AN INDUSTRY 4.0 MATURITY ASSESSMENT MODEL TO ASCERTAIN THE READINESS LEVEL OF MANUFACTURERS IN AFRICA

Submitted by Enyinna Okam

Supervisors:

Dr. Andy Lung*

Dr. Xianzhi Zhang

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Abstract

Manufacturing continues to be a critical force in both advanced and developing economies. The emergence of advanced technologies have brought changes to the sector in recent times, providing both new opportunities and challenges.

Industry 4.0, also referred to as smart manufacturing, has gone beyond a future trend as organisations around the world are starting to infuse Industry 4.0 technologies and strategies into their value chains and are already benefiting greatly from their implementation (PWC, 2016).

This project focuses on the development of an Industry 4.0 maturity assessment model for manufacturers in Africa and other regions of the world where there is low awareness of Industry 4.0. The model is used to assess the Industry 4.0 readiness of these manufacturers and to identify essential gaps that may hinder them from becoming digital enterprises. The novel model also serves as a tool that contributes towards promoting digital business resilience in African manufacturers.

The Industry 4.0 maturity assessment model built in this project is envisaged to contribute towards improving the awareness levels of Industry 4.0 technologies and strategies in Africa, whilst adding to the discourse on the implementation of Industry 4.0 in the region to ensure that organisations are leveraging the opportunities that the fourth industrial revolution brings.

The author sought to establish the need for a new Industry 4.0 assessment model by investigating multiple existing assessment models and identifying gaps in these models. The model developed in this research was based on the model created by the Warwick University's, Warwick Manufacturing Group (WMG). The gaps identified in the existing models investigated in this research were addressed to expand the assessment criteria of the novel model to make it more robust and suitable for the target regions.

The novel model was tested and validated using real-world data from four Nigerian manufacturers. The results generated by the assessment model established that half the participating manufacturers

were at Level 0 (outsider) Industry 4.0 readiness, whilst the other half achieved Level 1 (beginner) readiness.

The author collaborated with one of the participating manufacturers to design a bespoke five-year digital strategy for them. After which, the impact of the digital strategy was tested using the Industry 4.0 maturity assessment model developed in this research. It was forecast that the manufacturer would go from outsider (Level 0) to experienced (Level 3) status by implementing the five-year digital strategy. Lastly, the manufacturer endorsed the novel model, attesting to the model's ability to contribute towards the digitalisation of their value chain, whilst serving as a tool that can promote digital business resilience to see them become competitive in the age of advanced manufacturing.

Acknowledgement

I would like to express my appreciation to my supervisors, Dr Andy Lung and Dr. Xianzhi Zhang for their guidance throughout the course of my post graduate studies.

Special thanks to my family, especially my father Ven. Emmanuel Okam, without whom I would not have been able to start and complete this program. I appreciate his love and unwavering support throughout the duration of my studies at Kingston University.

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Glossary

a. **Dimensions:** These are the value chain of a manufacturer including manufacturing and operations, product and services, supply chain, business model, and strategy and organisation.

b. **Sub-dimensions:** These are the sub-categories of each dimension.

c. **Additional-Subdimension:** These are the sub-dimensions introduced by the author to broaden the assessment criteria of the novel model and allow for robust assessments.

d. **Elements:** These are the Industry 4.0 technologies that can be implemented in an organisation

e. **Element relevance:** This is the relevancy of the element to an organisation.

f. **Element features:** These are the constituent features of an element.

g. **Feature relevance:** This is the relevancy of the features of an element to a given organisation.

h. **Features implemented:** These are the features of an element that have been implemented by a given organisation.

i. **Total number of features**: The total number of features within an element.

j. **Total relevant features:** The total number of features of a given element that are relevant to an organisation.

k. **Element feature maturity score:** This score is used to determine in percentages the number of features that have been implemented for a given element.

l. **Industry 4.0 maturity level by element (Maturity Matrix by Element):** This is the level of implementation of a given element or practice. The maturity matrix employed for SM elements or practices can be seen below.

Level 0: There is little or no awareness of the digital technology or practice.

Level 1: There is awareness amongst management, and discussions are in progress about the benefits and potential implementation of the digital technology or practice within the organisation.

Level 2: A pilot program has been initiated for the digital technology or practice.

Level 3: The element has been implemented with at least 50% of its constituent features (i.e. achieving an element feature maturity score of at least 50%).

Level 4: The element has been fully implemented with all its constituent features (i.e. achieving an element feature maturity score of 100%).

m. **Industry 4.0 maturity by element (average):** This is the average of the Industry 4.0 maturity level of all the elements within a given dimension.

n. **Industry 4.0 maturity level by sub-dimension:** This the Industry 4.0 maturity level of the sub-dimensions of a given dimension. The maturity matrix employed can be seen in Tables 8–12.

o. **Overall Industry 4.0 readiness:** This the overall maturity level of a manufacturer, obtained by taking the maturity level average of all 5 dimensions.

Please see appendices B-D, which shows the interfaces of the novel model, where all the above-mentioned terms and metrics were used.

Chapter 1: Introduction

The current chapter provides an overview of the manufacturing sector in Africa. It covers key players in region's manufacturing sector, its intra-regional investments, challenges in the manufacturing sector, and Nigeria as a key player in Africa's manufacturing sector. The chapter also sheds light on the potential benefits of implementing Industry 4.0 in Africa's manufacturing sector.

1.1. The Manufacturing Sector

A robust manufacturing sector has contributed to the economic growth and sustainability of nations around the world, as seen in Germany, France, and Japan. It has also provided an avenue for job creation for a vast number of unskilled workers and led to an increase in household income and demand for goods and services. A recent example of the benefits of industrialisation is China's status as one of the world's fastest-growing economies, which is home to the largest middle class that the country has ever had (Signé, 2019). Thus, it can be argued that industrialisation drives development, creates structural change, and alleviates unemployment and poverty.

Industry is often linked to the creation of opportunities in other sectors, such as agriculture, mining, and services. In fact, some sectors depend on the manufacturing sector to remain competitive and grow. Furthermore, when there is a reduction in imports and diversification of exports, the manufacturing sector can strengthen a nation's external account balance, which ensures that a country is not significantly affected or influenced by external factors such as oil prices (KPMG, 2015).

1.2. The Manufacturing Sector in Africa

The manufacturing sector in Africa experienced significant growth in the post-independence era, which spanned the period from 1960 to the mid-1980s. Signe (2019) states that the manufacturing sector in Africa began to decline in the 1980s; this can be attributed to several external factors, including increased oil prices, limitations in domestic markets, a rise in the real interest rate, and a decrease in commodity prices. In the 1990s, measures were instituted to alleviate this situation, including structural adjustment reforms such as the privatisation of enterprises owned by the government and trade liberalisation. These measures improved the manufacturing sector in Africa by enabling it to compete globally. However, this growth did not last due to high demand for foreign products and the devaluation of African currencies (Noble, 1994).

Based on statistics from Cilliers (2018), Figure 1 shows a comparison of manufacturing as a percentage of gross domestic product (GDP) in African countries with a low-middle and upper-middle income and the rest of the world. These figures demonstrate that there was growth in the manufacturing sector of African countries with a low-middle income post-independence and throughout the mid-1980s, followed by a gradual decline until 2010, when it began to rise again. Meanwhile, African countries with an upper-middle income began to steadily de-industrialise in the 1980s and experienced a steep decline in the manufacturing sector until 2015. For both income categories, the manufacturing value added to the GDP of African nations with a low-middle and upper-middle income from 1990 to 2015 was approximately 6% less than the global average.

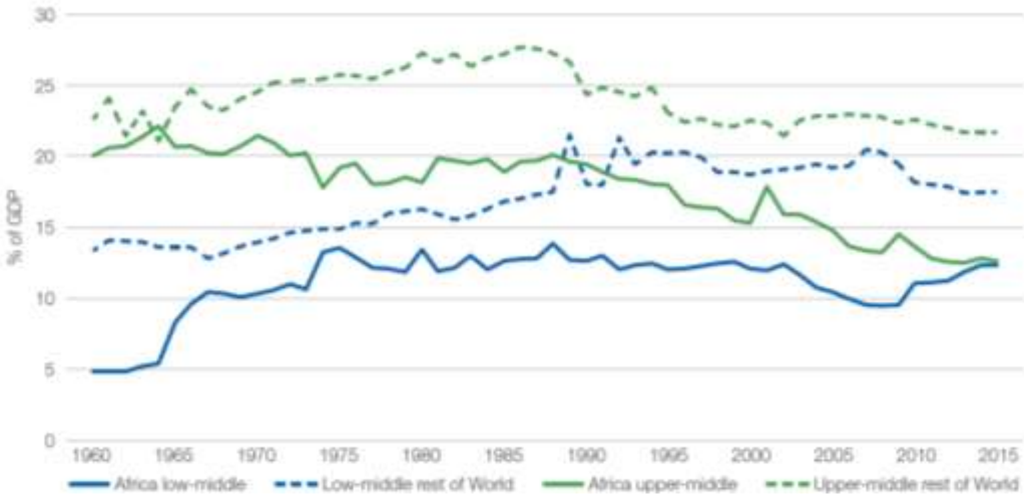

Figure 1. Manufacturing as a Percentage of GDP Based on Income (Cilliers, 2018)

More recently, the growth observed in the African manufacturing sector presents an opportunity to initiate Industry 4.0. Leveraging all of the opportunities that Industry 4.0 brings could contribute to economic growth and diversification in the region.

1.3. Smart Manufacturing

Industry 4.0 is also known as smart manufacturing (SM). According to Davis et al., (2012), '*Smart Manufacturing* is the dramatically intensified and pervasive application of networked information-based technologies throughout the manufacturing and supply chain enterprise'.

Industry 4.0 is accompanied by the Industrial Internet of Things (IIoT) and other digital technologies that revolutionise manufacturing, including big data analytics, the industrial cloud, and cyber-physical systems (CPS).

1.4. Evolution of Industry 4.0 and the Industrial Revolution

Technologies such as mechanisation, steam engines, iron production, the textile industry, mining, steam factories, machine tools, and metallurgy led to the first Industrial Revolution. Then, electrification, mass production, production lines, wide implementation of the telegraph, water supply, gas, globalisation, and engines or turbines led to the second Industrial Revolution. Subsequently, the introduction of the computer, internet, digital manufacturing, programmable logic controller, robotics, information technology and operation technology, digitalisation, automation, electronic/digital networks, and digital machines led to the third Industrial Revolution. Finally, Industry 4.0 introduced IIoT, convergence information technology and operational technology. autonomous machines, advanced robotics, big data analytics, digital ubiquity/cloud, smart factories, machine learning, artificial intelligence (AI), and CPS (Future IQ, 2018). Industry 4.0 is believed by experts in the field to lead to a fourth Industrial Revolution. Its evolution is shown in Figure 2.

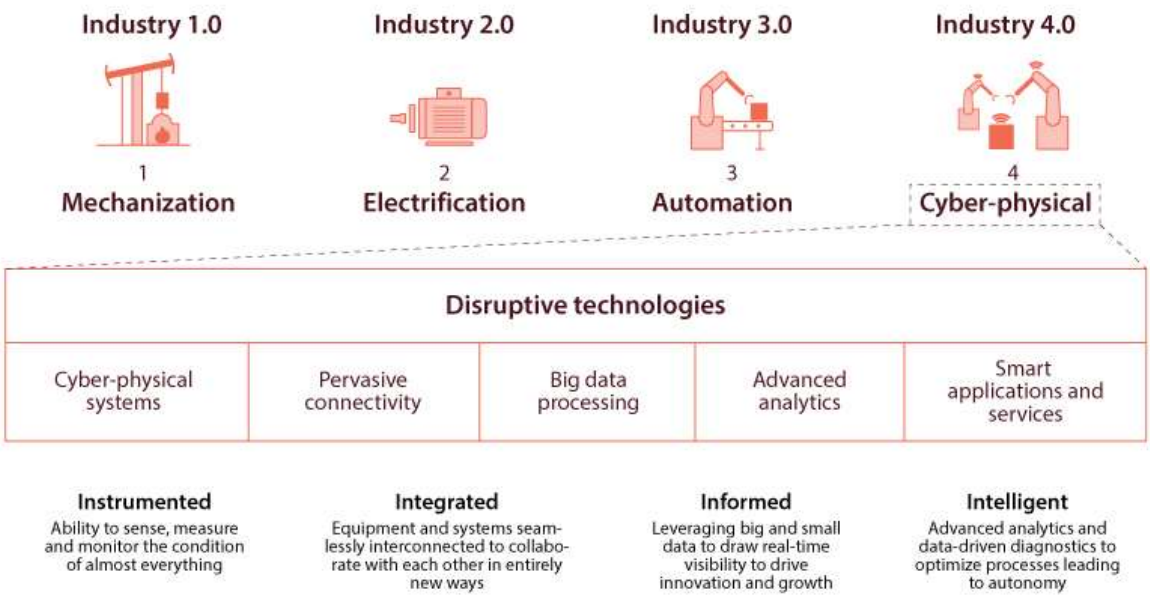

Figure 2. Evolution of Industry 4.0 (Enose and Ramachandran, 2019)

1.5. Design Principles of Industry 4.0

1.5.1. Interoperability

In Industry 4.0, machines, devices, sensors, and people are connected through IIoT. Wireless communication technologies play an important role by enabling the functionality of IIoT, a key element of Industry 4.0. The interconnectivity of Industry 4.0 enables a high level of inter departmental collaboration to reach common goals (Guisto et al., 2010). According to Schuh, Wesch-Potente, and Hauptvogel (2013), IIoT involves three types of collaboration: human-human, human-machine, and machine-machine. In Industry 4.0, the communication standard is flexible. For example, the automation giant Bosch offers rapid integration and flexible configuration in its Industry 4.0 package, which facilitate swift adaptability to fluctuations in market demand and changes in customer requirements.

