is based on a comprehensive literature review and conducting questionnaires, which is one of the quantitative research methods. The methodology part of the study is based on a comprehensive literature review of the factors and technologies that may affect the application of Industry 4.0 principles. The literature review aims for the researcher to determine the challenges, drivers and innovative solutions affecting manufacturing companies' adoption of Industry 4.0 and utilize them in questionnaire and model development. The maturity dimensions and sub-dimensions in the model have been prepared based on the studies in this field in the literature, existing maturity models and expert opinions.

Conducting a questionnaire is one of the quantitative analysis methods, and two questionnaires were conducted in this study.

Not every sub-dimension has the same importance, so the factor evaluation questionnaire (Appendix B) data will provide a framework for evaluating the weights by determining the perceived importance of sub-dimensions among manufacturing firms in Sweden. This questionnaire will only be sent to large-sized enterprise employees in this sector, as the maturity model targets large-sized enterprises.

The maturity assessment questionnaire (Appendix C) is part of the model and is designed in such a way that the respondents can examine the maturity level of their enterprises under 10 dimensions after the questionnaire, so with the help of the developed model and the data obtained from the maturity assessment survey, the overall maturity level of the manufacturing enterprises operating in the metal products sector in Sweden will be assessed. The maturity assessment questionnaire will be also used to examine the effective use of Industry 4.0 technologies by enterprise size and production types and was sent to micro-small-sized and medium-sized enterprises in addition to large-sized enterprises.

The framework methodology developed in the preparation of the model is based on Hevner's design science approach (2010) and Becker's study (2009), which provides a development method for maturity models. Industry 4.0 Maturity Model consists of 10 dimensions and 44 sub-dimensions with particular weights application. A detailed explanation of the model is provided in the third section, titled Model Development.

2.2. Literature review

One of the main goals of the literature review is to examine previous studies, assimilate existing knowledge, create research questions, and determine the research design. Additionally, the literature review is important for summarizing existing information on a research topic, developing a comprehensive research plan, identifying existing gaps, providing recommendations on how to fill these gaps, revealing deficiencies in existing knowledge, and establishing a foundation for future research. This thesis includes an advanced literature review. During the literature search, the aim was to examine the factors and technologies that may affect the successful implementation of Industry 4.0 principles. To better understand the research concept and to benefit from it in questionnaire and model development, the challenges, barriers, and driving forces that lead manufacturing companies to Industry 4.0 were identified in the literature review. The investigation of innovative solutions and models developed to address these challenges and barriers is also included in the literature review. The findings obtained from the literature review were used in the development of the survey and innovative model proposal during data collection. Existing maturity models and survey findings in the literature were utilized to develop a suitable maturity model for the target industry. After the draft of the model was prepared and the main dimensions and sub-dimensions were determined, additions and deductions were made in the findings with the help of the literature review.

2.3. Data collection process of industry 4.0 maturity

Evans and Mathur (2018) suggest several important considerations when designing a questionnaire. Firstly, the purpose and objectives of the questionnaire should be clearly defined to provide clear guidance throughout the design process. Secondly, the type of questionnaire and question format should be clarified. It is also important to ensure that the questionnaire is not too long and that there are clear instructions for respondents. Additionally, unnecessary questions should be avoided, and the estimated completion time should be reported. These considerations are essential for creating a well-designed questionnaire that will yield useful and reliable data. The questionnaires contain a clear and logical explanation of the study and short instructions on how to complete it. Complex or frustrating questions that could limit the respondent's answers were avoided. The wording of the questions was also carefully thought out to avoid misunderstandings or emotional reactions.

The questionnaire was conducted using the online survey tool Google Forms. Google Forms is a survey management tool that can be used in Google Workspace applications such as Google Docs Editors, Google Classroom, Google Docs, Google Sheets, and Google Slides (Google Workspace, 2023). It allows for quick and easy collection and processing of survey responses. Google Forms also allows for customization of the survey according to requirements and its simple design makes it easier for both survey developers and respondents to navigate the process.

In her study on "conducting online questionnaires," Ball (2019) identified several benefits of using online questionnaires for researchers. Online questionnaires are a quick and efficient way to distribute questions to a global audience and obtain responses in a short period of time. Researchers can easily contact respondents through email and social media, and the entire process of delivering and submitting the questionnaire is automated, resulting in significantly lower costs compared to face-to-face interviews. Additionally, online questionnaires offer flexibility to respondents, allowing for the collection of a large amount of data, and they also reduce social bias since respondents are free to answer questions without any assumptions or biases that may arise from the presence of an interviewer. Overall, these advantages make online questionnaires a valuable tool for researchers.

The factor evaluation questionnaire (Appendix B) consists of 6 questions in total, and the first 5 questions are for getting to know the business and the respondent. The last question, which is the aim of the survey, is to measure the importance of the sub-dimensions by the businesses and was prepared on a likert type scale between 1-5. The factor evaluation questionnaire is only for large enterprises in the industry and consists of respondents working in 12 companies.

Maturity assessment questionnaire (Appendix C) is part of the model and is designed in such a way that the respondents can examine the maturity level of their enterprises under 10 dimensions after the questionnaire, so with the help of the developed model and the data obtained from this questionnaire, the overall maturity level of the manufacturing enterprises operating in the metal products sector in Sweden will be assessed. Maturity assessment questionnaire will be also used to examine the effective use of Industry 4.0 technologies by enterprise size and production types and was sent to micro-small-sized and medium-sized enterprises in addition to large-sized enterprises.

Maturity assessment questionnaire consists of 16 questions in total. The first five questions in this questionnaire aim to collect demographic data and are the same as the first five questions of the factor assessment questionnaire, the 6th question is to determine the importance of Industry 4.0 technologies for businesses, and the 7-15 questions are to calculate the maturity dimensions. Questions 7-14 include the evaluation of specific factors within the framework of Industry 4.0 technologies, while the 15th question pertains to the evaluation of various expressions. The final question is for the respondents to share the email addresses of those who want to receive a maturity report for their business at the end of this study. Two respondents have provided their email addresses, and a maturity report will be sent to them following the completion of the study. In total, there were 16 respondents in the questionnaire, with two representing micro-small-sized enterprises, two representing medium-sized enterprises, and 12 representing large-sized enterprises.

Both questionnaires consist of closed-ended questions. To facilitate contact with the questionnaire respondents, assistance was sought from researchers affiliated with the university, who possess expertise in the relevant sector. Enterprises in the sector were listed and questionnaires were sent to their managers/employees via email and social media. Respondents consist of employees/managers working in departments such as Production and Operations, Research and Innovation, Information Technology (IT), Logistics and Supply Chain Management, and Project Management in companies operating in the metal products sector, including Iron/Steel Processing, Tool/Equipment Manufacturing, Mining and Mineral Processing, and Metal Processing and Shaping. Questionnaire respondents are expected to have knowledge about the research topic, so the respondents were selected from different companies working in the relevant sector in Sweden, who have sufficient knowledge and experience in Industry 4.0 and its technologies, and are experts in their fields. After conducting a comprehensive review of the scientific literature, the questionnaires were meticulously prepared. The data collection process started on 2nd May 2023 and was efficiently completed on 11th May 2023. Each respondent was informed that confidentiality and privacy would be protected both by email and in the description of the questionnaires.

2.4. Data analysis

In this section, the analysis of the data obtained through the survey is given. Two different questionnaires have been conducted and the findings are presented in the 4th section which is Empirical Research Findings.

2.4.1. The relationship of industry 4.0 technologies with sub-dimensions

Following the collection of the data, the next step involved preparing a correlation matrix to demonstrate the relationship between industry 4.0 technologies and the sub-dimensions in the maturity model. All data were recorded using SPSS (Statistical Package for Social Sciences), and the relationship between variables was examined using the Spearman correlation coefficient. The significance of the obtained values was interpreted using a significance level of 0.05. Correlation analysis is a statistical method used to determine the degree and direction of the relationship between variables, regardless of whether they are considered dependent or independent (Bhunia, 2013). The negative value of the correlation coefficient indicates an inverse relationship between the variables, while a positive value indicates a direct relationship, and as the coefficient approaches ±1, the strength of the relationship increases, whereas as it approaches 0, the relationship weakens (Durmuş et al., 2013). The correlation relationship is classified as Strong Relationship for $\pm 1 \leq r \leq \pm 0.7$, Moderate Relationship for $\pm 0.7 \leq r \leq \pm 0.3$, and Weak Relationship for $\pm 0.3 \leq r \leq \pm 0$ (Gürbüz and Şahin, 2018). The correlation matrix can be found in Appendix A.

There are statistically significant positive relationships ($p < 0.05$) between various technological factors and their respective outcomes, observed at different levels. At a high level,

AI values exhibit a statistically significant positive relationship with Decentralization (r = 0.91), Decision Making (r = 0.99), Quality Management (r = 0.82), and Product/Service Development (r = 0.70).

Similarly, **IoT** values show a statistically significant positive relationship with Logistics Tracking (r = 0.85), while demonstrating positive relationships at a high level with Productivity in Production (r = 0.75) and Optimization in Production (r = 0.74).

When considering **Big Data** values, a statistically significant positive relationship ($p < 0.05$) is found at a high level with Management of Customer Data (r = 0.88), as well as a statistically significant positive relationship ($p < 0.05$) at a moderate level with Competition (r = 0.68).

Cloud Computing values exhibit a statistically significant positive relationship ($p < 0.05$) at a high level with Data storage (r = 0.81) and positive relationships at a high level with Employee Autonomy (r = 0.71), Internal Information Sharing (r = 0.78), and Internal Communication (r = 0.74).

CPS values reveal statistically significant positive relationships ($p < 0.05$) at a high level with Automation (r = 0.83), Sustainability (r = 0.77), Resource Management (r = 0.80), and Interoperability (r = 0.77), as well as a statistically significant positive relationship ($p < 0.05$) at a moderate level with Cyber Security (r = 0.61).

Furthermore, **Simulation/Digital Twin** values exhibit statistically significant positive relationships ($p < 0.05$) at a high level with Cost Reduction in Production (r = 0.76), Optimization in Production (r = 0.81), Resource Management (r = 0.71), and Risk Management (r = 0.72), and a statistically significant positive relationship ($p < 0.05$) at a moderate level with Continuous Improvement (r = 0.65).

Lastly, **AR/VR** values demonstrate a statistically significant positive relationship ($p < 0.05$) at a high level with Sustainability (r = 0.88), while **Additive Manufacturing** exhibits statistically significant positive relationships ($p < 0.05$) at a high level with Personalization/Modularity (r = 0.98) and Product/Service Development (r = 0.92).

2.4.2. Questionnaire of the factor evaluation

The factor evaluation questionnaire consists of a total of 6 questions, with the first 5 questions designed to gather information about the enterpise and the respondent. The last question, which is the aim of the survey, is to measure the importance of the factors (sub-dimensions) by the businesses and was prepared on a likert type scale between 1-5. The factor evaluation questionnaire was sent exclusively to large-sized enterprises in the industry, and all responses from survey respondents were recorded in an Excel file. Subsequently, the average importance of each factor was computed using the data provided by 12 respondents representing various enterprises.

2.4.2.1. Demographics of the factor evaluation questionnaire

According to the factor evaluation survey data, demographic findings are examined below with their figures and explanations.

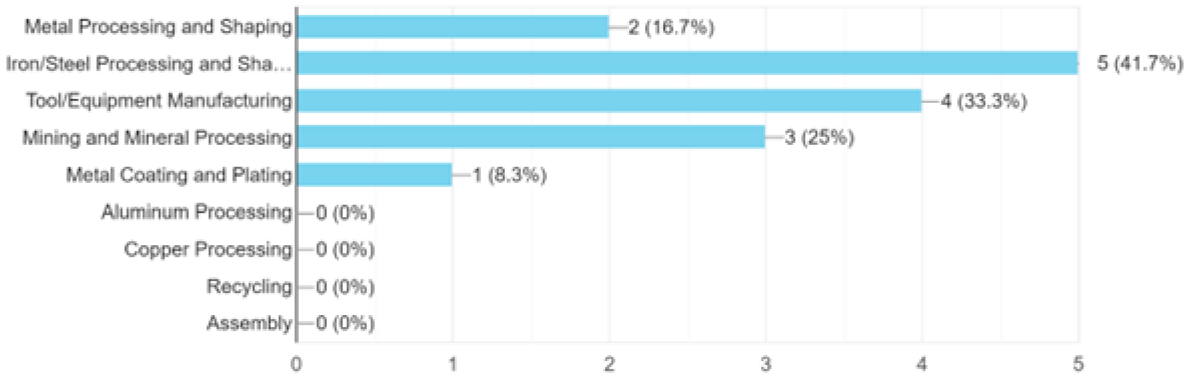


Fig. 2. Production types of the factor evaluation survey respondents

In an evaluation of the data gathered from the survey question, "Please select the production type(s) of your enterprise," the subsequent quantitative analysis reveals a distribution of responses across five distinct categories of production. In the context of the 12 respondents, the production type "Mining and Mineral Processing" was indicated by 25.00%, "Metal Processing and Shaping" was indicated by 16.67% of respondents, "Iron/Steel Processing and Shaping" was indicated by 41.67% of respondents, "Metal Coating and Plating" was represented by 8.33%, while "Tool/Equipment Manufacturing" was chosen by 33.33% of the enterprises.

Due to the provision that allowed respondents to select more than one production type, the total percentage exceeds 100%. This provides a nuanced understanding of the industrial sectors represented and the overlap that exists among them.

Further statistical analysis illustrates that, on average, each respondent indicated approximately 1.17 types of production, as computed from the dataset. In addition, the mode and median — the most frequently occurring value and the middle value respectively — were both 1. This indicates a trend towards respondents identifying their enterprise with a single type of production.

Fig. 3. Departments where factor assessment survey respondents work

In response to the survey question, "What department do you work in at your enterprise?" an analysis of the 12 responses reveals a range of roles across seven distinct departments. The "Production and Operations" department was identified by 25.00% of respondents, followed by both "Logistics and Supply Chain Management", "Research and Innovation" and "Information Technology (IT)" indicated by 16.67%. The departments of "Technical Support," "Project Management," and "Sales and Marketing" were indicated by one respondent, representing 8.33%.

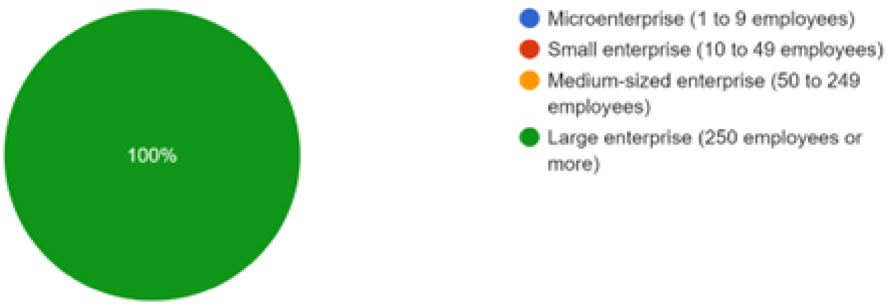


Fig. 4. Company sizes of the factor evaluation survey respondents

The importance of sub-dimensions included in the model has been evaluated only by large-sized enterprises since the developed maturity model targets large-sized enterprises. In regard to the survey query, "What is the size of your company?" it is found that all of the 12 respondents (100%) affirmed their association with a "Large enterprise (250 employees or more)." This consistency in responses aligns with the study's targeted focus on large-sized enterprises.

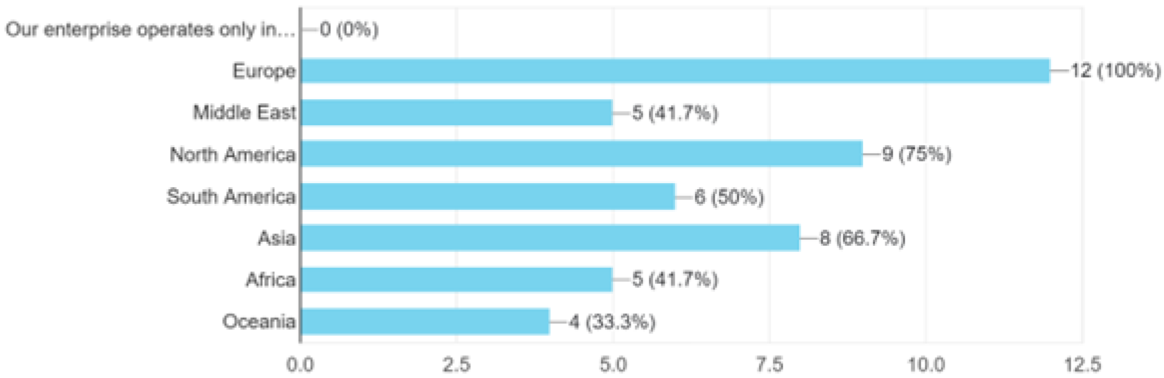


Fig. 5. Regions where the factor evaluation survey respondents operate

In response to the survey question, "In which region(s) outside of Sweden does your enterprise operate?", the data collected from the 12 respondents specifies a notable presence of these enterprises in various global regions. The most frequently cited region is Europe, mentioned by 100% of respondents, indicating a significant international operation within this geographical area. North America was indicated by 75.0% and Asia was indicated by 66.7% of the respondents, while operations in the Middle East and Africa were indicated by 41.67%. Notably, 33.33% of the respondents reported that their enterprises operate in Oceania. It is noteworthy that 4 respondents (33.33%) indicated that their enterprises operate in all seven regions, underscoring a global reach. 3 respondents (25.0%) reported operations only in Europe and none of the questionnaire respondents work for companies that operate exclusively in Sweden.

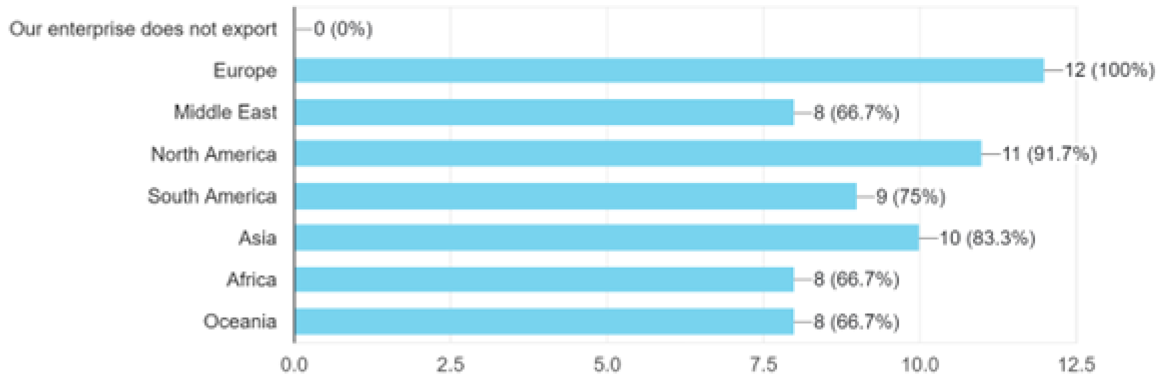


Fig. 6. Regions to which the factor evaluation respondents export

Upon analysing the data gathered from the survey question, "To which region(s) does your enterprise export?" the responses indicate a wide global export presence among the 12 enterprises surveyed. A total of seven enterprises, equating to 58.33% of respondents, reported exporting to all seven regions specified in the survey: Europe, Middle East, North America, South America, Asia, Africa, and Oceania. This suggests a highly diversified global export strategy among a significant proportion of respondents.