1.5.2. Virtualisation – Information Transparency

In Industry 4.0, CPS create a virtual world from the physical world to enable high-level visualisation of processes, machines, and objects, thereby contextualizing information. Industry 4.0 technologies provide large amounts of important data that operators can utilise to ensure that appropriate decisions are made. Moreover, the high level of interconnectivity provided by Industry 4.0 technologies allows operators to collect, store, manage, interpret, and analyse vast amounts of data from various areas of manufacturing and other value chain processes. These can be used to aid functionality and pinpoint areas of improvement (Bonner, 2017). In addition, manufacturing and other value chain data are embedded in assistance systems and made available to IIoT participants to support transparency (Gorecky, Schmitt and Zühlke, 2014).

1.5.3. Decentralised Decision Making

Interconnectivity between people, machines, sensors, and objects and transparency of information enable decentralised decision making. In turn, local and global data can be used to make better decisions and increase overall productivity (Malone, 1999). Under Industry 4.0, CPS technology and IIoT enable decentralised decision making and autonomous task completion. Tasks are only delegated to a higher level in case of exceptions, interference, or conflicting goals (Hompel and Otto, 2014).

1.5.4. Technical Assistance

In smart factories, the role of humans has progressed beyond that of machine operators to flexible problem solvers and strategic decision makers (Hermann, Pentek and Otto, 2016). This is because decision making is decentralised and more autonomy is afforded to systems in smart factories. Nonetheless, humans must receive support in the form of digital assistance systems, which aggregate data in a manner that can be comprehensibly visualised for decision making and problem solving purposes (Gorecky et al., 2014). The use of smart devices to connect people to IIoT is considered a form of technical assistance.

1.5.5. Real-Time Capability

In smart factories, data must be collected, stored, analysed, and utilised in real time. This real-time capability enables autonomy in manufacturing and other value chain processes, facilitates decentralised decision making, and significantly contributes to the flexibility and optimisation of production in smart factories.

1.5.6. Modularity

Modularity ensures that system components can be quickly and easily put together, taken apart, and recoupled. On a factory floor, this translates to the ability to add, relocate, or rearrange the production line with minimal time and effort (Koh, 2019). Thus, modularity enables the rapid integration of smart assets from various vendors.

1.5.7. Service Orientation

A service orientation strategy involves the design and production of products, the creation of related services, and their combined sale. According to Koh (2019), service orientation fosters the innovative improvement of core processes and, if necessary, the outsourcing or elimination of other processes.

1.6. The Global Industry 4.0 Market

The value of the global Industry 4.0 market was estimated at USD 71.7 billion in 2019 and is expected to reach USD 156.6 billion by 2024, assuming a compound annual growth rate of 16.9% between 2019 and 2024 (Business Wire, 2020). Worldwide growth in the Industry 4.0 market can be attributed to the benefits associated with increasing adoption of IIoT, the high levels of efficiency achieved by implementing advanced machines and systems, and the significant cost savings associated with these measures. There is also growing demand for industrial robotics, which is believed to be fuelling the growth of the Industry 4.0 market. Figure 3 illustrates the growth of the Industry 4.0 market from 2019 to 2020.

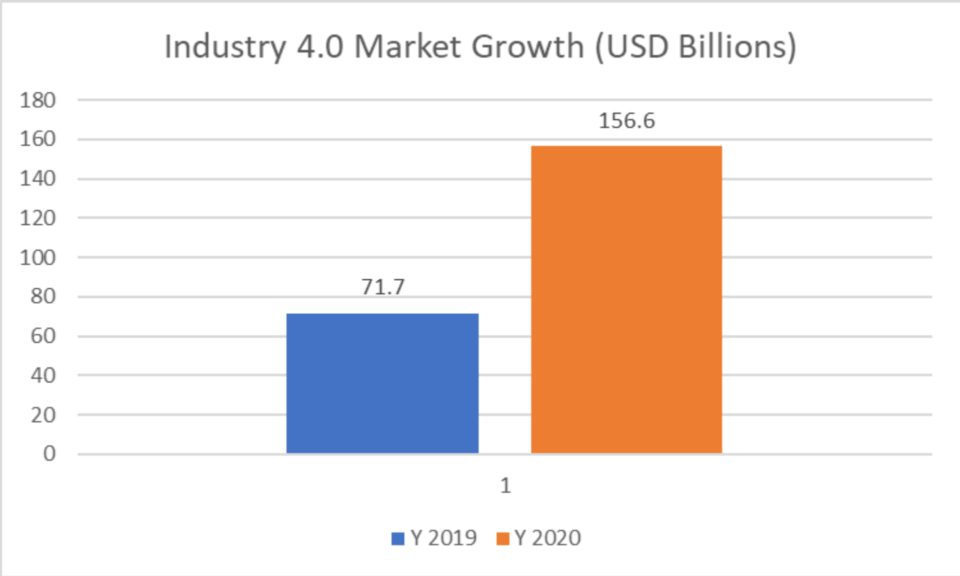

Figure 3. Growth of the Industry 4.0 Market (Business Wire, 2020)

1.7. Expected Return on Investment

It is expensive for organisations to digitalise their operations. Thus, it is important to assess the expected return on investment for Industry 4.0 projects. Price Waterhouse Coopers' (PWC) 2016 Industry 4.0 global research, which involved over 2,000 companies, yielded the following findings:

a. 55% of participating organisations believed that they would see a return on their investments in Industry 4.0 project within two years.

b. 37% of participants believed that they would see a return on their investments in Industry 4.0 projects within two to five years.

c. Only 8% of participating organisations believed that they would see a return on their investments in Industry 4.0 projects in over five years.

These numbers are encouraging, as most organisations expected to see a quick return on their investments (see Figure 4).

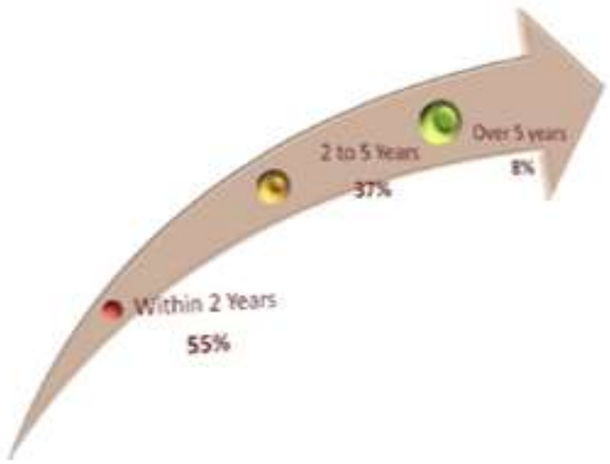

Figure 4. Return on Investment (PWC, 2016)

1.8. Aims, Objectives, Deliverables, and Structure of the Thesis

1.8.1. Project Aims

The aim of this project was to develop an Industry 4.0 maturity assessment model to ascertain the readiness level of manufacturers in Africa and identify gaps that may hinder them from becoming digital enterprises. The model is intended as a tool that can be used to promote digital business resilience. This project focuses on manufacturers in Africa, a developing region in which there is low awareness and use of SM.

1.8.2. Project Objectives

The objectives of this project are as follows:

1. Develop a multi-faceted Industry 4.0 assessment model with automated capability.
2. Establish industry contacts with manufacturers in Nigeria and obtain primary data through face-to-face interviews, phone or video calls, and a survey.
3. Test and validate the assessment model using the data obtained.

4. Assess the SM readiness level of participating manufacturers and identify essential gaps that may hinder them from becoming digital enterprises.

1.8.3. Project Deliverables

Project deliverables 1–5 focuses on the Industry 4.0 maturity assessment model's capabilities.

1. Ascertain the Industry 4.0 readiness level of manufacturers at a profound level (i.e. including dimensions, subdimensions, and Industry 4.0 elements).
2. Identify essential elements of Industry 4.0 that may not have been implemented or adequately implemented across an organisation's value chain.
3. Ascertain how various elements of Industry 4.0 have been deployed across an organisation's value chain.
4. Identify strengths and weaknesses.
5. Generate recommendations that may contribute to filling key identified gaps.
6. Develop a structure that enables recommendations to be made using essential features of the assessment model.
7. Closely collaborate with one or more of the participating manufacturers to design a digital strategy.
8. Measure the impact that the digital strategy would have if implemented with Industry 4.0

1.8.4. Structure of the Thesis

The introduction, aims, objectives, deliverables, and research methodology are covered in the first chapter, which also includes an overview of the manufacturing sector in Africa, the seven design principles of Industry 4.0, and the global industry 4.0 market.

The literature review is covered in Chapter 2. Three of the top-rated existing Industry 4.0 assessment models are investigated to establish the need and foundation for a new assessment model. The literature review also covers the extensive research conducted by the author to establish the various elements of Industry 4.0 within the boundaries of its seven design principles.

The Industry 4.0 maturity assessment model design process is covered in Chapter 3 of this thesis, which describes all the key steps taken to design the assessment model.

The model testing and validation process is presented in Chapter 4. In addition, a five-year digital strategy was developed. The impact of the proposed digital strategy is also analysed.

Conclusion, study limitations, contributions, and recommendations for future research can be found in Chapter 5 of this thesis.

1.9. Research Methodology

Multiple steps were taken to achieve the aims, objectives, and deliverables of this project. These steps are listed in Figure 8 and described in detail section 1.9.1 – 1.10.