In addition, "Europe" was a universal export destination for all enterprises, thereby serving as the most common region for exports. "North America" was noted as an export region by 11 enterprises (91.7%) while "Asia" was noted by 10 enterprises (83.3%). "Middle East," "Oceania," and "Africa" were each indicated by 8 enterprises (66.7%).

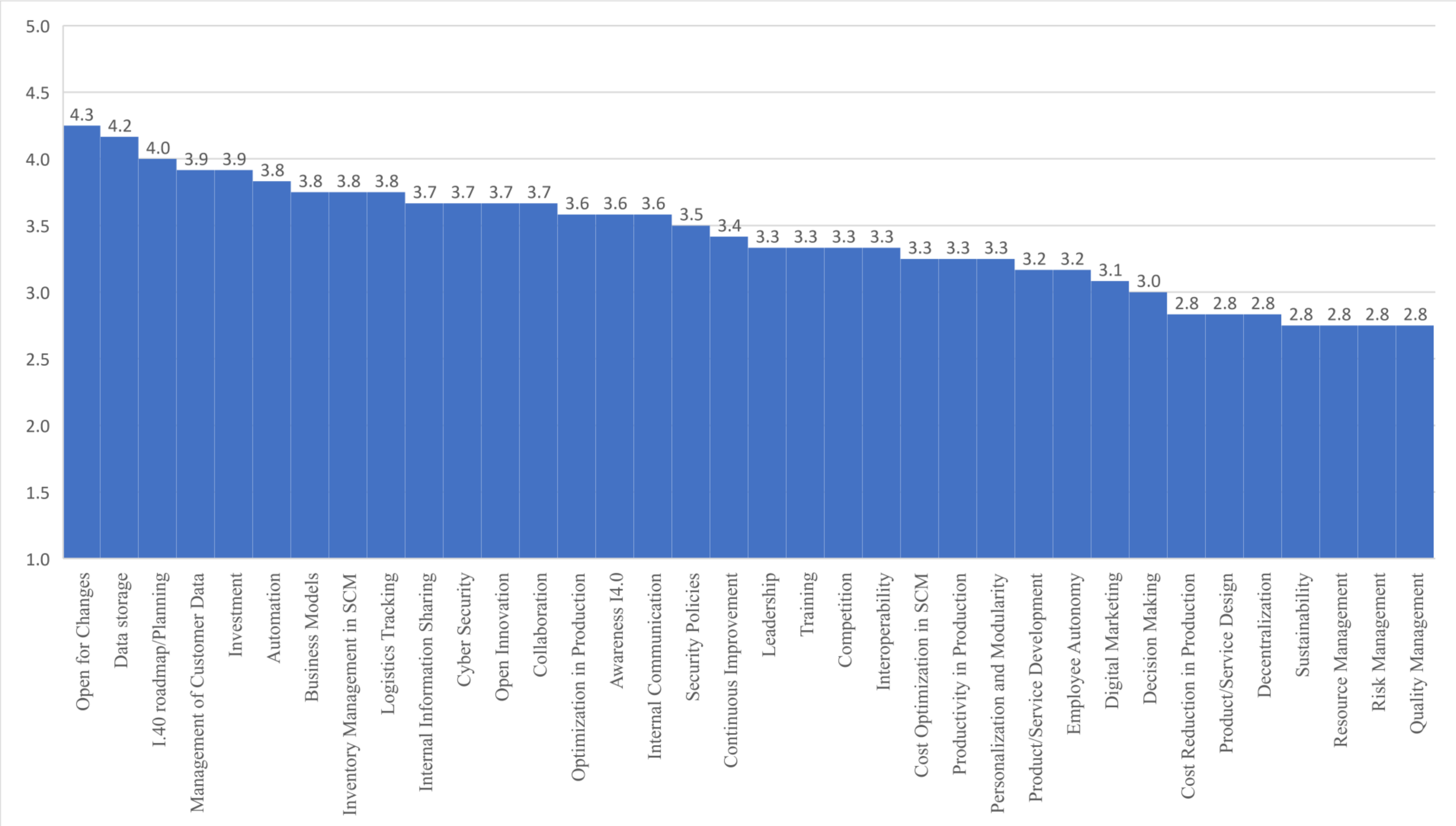
2.4.2.2. Evaluation of factor importance in the model

In the proposed maturity model, each maturity dimension encompasses relevant sub-dimensions. Given the variance in their importance, establishing the weight of these sub-dimensions is a crucial exercise. The weights assigned to dimensions and sub-dimensions were discerned utilizing insights from both the theoretical foundation of sub-dimension weighting and the importance of the sub-dimensions as indicated in the factor evaluation questionnaire.

The determination of the importance of these sub-dimensions, derived from this survey, provides a valuable framework for evaluating the weights of sub-dimensions in the development of the Industry 4.0 maturity model, fulfilling one of the research objectives.

Considering the prevalence of large enterprises within the sectors pertinent to the research subject, coupled with the observed variations in Industry 4.0 maturity levels among small, medium, and large enterprises, the survey was intentionally directed towards large-scale enterprises. This strategic targeting was deemed necessary to enhance the precision and relevancy of the research findings.

Fig. 7. Sub-dimensions' importance for manufacturing enterprises



Source: prepared by author, based on the factor evaluation survey results

According to the survey results, it is observed that factors such as Open for Changes (4.3), I.40 roadmap/Planning (4.0), Investment (3.9) are more important in Industry 4.0 for the respondents. One of the biggest reasons for this is that the respondents think that the cultural and strategic structure of the companies is one of the key points to the transition to the Industry 4.0 era. "Open for Changes" factor may reflect the ability of large enterprises to adapt to the rapidly changing business environment. The high scores of the respondents on this factor indicate that adopting an innovative culture, adapting quickly to changing market conditions and maintaining competitive advantages requires a flexible structure. It is extremely important that businesses adopt a strategic approach in the transition to Industry 4.0. Having an Industry 4.0 roadmap can lead businesses to take a planned approach to identifying and implementing their digital transformation strategies. Roadmaps play a role in enabling businesses to evaluate their current status, set goals and plan transformation steps. On the other hand, the respondents reveal the necessity for businesses to invest actively in order to successfully continue the transition to Industry 4.0. Investments can be directed to innovation, technological infrastructure, talent development and digital transformation projects.

In addition, the respondents rated Data storage (4.2) and Management of Customer Data (3.9) factor as of higher importance. These two factors are interrelated and help businesses effectively implement data-driven strategies in the digital transformation process. Especially for large businesses, data storage is important to be able to securely store and access large amounts of data. When enterprises have a strong data storage infrastructure, they can effectively manage data and optimize business processes in a data-driven way. By collecting, storing and analyzing customer data, businesses can improve the customer experience and more effectively guide their marketing strategy. A high score on this factor indicates that businesses act meticulously in the privacy, security and compliance of customer data and adopt a customer-oriented approach. The combination of data storage and Management of Customer Data factors reflects that businesses attach importance to data management and customer focus in the digital transformation process. These factors support businesses to gain competitive advantage and increase customer satisfaction by enabling them to effectively manage data security, data analytics and customer relations.

According to the survey results, the low evaluation of the respondents on factors such as Quality Management (2.8), Risk Management (2.8) and Resource Management (2.8) may be associated with various reasons. The results show that businesses give less priority to these factors compared to factors such as Automation or Logistics tracking in the Industry 4.0 transition. It may also mean that businesses neglect these factors or do not focus enough on them. Businesses may be more focused on short-term goals or immediate needs and not allocate sufficient resources to factors such as quality management, risk management or resource management.

The fact that the respondents did not fully understand or appreciate the importance of these factors due to insufficient awareness or knowledge may also be one of the reasons for the low results. They may not have enough information about the effects of these factors on business performance and competitive advantage. Businesses may have weak points such as not complying with certain standards in their quality management processes, not using risk management processes effectively enough or not having optimizing strategies for resource management.

On the other hand, respondents may be focusing more on improvement and innovation in their business activities. In this case, the Risk Management factor can be perceived as a reactive approach rather than proactive risk analysis and management. Businesses can focus more on areas such as new product/service development or market expansion to maintain growth and competitive advantage. Risk management may sometimes require businesses to deal with events that are unlikely to occur. Not being aware of such events or not fully understanding the future effects of risks can lead to underestimation of the Risk Management factor.

The management understanding, corporate culture and business processes of businesses can affect the evaluation of factors such as Risk Management, Resource Management and Quality Management. The reason why these factors are not of sufficient importance in enterprises may be that the necessary emphasis is not given to these issues by the management or that these factors are culturally seen as secondary. Evaluations of these factors may be low when management and cultural change is required in businesses.

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2.4.3. Questionnaire of industry 4.0 maturity level

The second questionnaire (industry 4.0 maturity level, Appendix C) consists of a total of 16 questions. The first 5 questions are the same as in the first questionnaire, the 6th question is used to determine the importance of Industry 4.0 technologies for businesses, and questions 7-15 are designed to measure maturity dimensions. The last question allows questionnaire respondents to provide email addresses of those interested in receiving a maturity report for their business at the end of the study.

The maturity assessment questionnaire servers the purpose of both determining the effective utilization of Industry 4.0 technologies based on the business size and production type and measuring the maturity level of businesses within the maturity model. This questionnaire was sent to companies of all sizes in each dimension. When calculating the effective utilization of each I4.0 technology, the averages of responses under each sub-dimensions were calculated separately based on production type and company size. These results are presented in the empirical research findings section.

While analyzing the results of the maturity assessment survey for the maturity model, the sub-dimensions under each question from 7 to 15 were coded, taking into account calculation difficulties. Sub-dimensions under each particular dimension were evaluated from different perspectives and with the inclusion of various technologies in this survey. For example, the "Product/Service Development" sub-dimension under the Innovation dimension was examined in relation to AR/VR, IoT, and Additive Manufacturing technologies, while the "Productivity" sub-dimension under the Production dimension was evaluated with regards to IoT, CPS, and Digital Twin technologies. Similarly, statements such as "The managers in our company provide the necessary support for the employees to adopt and use I4.0 technologies" were used to measure both the "Leadership" sub-dimension and to influence the "Training" sub-dimension. All sub-dimension' averages were determined to be used in identifying the overall maturity of the sector. The maturity levels were determined using the formulas explained in the model development, data obtained from the maturity assessment questionnaire and sub-dimension weights identified in the model development section.

2.4.3.1. **Demographics of industry 4.0 maturity level survey**

According to the maturity assessment survey data, demographic findings are examined below with their figures and explanations:

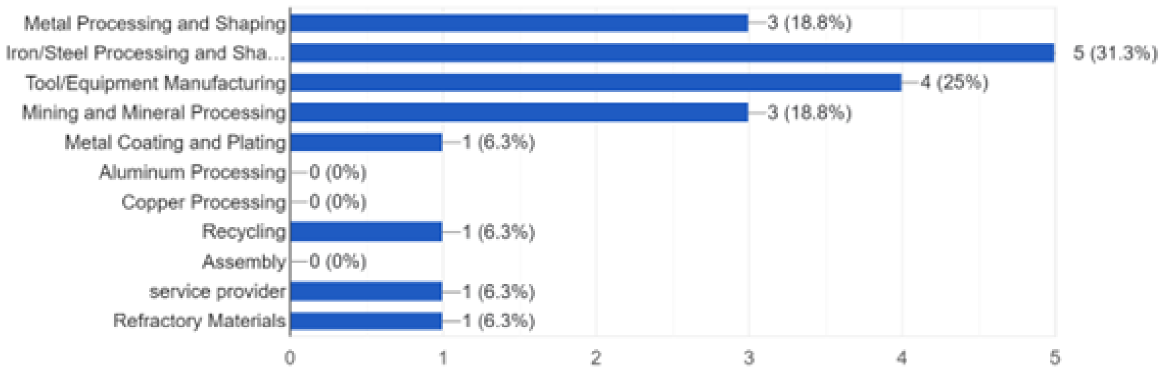

Fig. 8. Production types of the maturity assessment respondents

An examination of the survey data regarding the question, "Please select the production type(s) of your enterprise," reveals a distribution among six different categories of production, with an additional service provider category. Based on the 16 responses collected, "Tool/Equipment Manufacturing" was indicated by 25% of the enterprises, "Iron/Steel Processing and Shaping" was chosen by 31.3%, and "Mining and Mineral Processing" represented 18.8%. Furthermore, "Metal Processing and Shaping" was selected by 18.8% of respondents, the specific "Refractory Materials" category and "Recycling" each accounted for 6.3% of the responses, and one enterprise (6.3%) identified as a service provider.

The total percentage exceeds 100% due to the option for respondents to select multiple types of production. This elucidates the complexity and interconnectivity within the surveyed industrial sectors.

Additional statistical analysis shows that each respondent indicated approximately 1.19 production types on average. Both the mode and the median — denoting the most frequently occurring and middle values, respectively — were 1, demonstrating a tendency among respondents to identify their enterprises with a single type of production.

Fig. 9. Departments where the maturity assessment respondents work

Analyzing the responses to the survey question, "What department do you work in at your enterprise?" yields a distribution among seven distinct departments within the 16 enterprises surveyed. The "Production and Operations" department was the most frequently identified, indicated by 25.0% of respondents. The "Research and Innovation" and “Sales and Marketing” departments were chosen by 18.8% of respondents, while "Logistics and Supply Chain Management," and "Information Technology (IT)" were each identified by 12.5% of respondents. The "Technical Support" and "Project Management" departments were each indicated by one respondent, accounting for 6.25%.

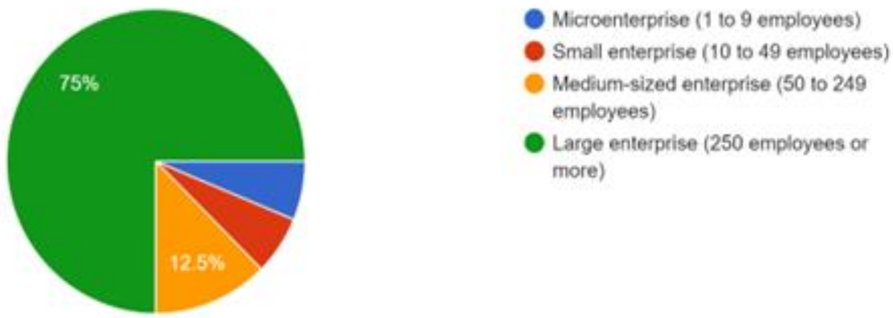

Fig. 10. Company sizes of the maturity assessment respondents

The survey data relating to the question, "What is the size of your company?" reveals a predominance of large-scale enterprises among the respondents. A significant majority, specifically 75.0% of the 16 respondents, indicated that they were part of a "Large enterprise (250 employees or more)." Moreover, 2 respondents, amounting to 12.5%, identified their companies as "Medium-sized enterprise (50 to 249 employees)." A single respondent, representing 6.25%, classified their company as a "Small enterprise (10 to 49 employees)," and another single respondent, also 6.25% of the total, labeled their company as a "Microenterprise (1 to 9 employees)".

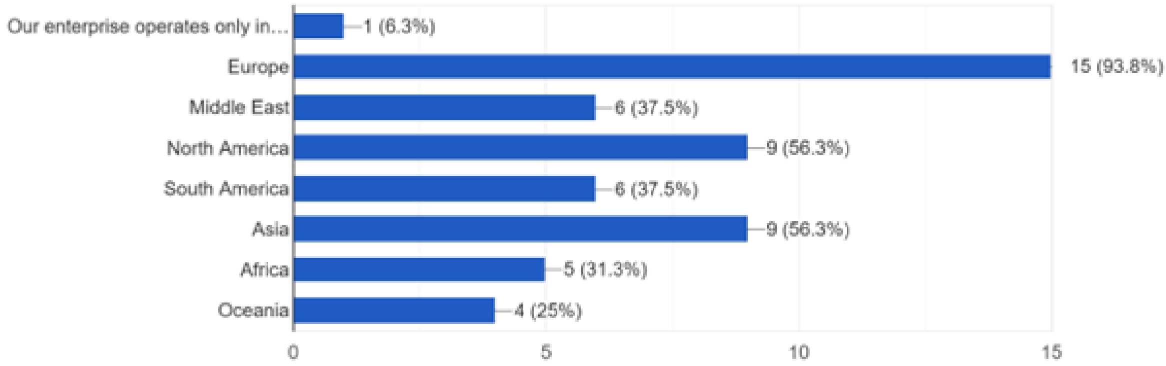

Fig. 11. Regions where the maturity assessment respondents operate

Responding to the question, "In which region(s) outside of Sweden does your enterprise operate?" the 16 enterprises surveyed offered varied responses, revealing their geographic reach across different continents. Among the enterprises surveyed, the most common response was "Europe," with 15 (93.8%) enterprises indicating operations within this region. "North America" and "Asia" were identified by 9 (56.3%) enterprises. "Middle East," and "South America," were reported by 6 (37.5%) enterprises. "Oceania" was indicated by 4 (25.0%) enterprises.

It is noteworthy that 4 enterprises (25.0%) reported operations in all seven regions mentioned in the survey: Europe, Middle East, North America, South America, Asia, Africa, and Oceania. These enterprises appear to have a truly global operational presence. One enterprise (6.25%) indicated that they operate solely within Sweden, with no operations outside of the country.

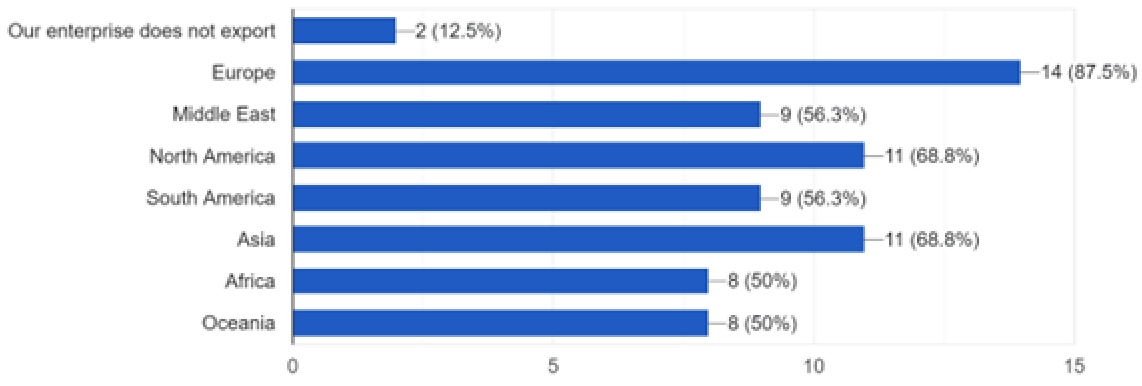

Fig. 12. Regions to which the maturity assessment respondents export

The survey question, "To which region(s) does your enterprise export?" elicited varied responses from the 16 enterprises, providing insight into their export activities across different global regions. The most commonly reported export destination was "Europe," indicated by 14 enterprises (87.5%). "North America" and "Asia" were reported as export destinations by 11 enterprises (68.8%). 9 enterprises (56.3%) identified the "Middle East," "South America," as export destinations. "Oceania" was reported by 8 enterprises (50.0%). Notably, 7 enterprises (43.75%) reported exporting to all 7 regions. However, 2 enterprises (12.5%) indicated that they do not engage in export activities and those which do not export are micro and small-sized companies.

3. MODEL DEVELOPMENT

One of the aims of this master's thesis is to develop a structured model for manufacturers in the metal products industry in Sweden to assess Industry 4.0 maturity level. The framework methodology developed in the preparation of the model is based on Hevner's design science approach (2010) and Becker's study (2009), which provides a development method for maturity models.

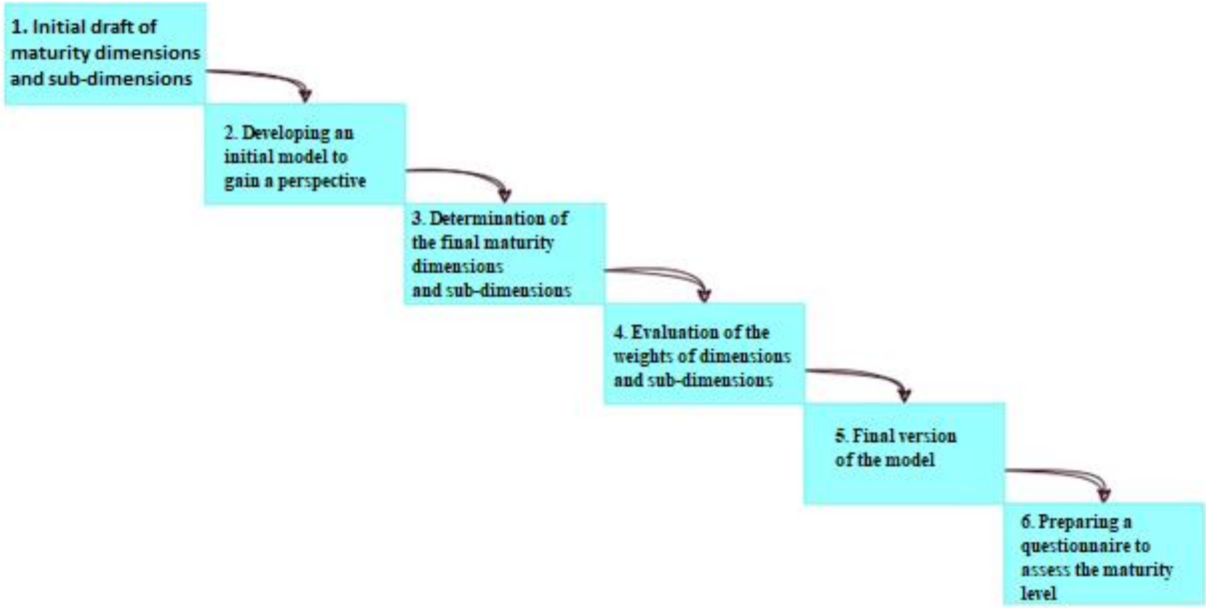

Fig. 13. Model development stages

Industry 4.0 Maturity Model consists of 10 dimensions and 44 sub-dimensions with particular weights application. During the process of establishing these dimensions and sub-dimensions, meticulous attention was given to their alignment with the specific industry under investigation. The determination of maturity dimensions and sub-dimensions for the development of the maturity model was accomplished through a systematic examination of scientific literature. Although the maturity models and evaluation factors found in the existing literature are often adapted to specific sectors, it is crucial to acknowledge the valuable contributions of both the literature and expert opinions in the development of the model proposed in this study. Subsequently, an initial model was designed to establish a framework for comprehending the underlying concept. The objective of this preliminary model was to facilitate a comprehensive understanding of the maturity model and to identify pertinent dimensions and sub-dimensions.

This approach afforded a broader framework and deeper insights into the trajectory of the model. After the initial model was designed and the main dimensions and sub-dimensions were determined, a systematic assessment was conducted using concept mapping techniques to further refine the findings. Consequently, a total of 10 main dimensions and 44 sub-dimensions were identified for the forthcoming development of the maturity model. The figure below illustrates the final representation of the maturity model, inclusive of its dimensions and sub-dimensions.

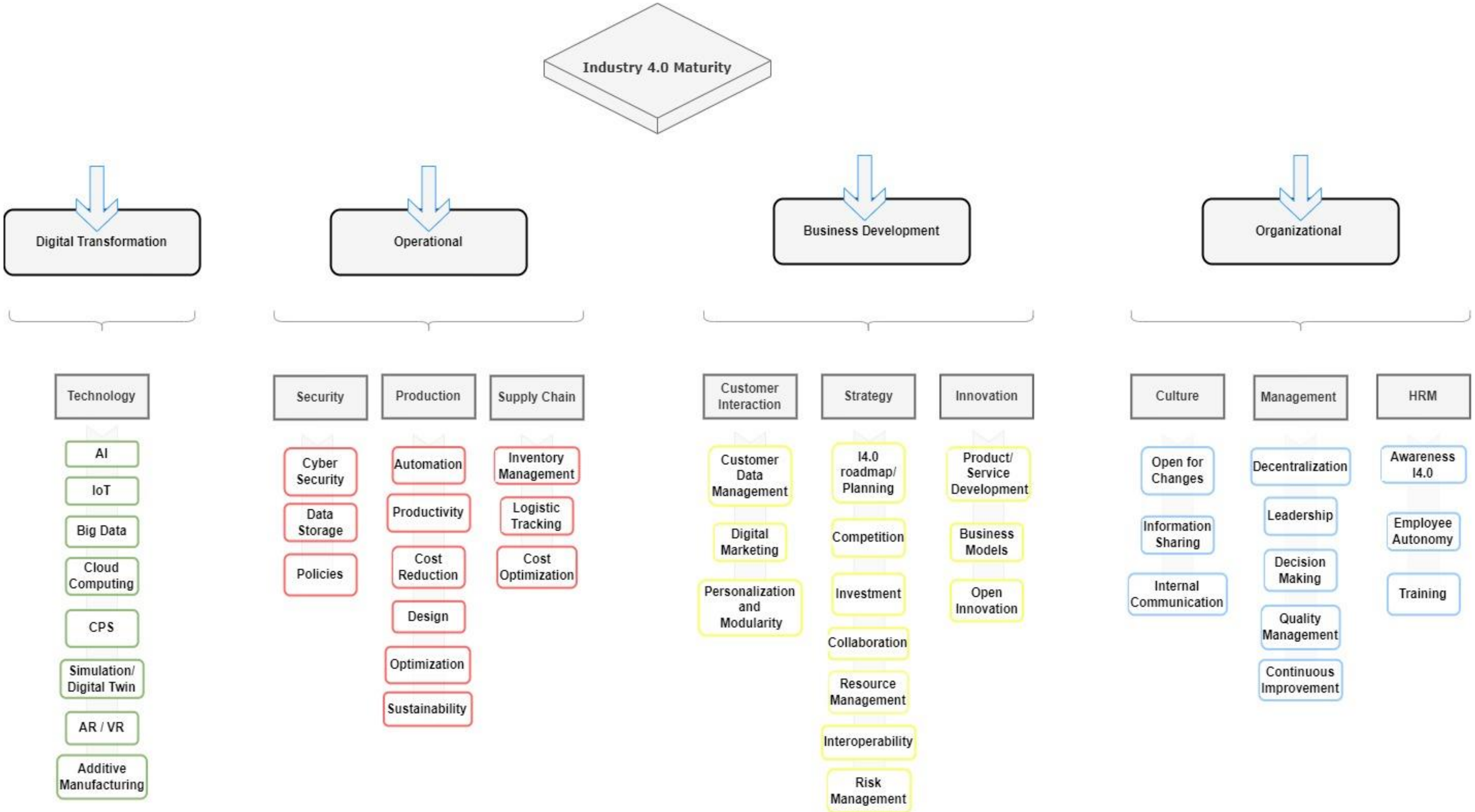

Fig. 14. Industry 4.0 maturity model

The dimensions have been devised in accordance with the areas of digital transformation, organizational structure, operational processes, and business development processes, which hold significant importance in determining the maturity level of companies during the transition to Industry 4.0. Sub-dimensions within each specific dimension have been evaluated from diverse perspectives and through the utilization of various technologies. For instance, the sub-dimension of "Product/Service Development" under the Innovation dimension was scrutinized with regard to technologies such as AR/VR, IoT, and Additive Manufacturing. Similarly, the sub-dimension of "Productivity" under the Production dimension was examined using technologies such as IoT, CPS, and Digital Twin. To provide another example, the statement "The managers in our company provide the necessary support for the employees to adopt and use I4.0 technologies" serves as both a measure for the "Leadership" sub-dimension and as an influencing factor for the "Training" sub-dimension.

Overall maturity level is assessed in 4 stages:

1. Determining the weights of maturity dimensions and sub-dimensions

2. Determining the maturity level of each dimension

3. Determining the overall maturity level

3.1. Determining the weights of maturity dimensions and sub-dimensions

The weights assigned to the dimensions within the Industry 4.0 maturity assessment model are based on their relative importance and impact on organizational readiness and progress in adopting Industry 4.0 capabilities. Some dimensions carry higher weights due to their direct influence on core operations, while others have lower weights as they play supporting roles or have comparatively less impact on overall maturity. The dimensions of Technology and Production hold higher weights of 20% each, reflecting their crucial roles in driving Industry 4.0 maturity. Technology plays a pivotal role in Industry 4.0, harnessing the power of artificial intelligence, IoT, and big data to drive automation, connectivity, and informed decision-making. Production focuses on advanced manufacturing techniques, directly impacting efficiency, quality, and flexibility. The significant needs required for implementing and integrating these dimensions justify their higher weights.

Table 2. Maturity dimensions, sub-dimensions and their weights

Technology (20%)			Production (20%)			Security (10%)			Supply Chain (10%)			Innovation (10%)		
Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment
AI	2.44%	2.25%	Automation	4.01%	4.50%	Cyber Security	3.30%	3.50%	Inventory Management	3.52%	3.60%	Product/Service Development	3.02%	3.33%
IoT	2.79%	3.25%	Productivity	3.40%	3.75%	Data Storage	3.60%	3.50%	Logistics tracking	3.52%	3.40%	Business Models	3.49%	3.33%
Big Data Analysis	3.21%	3.00%	Cost Reduction	2.97%	2.75%	Policies	3.10%	3.00%	Cost Optimization	3.06%	3.00%	Open Innovation	3.49%	3.33%
Cloud Computing	2.66%	2.50%	Design	2.97%	2.50%									
CPS	2.01%	2.25%	Optimization	3.75%	3.50%									
Simulation/Digital Twin	2.79%	2.75%	Sustainability	2.88%	3.00%									
AR / VR	2.21%	2.00%												
Additive Manufacturing	1.92%	2.00%												

Strategy (10%)			Customer Interaction (5%)			Management (5%)			HRM (5%)			Culture (5%)		
Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment	Subdimensions	Survey evaluations	Weights for maturity assessment
I40 roadmap/Planning	1.68%	1.85%	Management of customer data	1.89%	1.90%	Decentralization	0.93%	0.90%	Awareness I40	1.78%	1.70%	Open for Changes	1.85%	2.00%
Competition	1.39%	1.50%	Digital Marketing	1.50%	1.50%	Leadership	1.09%	0.95%	Employee Autonomy	1.58%	1.65%	Information sharing	1.59%	1.50%
Investment	1.64%	2.00%	Personalization and Modularity	1.60%	1.60%	Decision Making	0.98%	0.90%	Training	1.63%	1.65%	Communication	1.56%	1.50%
Collaboration	1.55%	1.30%				Quality Management	0.90%	1.00%						
Resource Management	1.18%	1.05%				Continuous Improvement	1.12%	1.25%						
Interoperability	1.39%	1.25%												
Risk management	1.18%	1.05%												

Dimensions such as Security, Supply Chain, Strategy, and Innovation hold weights of 10% each, striking a balance between their significance and relative impact. Security safeguards interconnected systems and data, while Supply Chain optimization enhances operational efficiency and customer satisfaction. Strategy aligns initiatives with business goals, and Innovation fosters a culture of creativity and experimentation. These dimensions play critical roles but have slightly lesser weights compared to Technology and Production. Meanwhile, dimensions like Customer Interaction, Management, Culture, and HRM carry lower weights of 5%. This acknowledges their supporting roles in the Industry 4.0 journey. Customer Interaction enhances engagement and experiences, while Management, Culture, and HRM facilitate and govern transformation efforts. While acknowledging the importance of dimensions such as Customer Interaction, management, culture, and hrm in the context of ındustry 4.0, their influence on the overall maturity level of implementation is relatively modest in magnitude.

The total weight of the particular sub-dimensions in this model is equal to the weight of the corresponding parent dimension. However, it has been acknowledged that not all sub-dimensions carry equal importance. For instance, within the "Production" dimension, the sub-dimension of "Automation" may hold greater significance compared to the sub-dimension of "Cost Reduction". The determination of the weight of sub-dimensions was achieved through a two-step process. Initially, an exhaustive literature review was conducted to establish a theoretical foundation and pinpoint key thematic areas. Subsequently, to provide a framework for evaluating the weights by determining the perceived importance of sub-dimensions among manufacturing firms in Sweden, the factor evaluation questionnaire was conducted. The respondents, exclusively consisting of employees from large-scale manufacturing companies, rated each sub-dimension's importance on a scale of 1 to 5 (5 being the highest importance). The reason why small-medium-sized companies were not included in this survey, as examined in the maturity assessment survey findings, is that small-medium-sized enterprises are at different stages in the transition to Industry 4.0 compared to large-scale companies, and this may cause a decrease in the accuracy of the assessment. Finally, the weights of the dimensions and sub-dimensions were determined with the perspectives provided by the theoretical basis of the weighting of the sub-dimensions and the importance of the sub-dimensions obtained from the empirical results. The table 2 above presents the weights of all dimensions and sub-dimensions, as well as the percentage representation of sub-dimensions' importance for businesses based on survey responses.

3.2. Determining the maturity level of each dimension

After determining the weights of the sub-dimensions under the particular dimensions, a second questionnaire was prepared to measure the maturity level of manufacturing enterprises operating in the Metal products sector in Sweden. This questionnaire is an indispensable part of the maturity model because companies need these survey results to determine their maturity level. The answers given on a scale of 1-5 are aimed at determining the maturity of the sub-dimensions included in the maturity model in the company. The formula used to calculate the maturity of the dimensions is given in the Fig. 15.

$$M_D = \frac{\sum_{s=1}^{n} M_{D/s} \ x \ g_{D/s}}{g_D}$$

M: Maturity
D: Dimension
s: Sub-dimension
g: Weighting factor
n: Number of sub-dimensions

Fig. 15. Maturity dimesion assessment formula

The maturity level of each dimension (M_D) is determined by dividing the sum obtained by multiplying the sub-dimensions ($M_{D/s}$) evaluated through the second questionnaire by their weights ($g_{D/s}$), by the weight of the relevant main dimension (g_D).

In the maturity dimension assessment formula, the numerator represents the summation obtained by multiplying the evaluations of the sub-dimensions ($M_{D/s}$) with their respective weights ($g_{D/s}$). On the other hand, the denominator represents the weight assigned to the dimension (g_D). By dividing the numerator by the denominator, we calculate the maturity level (M_D) for the specific dimension.

For a better understanding of the calculation method, the calculations of "Supply Chain Management", one of the maturity dimensions, are shown below.

$M_{4/1}$ (Inventory Management) = 3.1 , $g_{4/1}$ = 0.036

$M_{4/2}$ (Logistics Tracking) = 3.0 , $g_{4/2}$ = 0.034

$M_{4/3}$ (Cost Optimization) = 2.8 , $g_{4/3}$ = 0.030

Fig. 16. Supply chain maturity level

$$M_4 = \frac{(3.1*0.036)+(3.0*0.034)+(2.8*0.030)}{0.10} = \mathbf{2.98}$$

Based on the calculations above, the maturity level of the Supply Chain dimension has been determined to be 2.98.

The empirical research findings section presents radar charts illustrating the evaluation of the maturity levels for the 10 dimensions and the overall maturity using the developed model and data collected from respondents representing manufacturing enterprises in the metal products sector in Sweden. These radar charts offer a visual representation of the assessed maturity levels, allowing for a comprehensive understanding of the relative strengths and weaknesses across different dimensions and the overall maturity level of the organizations studied.

3.3. Determining the overall maturity level

After assessing the maturity level of each dimension, the following formula should be used in the final step to calculate the overall maturity level:

$$M_O = \sum (g_D \; x \, M_D)$$

M_O : *Overall maturity level*
g_D : *Weight of maturity dimension*
M_D : *Level of maturity dimension*

Fig. 17. Overall maturity level assessment formula

Overall_Maturity = (Technology_Weight * Technology_Dimension_Level) + (Production_Weight * Production_Dimension_Level) + … + (Culture_Weight * Culture_Dimension_Level)

The overall maturity model will take a value on a scale of 1 to 5 after all calculations, and in line with this value, the Industry 4.0 maturity of the enterprise is determined according to the following scale.

1-1.5: Very low maturity level - Manufacturing companies in the metal products sector at this maturity level have minimal adoption of Industry 4.0 technologies and practices. They may have limited automation, manual data collection processes, and a low level of connectivity between machines and systems. There is little integration of digital technologies into their manufacturing processes, and they may not have a clear strategy for digital transformation.

1.5-2.5: Low maturity level - Companies at this level have started exploring and implementing some Industry 4.0 technologies but are still in the early stages of adoption. They may have implemented basic automation and data collection systems, but these are often isolated and not fully integrated. There might be limited connectivity between different machines or systems, and the data collected may not be fully utilized for decision-making or process optimization.

2.5-3.5: Moderate maturity level - Manufacturing companies at this level have made significant progress in adopting Industry 4.0 technologies and practices. They have implemented automation and data collection systems that are more integrated and interconnected. They leverage data analytics to some extent for process optimization and decision-making. However, there is still room for improvement in terms of the breadth and depth of digitalization across their manufacturing operations.