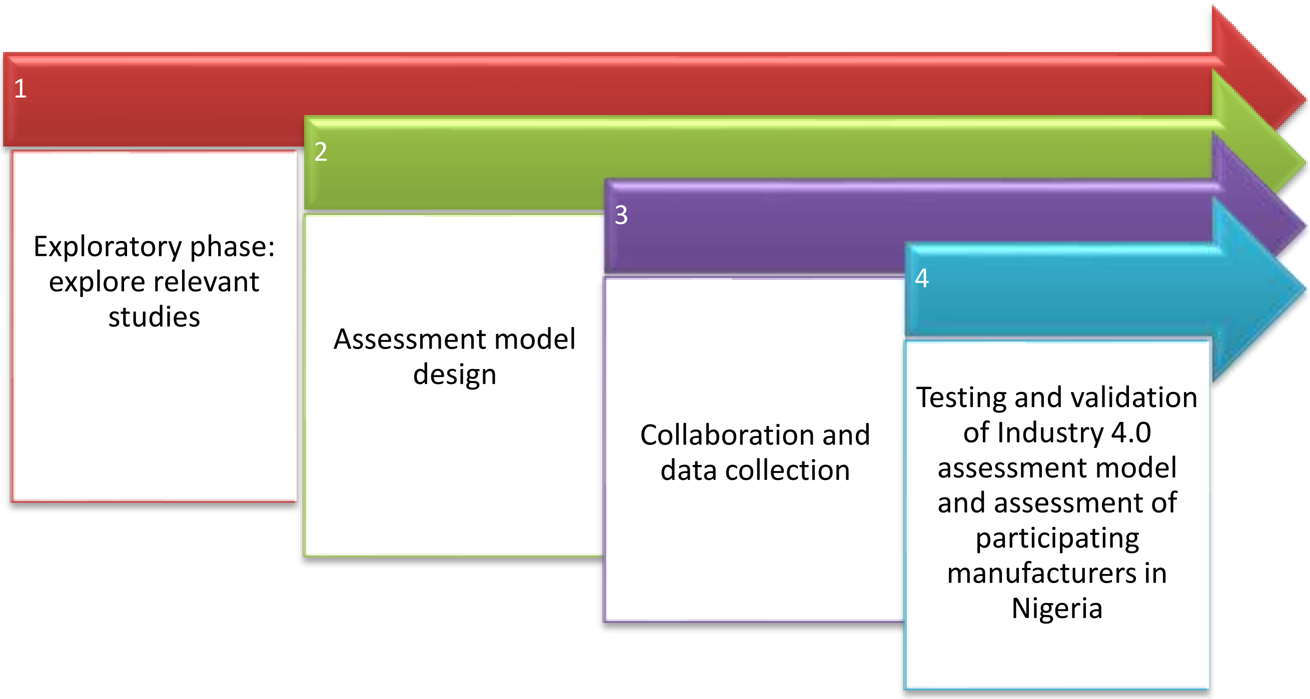

Figure 5. Research Methodology

1.9.1. Exploratory Phase

The exploratory phased involved research on all the industrial revolution to fully understand the transition from Industry 1.0 to Industry 4.0. Furthermore, the design principles and numerous digital technologies of Industry 4.0 were explored. Finally, the growth of the global Industry 4.0 market and returns on investments in Industry 4.0 projects were investigated.

1.9.2. Design of Industry 4.0 Assessment Model

The assessment model developed in this research was designed to cater to manufacturers of all sizes. It contains broad assessment parameters that enable comprehensive evaluations to be conducted regardless of the company's size, region, or manufactured product. The novel assessment model is based on the tried-and-tested Industry 4.0 assessment model designed by the Warwick Manufacturing Group (WMG) at the University of Warwick, which has been used to assess manufacturers of all sizes. The WMG model has been evaluated and endorsed by multinational organisations, including Tata Steel and Catapult; the former used it to assess their Industry 4.0 readiness level.

The design of the Industry 4.0 assessment model included three phases:

Phase 1: Exploration of existing Industry 4.0 assessment tools to establish the foundation for a new assessment model.

Phase 2: Selection and modification of an existing assessment model, identification and utilisation of essential SM elements as key components of the assessment model, and addition of new sub-dimensions

Phase 3: Development of an integrated and automated Industry 4.0 assessment model

1.9.3. Collaboration and Data Collection

The author collaborated with four Nigerian manufacturers on this research. The manufacturing sector in Nigeria has demonstrated significant growth; in 2021, 15% of the nation's GDP was attributed to the manufacturing sector (Statista 2021). This made Nigeria a suitable country for a case study in this research.

The author collaborated with micro, small, and medium enterprises (MSMEs) in Nigeria, as they comprise the vast majority of the nation's manufacturing sector. According to Bank of Industry in Nigeria, (2020), MSMEs are organisations with a maximum of 200 employees, an annual turnover of up to N500 million, and total assets of up to N500 million.

Furthermore, three out of four participating organisations are fast-moving consumer goods (FMCG) manufacturers. FMCG are one of the largest industries in Nigeria and contributed approximately 5% of the nation's GDP in 2019 (KPMG, 2020).

The above statistics provided the rationale for the author's decision to collaborate with Nigerian manufacturers, specifically MSMEs and FMCG manufacturers. The author approached several Nigerian manufacturers in the above categories. The four selected manufacturers agreed to be evaluated with the Industry 4.0 assessment model developed for this project.

Data were collected through face-to-face interviews at the manufacturers' plants, phone, or video interviews, and/or a survey. The interview and survey questions covered products and services, manufacturing and operations, strategy and organisation, supply chains, business models, and the digital technologies implemented by manufacturers. The collected data were incorporated into the Industry 4.0 maturity assessment model to evaluate the participants' readiness level and to test and validate the assessment model itself. All four organisations were anonymised and referred to as Organisations A–D. Table 1 shows the data collection methods used across these organisations.

Data collection methods	Organisation A	Organisation B	Organisation C	Organisation D
Telephone or video interviews			✓	✓
Face-to-face interviews	✓	✓		
Survey				✓

Table 1. Data Collection Methods

Face-to-face interviews were held with factory managers at Organisations A and B. They were responsible for all factory activities, had knowledge on different value chains, and were in a position to liaise with other departments to obtain relevant information for the research. The data collection process with Organisations A and B was collaborative in nature. Questions asked to participants at both manufacturers are shown in Tables 8–12. The interviewer (i.e. the author) also asked questions about the level of implementation for all 33 elements of Industry 4.0 identified this research (see Appendix B for a summary of these elements and their constituent features). The data were incorporated into the model developed for this research (see Chapter 3 for more on the model design and data input).

In addition, data were obtained from Organisation C through telephone interviews. The questions asked were the same as for Organisations A and B. Finally, data were collected from Organisation D through telephone or video interviews and a survey (see Appendix A for the survey). Using the assessment guide developed for this project, questions were asked about the organisation's readiness level with regard to the elements of Industry 4.0. Furthermore, the author collaborated with Organisation D to develop a five-year digital strategy that would allow them to become a digital enterprise within the specified timeline.

1.9.4. Testing and Validation of the Industry 4.0 Assessment Model and Assessment of Participating Manufacturers in Nigeria

The Industry 4.0 assessment model developed for this project was tested and validated using a collaborative approach which involved multiple manufacturers in Nigeria.

Although it is apparent that the manufacturers assessed in this project are at low level of readiness for Industry 4.0, this evaluation was deemed important for ascertaining their current state and identifying gaps that may hinder from becoming digital enterprises. This exercise also raised awareness of digital technologies and practices amongst the participating manufacturers and led to the design of a five-year strategy to digitalise the value chain of a manufacturer involved in this research.

The testing and validation phase led to the incorporation of data obtained from the participating manufacturers into the Industry 4.0 maturity assessment model, which was then used to assess their Industry 4.0 readiness level.

Lastly, Organisation D issued a letter of endorsement that attested to the novel Industry 4.0 assessment model's ability to evaluate the company, identify gaps, and serve as a tool for supporting the digitalisation of the organisation's value chain and promoting digital business resilience. The letter of endorsement can be found in Appendix E.

1.10. Software Used

The assessment model designed for this thesis encompasses multiple facets. Therefore, it was imperative to use an application that could adequately integrate these facets; ultimately, the Industry 4.0 assessment model was developed in Microsoft Office Excel 2019. This application is efficient, user-friendly, has several built-in functions, and is widely available and recognisable. The model was constructed using several built-in Excel functions; for example, the logic functions were vital in making key calculations and integrating different facets of the model.

Chapter 2: Literature Review

The current chapter discusses three of the leading Industry 4.0 readiness models, which were developed by WMG, Verband Deutscher Maschinen- und Anlagenbau (VDMA) IMPULS, and PWC. In addition, gaps in these models were identified. Finally, this chapter provides the need for the new Industry 4.0 assessment model developed in this research and the existing Industry 4.0 assessment model which the new assessment model is based on.

2.1. Industry 4.0 Readiness Model Developed by Warwick Manufacturing Group

This self-assessment model was developed by WMG at the University of Warwick; Crimson & Co, a global management consultancy that specialises in supply chains; and Pinsent Masons, a full-service international law firm. Organisations can use it to evaluate their Industry 4.0 readiness level and future ambitions. According to WMG, Tata Steel is one of the organisations that has already benefited from using the Industry 4.0 assessment model.

WMG's assessment model looks beyond Industry 4.0 technologies by considering six core dimensions and 37 sub-dimensions of Industry 4.0 readiness. The six core dimensions including Products and services, Manufacturing and operations, Strategy and organisation, Supply chains, Business model, and Legal considerations.

Furthermore, the Industry 4.0 assessment model comprises four readiness levels: beginner (Level 1), intermediate (Level 2), experienced (Level 3), and expert (Level 4). It provides explicit guidelines about what needs to be achieved to attain a given level of readiness across all sub-dimensions. The model also provides a benchmark for current Industry 4.0 readiness across a group of 53 companies.

WMG's Industry 4.0 survey involved 53 respondents from 22 countries in the Americas, Australia, far and Southeast Asia, the Middle East and Africa, and Europe. Seventy-four percent of respondents were senior management or executives, whilst 19% were part of middle management and 8% were junior employees. Participants worked in a broad range of areas, including production and manufacturing, research and development, and supply chains. Figure 6 provides a breakdown of respondent demographics from the survey.

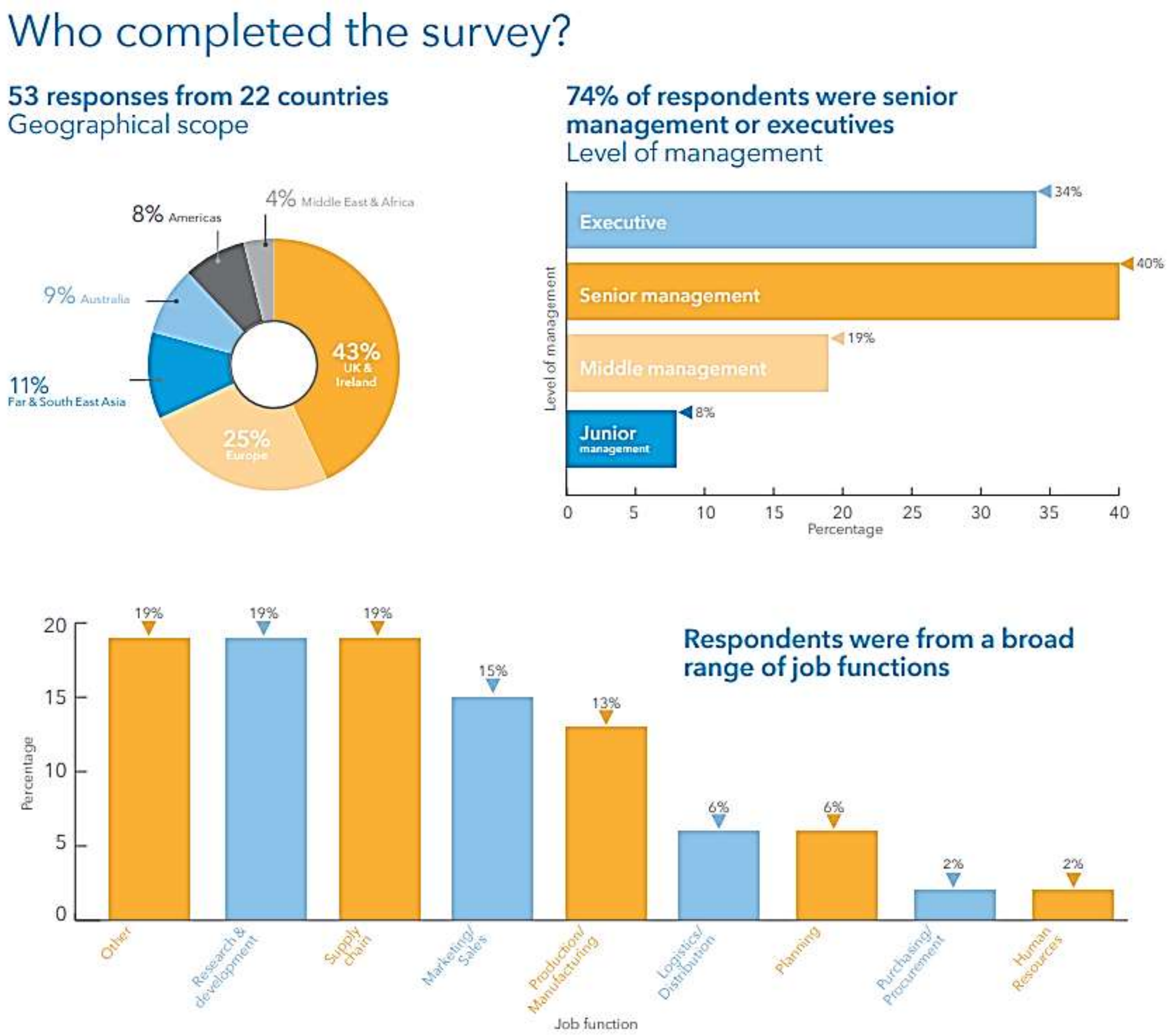

Figure 6. WMG's Research Survey Statistics (WMG, 2017)

2.1.1. Findings from WMG's Research

Overall, the readiness level of all participating organisations in the WMG survey was intermediate (Level 2). Strategy and organisation was the dimension on which companies reported the least preparation, whilst legal considerations was the dimension on which they reported the most preparation (see Figure 7).