3.5-4.5: High maturity level - Companies in the metal products sector at this maturity level have achieved a high level of adoption and integration of Industry 4.0 technologies. They have extensive automation and connectivity across their manufacturing processes, with a high degree of interoperability between machines, systems, and data sources. They use advanced analytics, machine learning, and artificial intelligence to optimize their operations, improve quality, and enhance productivity. They have a well-defined digital strategy and actively invest in digital transformation initiatives.

4.5-5: Very high maturity level - Manufacturing companies at this maturity level are at the forefront of Industry 4.0 adoption and innovation. They have fully embraced advanced technologies such as the Internet of Things (IoT), big data analytics, cloud computing, and cyber-physical systems. Their manufacturing processes are highly automated and digitally connected, enabling real-time data exchange and decision-making. They leverage advanced predictive analytics and machine learning algorithms to optimize their entire value chain. These companies continuously explore emerging technologies and drive industry-wide digital transformation.

4. EMPIRICAL RESEARCH FINDINGS OF INDUSTRY 4.0

In the empirical research results section, the results of the conducted survey and the overall maturity findings assessed with the help of the developed model are included.

4.1. The effective use of I4.0 technologies by the different company sizes

The results of the maturity assessment survey demonstrate the extent to which companies of different sizes (micro-small, medium, and large) utilize Industry 4.0 technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Big Data, Cloud Computing, Cyber-Physical Systems (CPS), Simulation/Digital Twin, Augmented/Virtual Reality (AR/VR), and Additive Manufacturing.

Table 3. Effective use of industry 4.0 technologies by the different company sizes

Company size	AI	IoT	Big Data	Cloud Computing	CPS	Simulation/ Digital Twin	AR / VR	Additive Manufacturing
Micro-small	1,6	1,9	1,8	1,8	1,3	1,0	1,0	2,0
Medium	1,0	2,3	2,1	2,4	1,2	2,1	1,3	1,5
Large	1,9	3,3	2,9	2,7	2,3	2,2	1,8	2,3
Average	1,8	3,0	2,6	2,6	2,0	2,0	1,7	2,2

Source: prepared by author, based on the maturity assessment survey results

According to the survey results, a clear trend is observed in the use of Industry 4.0 technologies. Generally, it is seen that large companies use these technologies more. This may be because large companies often have more resources and the ability to invest in such technologies. Also, because large companies often have more complex business processes, they take advantage of the efficiency and automation benefits provided by these technologies.

In general, we see that IoT, Big Data and Cloud Computing technologies are the most widely used technologies in all company sizes, although the average values of the usage rates of Industry 4.0 technologies are low to medium. This highlights that data is becoming more and more important in business processes and decision-making, and the importance of the IoT's ability to collect this data.

The effective use of Industry 4.0 technologies by different company sizes is shown in a radar chart as below.

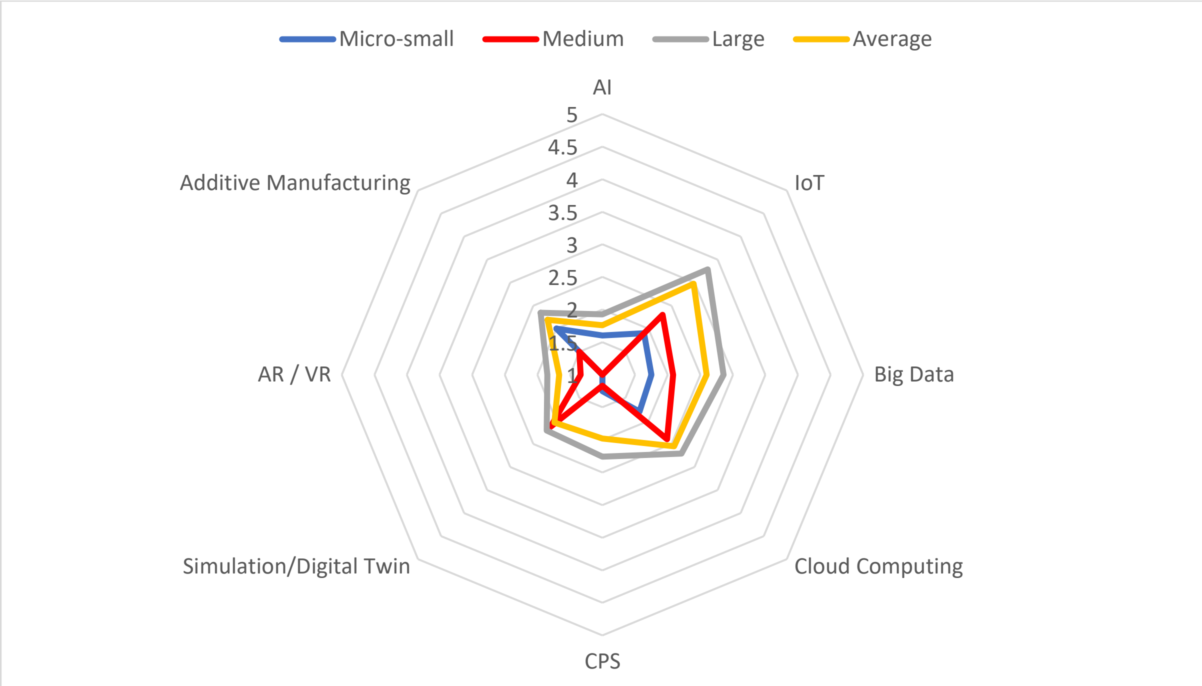

Fig. 18. Effective use of industry 4.0 technologies by the company size

On the other hand, the use of Artificial Intelligence (AI), CPS, AR/VR technologies is generally lower. This could mean that these technologies require more complex and perhaps more specialized knowledge. In particular, AI and Simulation/Digital Twin technologies may require a high level of technical skill and therefore may be less common.

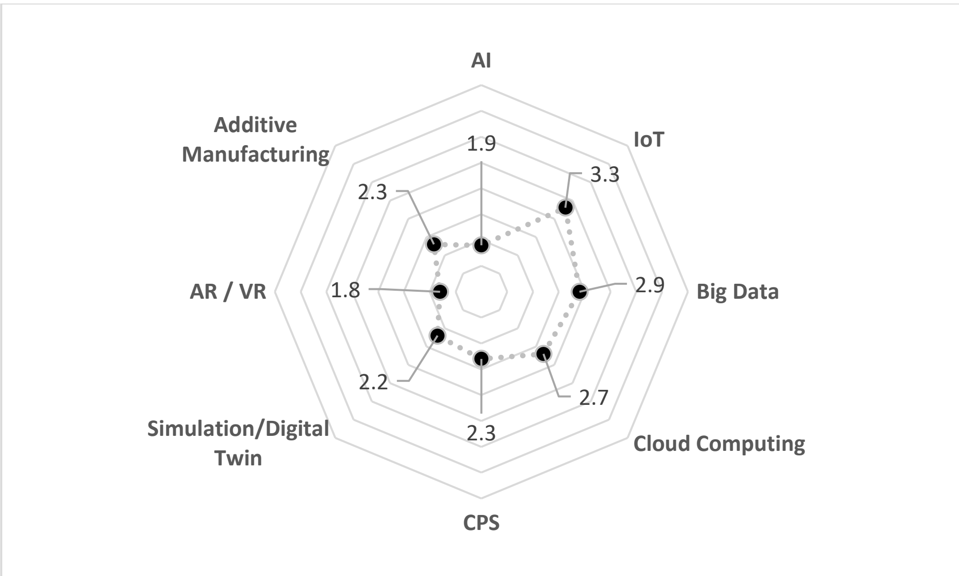

Fig. 19. Effective use of industry 4.0 technologies by large-sized enterprises

Large companies are more active in all areas of technology in general. This is particularly striking in the fields of IoT (3.3), Big Data (2.9) and Cloud Computing (2.7). The fact that large companies operate more in technology areas can be associated with these companies having more resources and finance. Large companies can more easily access and implement new technologies. This is of great importance in terms of gaining competitive advantage and supporting innovation.

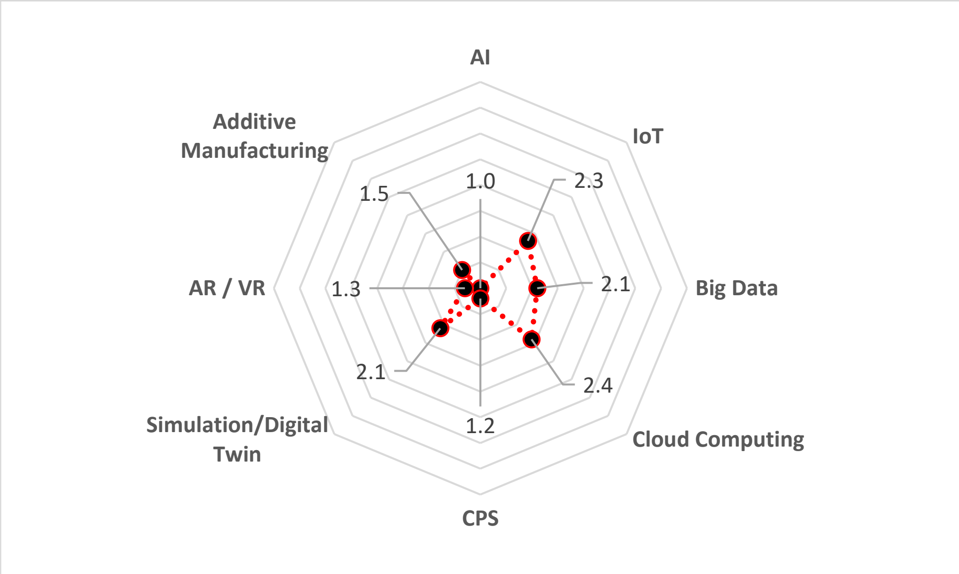

Fig. 20. Effective use of industry 4.0 technologies by medium-sized enterprises

Medium-sized companies have the highest activity in IoT (2,3) and Cloud Computing (2,4), while lower activity in CPS (1,2) and AR/VR (1.3). The higher activity level of mid-sized companies in IoT and Cloud Computing may be related to the fact that these technologies offer significant advantages in terms of scalability and efficiency. Cloud Computing offers flexibility and lower infrastructure costs, while IoT helps companies optimize their operations and reduce costs.

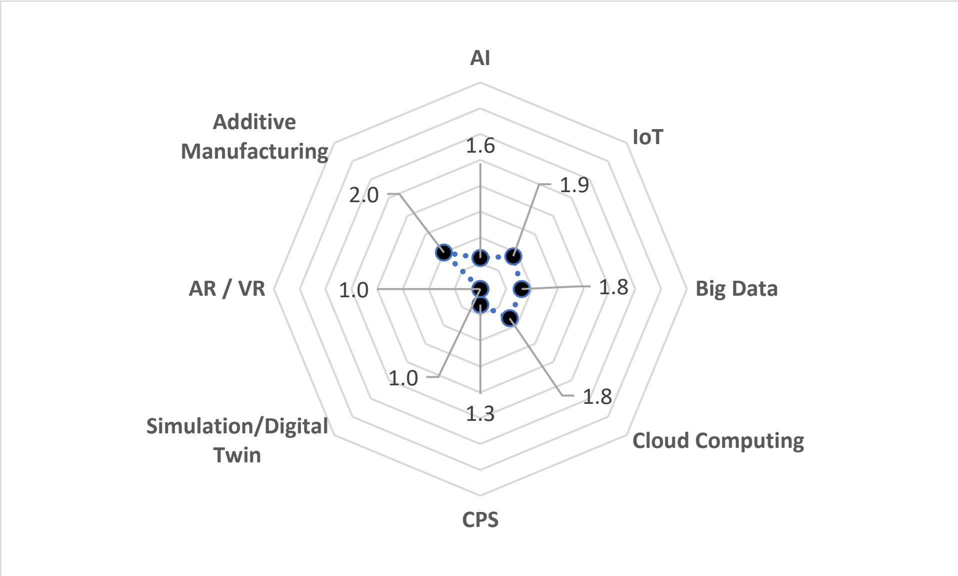

Fig. 21. Effective use of industry 4.0 technologies by micro-small-sized enterprises

Micro-Small Companies are generally fewer users of technologies. Additive Manufacturing (2.0) scores the highest for this group, while Simulation/Digital Twin and AR/VR (both 1.0) score the lowest. This may be because micro-small companies often have fewer resources and have more difficulty investing in such advanced technologies. However, the high score of Additive Manufacturing indicates that such companies are able to focus on certain technologies and make progress in certain areas.

The results show that there is a direct relationship between company size and the level of activity in technology areas. It is seen that large companies can adapt to new technologies faster and operate more in these areas with more resources and financing. Small and medium-sized companies, on the other hand, may have to prioritize technology investments because they have more limited resources. This leads to lower activity levels in some areas. Understanding and analyzing companies' activity levels in these technology areas can help companies plan their future strategies, use their resources in the most effective way, and invest in technologies that can provide a competitive advantage.

4.2. The effective use of I4.0 technologies by different production types

The survey results also show the extent to which companies in different types of production (Tool/Equipment, Metal, Iron/Steel, Mining, Refractory, Recycling and Service Provider) benefit from Industry 4.0 technologies.

Table 4. Effective use of industry 4.0 technologies by the different production types

Company Production Type	AI	IoT	Big Data	Cloud Computing	CPS	Simulation/ Digital Twin	AR / VR	Additive Manufacturing
Tool/Equipment	1,9	4,1	2,8	3,5	2,7	2,8	2,3	2,7
Metal	1,7	1,7	1,8	1,3	1,3	1,7	1,1	1,2
Iron/Steel	1,4	2,1	2,4	2,1	1,5	1,5	1,3	1,1
Mining	2,7	3,8	3,6	2,9	3,1	2,8	2,3	3,9
Refractory Materials	1,0	3,6	3,2	3,8	1,3	3,3	1,7	2,0
Recycling	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Service Provider	2,2	2,8	2,5	2,6	1,5	1,0	1,0	3,0
Average	1,8	3,0	2,6	2,6	2,0	2,0	1,7	2,2

Source: prepared by author, based on the maturity assessment survey results

Survey results show that industries are adopting Industry 4.0 technologies in different ways and to varying degrees. What is particularly evident is the high usage rates of IoT and Big Data across industries. Thanks to their data collection and analysis capabilities, these technologies appear to play a critical role in monitoring the operations of various industries, improving their processes and empowering their decision-making processes.

The Tools/Equipment, Mining and Refractory Materials sectors make particularly heavy use of these technologies and Cloud Computing. These industries often process large volumes of data and require sophisticated technologies to analyze and store this data. Therefore, it is not surprising that these sectors invest heavily in Cloud Computing. In addition, the Mining and Tool/Equipment sectors have also scored highly on Additive Manufacturing, which may mean they need a fast and efficient on-site production of certain parts or equipment. These industries also need these technologies to increase the efficiency and reliability of their business processes, often due to the complexity and scale of their operations.

The Iron/Steel and Metal sectors generally use Industry 4.0 technologies at a slightly below-average level. However, these industries have slightly higher scores in IoT and Big Data. This may reflect the need for industries to use data collection and analysis capabilities on a larger scale. However, we see that these sectors have lower scores in Cloud Computing, Simulation/Digital Twin and Additive Manufacturing. This may indicate that these technologies are perhaps not well suited to the specific business processes of these industries or that there is difficulty in fully understanding the potential returns from investing in these technologies.

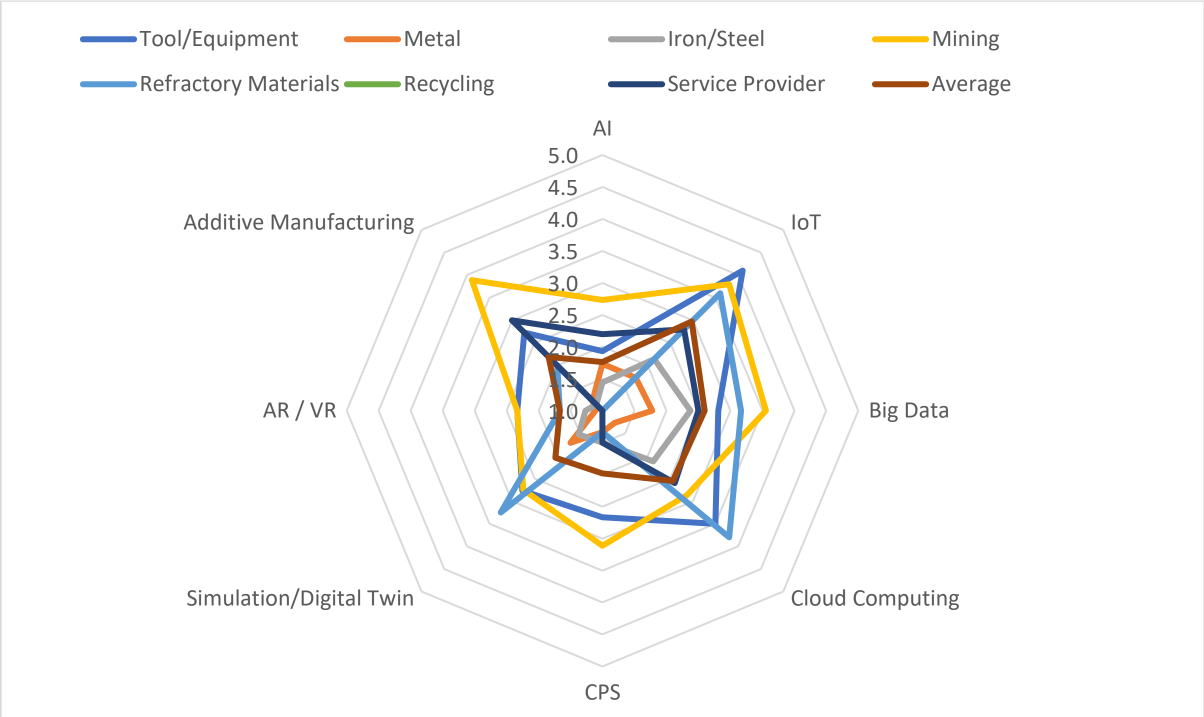

Fig. 22. Effective use of industry 4.0 technologies by production types

The recycling industry shows low usage rates in all technologies. This may indicate that the recycling industry is perhaps more constrained in technological investments, or that there is uncertainty about how suitable these technologies are for certain business processes. This may indicate that the industry is hesitant to invest in these technologies, perhaps due to difficulties in accessing technology or perhaps a lack of understanding of the return on technological investments.

Service Providers make particularly heavy use of Artificial Intelligence and IoT technologies. As the service industry is generally less impacted by physical manufacturing, these technologies may be investing more in customer service, automation of business processes, and overall operational efficiency. This shows that service providers are proactive in using technology to improve business processes and customer experiences.

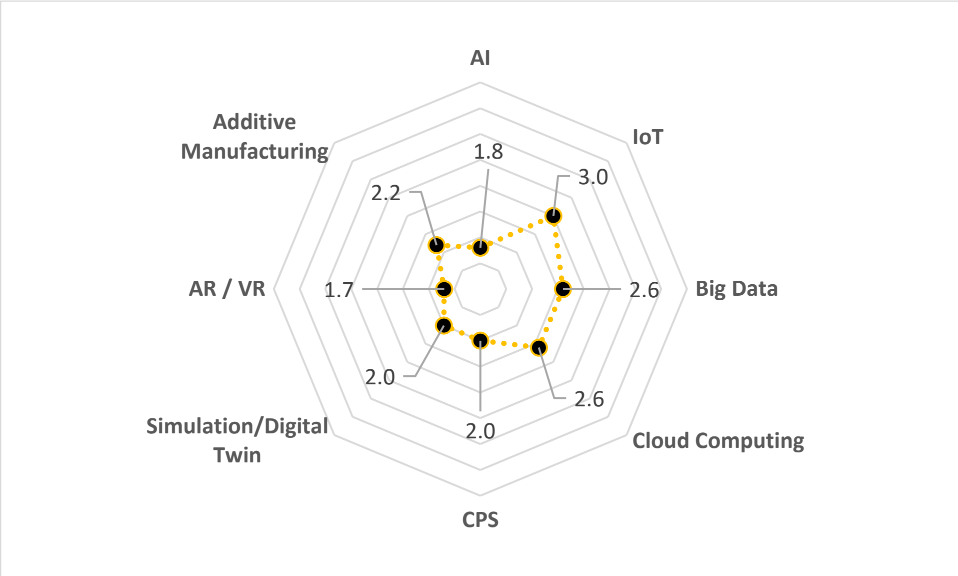

Fig. 23. Average of effective use of industry 4.0 technologies

When the two result tables are evaluated together, some common trends and differences are observed in the activities in the fields of technology according to the size of the company and the type of production. IoT, Cloud Computing and Big Data are the most popular and widely used technologies by both company size and production type. Large companies generally have higher levels of activity in all technology areas. This shows that large companies have more resources and budgets and therefore can make technology investments in a wider area. Small and micro companies, on the other hand, tend to offer customized products and services, focusing on more specific technologies.

4.3. Industry 4.0 maturity of manufacturers in the metal products sector in Sweden

The overall maturity level of Industry 4.0 was assessed by the developed model and maturity assessment survey data obtained from nine different manufacturing enterprises in the metal products industry in Sweden, including Metal Processing and Shaping, Iron/Steel Processing and Shaping, Tool/Equipment Manufacturing, and Metal Coating and Plating production types. The calculation of the sector's overall maturity level was conducted using the developed model, and the maturity radar charts for each dimension are provided in the following sections.

4.3.1. Maturity of the technology dimension

The technology maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

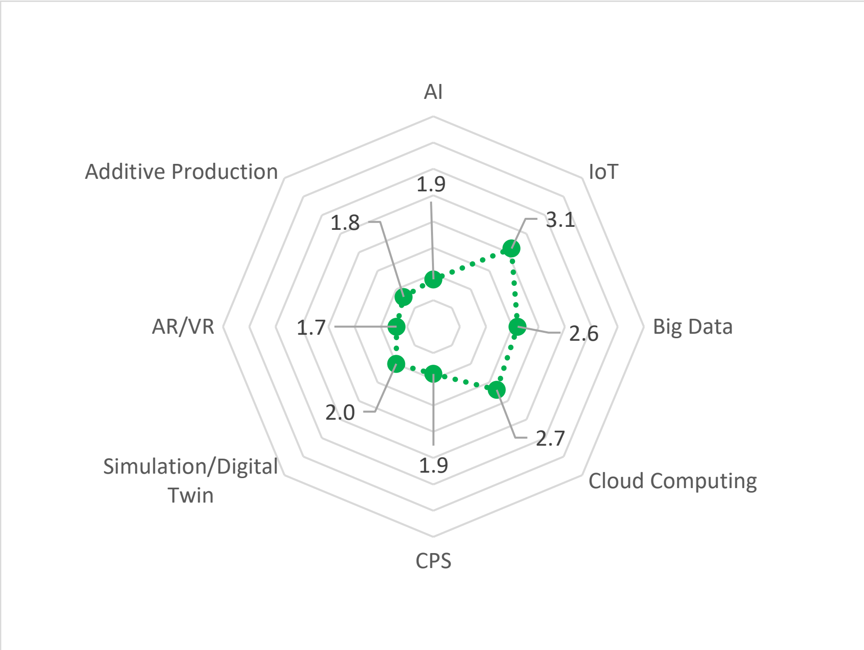

Fig. 24. Technology maturity level

The technology maturity dimension shows a relatively low adoption rate for certain Industry 4.0 technologies within the surveyed companies. Specifically, Artificial Intelligence (AI) and Cyber-Physical Systems (CPS) both received a score of 1.9 out of 5, indicating a limited application of these technologies. In contrast, the Internet of Things (IoT) has achieved a moderate adoption level, scoring 3.1. This exhibits a partial implementation of IoT technologies within these organizations. Big Data and Cloud Computing, scoring 2.6 and 2.7 respectively, also reflect a medium degree of adoption. Technologies such as Simulation/Digital Twin, AR/VR, and Additive Manufacturing scored relatively lower with 2.0, 1.7, and 1.8, respectively, indicating an area of potential growth and focus for these companies. While a certain level of technological maturity is evident in IoT (3.1), Big Data (2.6), and Cloud Computing (2.7), there is scope for significant improvement in the adoption of AI (1.9), CPS (1.9), Simulation/Digital Twin (2.0), AR/VR (1.7), and Additive Manufacturing (1.8). Finally, the maturity level of the Technology dimension was calculated as 2.28 with the method mentioned in model development.

4.3.3. Maturity of the security dimension

The security maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

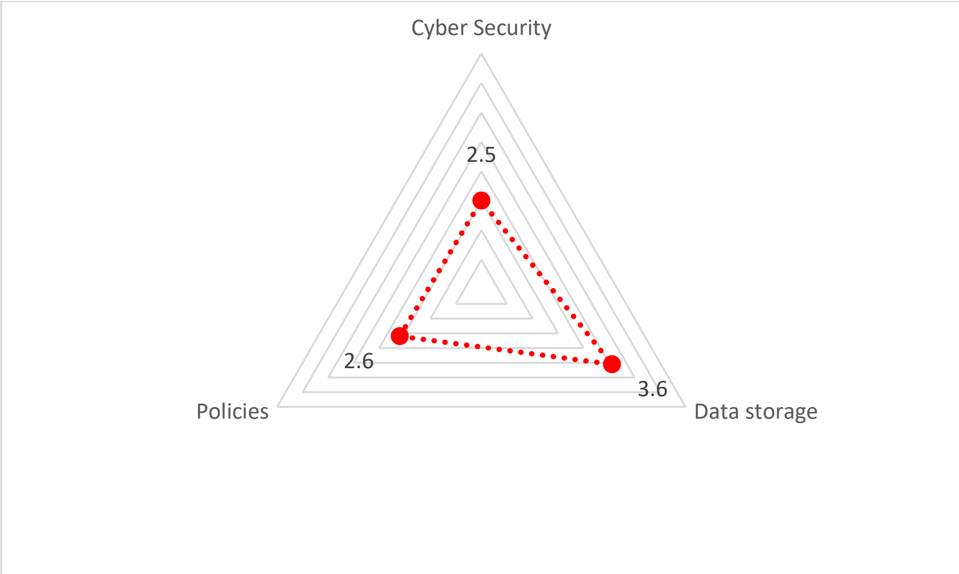

Fig. 25. Security maturity level

The Security dimension, a key facet of Industry 4.0 adoption, exhibits a range of adoption levels within the surveyed organizations. Data Storage stands out with a high adoption score of 3.6, indicating a solid implementation of this sub-dimension. This suggests that companies are recognizing the importance of robust data storage systems as part of their security infrastructure. The Cyber Security sub-dimension displays a more moderate level of implementation with a score of 2.5. This finding indicates a need for increased focus on enhancing cyber security measures, given its paramount importance in Industry 4.0 framework. The implementation of Policies, another critical sub-dimension of the Security dimension, shows a similar pattern to Cyber Security with a score of 2.6, suggesting that there is room for further strengthening of security-related policies and procedures. The reason why Policies had a low result is that companies may not have fully realized the importance of Industry 4.0 policies and may not have given enough importance to the policy formulation process. In addition, the creation of Industry 4.0 policies can be a complex process and companies may not have sufficient knowledge or resources in this regard. In summary, while Data Storage shows a high level of adoption (3.6) comparatively, Cyber Security (2.5) and Policies (2.6) have not reached the same level of maturity. The overall maturity level of the Security dimension was assessed as 2.90, which is the third-highest maturity dimension among the other dimensions.

4.3.2. Maturity of the production dimension

The production maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

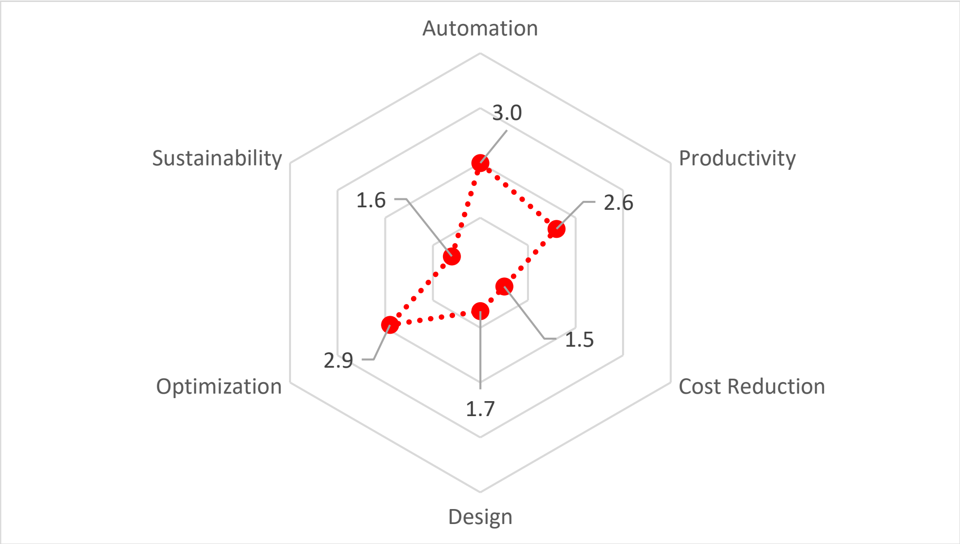

Fig. 26. Production maturity level

Automation and Optimization technologies appear to have a moderate adoption level, scoring 3.0 and 2.9, respectively, implying their partial integration into these organizations' practices. In contrast, the focus on Productivity measures is somewhat lower, with a score of 2.6, signifying that there's room for further improvement in the application of these strategies. Cost Reduction (1.5) and Design (1.7) strategies score considerably lower, this signifies a considerable underutilization of these strategic components of Industry 4.0 within these companies. In terms of cost reduction, companies have a low level of transition and there may be a need to invest more in digital optimization and cost-effective technologies. Sustainability (1.6), another crucial aspect of contemporary industrial practices, also scores low demonstrating a significant potential area for development and alignment with global sustainable production trends. While a moderate level of maturity is visible in Automation (3.0) and Optimization (2.9), there are substantial opportunities for growth and improvement in the adoption of strategies aimed at Productivity (2.6), Cost Reduction (1.5), Design (1.7), and Sustainability (1.6). Finally, the maturity level of the Production dimension was computed as 2.33 using the method outlined in the model development.

4.3.4. Maturity of the supply chain management dimension

The supply chain management maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

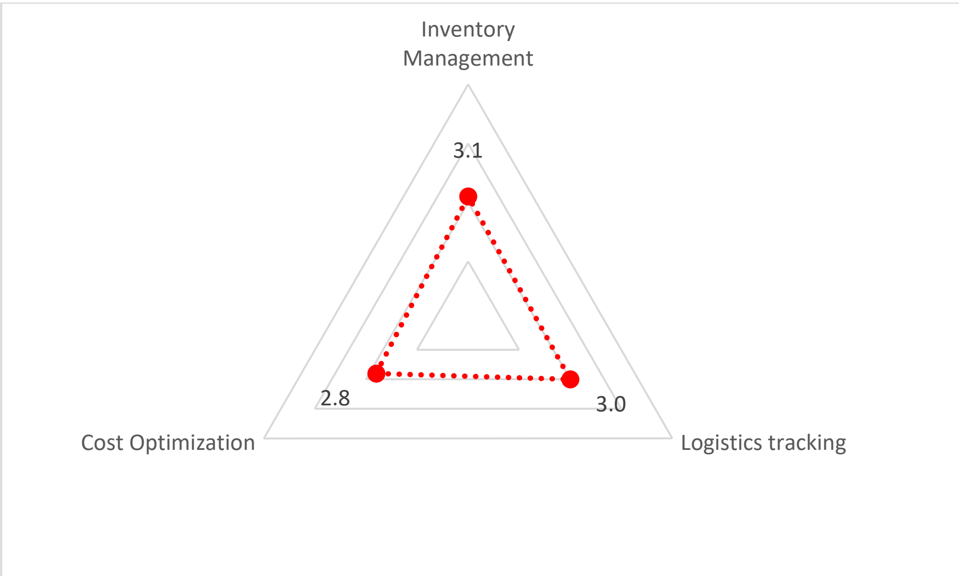

Fig. 27. Supply chain maturity level

The Supply Chain dimension reflects one of the highest levels of maturity along with the Security and Culture dimension for the Metal products industry. Inventory Management (3.1) and Logistics Tracking (3.0) are perceived with moderate levels of adoption. These scores suggest a noteworthy degree of implementation of these sub-dimensions in the organizations' supply chain strategies. The Cost Optimization sub-dimension, however, has a slightly lower score of 2.8, indicating that while this area is recognized, there remains potential for further optimization and implementation of cost-saving measures. By using more advanced cost analysis and optimization tools, companies can reduce material and labour costs, optimize logistics costs and improve operational efficiency. Eventually, Inventory Management (3.1), Logistics Tracking (3.0) and Cost Optimization (2.8) show moderate levels of adoption. The overall maturity level of the Supply Chain dimension is evaluated as 2.98, which is the highest maturity level among all dimensions.

4.3.5. Maturity of the strategy dimension

The strategy maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

Fig. 28. Strategy maturity level

The Strategy dimension is an essential aspect of Industry 4.0 implementation. The Investment and Collaboration sub-dimensions have scored 2.9 and 2.8 respectively, indicating a moderate level of adoption. The sub-dimensions of I4.0 roadmap/Planning (2.6) and Competition (2.7) reflect a slightly lower level of adoption. While these scores indicate a certain degree of strategic focus on planning and competitive dynamics, there's potential for further emphasis on these areas. Substantially lower scores are observed in Resource Management (1.9), Interoperability (2.0), and Risk Management (1.9) sub-dimensions and these represent areas that have not yet reached the same level of maturity as the other sub-dimensions, revealing considerable scope for development and integration of these strategic aspects into the overall framework. The reasons for the low level of the Risk Management sub-dimension may include factors such as companies' inability to fully assess the risks associated with Industry 4.0 technologies, lack of risk management strategies and policies, and lack of adequate measures against security threats. The low level of Resource Management can be attributed to factors such as companies' lack of effective management of resources for Industry 4.0 technologies and lack of appropriate skills. To summarise, while Investment (2.9), I40 roadmap/Planning (2.6), Competition (2.7) and Collaboration (2.8) reflect moderate maturity levels, significant improvement opportunities exist for Resource Management (1.9), Interoperability (2.0), and Risk Management (1.9). The strategy dimension is observed to be at an average level when the maturity levels of other dimensions are taken into consideration and the overall maturity level is 2.48.

4.3.6. Maturity of the innovation dimension

The innovation maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

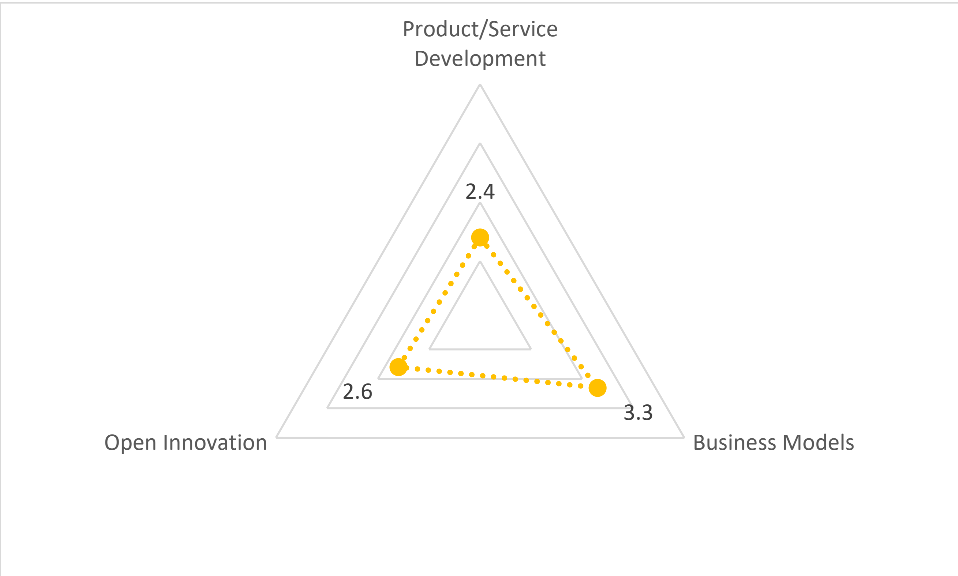

Fig. 29. Innovation maturity level

The Innovation dimension, which is one of the most important dimensions in Industry 4.0 implementation, shows different levels according to different sub-dimensions. Particularly, the Business Models sub-dimension scores highest with 3.3, and this implies that these organizations are actively exploring and implementing innovative business models in alignment with Industry 4.0 principles. Developing more flexible, innovative and value-oriented business models can provide a competitive advantage in the Industry 4.0 transformation process.

However, Product/Service Development (2.4) and Open Innovation (2.6) sub-dimensions have lower scores relatively. While these scores indicate a certain level of recognition and adoption, they also suggest potential areas for growth and deeper integration into organizational strategies. The level of the innovation maturity dimension was determined as 2.77 at the end of the calculations as having a level above the average compared to other dimensions.

4.3.7. Maturity of the customer interaction dimension

The customer interaction maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

Fig. 30. Customer interaction maturity level

The Management of Customer Data sub-dimension scored highest at 2.8 among other sub-dimensions, reflecting a moderate level of adoption. On the other hand, Digital Marketing and Personalization and Modularity sub-dimensions display lower scores of 2.3 and 1.9, respectively. This specifies that although companies have made moderate progress in effectively managing customer data, they still need improvements in fully adopting digital marketing strategies and personalization. It is important for companies to use customer data more effectively, improve their digital marketing strategies and work more on personalization/modularity in order to increase customer satisfaction and gain a competitive advantage. These scores point to areas with potential for enhancement, as they play vital roles in customer engagement and satisfaction in the context of Industry 4.0. The overall maturity level of the Customer Interaction dimension, computed using the outlined calculations in model development, is 2.36.