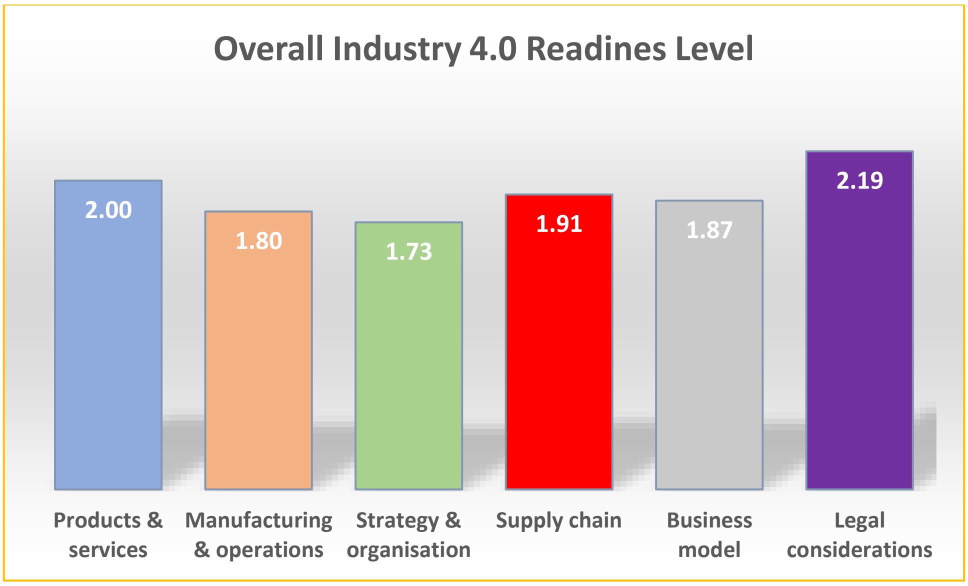

Figure 7. Overall Industry 4.0 Readiness Level (WMG, 2017)

Tables 2–7 summarise the findings across all six dimensions of WMG's model.

Products and services	
Sub-dimensions	
Product customisation	▪ 15% of companies only produced standardised products. ▪ Late product differentiation was the norm amongst 6% of companies. ▪ Most businesses had a standard base for their products and offered limited customisation.
Digital features in products	▪ 28% of companies achieved the highest level of maturity, where products exhibited high digital features and value from intellectual property. ▪ 36% of companies offered products with only physical value.
Data-driven services	▪ 9% of companies that participated in the survey offered data-driven services that were fully integrated with the customer. ▪ 19% offered services with no integration. ▪ The majority offered a limited degree of customer integration.
	▪ Data usage had the highest overall average.

Data usage	▪ Only 13% of companies used no data. ▪ 17% of companies used more that 20% of the data that they collected. ▪ 28% of companies used more than 50% of the data that they collected.
Share of revenue	▪ Data-driven services had the lowest average share of revenue. ▪ Data-driven services accounted for less than 2.5% of revenue in 48% of the companies surveyed. ▪ Data-driven services accounted for more than 10% of revenue at only 15% of companies.

Table 2. Dimension of Products and Services (WMG, 2017)

Manufacturing and Operations	
Sub-dimensions	
▪ Operations data collection ▪ Operations data usage ▪ Cloud storage usage ▪ Information technology (IT) and data security	▪ The survey showed that companies may not leverage the full range of operational data collection opportunities, as they were at an average level of 1.87. However, they were more effective at utilising the data that they collected, as reflected in their operations data usage, which was at an average readiness level of 2.45. ▪ Potential areas of improvement included cloud storage usage and ensuring integrity through IT and data security.
▪ Self-optimisation process ▪ Autonomously guided workpieces	▪ Only 8% of companies used self-optimisation processes, which was the sub-dimension with the lowest overall score. ▪ Only 9% of surveyed companies adopted autonomously guided workpieces.
▪ Digital modelling ▪ Equipment readiness for Industry 4.0 ▪ Automation ▪ Machine and systems integration	▪ Another potential area for development was resource capability, as only 6% of surveyed companies used digital modelling for their full range of processes. ▪ Only 6% of companies believed that their equipment were Industry 4.0 ready; 25% stated that a substantial overhaul of their current equipment would be necessary. ▪ Automation, machines, and systems integration was a sub-dimension that showed progress; 30% of companies stated that most of their machines could be controlled through automation, whilst 33% reported either partial or full machine and systems integration. ▪ Conversely, 21% of companies stated that their machines could not be controlled through automation and that they had no machine or operations system integration.

Table 3. Dimension of Production and Services (WMG, 2017)

Strategy and organisation	
Sub-dimensions	
▪ Leadership ▪ People capabilities ▪ Measurement ▪ Collaboration ▪ Investments	▪ Although business leaders are aware of the benefits of Industry 4.0, work remains to be done with respect to its widespread implementation across businesses. ▪ There was a lack of digital culture and skills across the surveyed companies.

▪ Degree of strategy implementation ▪ Finance	▪ Business metrics and personal performance measurements did not drive Industry 4.0 adoption. ▪ Leadership across the surveyed companies stated that they were aware of the benefits of Industry 4.0 and planning to invest in Industry 4.0 technologies, however, the overall evidence called into question their level of commitment to Industry 4.0. ▪ Limited structured training programmes are available to staff despite a need for new skills and approaches. ▪ Inter-departmental collaboration was not driven by personal performance indicators. ▪ Although companies are prepared to invest significantly in Industry 4.0, measurement of returns is limited.

Table 4. Dimension of Strategy and Organisation (WMG 2017)

Supply chain	
Sub-dimensions	
▪ Supply chain integration ▪ Supply chain visibility ▪ Supply chain flexibility	▪ Extensive integration of data into supply chains presents new collaborative opportunities that can be beneficial to businesses. Many companies that part in the survey stated that they had such collaborative opportunities in sight, but 30% also reported that they had no integration with suppliers or customers. ▪ Regarding supply chain flexibility, over 32% of respondents stated that there was moderate response to market changes and general shifts in customer requirements within their supply chains. ▪ Approximately 40% of respondents said that basic communication and data sharing were required with suppliers and customers (Level 2 readiness).

Table 5. Dimension of Supply Chain (WMG, 2017)

Business model	
Sub-dimensions	
▪ IT-supported business ▪ Data-driven decisions	▪ 40% of companies reported achieving full IT support for their processes, and 19% reported achieving full integration. ▪ Only 9% of companies used all of the relevant data gathered to inform business decisions, 21% used most of the relevant data gathered to inform business decisions, and 25% used some of the relevant data gathered to inform business decisions.
▪ Real-time automated scheduling	▪ Overall, 25% of companies did not consider the sub-dimensions of real-time tracking and real-time automated scheduling to be relevant to their business. Only 8% of companies surveyed could track products

▪ Real-time tracking ▪ Integrated marketing channels	across their complete lifecycle and automatically diagnose and schedule maintenance. ▪ Integrated marketing channels and customer touchpoints were identified as areas of improvement, as only 8% of companies offered a fully integrated customer experience across all channels. Moreover, 36% of companies reported integration within their offline and online channels but no integration *between* their online and offline channels. ▪ Only 17% of companies implemented the 'As a service' business model, although the majority (45%) were aware of the concept and had plans to implement it. However, 34% had no awareness of this model.

Table 6. Dimension of Business Model (WMG, 2017)

Legal considerations	
Sub-dimensions	
Contracting model	In general, 50% of respondents reported that their contract processes were linear and unchanged.
Legal risks	Most respondents (54%) had neither considered nor addressed the legal risks associated with Industry 4.0, as they were not aware of these risks.
Data protection	▪ 32% of respondents had a good understanding of data protection and robust policies and procedures in place for its adherence, whilst 11% had no data protection policies or procedures in place. ▪ Only 9% of respondents had conducted a general data protection regulation audit and were confident that they had met the legal requirements for data use and protection compliance with regard to Industry 4.0.
Intellectual property	Amongst 13% of respondents, intellectual property ownership of products and services had not been identified or protected. However, 30% of companies had identified, assessed, and taken the necessary actions to secure these protections.

Table 7. Dimension of Legal Considerations (WMG, 2017)

2.2. Industry 4.0 Readiness Model Developed by Verband Deutscher Maschinen- und Anlagenbau IMPULS

The Industry 4.0 readiness model developed by VDMA IMPULS is a self-assessment tool that includes six dimensions: strategy and organisation, smart factory, smart operations, smart products, data-driven services, and employees.

Each dimension encompasses six levels of readiness: Level 0 (outsider), in which digitalisation has not been undertaken; Level 1 (beginner), in which the company has begun to digitalise their value chain and adopt Industry 4.0 principles; Level 2 (intermediate); Level 3 (experienced); Level 4 (expert); and Level 5 (top performer). Organisations are categorised as newcomers, learners, or leaders based on their readiness level (see Figure 8).

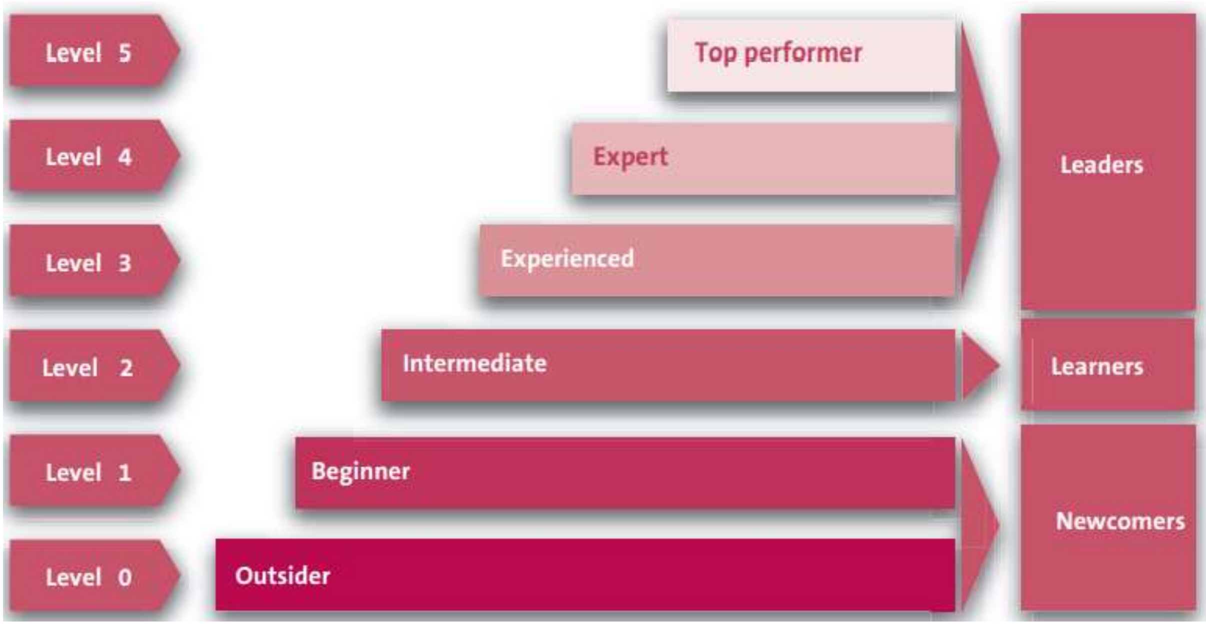

Figure 8. VDMA IMPULS – Industry 4.0 Readiness Levels (VDMA IMPULS 2015)

2.2.1. Findings from VDMA IMPULS' Research

VDMA IMPULS' survey research involved 289 participants from organisations in Germany whose size ranged from 20 to over 500 employees.

2.2.1.1. Motivations for Implementing Industry 4.0

Overall, 66% of participants were motivated by the prospect of increased efficiency for production systems, whilst 64% and 46.1% were motivated by the prospect of higher revenues and increased efficiency for management systems, respectively (see Figure 9).

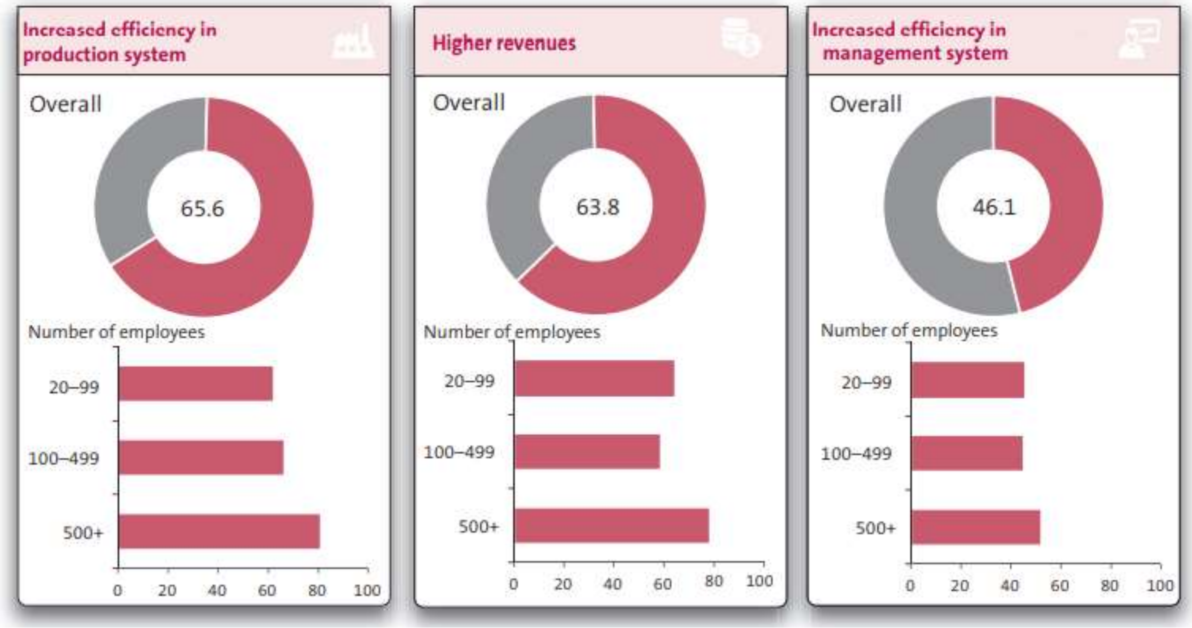

Figure 9. Motivations for Implementing Industry 4.0 (VDMA IMPULS 2015)

2.2.1.2. Readiness Level of Participants Across All Dimensions

On the dimension of Strategy and Organisation, 76.6% of respondents were categorised as newcomers, 14.8% were categorised as leaners, and 8.6% were categorised as leaders (see Figure 10).

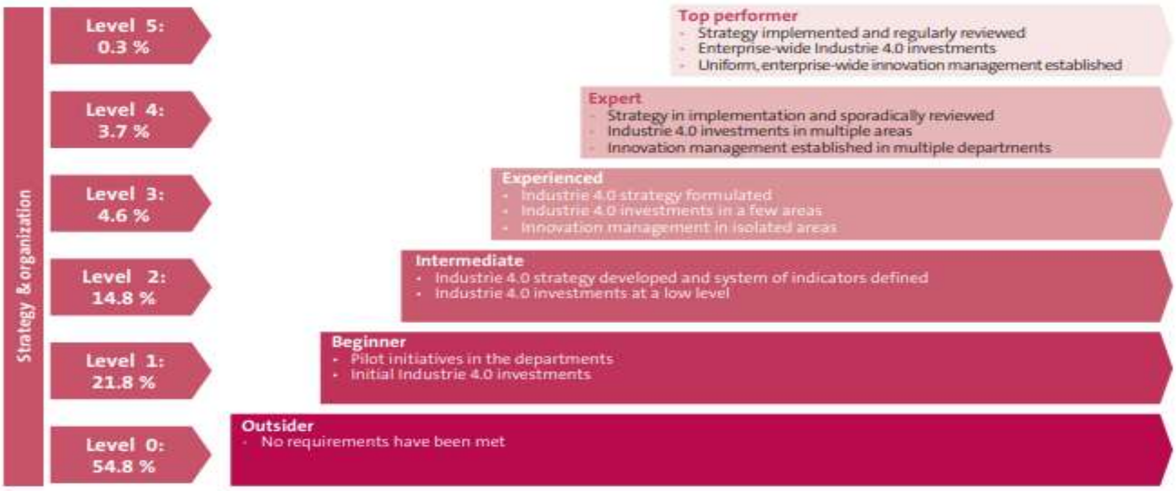

Figure 10. Readiness Level on the Dimension of Strategy and Organisation (VDMA IMPULS 2015)

On the dimension of Smart Factory , 77% of respondents were categorised as newcomers, whilst 18.3% and 4.6% were categorised as leaners and leaders, respectively (see Figure 11).

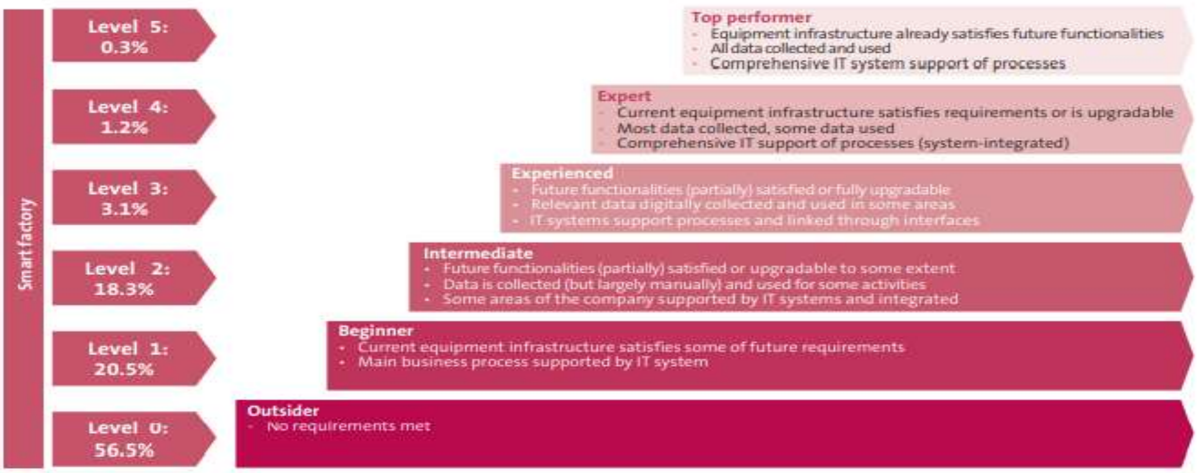

Figure 11. Readiness Level on the Dimension of Smart Factory (VDMA IMPULS 2015)

On the dimension of Smart Operations, 39.7% of respondents were categorised as newcomers, whilst 45.3% and 15.1% were categorised as leaners and leaders, respectively (see Figure 12).

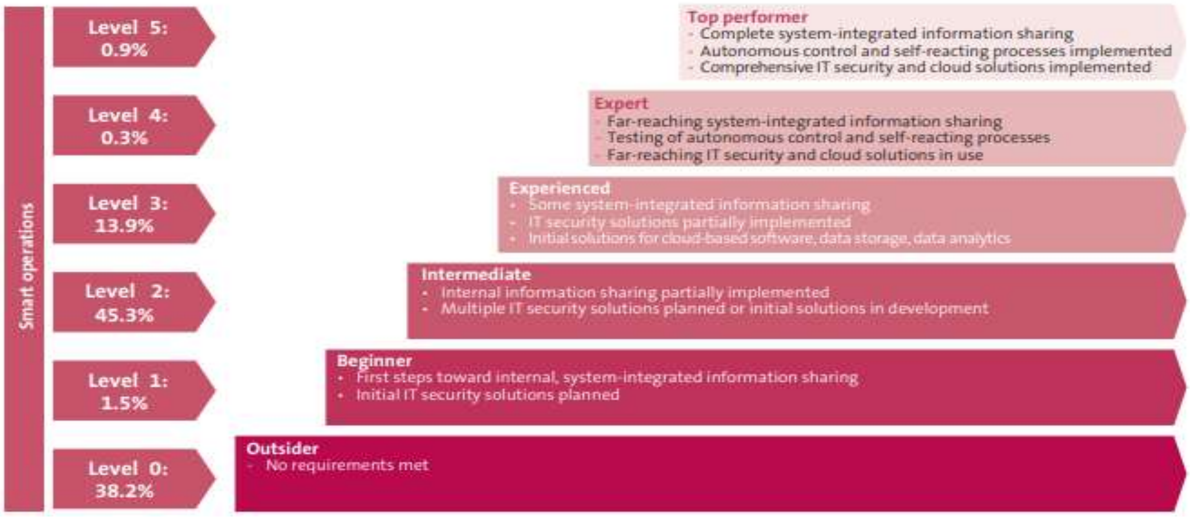

Figure 12. Readiness Level on the Dimension of Smart Operations (VDMA IMPULS 2015)

Overall, 68.7% of respondents were categorised as newcomers, whilst 4.9% and 11.9% were categorised as leaners and leaders, respectively (see Figure 13).

Figure 13. Readiness Level on the Dimension of Smart Products (VDMA IMPULS 2015

On the dimension of Data-Driven-Services, 89.6% of respondents were categorised as newcomers, whilst 5.2% and 5.1% were categorised as leaners and leaders, respectively (see Figure 14).

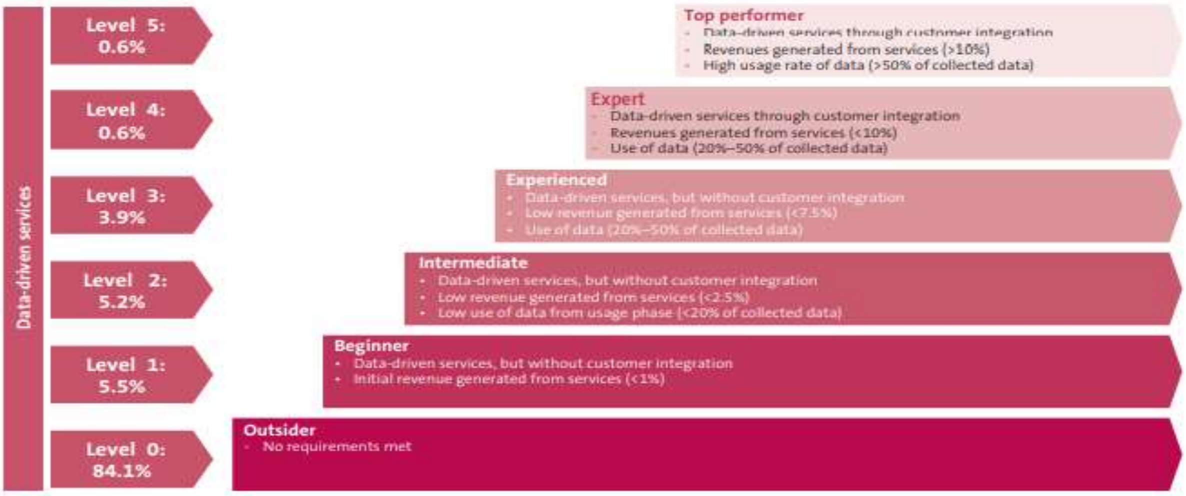

Figure 14. Readiness Level on the Dimension of Data-Driven Services (VDMA IMPULS 2015)

On the dimension of employees, 63.3% of respondents were categorised as newcomers, whilst 12.2% and 24.4.% were categorised as leaners and leaders, respectively (see Figure 15).

Figure 15. Readiness Level on the Dimension of Employees (VDMA IMPULS, 2015)

Overall Readiness Level

Amongst all participants, 76.5% were considered newcomers, whilst 17.9% and 5.6% were considered leaners and leaders, respectively (see Figure 16).