4.3.8. Maturity of the management dimension

The management maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

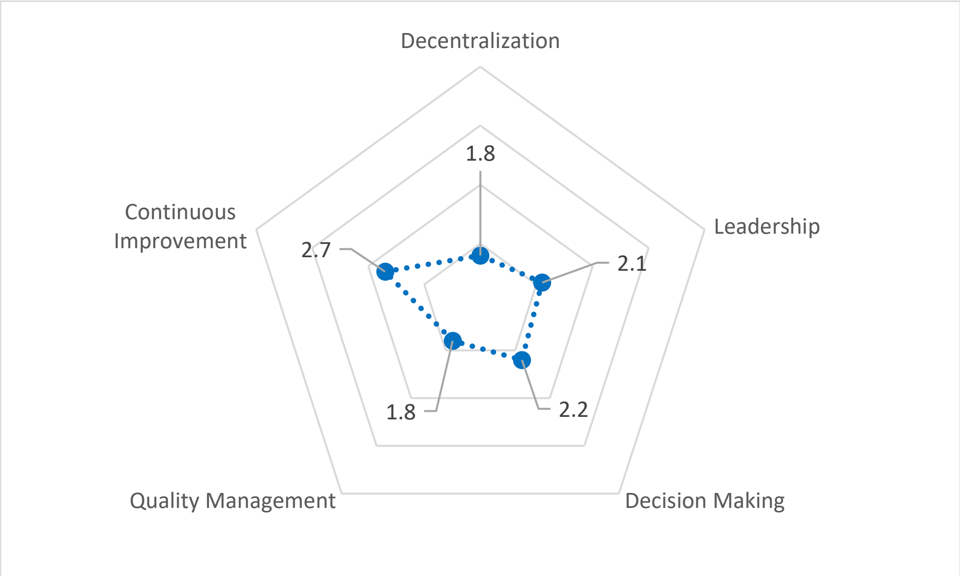

Fig. 31. Management maturity level

The Management dimension exhibits one of the lowest maturity levels of within the metal products industry. The Continuous Improvement (2.7) sub-dimension shows the highest score, indicating a moderate level of adoption. This suggests that firms within the industry recognize the importance of continuous improvement in alignment with Industry 4.0 principles. However, the scores for Decentralization and Quality Management are significantly lower at 1.8 each. Similarly, Leadership and Decision Making sub-dimensions score only slightly higher at 2.1 and 2.2 respectively. These scores indicate substantial potential for improvement in these areas, crucial for successful management in the context of Industry 4.0. In Industry 4.0, management is crucial in effectively aligning corporate strategies, processes and resources to drive digital transformation and maximize the benefits of emerging technologies. However, the overall maturity level of the Management dimension is assessed as 2.15, one of the lowest along with the HRM dimension.

4.3.9. Maturity of the culture dimension

The culture maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

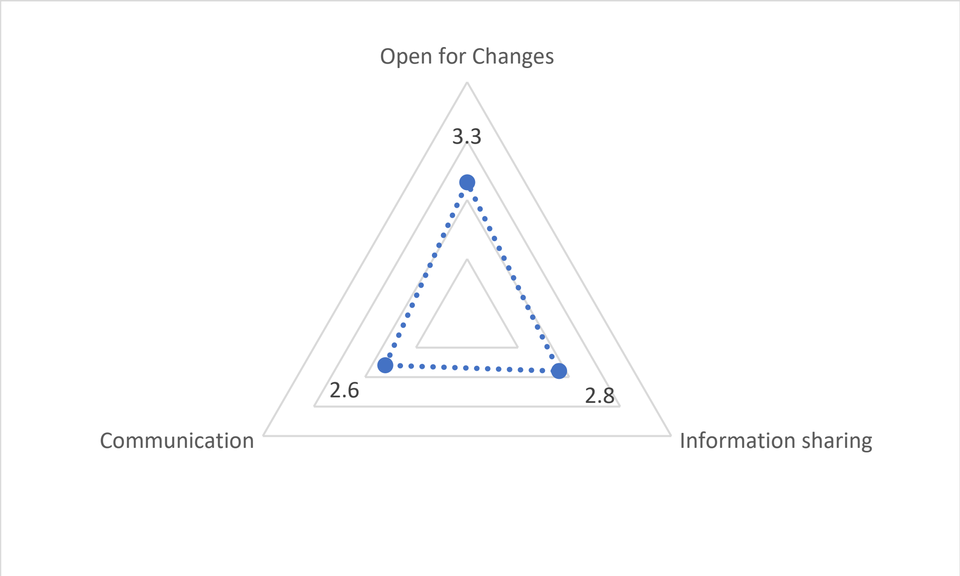

Fig. 32. Culture maturity level

The Culture dimension, integral to successful Industry 4.0 implementation, shows levels of sub-dimension maturity in the Metal products industry. Notably, the Open for Changes (3.3) sub-dimension scores the highest level of maturity in the Culture dimension. This indicates the organizations in the sector have cultivated an openness to change, a critical element for the successful integration of Industry 4.0 principles. Additionally, Information Sharing and Communication sub-dimensions have scored 2.8 and 2.6 respectively. While these scores indicate some degree of adoption, they also highlight potential areas for growth. Ensuring effective information sharing and communication is vital for fostering a culture conducive to Industry 4.0. The Culture dimension's overall maturity level was determined to be 2.94, ranking it second in terms of maturity among all dimensions assessed.

4.3.10. Maturity of the human resource management dimension

The human resource management maturity level of manufacturers operating in the metal products sector in Sweden was assessed using survey data and the developed model, as follows:

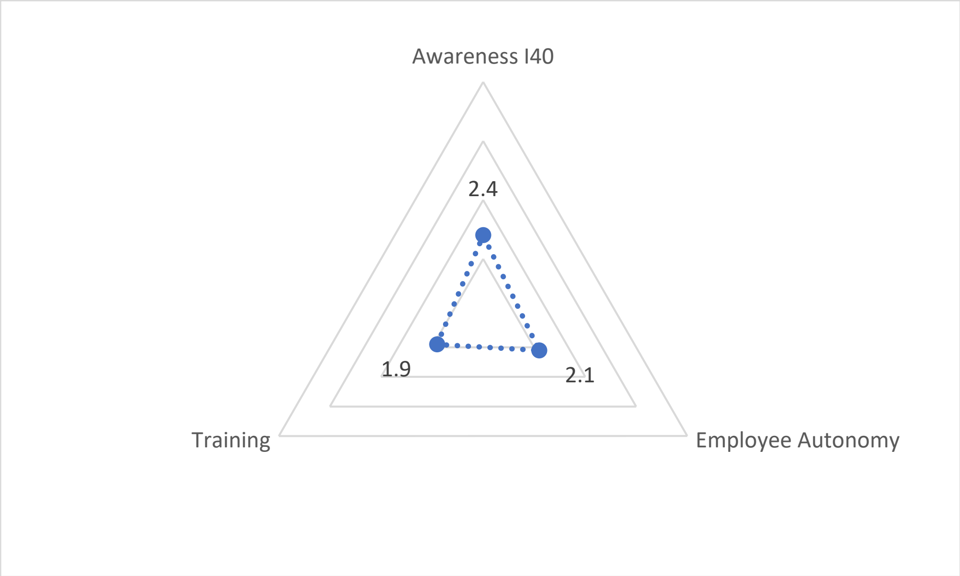

Fig. 33. Human resources maturity level

The HRM (Human Resource Management) dimension displays the lowest maturity level among the other dimensions within the metal products industry. The sub-dimensions assessed within HRM are Awareness of Industry 4.0, Employee Autonomy, and Training. Awareness of Industry 4.0 scored 2.4, indicating that there is still a need for improvement in raising awareness to a higher level. Employee Autonomy (2.1) score reveals a low level of empowerment and decision-making authority given to employees. Further efforts could be made to increase employee autonomy, which is important for fostering innovation and adaptability. Training, with a score of 1.9, indicates a lower level of emphasis on training programs specific to Industry 4.0 technologies and practices. Enhancing training initiatives better equips employees with the necessary skills and knowledge required for the successful implementation of Industry 4.0 solutions. Nevertheless, the overall maturity level of the HRM dimension was calculated as 2.14, which is the lowest maturity dimension level.

4.3.11. Overall maturity level

Finally, the levels of the 10 maturity dimensions of the Metal products sector processors in Sweden are shown in a single radar chart.

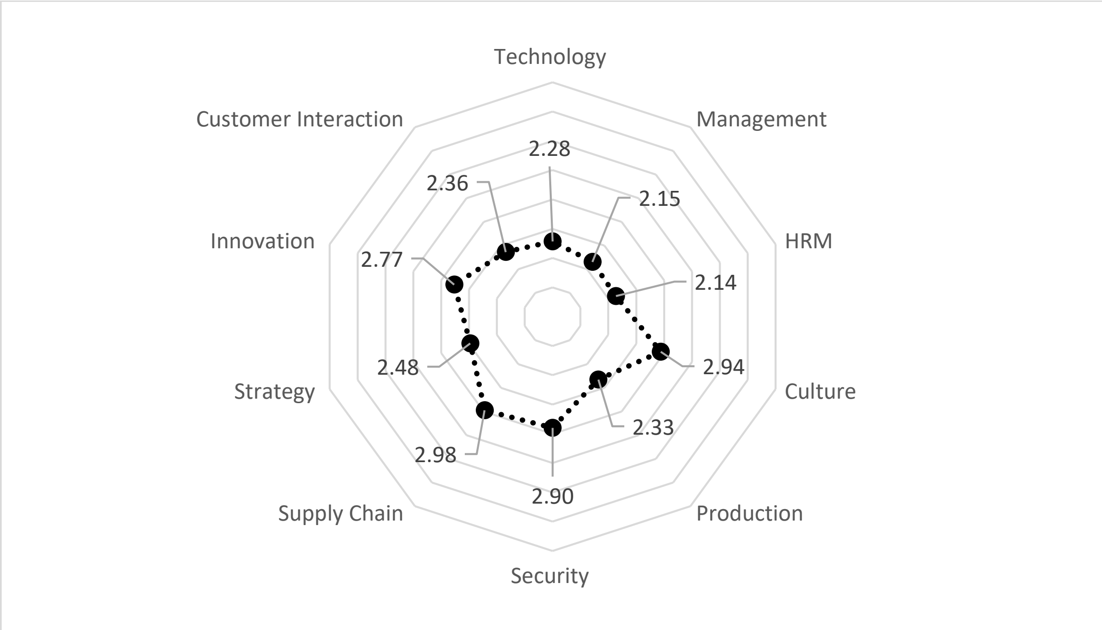

Fig. 34. Maturity levels of all dimensions

According to the overall maturity assessment formula (Fig. 17.) in the model development section, the overall maturity of the sector is as follows:

Overall Maturity = Σ (dimension_weight * dimension_maturity)

Overall maturity level = (0.20 * 2.28) + (0.20 * 2.33) + (0.10 * 2.90) + (0.10 * 2.98) + (0.10 * 2.48) + (0.10 * 2.77) + (0.05 * 2.36) + (0.05 * 2.15) + (0.05 * 2.94) + (0.05 * 2.14) = **2.52**

Based on calculations using survey data and a developed model, manufacturers operating in the metal products sector in Sweden were assessed with an overall maturity level of 2.52 out of 5. According to the scale outlined in the model development section, this indicates that the manufacturers in the sector have achieved a moderate level of maturity. In other words, these manufacturing companies have made significant progress in adopting Industry 4.0 technologies and practices. They have implemented integrated and interconnected automation and data collection systems within their operations. They also leverage data analytics to some extent for optimizing processes and making informed decisions. However, there is still a need for improvement in terms of expanding and deepening the digitalization efforts across their manufacturing operations.

CONCLUSIONS AND RECOMMENDATIONS

This master's thesis aimed to investigate the challenges faced by enterprises in Industry 4.0 and the factors impacting its successful implementation, through a scientific literature review, and to develop an Industry 4.0 maturity level for manufacturing enterprises within Sweden's Metal Products Industry and assess the overall maturity of the sector by conducting empirical research. The research addressed the lack of comprehensive models to determine the maturity of manufacturing enterprises in the Metal products industry and aimed to bridge this gap.

1. Successfully implementing Industry 4.0 necessitates a holistic approach encompassing interoperability, efficient data management, robust cybersecurity, and workforce development. Overcoming challenges, such as high upfront costs, lack of standardization, and data privacy concerns, is essential. An adaptive strategy combining people, processes, and technology is key to optimizing operations and maintaining competitiveness in the digital era.
2. Based on empirical research findings, it has been established that Micro-small-sized and medium-sized enterprises exhibit limited efficacy in the utilization of Industry 4.0 technologies. Conversely, large-sized companies have demonstrated moderate progress in incorporating IoT (3.3), Big Data (2.9), and Cloud Computing (2.7) technologies, but their efficiency in employing AI (1.9) and AR/VR (1.8) technologies remains low. Notably, enterprises engaged in Mining and Mineral Processing and Tool/Equipment production have been evaluated as surpassing the average in effectively leveraging these technologies. In terms of production type and company size, IoT (3.0) emerges as the most proficiently utilized Industry 4.0 technology, while AR/VR (1.7) technology is perceived as the least effectively employed.
3. In the maturity assessment findings, the overall Industry 4.0 maturity of the metal products industry in Sweden was assessed by using the developed model in this study.

   The Security dimension (2.90) has one of the highest levels among all dimensions. However, Cyber Security (2.5) and security-related Policies (2.6) still require further strengthening. Companies should prioritize cyber security measures by implementing robust data protection systems, encryption protocols, and continuous monitoring.

   Automation (3.0) and Optimization (2.9) subdimensions have reached a moderate level of adoption under the Production dimension (2.33) during the Industry 4.0 adoption, while strategies related to Cost reduction (1.5), Design (1.7), and Sustainability (1.6) are underutilized. To improve production processes, organizations should focus on implementing cost reduction measures, enhancing design capabilities, and prioritizing sustainable practices. To maximize the benefits of Industry 4.0, companies need to prioritize effective Resource Management (1.9), develop strategies for seamless Interoperability (2.0), and implement robust Risk Management (1.9) practices.

Business Models (3.3) have shown the highest level of maturity in the Innovation dimension (2.77), indicating that organizations are actively exploring and implementing innovative approaches. By further exploring and implementing innovative business models, improving Product/Service Development (2.4) processes, and leveraging Digital Marketing (2.3) strategies and Personalization/Modularity (1.9), organizations can enhance customer engagement, increase customer satisfaction, and gain a competitive advantage in the market.

The Management dimension (2.15) demonstrates a low level of maturity since subdimensions like Decentralization (1.8), Quality Management (1.8), Leadership (2.1), and Decision Making (2.2) require significant improvement. Additionally, the Culture dimension (2.94) reflects moderate maturity levels in Openness to Change (3.3) and Information Sharing (2.8), but further efforts can be made to enhance Communication (2.6) within organizations. Therefore, companies should focus on improving these factors under Industry 4.0 implementation to build a culture of continuous improvement and adaptability.

The HRM (2.14) dimension lags behind other dimensions in terms of maturity, with low scores in Awareness of Industry 4.0 (2.4), Employee Autonomy (2.1), and Training (1.9). Organizations need to invest in raising awareness about Industry 4.0 among employees and provide comprehensive training programs to upskill the workforce.

To conclude, companies in the metal products industry in Sweden have made moderate progress in adopting Industry 4.0 technologies, but there is still a long way to go to achieve higher maturity levels. It is recommended that companies allocate resources to adopt innovative technologies, improve production processes, strengthen security measures, enhance innovation capabilities, focus on customer satisfaction, and cultivate a supportive organizational culture. These recommendations can contribute to a more successful Industry 4.0 transformation and enable companies to gain a competitive edge in the evolving landscape of the Metal Products Industry.

Future work:

Future studies in this area can turn the developed maturity model into a software tool, and after the survey, the respondents can instantly see the maturity level of their companies. On the other hand, adapting or extending the research to different sectors within the manufacturing sector can provide a more comprehensive understanding of the maturity levels and challenges in the transition to Industry 4.0. Considering the evolving landscape of Industry 4.0 and staying updated with emerging technologies and trends would enable continuous refinement and improvement of the developed model.