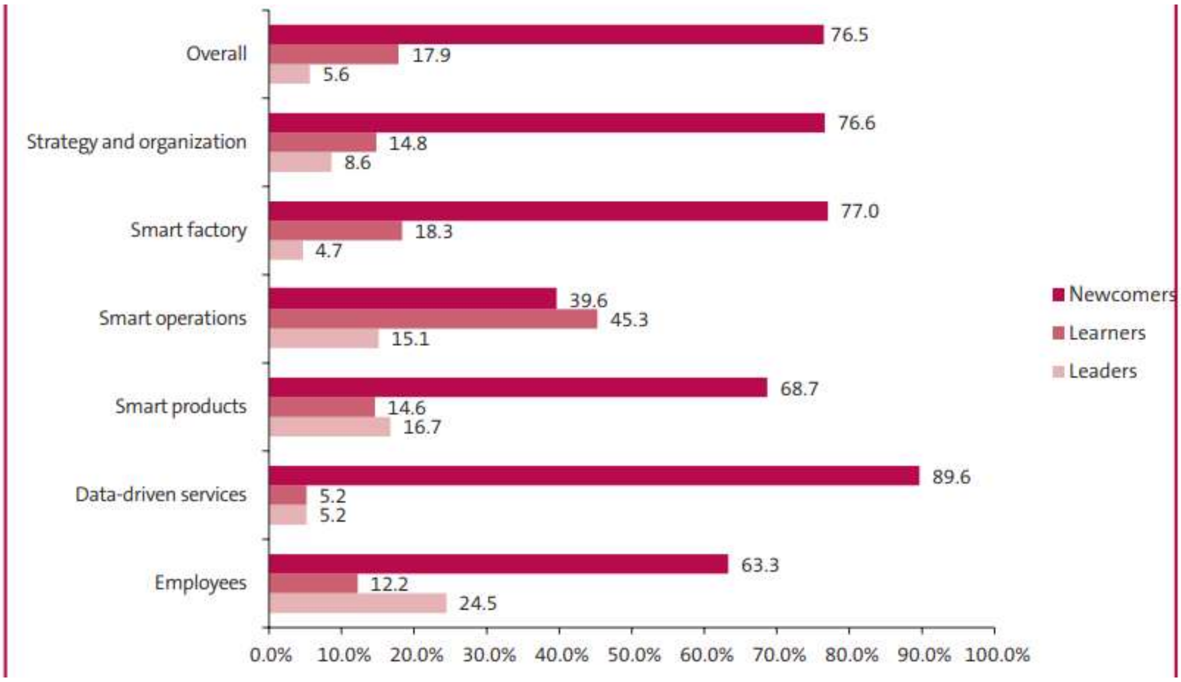

Figure 16. Readiness Level on Overall Readiness (VDMA IMPULS, 2015)

2.3. Industry 4.0 Digital Operations Self-Assessment Model Developed by Price Waterhouse Coopers

The assessment tool developed by PWC includes seven dimensions: (1) digital business models and customer access; (2) digitalisation of products and services; (3) digitalisation and integration of vertical and horizontal value chains; (4) data and analytics as core capabilities; (5) agile information technology (IT) architecture, compliance, security, legal, and tax organisation; (6) employees; and (7) digital culture. Each category encompasses four readiness levels: digital novice, vertical integrator, horizontal collaborator, and digital champion.

2.3.1. Readiness Level Across All Dimensions

a) <u>Digital Novice</u>

Digital novices have only recently begun the digitalisation of their business models and operations. Their focus is on initiating internal integration. Their vertical and horizontal value chains are limited, and their portfolios are mainly dominated by physical products (see Figure 17).

	1 Digital Novice
Business Models, Product & Service Portfolio	**First digital solutions** and isolated applications
Market & Customer Access	Online presence is separated from offline channels, **product focus** instead of customer focus
Value Chains & Processes	**Digitized** and automated **sub processes**
IT Architecture	Fragmented IT architecture inhouse
Compliance, Legal, Risk, Security & Tax	Traditional structures, **digitization not in focus**
Organization & Culture	Functional **focus in „silos"**

Figure 17. Readiness Level of Digital Novices (PWC, 2016)

b) <u>Vertical Integrator</u>

Vertical integrators are organisations that have added digital features to their products and/or digital products and services to their portfolios. These organisations utilise data to create value and have achieved some level of integration in their vertical value chains (i.e. from enterprise resource planning on the shop floor to manufacturing machines and even to products; see Figure 18).

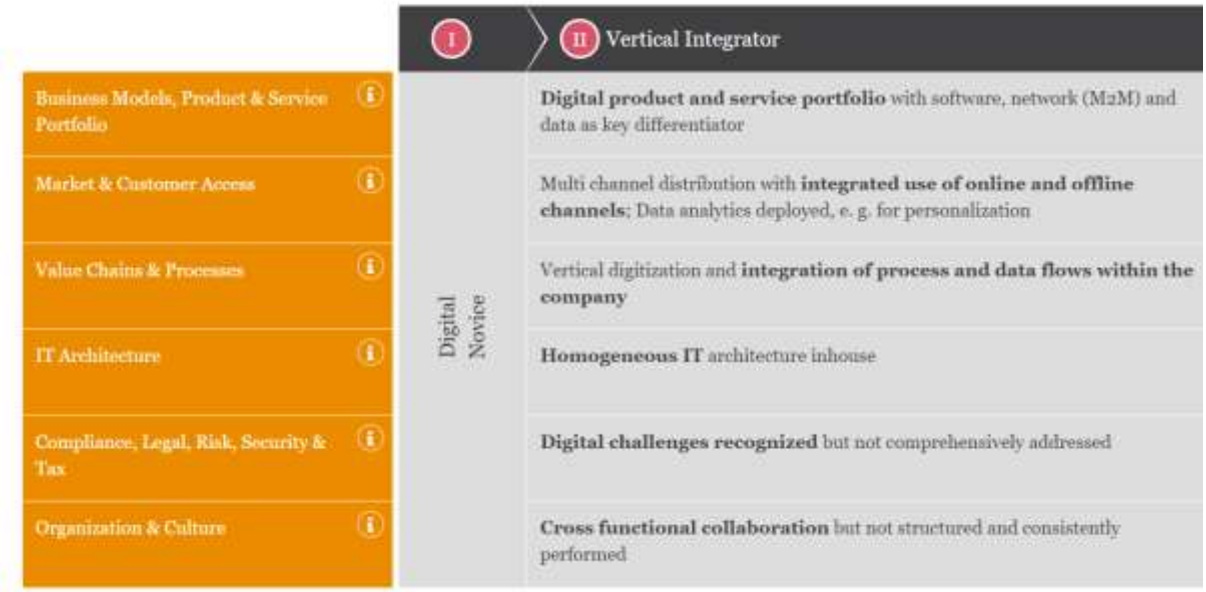

Figure 18. Readiness Level of Vertical Integrators (PWC, 2016)

c) <u>Horizontal Collaborator</u>

Horizontal collaborators are organisations that have already achieved a significant level of vertical integration and currently focus on collaboration and integration with partners, customers, and suppliers. In addition to achieving horizontal processes and IT integration, they have formed value networks with their partners to meet customers' needs (see Figure 19).

Figure 19. Readiness Level of Horizontal Collaborators (PWC, 2016)

d) <u>Digital Champion</u>

Organisations that have already implemented vertical and horizontal integration are considered digital champions. Their focus is to develop new and disruptive data-driven business models and innovative product and service portfolios to meet customers' needs. One of the value drivers at this level is collaboration (see Figure 20).

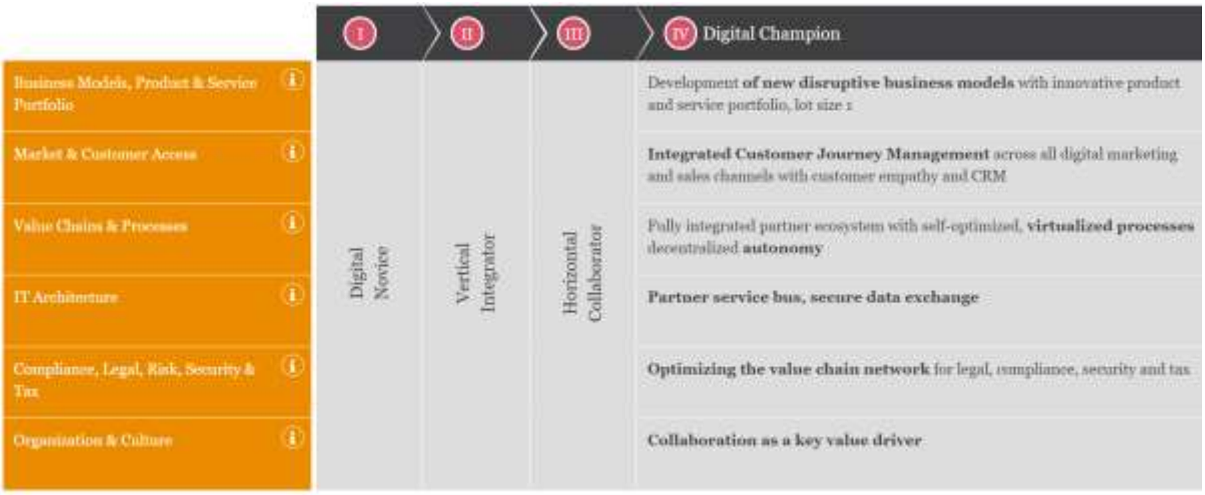

Figure 20. Readiness Level of Digital Champions (PWC, 2016)

2.4. Key Gaps Identified in the Existing Industry 4.0 Assessment Models Assessed and Modifications Made Novel Assessment Model in Response

The author Identified the following gaps in the aforementioned Industry 4.0 assessment models and made several modifications to the novel Industry 4.0 assessment model to address them, as described below.

a. All three of the selected Industry 4.0 models are online self-assessment tools. This approach is unsuitable for organisations with low awareness of Industry 4.0, as they would not be able to adequately self-assess using these models. By contrast, the novel assessment model is suitable for manufacturers of all sizes in developing regions of the world, where there is generally low awareness of Industry 4.0. Furthermore, it is not a self-assessment model; in fact, it requires a high level of collaboration with the company being assessed and is intended to increase awareness of Industry 4.0 within the organisation and promote digital business resilience.

b. All three of the selected Industry 4.0 assessment models focus on dimensions and sub-dimensions, not Industry 4.0 technologies. For instance, in WMG's assessment model, the sub-dimension of automation focuses on the number of automated machines and systems within a company, not the digital technologies that contribute to automation (e.g., IIoT, CPS, the industrial cloud, and digital twins). By contrast, the novel assessment model focuses on both dimensions and the digital technologies that contribute to each sub-dimension. This enables a deeper level of assessment, as the model not only evaluates whether these technologies have been implemented but also identifies the extent to which they have they been implemented and how they have been deployed across a company's value chain.

c. VDMA IMPULS's Industry 4.0 assessment model is not industry-specific; it was designed to assess all companies, without consideration of their industry. This could impact the quality of the assessment, as some dimensions and sub-dimensions may not be applicable to some companies. By contrast, the Industry 4.0 assessment model developed for this project is industry-specific, which means that the assessment can be tailored to the company being assessed.

d. Finally, none of the three examined Industry 4.0 assessment models explored are company specific. They were designed to assess all companies, without considering the products that they manufacture, company size, and other factors. By contrast, the novel assessment model is company-specific and allows a custom evaluation of each organisation.

2.5. Foundation for a New Assessment Model

The decision was made to base the novel Industry 4.0 assessment model on WMG's assessment model for the following reasons:

a. WMG's research involved organisations in both developed and developing regions of the world, including Africa. In total, 53 companies from 22 countries participated in the research.

b. WMG's assessment tool includes six dimensions and 37 sub-dimensions, which makes it broader in scope than the two other Industry 4.0 assessment models explored in this thesis. Stephen Marshall of the Advanced Forming Research Centre, a member of the High Value Manufacturing Catapult, attested that WMG's Industry 4.0 assessment model has a broad scope, which enables robust assessments (WMG, 2017).

c. WMG's assessment tool has relevant dimensions that are suitable for evaluation of micro, small and medium manufacturers.

d. Tata Steel, a multinational company, used and endorsed WMG's Industry 4.0 assessment model. Deirdre Fox, the company's director of strategic business development, said, 'The

Industry 4.0 concept has already had a profound impact on the actions we at Tata Steel have taken to shape, not only our own business, but on our relationships with our customers and suppliers throughout the supply chain' (WMG, 2017).

e. WMG's assessment model is very transparent about the steps taken to calculate a company's readiness level, which makes it quite user-friendly.

2.6. Identification and Use of Smart Manufacturing Elements as Key Components of the New Assessment Model

One of the modifications made to the WMG assessment model was the use of SM elements as key components of the new assessment model developed for this project. This required extensive research to identify digital technologies and practices that fall within the scope of the seven design principles of Industry 4.0 (i.e. decentralisation, virtualisation, service orientation, modularity, interoperability, real-time capability, and technical assistance; see Section 1.5).

This approach was used to identify which SM elements are implemented in organisations and how they are deployed across the value chain. This ensured a deeper level of assessment and enabled the identification of areas of improvement.

The author identified SM elements that could contribute to each design principle. For example, IIoT, CPS, digital twins, and AI facilitate decentralised decision making, whilst augmented reality and human-robot collaboration (COBOTS) contribute to technical assistance. In total, the author identified 38 key elements of SM through extensive research on existing digital technologies and smart factories; moreover, the offerings of automation vendors such as Siemens, ABB, Emerson, and Bosch were investigated. These identified elements include the following:

1. Industrial Internet of Things (IIoT)

IIoT refers to the application of the internet in manufacturing production and other value chain networks. IIoT is a vital element of SM because it

a. enables the remote accessibility and tracking of objects and machines.

b. makes new products available to the market more quickly.

c. enables a more dynamic reaction to product demand.

d. enables real-time optimisation throughout a value chain network.

e. enables enhanced analytics, and

f. reduces human intervention, which leads to enhanced efficiency and accuracy.

To remain competitive, manufacturers must leverage IIoT and digitalisation to become more agile and efficient (Ericsson, 2020).

2. Distributed Intelligence

Distributed intelligence enables decentralised decision making. Machines can autonomously and independently make decisions and appropriate adjustments to achieve optimisation (Bosch Rexroth, 2016).

3. Digital Twins

According to GE (2020), 'Digital Twin is most commonly defined as a software representation of a physical asset, system or process designed to detect, prevent, predict, and optimise through real time analytics to deliver business value'. Digital twin enables the virtualisation of a factory floor and processes, and integrate the virtual world with the real world. Digital twins enable real-time communication between objects, machines, and humans, which facilitates a high level of autonomy and enables decentralised decision making.

4. Big Data Analytics

The information contained in data streams that pour into a factory can transform how operations are managed, how issues are solved, and how changes are adapted to (Rockwell, 2020). Big data analytics software can collect and organise data in real time, adding context to the data to provide and recommend actionable insights. Big data analytics also enable the early detection of defects and production failures, which allows the appropriate preventive steps to be taken. Another preventive feature made possible by big data analytics is predictive maintenance. According to Deloitte (2017), 'Predictive Maintenance utilises a wealth of process data and advanced analytical methods to predict failures well before immediate action has to be taken'.

5. Industrial Communications Technology

Industrial communications technology enables horizontal and vertical integration by facilitating communication between machines, humans, and objects in a factory. It also allows data to be disseminated and received from remote locations.

6. The Industrial Cloud

In advanced manufacturing, vast amounts of operational data are generated by large capital assets, including plants, equipment, and machines vehicles. These data can be transmitted through a cloud infrastructure to applications used by operators on their computers or mobile devices. These data can also be transmitted to software programs that automate workflow (Siemens 2018).

7. Autonomous Robots

In recent times, robots have become a key element in various industrial fields, not only as workmates but also competitors to humans. The emergence of AI has enabled robots to evolve from stationary machines that perform repetitive tasks to intelligent systems that can autonomously sense, learn, and act (Siemens, 2017).

8. Industrial Security

The implementation of digital technologies and expansion of digital ecosystems entails significant risk with regard to digital susceptibility (BAE, 2020). Therefore, organisations must take steps to ensure digital security and a meticulous and proactive approach to cyber security issues.

9. Predictive Maintenance

Traditionally, the scheduled maintenance and routine repair of machine parts are conducted in a factory to prevent downtime. Although this preventive approach has its benefits, it unnecessarily consumes resources and is neither time- nor cost-effective. Therefore, a predictive approach is required to prevent asset failure by analysing production data to detect patterns. Predictive maintenance involves implementation of IIoT and other digital technologies to monitor asset health, optimise maintenance schedules, identify operational risks in real time, maximise uptime, save costs, and improve production throughput (Yang and Lin, 2015).

10. Remote Monitoring

Remote monitoring is important in today's competitive landscape, as it enables the optimisation of machine functions, extends uptime, and helps eliminate downtime (Wald, 2020). Moreover, remote monitoring facilitates real-time monitoring of assets in a factory. Sensors, IIoT, and other digital technologies can be used to constantly monitor assets and production status. The collected data can be stored in the cloud in real time and later used to facilitate predictive maintenance analysis to drive productivity and lower maintenance costs.

11. Remote Maintenance

In remote maintenance, IIoT, software, and other digital technologies enable the real-time remote accessibility of machines for diagnostic purposes and other maintenance activities. This approach streamlines maintenance, improves productivity, saves costs, and limits downtime. Sensors can be used in remote maintenance to detect abnormal conditions, such as excessive motor vibrations or high temperatures; this allows maintenance personnel to be notified of a potential problem and prevent unplanned downtime (Laplante, 2020).

12. Cyber-Physical Systems

According to Ericsson (2018), ‘CPSs are integrations of computation, networking, and physical processes: the combination of several systems of different nature whose main purpose is to control a physical process and, through feedback, adapt itself to new conditions, in real time’.

13. Human-Robot Collaboration

In human-robot collaboration, human operators are assisted by robots. Thus, humans are not replaced by robots; rather, robots complement their capabilities and relieve them of laborious tasks. Human-robot collaboration combines human capabilities with the efficiency and precision of machines (KUKA AG, 2019). It can increase efficiency, enhance productivity, and save time and costs.

14. Smart Sensors

Smart sensors are used to gather input from the physical environment. Once specific inputs are detected, they use built-in computing resources to perform predefined functions, thus pre-processing the data before transferring it on to be stored. Smart sensors enable data to be more accurately and automatically collected from the environment. They have local computing power and wireless capabilities that enable complex calculations to be locally conducted on measured data in the sensor module (CMTC, 2020). Smart sensors’ wireless capabilities enable connection to the internet, thereby contributing to real-time features in a smart factory.

15. Product Data Utilisation

Manufacturers must invest in performance-based analysis. Product data allows businesses to understand how products behave in the field (Rudek, 2015). This advanced approach leverages data from a fleet of smart connected products; it is vital to manufacturers that design or enhance smart products.

16. Additive Manufacturing

According to GE Aviation (2020), 'Additive manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems'. Additive manufacturing allows the creation of personalised products with lower development costs, energy consumption, lead times, and generated waste materials. Additive manufacturing can be leveraged to manufacture complex parts, reduce inventory, make products on demand, and create smaller localised environments.

17. Augmented Reality

Augmented reality (AR) technology allows users to experience an augmented world by placing virtual data in the real world. This enables AR users to access both the virtual and real worlds whilst receiving data in real time. AR can be beneficial to technicians and workers, as it represents relevant data to them and grants them access real-time information about their work. In addition, AR technology enables digitalised directions to be easily pulled up in the line of sight of workers to be studied and followed (GE, 2017). AR can also enhance industrial training and learning and reduce risks and costs (Mavers and Osbourne 2019).

18. Enterprise Manufacturing Intelligence

Enterprise manufacturing intelligence refers to software that gathers an organisation's manufacturing-related data to enable their reporting, analysis, visualisation, and transfer between enterprise- and plant-level systems (Infinity QS, 2019). The combination of data from various sources in enterprise manufacturing intelligence software enables them to be utilised more appropriately and efficiently by providing users with a clear view and understanding of these data.

19. Demand Forecasting Through Predictive Analytics

Obtaining foresight on the products and services that customers want and when they want them can greatly benefit organisations. To this end, predictive models can be implemented in precision marketing to better comprehend and meet customers' needs and expectations (You et al., 2015).

Demand forecasting involves the utilisation of complex algorithms based on datasets to ascertain customers' product or service demands and can help organisations make appropriate changes in how they market, price, and plan product sales.

20. <u>Machine Learning</u>

Machine learning uses an iterative approach to independently adapt to new data and learn from previous computations to produce repeatable and reliable results and decisions (Siemens, 2018). This leads to a high level of autonomy, which facilitates decentralised decision making.

21. <u>Digital Human Resource Management</u>

Digital human resource (digital HR) management involves the digitalisation of human resource management services and processes using social, mobile, analytics, and cloud (SMAC) technologies. Digitalisation in human resource management includes changes to both approach and execution, which enhance the employee experience and contribute to organisational success.

According to Techtarget (2019), digital HR takes a cloud-first, mobile-first, data-driven, collaborative, and iterative approach to human resource services and processes in business strategy and employee experience. Digital HR utilises human capital management (HCM) and talent management systems to enable easier deployment, automatic upgrades, fewer technical challenges, improved automation, cost savings, and ease of integrating new technologies.

22. <u>Open Innovation</u>

According to a Chesbrough (2006), open innovation is 'the use of purposive inflows and outflows of knowledge to accelerate innovation and to expand the markets for external use of innovation'. According to Atos (2019), open innovation comprises three main approaches:

- Outside in: This approach involves the integration of external knowledge into an organisation's innovation processes and can improve the quality and speed of innovation processes. External knowledge may include contributions from customers and/or suppliers.

- Inside out: This approach involves the externalisation of internal knowledge that is not part of an organisation's core business to commercialise this knowledge (e.g. licensing to third parties).
- Combination of the outside-in and inside-out approaches: This approach aims to create standards and build up markets.

23. Open Standards

Making changes to an organisation's production system require making changes in the corresponding software. This often leads to manual efforts that are time- and cost-intensive and prone to error. Therefore, the use of a standardised language that is comprehensible to various components of a production system and production IT can be very beneficial. Open standards can promote collaboration between manufacturers by allowing data to be rationalised into similar formats and communicated across standard protocols. Thus, open standards enable SMEs to compete (Bowne, 2017).

24. Manufacturing Execution System

A manufacturing execution system (MES) facilitates order flow and production execution, tracks the transformation of products from raw materials to finished goods, and evaluates and analyses conditions on plant floors and plant resource utilisation, yield, and quality (Aveva 2020). MESs also possess real-time capabilities that facilitate control of various elements of production processes, including machines, inputs, and support services.

25. Enterprise Resource Planning

Enterprise resource planning (ERP) is a business management software that enables organisations to use a suite of integrated applications to collect, store, manage, and interpret data from various facets of their operations, including manufacturing, services, supply chains, and procurement (Perkins 2020).

26. Supervisory Control and Data Acquisition

Supervisory control and data acquisition (SCADA) encompasses software and hardware that control industrial processes and monitor, gather, and process real-time data. SCADA systems directly interact with objects (including sensors, valves, motors, and pumps) through the utilisation of human-machine interface software and record events in a log file (Inductive Automation, 2019). SCADA is beneficial to manufacturers, as it helps maintain efficiency, enable decision makers to make appropriate decisions based on the data that they produced, and mitigate downtime.

27. Advanced Planning and Scheduling

Advanced planning and scheduling (APS) involves computer-based optimisation decision support tools for planning and scheduling. APS systems can quickly analyse and calculate achievable production schedules whilst considering several constraints (Siemens 2017).

28. Programmable logic controller (PLC)

Programmable logic controller (PLC) are connected sensors or input devices that receive data for processing and create outputs based on pre-programmed parameters. PLCs can be used to monitor and record runtime data (e.g., machine productivity and operating temperatures) and initiate or terminate processes and issue notifications when machines malfunction. In the era of IIoT, PLCs are used to communicate data through the internet and connect to databases through structured query language (SQL) and to cloud data using message queuing telemetry transport (MQTT; Ultrasonics 2019).

29. Intelligent and Individualised Workstations

Intelligent and individualised workstations provide digital assistance by making production-related information available to individuals and offers enhanced ergonomics. Furthermore, individualised workstation optimisation and digital assistance can automatically identify a worker and tailor a work environment to them by offering personalised instructions and smart tools and devices that are intuitive to operate (Bosch, 2019).

30. Digital Lifecycle Management

To fully harness the potential of connected digital technologies, manufacturers must consider the entire lifecycle of a product, from initial design to servicing. Digital lifecycle management (DLM) is a transformative framework that integrates data from interconnected systems into product simulation and manufacturing processes. This results in predictive and prescriptive operations that ensure resilient performance in production systems. However, to achieve this, there must be development and implementation of in-process monitoring, analytics-driven defect identification, root-cause analysis, and corrective and preventive measures (The Manufacturer 2019).