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Appendix A: Correlation Matrix

		AI	IoT	Big Data	Cloud Computin g	CPS	Simulatio n/Digital Twin	AR / VR	Additive Manufactu ring	Cyber Security	Data storage	Security Policies	Inventory Managem ent in SCM	Logistics Tracking	Cost Optimizati on in SCM	Automatio n	Productivi ty in Productio n	Cost Reduction in Productio n	Product/S ervice Design	Optimizati on in Productio n	Sustainab ility	Decentrali zation	Leadershi p
AI	r	1.00	0.58	0.27	0.14	0.64	0.80	0.15	0.53	0.30	0.19	0.06	0.16	0.28	-0.07	0.74	0.55	0.56	0.17	0.76	0.37	0.91	0.51
	p		0.06	0.45	0.67	0.03	0.00	0.67	0.09	0.37	0.58	0.86	0.65	0.40	0.84	0.01	0.08	0.08	0.61	0.01	0.26	0.00	0.11
IoT	r	0.58	1.00	0.55	0.81	0.89	0.70	0.56	0.63	0.67	0.61	0.57	0.56	0.85	0.49	0.57	0.75	0.66	0.06	0.74	0.77	0.33	0.58
	p	0.06		0.08	0.00	0.00	0.01	0.07	0.03	0.02	0.04	0.05	0.06	0.00	0.10	0.05	0.01	0.02	0.86	0.01	0.00	0.29	0.05
Big Data	r	0.27	0.55	1.00	0.71	0.75	0.61	0.31	0.63	0.49	0.41	0.39	0.36	0.37	0.50	0.48	0.26	0.58	0.48	0.29	0.56	0.15	0.78
	p	0.45	0.08		0.01	0.01	0.04	0.38	0.04	0.12	0.22	0.23	0.28	0.26	0.12	0.14	0.44	0.06	0.14	0.39	0.07	0.66	0.00
Cloud Computin	r	0.14	0.81	0.71	1.00	0.69	0.46	0.63	0.39	0.74	0.81	0.61	0.60	0.79	0.75	0.30	0.61	0.45	0.02	0.46	0.72	-0.05	0.43
	p	0.67	0.00	0.01		0.02	0.14	0.04	0.21	0.01	0.00	0.03	0.04	0.00	0.01	0.35	0.03	0.14	0.96	0.14	0.01	0.89	0.16
CPS	r	0.64	0.89	0.75	0.69	1.00	0.68	0.49	0.75	0.61	0.48	0.40	0.76	0.72	0.57	0.83	0.53	0.79	0.35	0.58	0.77	0.67	0.71
	p	0.03	0.00	0.01	0.02		0.02	0.12	0.01	0.04	0.13	0.22	0.01	0.01	0.07	0.00	0.09	0.00	0.29	0.06	0.01	0.02	0.01
Simulatio n/Digital	r	0.80	0.70	0.61	0.46	0.68	1.00	0.22	0.77	0.28	0.26	0.44	0.20	0.50	0.06	0.59	0.50	0.76	0.08	0.81	0.40	0.45	0.80
	p	0.00	0.01	0.04	0.14	0.02		0.52	0.00	0.38	0.42	0.15	0.53	0.10	0.86	0.04	0.10	0.00	0.80	0.00	0.19	0.14	0.00
AR / VR	r	0.15	0.56	0.31	0.63	0.49	0.22	1.00	0.45	0.30	0.25	0.62	0.37	0.65	0.69	0.22	0.74	0.46	0.39	0.02	0.88	0.22	0.33
	p	0.67	0.07	0.38	0.04	0.12	0.52		0.16	0.37	0.45	0.04	0.27	0.03	0.02	0.51	0.01	0.15	0.24	0.96	0.00	0.51	0.33
Additive Manufactu	r	0.53	0.63	0.63	0.39	0.75	0.77	0.45	1.00	0.06	0.00	0.49	0.51	0.64	0.35	0.52	0.34	0.96	0.43	0.42	0.62	0.42	0.84
	p	0.09	0.03	0.04	0.21	0.01	0.00	0.16		0.85	1.00	0.11	0.09	0.02	0.26	0.08	0.28	0.00	0.16	0.17	0.03	0.17	0.00
Cyber Security	r	0.30	0.67	0.49	0.74	0.61	0.28	0.30	0.06	1.00	0.84	0.24	0.42	0.42	0.53	0.60	0.60	0.11	-0.17	0.45	0.52	0.27	0.22
	p	0.37	0.02	0.12	0.01	0.04	0.38	0.37	0.85		0.00	0.45	0.18	0.17	0.08	0.04	0.04	0.73	0.60	0.15	0.08	0.40	0.49
Data storage	r	0.19	0.61	0.41	0.81	0.48	0.26	0.25	0.00	0.84	1.00	0.43	0.52	0.50	0.56	0.34	0.50	0.11	-0.30	0.53	0.37	0.06	0.20
	p	0.58	0.04	0.22	0.00	0.13	0.42	0.45	1.00	0.00		0.17	0.09	0.10	0.06	0.28	0.10	0.74	0.35	0.08	0.23	0.86	0.52
Security Policies	r	0.06	0.57	0.39	0.61	0.40	0.44	0.62	0.49	0.24	0.43	1.00	0.31	0.54	0.56	0.10	0.55	0.45	-0.03	0.40	0.53	-0.02	0.65
	p	0.86	0.05	0.23	0.03	0.22	0.15	0.04	0.11	0.45	0.17		0.32	0.07	0.06	0.75	0.07	0.14	0.93	0.20	0.08	0.96	0.02
Inventory Managem	r	0.16	0.56	0.36	0.60	0.76	0.20	0.37	0.51	0.42	0.52	0.31	1.00	0.75	0.76	0.39	0.17	0.61	0.21	0.20	0.53	0.14	0.32
	p	0.65	0.06	0.28	0.04	0.01	0.53	0.27	0.09	0.18	0.09	0.32		0.00	0.00	0.22	0.60	0.03	0.51	0.54	0.08	0.66	0.31
Logistics Tracking	r	0.28	0.85	0.37	0.79	0.72	0.50	0.65	0.64	0.42	0.50	0.54	0.75	1.00	0.64	0.32	0.57	0.73	0.20	0.46	0.76	0.10	0.40
	p	0.40	0.00	0.26	0.00	0.01	0.10	0.03	0.02	0.17	0.10	0.07	0.00		0.03	0.31	0.05	0.01	0.54	0.13	0.00	0.75	0.20
Cost Optimizati	r	-0.07	0.49	0.50	0.75	0.57	0.06	0.69	0.35	0.53	0.56	0.56	0.76	0.64	1.00	0.18	0.41	0.40	0.18	-0.04	0.69	-0.05	0.28
	p	0.84	0.10	0.12	0.01	0.07	0.86	0.02	0.26	0.08	0.06	0.06	0.00	0.03		0.57	0.18	0.20	0.58	0.90	0.01	0.88	0.39
Automatio n	r	0.74	0.57	0.48	0.30	0.83	0.59	0.22	0.52	0.60	0.34	0.10	0.39	0.32	0.18	1.00	0.45	0.53	0.17	0.51	0.47	0.85	0.60
	p	0.01	0.05	0.14	0.35	0.00	0.04	0.51	0.08	0.04	0.28	0.75	0.22	0.31	0.57		0.14	0.08	0.60	0.09	0.12	0.00	0.04
Productivi ty in	r	0.55	0.75	0.26	0.61	0.53	0.50	0.74	0.34	0.60	0.50	0.55	0.17	0.57	0.41	0.45	1.00	0.37	0.09	0.54	0.76	0.45	0.34
	p	0.08	0.01	0.44	0.03	0.09	0.10	0.01	0.28	0.04	0.10	0.07	0.60	0.05	0.18	0.14		0.24	0.79	0.07	0.00	0.14	0.28
Cost Reduction	r	0.56	0.66	0.58	0.45	0.79	0.76	0.46	0.96	0.11	0.11	0.45	0.61	0.73	0.40	0.53	0.37	1.00	0.50	0.46	0.63	0.43	0.75
	p	0.08	0.02	0.06	0.14	0.00	0.00	0.15	0.00	0.73	0.74	0.14	0.03	0.01	0.20	0.08	0.24		0.10	0.13	0.03	0.16	0.00
Product/S ervice	r	0.17	0.06	0.48	0.02	0.35	0.08	0.39	0.43	-0.17	-0.30	-0.03	0.21	0.20	0.18	0.17	0.09	0.50	1.00	-0.19	0.48	0.31	0.22
	p	0.61	0.86	0.14	0.96	0.29	0.80	0.24	0.16	0.60	0.35	0.93	0.51	0.54	0.58	0.60	0.79	0.10		0.56	0.11	0.33	0.50
Optimizati on in	r	0.76	0.74	0.29	0.46	0.58	0.81	0.02	0.42	0.45	0.53	0.40	0.20	0.46	-0.04	0.51	0.54	0.46	-0.19	1.00	0.26	0.41	0.55
	p	0.01	0.01	0.39	0.14	0.06	0.00	0.96	0.17	0.15	0.08	0.20	0.54	0.13	0.90	0.09	0.07	0.13	0.56		0.41	0.19	0.06
Sustainab ility	r	0.37	0.77	0.56	0.72	0.77	0.40	0.88	0.62	0.52	0.37	0.53	0.53	0.76	0.69	0.47	0.76	0.63	0.48	0.26	1.00	0.38	0.48
	p	0.26	0.00	0.07	0.01	0.01	0.19	0.00	0.03	0.08	0.23	0.08	0.08	0.00	0.01	0.12	0.00	0.03	0.11	0.41		0.23	0.11
Decentrali zation	r	0.91	0.33	0.15	-0.05	0.67	0.45	0.22	0.42	0.27	0.06	-0.02	0.14	0.10	-0.05	0.85	0.45	0.43	0.31	0.41	0.38	1.00	0.45
	p	0.00	0.29	0.66	0.89	0.02	0.14	0.51	0.17	0.40	0.86	0.96	0.66	0.75	0.88	0.00	0.14	0.16	0.33	0.19	0.23		0.14
Leadershi p	r	0.51	0.58	0.78	0.43	0.71	0.80	0.33	0.84	0.22	0.20	0.65	0.32	0.40	0.28	0.60	0.34	0.75	0.22	0.55	0.48	0.45	1.00
	p	0.11	0.05	0.00	0.16	0.01	0.00	0.33	0.00	0.49	0.52	0.02	0.31	0.20	0.39	0.04	0.28	0.00	0.50	0.06	0.11	0.14	
Decision Making	r	0.99	0.40	0.12	0.03	0.69	0.51	0.15	0.46	0.23	0.18	0.06	0.28	0.22	0.00	0.74	0.44	0.51	0.25	0.58	0.33	0.92	0.45
	p	0.00	0.20	0.72	0.94	0.02	0.09	0.66	0.14	0.47	0.57	0.84	0.37	0.50	1.00	0.01	0.15	0.09	0.43	0.05	0.29	0.00	0.14
Quality Managem	r	0.82	0.70	0.55	0.46	0.83	0.64	0.60	0.68	0.45	0.26	0.28	0.35	0.54	0.34	0.74	0.73	0.68	0.42	0.48	0.81	0.77	0.61
	p	0.00	0.01	0.08	0.13	0.00	0.02	0.05	0.01	0.14	0.41	0.38	0.26	0.07	0.28	0.01	0.01	0.02	0.17	0.11	0.00	0.00	0.04
Continuou s	r	0.87	0.46	0.44	0.21	0.76	0.65	0.10	0.52	0.42	0.35	0.13	0.34	0.23	0.08	0.91	0.38	0.55	0.15	0.60	0.32	0.88	0.65
	p	0.00	0.14	0.17	0.52	0.01	0.02	0.77	0.08	0.17	0.27	0.70	0.28	0.48	0.79	0.00	0.23	0.06	0.63	0.04	0.31	0.00	0.02
Product/S ervice	r	0.70	0.77	0.70	0.48	0.83	0.83	0.49	0.92	0.30	0.16	0.55	0.38	0.59	0.34	0.64	0.57	0.85	0.30	0.59	0.71	0.54	0.88
	p	0.02	0.00	0.02	0.11	0.00	0.00	0.12	0.00	0.35	0.63	0.06	0.22	0.04	0.29	0.03	0.05	0.00	0.34	0.04	0.01	0.07	0.00
Business Models	r	0.56	0.20	-0.27	-0.23	0.26	0.18	0.39	0.28	0.00	-0.27	0.12	-0.14	0.01	-0.05	0.38	0.54	0.20	0.19	0.14	0.37	0.69	0.19
	p	0.08	0.54	0.42	0.48	0.45	0.58	0.24	0.38	1.00	0.40	0.70	0.66	0.97	0.89	0.22	0.07	0.54	0.56	0.66	0.24	0.01	0.56
Open Innovation	r	0.67	0.39	-0.04	0.05	0.51	0.50	0.31	0.43	0.21	0.14	0.45	0.14	0.20	0.12	0.58	0.59	0.45	0.11	0.51	0.32	0.71	0.50
	p	0.02	0.21	0.91	0.89	0.11	0.10	0.36	0.16	0.52	0.67	0.14	0.66	0.54	0.71	0.05	0.04	0.14	0.74	0.09	0.31	0.01	0.10
Awarenes s I4.0	r	0.70	0.65	0.56	0.34	0.74	0.88	0.22	0.81	0.25	0.24	0.55	0.34	0.45	0.13	0.71	0.42	0.79	0.17	0.76	0.41	0.60	0.91
	p	0.02	0.02	0.07	0.27	0.01	0.00	0.51	0.00	0.42	0.45	0.06	0.27	0.14	0.68	0.01	0.17	0.00	0.61	0.00	0.19	0.04	0.00
Employee Autonomy	r	0.23	0.64	0.55	0.71	0.76	0.20	0.76	0.48	0.62	0.45	0.33	0.71	0.70	0.86	0.47	0.58	0.53	0.43	0.04	0.89	0.28	0.30
	p	0.49	0.03	0.08	0.01	0.01	0.53	0.01	0.12	0.03	0.14	0.29	0.01	0.01	0.00	0.12	0.05	0.08	0.16	0.89	0.00	0.38	0.34
Training	r	0.51	0.58	0.78	0.43	0.71	0.80	0.33	0.84	0.22	0.20	0.65	0.32	0.40	0.28	0.60	0.34	0.75	0.22	0.55	0.48	0.45	1.00
	p	0.11	0.05	0.00	0.16	0.01	0.00	0.33	0.00	0.49	0.52	0.02	0.31	0.20	0.39	0.04	0.28	0.00	0.50	0.06	0.11	0.14	
I.40	r	0.35	0.45	0.42	0.21	0.46	0.57	0.49	0.65	0.11	-0.08	0.60	-0.02	0.24	0.14	0.45	0.43	0.47	0.02	0.29	0.46	0.38	0.78

		Decision Making	Quality Managem ent	Continuou s Improvem ent	Product/S ervice Developm ent	Business Models	Open Innovation	Awarenes s I4.0	Employee Autonomy	Training	I.40 roadmap/ Planning	Competiti on	Investmen t	Collaborat ion	Resource Managem ent	Interopera bility	Risk Managem ent	Managem ent of Customer Data	Digital Marketing	Personali zation and Modularity	Open for Changes	Internal Informatio n Sharing	Internal Communi cation
AI	r	0.99	0.82	0.87	0.70	0.56	0.67	0.70	0.23	0.51	0.35	0.11	0.21	0.19	0.50	0.60	0.56	0.37	0.24	0.57	0.35	0.01	0.00
	p	0.00	0.00	0.00	0.02	0.08	0.02	0.02	0.49	0.11	0.30	0.74	0.53	0.57	0.12	0.05	0.07	0.27	0.48	0.07	0.29	0.97	1.00
IoT	r	0.40	0.70	0.46	0.77	0.20	0.39	0.65	0.64	0.58	0.45	0.23	0.34	0.11	0.77	0.53	0.59	0.62	0.34	0.70	0.07	0.60	0.48
	p	0.20	0.01	0.14	0.00	0.54	0.21	0.02	0.03	0.05	0.14	0.47	0.27	0.74	0.00	0.08	0.04	0.03	0.28	0.01	0.83	0.04	0.11
Big Data	r	0.12	0.55	0.44	0.70	-0.27	-0.04	0.56	0.55	0.78	0.42	0.68	0.22	0.12	0.57	0.56	0.68	0.88	0.49	0.70	-0.16	0.31	0.36
	p	0.72	0.08	0.17	0.02	0.42	0.91	0.07	0.08	0.00	0.20	0.02	0.52	0.73	0.07	0.08	0.02	0.00	0.13	0.02	0.64	0.36	0.27
Cloud Computin	r	0.03	0.46	0.21	0.48	-0.23	0.05	0.34	0.71	0.43	0.21	0.40	0.11	-0.04	0.62	0.30	0.43	0.63	0.45	0.51	-0.17	0.78	0.74
	p	0.94	0.13	0.52	0.11	0.48	0.89	0.27	0.01	0.16	0.51	0.20	0.74	0.90	0.03	0.35	0.17	0.03	0.14	0.09	0.61	0.00	0.01
CPS	r	0.69	0.83	0.76	0.83	0.26	0.51	0.74	0.76	0.71	0.46	0.51	0.46	0.32	0.80	0.77	0.79	0.84	0.43	0.84	0.21	0.52	0.57
	p	0.02	0.00	0.01	0.00	0.45	0.11	0.01	0.01	0.01	0.15	0.11	0.15	0.33	0.00	0.01	0.00	0.00	0.19	0.00	0.54	0.10	0.07
Simulatio n/Digital	r	0.51	0.64	0.65	0.83	0.18	0.50	0.88	0.20	0.80	0.57	0.47	0.40	0.35	0.71	0.70	0.72	0.55	0.62	0.79	0.24	0.21	0.07
	p	0.09	0.02	0.02	0.00	0.58	0.10	0.00	0.53	0.00	0.05	0.13	0.20	0.27	0.01	0.01	0.01	0.07	0.03	0.00	0.44	0.52	0.84
AR / VR	r	0.15	0.60	0.10	0.49	0.39	0.31	0.22	0.76	0.33	0.49	0.30	0.49	0.51	0.60	0.50	0.58	0.34	0.45	0.49	0.45	0.63	0.74
	p	0.66	0.05	0.77	0.12	0.24	0.36	0.51	0.01	0.33	0.13	0.37	0.13	0.11	0.05	0.12	0.06	0.31	0.17	0.13	0.16	0.04	0.01
Additive Manufactu	r	0.46	0.68	0.52	0.92	0.28	0.43	0.81	0.48	0.84	0.65	0.66	0.70	0.61	0.89	0.87	0.93	0.69	0.64	0.98	0.25	0.33	0.26
	p	0.14	0.01	0.08	0.00	0.38	0.16	0.00	0.12	0.00	0.02	0.02	0.01	0.03	0.00	0.00	0.00	0.01	0.02	0.00	0.44	0.30	0.41
Cyber Security	r	0.23	0.45	0.42	0.30	0.00	0.21	0.25	0.62	0.22	0.11	0.02	-0.12	-0.25	0.25	0.11	0.17	0.56	-0.02	0.19	-0.06	0.39	0.45
	p	0.47	0.14	0.17	0.35	1.00	0.52	0.42	0.03	0.49	0.73	0.94	0.72	0.44	0.43	0.73	0.60	0.06	0.94	0.56	0.86	0.21	0.14
Data storage	r	0.18	0.26	0.35	0.16	-0.27	0.14	0.24	0.45	0.20	-0.08	0.21	-0.15	-0.27	0.26	0.10	0.03	0.41	0.21	0.14	-0.17	0.69	0.67
	p	0.57	0.41	0.27	0.63	0.40	0.67	0.45	0.14	0.52	0.82	0.52	0.63	0.40	0.41	0.76	0.93	0.19	0.51	0.66	0.60	0.01	0.02
Security Policies	r	0.06	0.28	0.13	0.55	0.12	0.45	0.55	0.33	0.65	0.60	0.56	0.67	0.56	0.56	0.60	0.36	0.31	0.53	0.48	0.35	0.69	0.57
	p	0.84	0.38	0.70	0.06	0.70	0.14	0.06	0.29	0.02	0.04	0.06	0.02	0.06	0.06	0.04	0.25	0.33	0.08	0.12	0.26	0.01	0.05
Inventory Managem	r	0.28	0.35	0.34	0.38	-0.14	0.14	0.34	0.71	0.32	-0.02	0.50	0.23	0.10	0.67	0.42	0.47	0.65	0.40	0.59	-0.23	0.70	0.72
	p	0.37	0.26	0.28	0.22	0.66	0.66	0.27	0.01	0.31	0.95	0.10	0.48	0.76	0.02	0.18	0.12	0.02	0.19	0.04	0.47	0.01	0.01
Logistics Tracking	r	0.22	0.54	0.23	0.59	0.01	0.20	0.45	0.70	0.40	0.24	0.34	0.33	0.16	0.85	0.46	0.61	0.53	0.54	0.72	-0.04	0.80	0.70
	p	0.50	0.07	0.48	0.04	0.97	0.54	0.14	0.01	0.20	0.45	0.29	0.30	0.62	0.00	0.13	0.03	0.08	0.07	0.01	0.89	0.00	0.01
Cost Optimizati	r	0.00	0.34	0.08	0.34	-0.05	0.12	0.13	0.86	0.28	0.14	0.49	0.26	0.21	0.55	0.32	0.40	0.60	0.36	0.42	-0.10	0.73	0.83
	p	1.00	0.28	0.79	0.29	0.89	0.71	0.68	0.00	0.39	0.66	0.10	0.41	0.50	0.06	0.31	0.20	0.04	0.25	0.18	0.77	0.01	0.00
Automatio n	r	0.74	0.74	0.91	0.64	0.38	0.58	0.71	0.47	0.60	0.45	0.27	0.32	0.28	0.46	0.66	0.62	0.66	0.22	0.58	0.42	0.12	0.20
	p	0.01	0.01	0.00	0.03	0.22	0.05	0.01	0.12	0.04	0.14	0.40	0.30	0.38	0.13	0.02	0.03	0.02	0.50	0.05	0.17	0.72	0.53
Productivi ty in	r	0.44	0.73	0.38	0.57	0.54	0.59	0.42	0.58	0.34	0.43	-0.02	0.25	0.22	0.54	0.42	0.43	0.25	0.24	0.40	0.41	0.46	0.43
	p	0.15	0.01	0.23	0.05	0.07	0.04	0.17	0.05	0.28	0.17	0.94	0.43	0.50	0.07	0.18	0.17	0.43	0.45	0.20	0.19	0.13	0.17
Cost Reduction	r	0.51	0.68	0.55	0.85	0.20	0.45	0.79	0.53	0.75	0.47	0.64	0.56	0.51	0.96	0.83	0.93	0.63	0.74	0.98	0.16	0.44	0.37
	p	0.09	0.02	0.06	0.00	0.54	0.14	0.00	0.08	0.00	0.13	0.03	0.06	0.09	0.00	0.00	0.00	0.03	0.01	0.00	0.61	0.15	0.23
Product/S ervice	r	0.25	0.42	0.15	0.30	0.19	0.11	0.17	0.43	0.22	0.02	0.18	0.13	0.20	0.49	0.36	0.58	0.09	0.32	0.49	0.03	0.10	0.19
	p	0.43	0.17	0.63	0.34	0.56	0.74	0.61	0.16	0.50	0.96	0.58	0.70	0.54	0.10	0.24	0.05	0.78	0.31	0.10	0.93	0.75	0.55
Optimizati on in	r	0.58	0.48	0.60	0.59	0.14	0.51	0.76	0.04	0.55	0.29	0.13	0.16	-0.01	0.48	0.44	0.30	0.29	0.29	0.48	0.09	0.31	0.08
	p	0.05	0.11	0.04	0.04	0.66	0.09	0.00	0.89	0.06	0.36	0.69	0.63	0.96	0.11	0.16	0.34	0.37	0.36	0.12	0.78	0.33	0.81
Sustainab ility	r	0.33	0.81	0.32	0.71	0.37	0.32	0.41	0.89	0.48	0.46	0.26	0.42	0.30	0.77	0.56	0.71	0.57	0.34	0.69	0.22	0.61	0.65
	p	0.29	0.00	0.31	0.01	0.24	0.31	0.19	0.00	0.11	0.13	0.41	0.18	0.34	0.00	0.06	0.01	0.05	0.28	0.01	0.48	0.04	0.02
Decentrali zation	r	0.92	0.77	0.88	0.54	0.69	0.71	0.60	0.28	0.45	0.38	0.08	0.32	0.36	0.35	0.64	0.52	0.31	0.11	0.44	0.59	-0.05	0.03
	p	0.00	0.00	0.00	0.07	0.01	0.01	0.04	0.38	0.14	0.23	0.81	0.31	0.25	0.26	0.03	0.08	0.33	0.73	0.15	0.04	0.88	0.92
Leadershi p	r	0.45	0.61	0.65	0.88	0.19	0.50	0.91	0.30	1.00	0.78	0.76	0.73	0.63	0.67	0.90	0.75	0.68	0.59	0.82	0.40	0.31	0.25
	p	0.14	0.04	0.02	0.00	0.56	0.10	0.00	0.34		0.00	0.00	0.01	0.03	0.02	0.00	0.00	0.01	0.04	0.00	0.20	0.32	0.43
Decision Making	r	1.00	0.73	0.87	0.55	0.60	0.74	0.66	0.23	0.45	0.23	0.13	0.26	0.27	0.45	0.63	0.47	0.27	0.19	0.49	0.39	0.10	0.09
	p		0.01	0.00	0.06	0.04	0.01	0.02	0.47	0.14	0.48	0.68	0.42	0.40	0.14	0.03	0.13	0.40	0.56	0.11	0.21	0.75	0.78
Quality Managem	r	0.73	1.00	0.71	0.82	0.55	0.50	0.62	0.66	0.61	0.51	0.25	0.38	0.33	0.70	0.70	0.79	0.60	0.32	0.73	0.37	0.30	0.34
	p	0.01		0.01	0.00	0.06	0.10	0.03	0.02	0.04	0.09	0.43	0.23	0.30	0.01	0.01	0.00	0.04	0.31	0.01	0.23	0.35	0.28
Continuou s	r	0.87	0.71	1.00	0.61	0.33	0.64	0.77	0.28	0.65	0.35	0.40	0.29	0.31	0.46	0.72	0.58	0.55	0.36	0.58	0.41	0.14	0.18
	p	0.00	0.01		0.04	0.29	0.03	0.00	0.37	0.02	0.26	0.20	0.37	0.33	0.14	0.01	0.05	0.06	0.25	0.05	0.19	0.66	0.57
Product/S ervice	r	0.55	0.82	0.61	1.00	0.44	0.54	0.85	0.51	0.88	0.77	0.51	0.68	0.54	0.82	0.85	0.85	0.70	0.46	0.90	0.34	0.29	0.21
	p	0.06	0.00	0.04		0.15	0.07	0.00	0.09	0.00	0.00	0.09	0.01	0.07	0.00	0.00	0.00	0.01	0.13	0.00	0.29	0.37	0.50
Business Models	r	0.60	0.55	0.33	0.44	1.00	0.72	0.31	0.19	0.19	0.50	-0.22	0.48	0.49	0.20	0.42	0.28	-0.03	-0.19	0.19	0.66	-0.19	-0.17
	p	0.04	0.06	0.29	0.15		0.01	0.33	0.56	0.56	0.10	0.48	0.12	0.10	0.53	0.17	0.37	0.93	0.56	0.55	0.02	0.55	0.61
Open Innovation	r	0.74	0.50	0.64	0.54	0.72	1.00	0.71	0.18	0.50	0.48	0.17	0.52	0.58	0.45	0.68	0.39	0.13	0.27	0.41	0.63	0.14	0.09
	p	0.01	0.10	0.03	0.07	0.01		0.01	0.58	0.10	0.12	0.59	0.08	0.05	0.14	0.02	0.21	0.70	0.40	0.19	0.03	0.68	0.79
Awarenes s I4.0	r	0.66	0.62	0.77	0.85	0.31	0.71	1.00	0.22	0.91	0.65	0.57	0.63	0.54	0.72	0.88	0.70	0.55	0.57	0.81	0.40	0.28	0.16
	p	0.02	0.03	0.00	0.00	0.33	0.01		0.49	0.00	0.02	0.05	0.03	0.07	0.01	0.00	0.01	0.06	0.06	0.00	0.19	0.38	0.62
Employee Autonomy	r	0.23	0.66	0.28	0.51	0.19	0.18	0.22	1.00	0.30	0.22	0.29	0.22	0.16	0.66	0.40	0.63	0.68	0.28	0.57	0.00	0.57	0.71
	p	0.47	0.02	0.37	0.09	0.56	0.58	0.49		0.34	0.50	0.35	0.50	0.63	0.02	0.20	0.03	0.02	0.38	0.05	0.99	0.05	0.01
Training	r	0.45	0.61	0.65	0.88	0.19	0.50	0.91	0.30	1.00	0.78	0.76	0.73	0.63	0.67	0.90	0.75	0.68	0.59	0.82	0.40	0.31	0.25
	p	0.14	0.04	0.02	0.00	0.56	0.10	0.00	0.34		0.00	0.00	0.01	0.03	0.02	0.00	0.00	0.01	0.04	0.00	0.20	0.32	0.43
I.40	r	0.23	0.51	0.35	0.77	0.50	0.48	0.65	0.22	0.78	1.00	0.43	0.87	0.77	0.41	0.73	0.58	0.49	0.26	0.55	0.70	0.07	0.05

Appendix B: Questionnaire of factor evaluation

Importance of Industry 4.0 Subdimensions

This survey is designed to evaluate the importance of the sub-dimensions in the Industry 4.0 maturity model to be developed for manufacturers operating in the Metal products industry in Sweden.
The answers you provide in this survey will be used to develop the Industry 4.0 maturity model, which is the objective of the master's thesis.

The survey will take approximately 2-3 minutes to complete, and your responses will only be used in aggregate. **Your answers will remain confidential and anonymous, and your privacy will be ensured.**

Thank you for taking the time to participate in this survey.

1. Please select the production type(s) of your enterprise *

- ☐ Metal Processing and Shaping
- ☐ Iron/Steel Processing and Shaping
- ☐ Tool/Equipment Manufacturing
- ☐ Mining and Mineral Processing
- ☐ Metal Coating and Plating
- ☐ Aluminum Processing
- ☐ Copper Processing
- ☐ Recycling
- ☐ Assembly
- ☐ Other: ____________

2. What department do you work in at your enterprise? *

- ◯ Sales and Marketing
- ◯ Human Resources
- ◯ Accounting and Finance
- ◯ Administration and General Services
- ◯ Research and Innovation
- ◯ Production and Operations
- ◯ Information Technology (IT)
- ◯ Logistics and Supply Chain Management
- ◯ Quality Control and Assurance
- ◯ Other: ____________________

3. What is the size of your company? *

- ◯ Microenterprise (1 to 9 employees)
- ◯ Small enterprise (10 to 49 employees)
- ◯ Medium-sized enterprise (50 to 249 employees)
- ◯ Large enterprise (250 employees or more)

4. In which region(s) outside of Sweden does your enterprise operate? *

- ☐ Our enterprise operates only in Sweden
- ☐ Europe
- ☐ Middle East
- ☐ North America
- ☐ South America
- ☐ Asia
- ☐ Africa
- ☐ Oceania

5. To which region(s) does your enterprise export? *

- ☐ Our enterprise does not export
- ☐ Europe
- ☐ Middle East
- ☐ North America
- ☐ South America
- ☐ Asia
- ☐ Africa
- ☐ Oceania

6. Please rate the importance of the following factors in the Industry 4.0 process on a scale of 1 to 5 *
(1: Not at all, 2: Slightly, 3: Moderately, 4: High, 5: Very high)

	1	2	3	4	5
Cyber Security	○	○	○	○	○
Data storage	○	○	○	○	○
Security Policies	○	○	○	○	○
Inventory Management in Supply Chain	○	○	○	○	○
Logistics Tracking	○	○	○	○	○
Cost Optimization in Supply Chain	○	○	○	○	○
Automation	○	○	○	○	○
Productivity in Production	○	○	○	○	○
Cost Reduction in Production	○	○	○	○	○
Product/Service Design	○	○	○	○	○
Optimization in Production	○	○	○	○	○
Sustainability	○	○	○	○	○
Decentralization	○	○	○	○	○

Leadership	○	○	○	○	○
Decision Making	○	○	○	○	○
Quality Management	○	○	○	○	○
Continuous Improvement	○	○	○	○	○
Product/Service Development	○	○	○	○	○
Business Models	○	○	○	○	○
Open Innovation	○	○	○	○	○
Awareness I4.0	○	○	○	○	○
Employee Autonomy	○	○	○	○	○
Training	○	○	○	○	○
I.40 roadmap/Planning	○	○	○	○	○
Competition	○	○	○	○	○
Investment	○	○	○	○	○
Collaboration	○	○	○	○	○

Resource Management	○	○	○	○	○
Interoperability	○	○	○	○	○
Risk Management	○	○	○	○	○
Management of Customer Data	○	○	○	○	○
Digital Marketing	○	○	○	○	○
Personalization and Modularity	○	○	○	○	○
Open for Changes	○	○	○	○	○
Internal Information Sharing	○	○	○	○	○
Internal Communication	○	○	○	○	○

Appendix C: Questionnaire of maturity assessment

Industry 4.0 Maturity Level

This survey is designed to assess the Industry 4.0 maturity level of manufacturers operating in the Metal products industry in Sweden.
The answers you provide in this survey will be used to assess the Industry 4.0 maturity level, which is one of the master's thesis objectives.

The survey will take approximately 5 minutes to complete, and your responses will only be used in aggregate.
Your answers will remain confidential and anonymous, and your privacy will be ensured.

If you want your company's Industry 4.0 maturity level to be sent to you as a report later, you can share your email address at the end.
Thank you for taking the time to participate in this survey.

1. Please select the production type(s) of your enterprise *

- [ ] Metal Processing and Shaping
- [ ] Iron/Steel Processing and Shaping
- [ ] Tool/Equipment Manufacturing
- [ ] Mining and Mineral Processing
- [ ] Metal Coating and Plating
- [ ] Aluminum Processing
- [ ] Copper Processing
- [ ] Recycling
- [ ] Assembly
- [ ] Other: ____________

2. What department do you work in at your enterprise? *

- ○ Sales and Marketing
- ○ Human Resources
- ○ Accounting and Finance
- ○ Administration and General Services
- ○ Research and Innovation
- ○ Production and Operations
- ○ Information Technology (IT)
- ○ Logistics and Supply Chain Management
- ○ Quality Control and Assurance
- ○ Other: ____________

3. What is the size of your company? *

- ◯ Microenterprise (1 to 9 employees)
- ◯ Small enterprise (10 to 49 employees)
- ◯ Medium-sized enterprise (50 to 249 employees)
- ◯ Large enterprise (250 employees or more)

4. In which region(s) outside of Sweden does your enterprise operate? *

- ☐ Our enterprise operates only in Sweden
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- ☐ Middle East
- ☐ North America
- ☐ South America
- ☐ Asia
- ☐ Africa
- ☐ Oceania

5. To which region(s) does your enterprise export? *

- ☐ Our enterprise does not export
- ☐ Europe
- ☐ Middle East
- ☐ North America
- ☐ South America
- ☐ Asia
- ☐ Africa
- ☐ Oceania

6. Please rate the importance level of the following Industry 4.0 technologies for your business from 1 to 5 *
(0: Unsure 1: Not at all, 2: Slightly, 3: Moderately, 4: High, 5: Very high)

	0	1	2	3	4	5
Artificial Intelligence (AI)	○	○	○	○	○	○
Internet of Things (IoT)	○	○	○	○	○	○
Big Data Analysis	○	○	○	○	○	○
Cloud computing	○	○	○	○	○	○
Cyber-Physical Systems (CPS)	○	○	○	○	○	○
Simulation/Digital Twin	○	○	○	○	○	○
Augmented Reality (AR) / Virtual Reality (VR)	○	○	○	○	○	○
Additive Manufacturing	○	○	○	○	○	○

7. Please rate how effectively ***AI*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Product/Service Development	○	○	○	○	○	○
Quality Management	○	○	○	○	○	○
Decision Making	○	○	○	○	○	○
Decentralization	○	○	○	○	○	○
Reducing Human Labor	○	○	○	○	○	○

8. Please rate how effectively ***IoT*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Automation	○	○	○	○	○	○
Optimization in Production	○	○	○	○	○	○
Productivity in Production	○	○	○	○	○	○
Inventory Management	○	○	○	○	○	○
Logistics Tracking	○	○	○	○	○	○

9. Please rate how effectively ***Big Data Analysis*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Decision Making	○	○	○	○	○	○
Management of Customer Data	○	○	○	○	○	○
Continuous Improvement	○	○	○	○	○	○
Digital Marketing	○	○	○	○	○	○
Competitor Analysis	○	○	○	○	○	○
Cost Optimization in Supply Chain	○	○	○	○	○	○

10. Please rate how effectively ***Cloud Computing*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Data Storage	○	○	○	○	○	○
Digital Marketing	○	○	○	○	○	○
Internal Information sharing	○	○	○	○	○	○
Internal Communication	○	○	○	○	○	○
Employee autonomy	○	○	○	○	○	○

11. Please rate how effectively ***Cyber-Physical Systems (CPS)*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Productivity in Production	○	○	○	○	○	○
Automation	○	○	○	○	○	○
Sustainability	○	○	○	○	○	○
Reducing Human Labor	○	○	○	○	○	○
Reducing Waste	○	○	○	○	○	○
Cyber Security	○	○	○	○	○	○

12. Please rate how effectively ***Simulation/Digital Twin*** is used for your enterprise * on a scale of 1-5 in the following factors

	0	1	2	3	4	5
Optimization in Production	○	○	○	○	○	○
Productivity in Production	○	○	○	○	○	○
Continuous Improvement	○	○	○	○	○	○
Decision Making	○	○	○	○	○	○
Reducing Human Labor	○	○	○	○	○	○
Reducing Waste	○	○	○	○	○	○
Risk Management	○	○	○	○	○	○
Cost Reduction in Production	○	○	○	○	○	○

13. Please rate how effectively ***AR / VR*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Design	○	○	○	○	○	○
Sustainability	○	○	○	○	○	○
Product/Service Development	○	○	○	○	○	○

14. Please rate how effectively ***Additive Manufacturing*** is used for your enterprise on a scale of 1-5 in the following factors *

	0	1	2	3	4	5
Personalization and Modularity	○	○	○	○	○	○
Product/Service Development	○	○	○	○	○	○
Design	○	○	○	○	○	○

15. Please evaluate the following statements on a scale of 1 to 5 *

	0	1	2	3	4	5
Our company embraces changing industrial trends and renews its approach to integrating I4.0 technologies	○	○	○	○	○	○
The employees in our company have knowledge of I4.0 and its technologies	○	○	○	○	○	○
Managers in our company have knowledge and experience in I4.0 technologies	○	○	○	○	○	○
Managers in our company provide the necessary support for employees to adopt and use I4.0 technologies	○	○	○	○	○	○

Our company creates an I4.0 roadmap to move toward our goals	○	○	○	○	○	○
Our company incorporates I4.0 technologies into its investment plans	○	○	○	○	○	○
Our company cooperates with various companies and supply chain stakeholders about I4.0	○	○	○	○	○	○
Our company ensures the compatibility and integration of I4.0 technologies by sharing data between different systems	○	○	○	○	○	○
Our company employs open innovation methods with partners and customers to enhance its products and services	○	○	○	○	○	○

Our company implements an updated security policy for I4.0 technologies	○	○	○	○	○	○

16. *You can share your email address if you would like to learn about your company's Industry 4.0 maturity level*

Your answer