31. Digital Customer Co-Creation and Customer Relationships

Digital co-creation occurs when multiple perspectives are gathered with digital technology to create transformational outcomes. In digital customer co-creation, digital ecosystems of inputs and insights from customers, end users, research organisations, and academia are collected with a portfolio of connected services by harnessing the potential of digital technologies, including IIoT, cloud, and AI (Fugitsu 2018). Digital customer co-creation allows customers to contribute to product development and creative processes. As a result, organisations can harness the power of IIoT and other digital technologies to improve the customer experience and build stronger relationships with customers.

32. Design to Value

According to McKinsey (2013), ‘Design to value (DTV) is a portfolio-optimization approach that helps businesses understand which product features are important to consumers and whether they are willing to pay for these features’. This approach combines insights on what customers value in products, competitive insights on offerings made by other organisations to meet their customers’ needs, and supplier insights on new technologies and the costs of manufacturing products to maximise the value of a design.

33. Advanced Virtual Self-Services

Advanced virtual self-services involve the utilisation of AI through machine learning and natural language processing (NPL) to deliver an enhanced customer experience. Advanced virtual self-services can be used to predict what customers want, personalise interactions with customers, and determine appropriate actions to deliver successful outcomes.

34. Digital Supply Chain Management

Digital supply chain management involves the application of IIoT and big data analytics, amongst other digital technologies, to supply chain management. The aim is to significantly improve performance and customer satisfaction and save time and costs. According to McKinsey (2016), the benefits of digital supply chain managements are as follows:

a. Enhanced product distribution and reduced delivery time: This outcome depends on advanced forecasting approaches, which use predictive analytics to determine both internal and external factors (e.g., changes in demand, market trends, and weather).
b. Flexibility: The utilisation of ad hoc and real-time planning enables flexible responses to change in supply and demand. The level of flexibility that digitalisation affords to supply chain management allows planning to be a continuous process, which enables organisations to react dynamically to changes in requirements or constraints. Furthermore, this level of flexibility improves delivery processes by allowing customers to reroute shipments to more appropriate destinations.
c. Increased granularity: Increasing demand for individualised products has led to micro-segmentation and mass customisation. Thus, a more granular approach is needed to

offer multiple logistics menus to customers, which allows them to select the most suitable options for their situation.

d. Maximum transparency: The digitalisation of supply chain management ensures a continuous flow of information about the location and condition of deliveries through real-time tracking and advanced sensor technology.

Implementing digital supply chain management enables the automation of physical tasks and planning through the application of digital technologies, which can significantly enhance efficiency and achieve considerable cost and time savings.

Digital Inventory Management

Digital inventory management systems are cloud-based, which allows inventories to be managed in real time and enables a high level of transparency and traceability. According to DEAR Systems (2018), the benefits of cloud inventory management are as follows:

a. Enhanced accessibility: Cloud-based inventory management enables better accessibility from anywhere through the use of IIoT.
b. Enhanced visibility: Organisations can track inventories and the movement of stock across all channels through cloud-based inventory management. This prevents both out-of-stock events and overstocking.
c. Automation: The digitalisation of inventory management represents a more automated approach to supply chains, which requires less human intervention and improves performance and efficiency.
d. Enhanced customer service: Cloud-based inventory management systems can lead to significant improvements in customer service by providing customers with multiple shipping options, which allows them to choose the most convenient solution for their situation.

35. Digital Customer Relationship Management

Digital customer relationship management (CRM) involves the implementation of digital technologies (e.g., the cloud, IIoT, and big data analytics) in CRM. Cloud-based CRM software can be accessed from any device, at any time, and from anywhere, as long as the user is connected via IoT (Vyas, 2018).

36. Product Digitalisation

Scantrust (2020) established five steps to digitalising products:

a. Identification of goals for digitalisation: This step addresses questions about the type of data-derived insights required by marketing managers, brand managers, and category managers and how digitalisation can be used to gather the data needed to generate these actionable insights.
b. Physical aspect: This step involves ascertaining the best way to place digital assets on physical products. This can be accomplished by printing on product packaging, as this enables a high level of visibility to end consumers along the supply chain. However, since this is not always practical, other approaches include the use of printed labels and product tags.
c. Embedding: This step involves adding a physically unique, tamper-proof identifier on physical products in the form of barcodes, quick response (QR) codes, complex number sequences, sensor tags, etc. This step may also involve a combination of two or more unique identifiers.
d. Enabling: In this step, the digital ID is connected to the appropriate digital asset by entering it in a database or blockchain. To achieve this, the physically unique, tamper-proof identifier must be digitally registered and activated. This transforms a physical product into digital data, as it becomes a digital record in the system. Cloud computing can also be implemented.

e. Using the data: Product digitalisation is incomplete unless it harnesses the collected data through product digitalisation. Subsequently, the data can be analysed to improve a company's operations, customer service, and bottom line.

37. Quality 4.0

According to Javaneh and Javad (2020), 'Quality 4.0 is a branch of I4.0 with the aim of boosting quality by employing smart solutions and intelligent algorithms'. Quality 4.0 combines digital technologies (e.g. IIoT, machine learning, AI, big data analytics, and the cloud), new forms of collaboration (e.g. social media and blockchains), and traditional quality control methods to facilitate operational excellence, performance, and innovation.

Digital quality management is very data-driven, as it involves the exploitation of data accumulated from sensors, social media, operating systems, and other sources through big data analytics technology. Furthermore, digital quality management leverages analytical technologies such as machine learning and AI to sift through large amounts of data and identify patterns that can be harnessed. Based on these insights, alerts can be sent out, future events predicted, and autonomous decisions can be made. Thus, digital quality management provides new insights and promotes innovation and connectivity between people.

2.6. Summary

The gaps identified in an evaluation of three of the leading Industry 4.0 assessment models provided the basis for the novel Industry 4.0 assessment model developed in this research. WMG's Industry 4.0 assessment model provided the foundation for the new assessment model; several modifications were made in the process, which are further discussed in the next chapter (see Section 3.1).

Chapter 3: Industry 4.0 Assessment Model Design

The current chapter covers the design process for the novel Industry 4.0 assessment model, which was based on gaps identified in three of the leading Industry 4.0 assessment models investigated in the previous chapter. This process encompassed three design phases (see Figure 21).

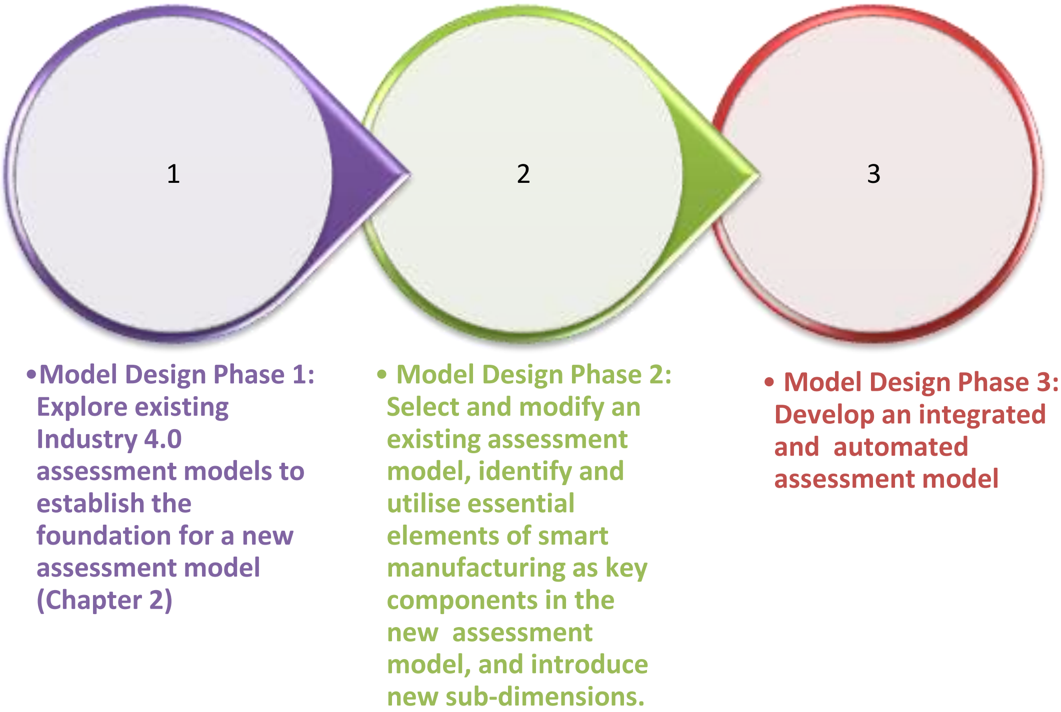

Figure 21. Industry 4.0 Assessment Model Design Flowchart

3.1. Model Design Phase 1

Phase 1 was the exploratory phase and involved extensive research on the design principles, technologies, and strategies of Industry 4.0. At this stage, various existing Industry 4.0 assessment models were explored. Then, three of the leading Industry 4.0 assessment models were reviewed (see Chapter 2).

3.2. Model Design Phase 2

Phase 2 of the model design included three sub-phases: (a) selection and modification of an existing assessment model; (b) identification and utilisation of important SM elements as key components of the assessment model; and (3) addition of new sub-dimensions, which expanded the assessment criteria.

3.2.1. Selection and Modification of an Existing Assessment Model

The assessment model developed for this project is based on WMG's Industry 4.0 assessment model, which the author modified for application to manufacturers in Africa. This was achieved by identifying gaps in WMG's assessment model and other existing models (see section 2.4-2.6), and addressing those gaps in the novel assessment model developed (section 3.1-3.4).

3.2.2. Identification and Utilisation of Important Smart Manufacturing Elements as Key Components of the New Assessment Model

The identification of SM elements was based on the seven design principles of Industry 4.0. All 38 identified elements were described in detail in Section 2.6 of the literature review.

3.2.3. Additional Sub-Dimensions

New sub-dimensions were added to the assessment model (see Tables 8–12). These sub-dimensions were based on the seven design principles of Industry 4.0 (see Chapter 1). Virtualisation and technical assistance are key design principles of Industry 4.0 that were not included in WMG's model, as the latter was developed to focus on dimensions themselves and not the digital technologies that they encompass. Some of the elements identified in this project do not fall under any of the sub-dimensions in WMG's assessment model, which led the author to add sub-dimensions to the current project (e.g. virtualisation, technical assistance, etc). The addition of these sub-dimensions broadens the assessment criteria of the novel Industry 4.0 assessment model, which enables a more robust assessment.

3.3. Model Design Phase 3

The third phase of the model design involved the integration of all the facets in the design phase to create an automated whole. These facets included data input, results, identification of gaps, and support interface for making recommendations , all of which are covered in this chapter.

3.3.1. List of Key Terms and Metrics

The list of key terms and metrics used in this project include dimensions, sub-dimensions, additional sub-dimensions, elements, element relevance, element features, element relevance, feature relevance, features implemented, total number of features, total relevant features, element feature maturity score, Industry 4.0 maturity level by element (maturity matrix by element), Industry 4.0 maturity by element (average), Industry 4.0 maturity level by sub-dimension, and overall Industry 4.0 readiness. These terms and metrics are defined in the glossary.

3.3.2. Key Formulae

The following list contains the key formulae used to determine the Industry 4.0 readiness level of organisations.

a. Element feature maturity score

$$= Features\ Implemented \times 100\% / _{Total\ Relevant\ Features}$$

Example from Figure 23:

** Features implemented = 6*

** Total relevant features = 6*

Element feature maturity score $= 6 \; x \; 100\% / 6$

Therefore, the element feature maturity score = 100% (see Figure 23).

b. Industry 4.0 maturity level by sub-dimension = *Average of Industry 4.0 maturity level by elements and sub-dimension Industry 4.0 readiness level.*

Example from Figure 22:

** Average of Industry 4.0 maturity level by elements for the sub-dimension of share of revenue = 3*

** Sub-dimension readiness level for the sub-dimension of share of revenue = 1*

Industry 4.0 maturity level by sub-dimension = Average of Industry 4.0 maturity level by elements for sub-dimension of share of revenue and sub-dimension readiness level (sub-dimension of share of revenue)

Industry 4.0 maturity level by sub-dimension = (3+1)/2

Therefore, the Industry 4.0 maturity level by sub-dimension = 2 (see Figure 22).

c. Industry 4.0 maturity level by dimension = *Average of maturity levels for all sub-dimensions*

Example from Figure 22:

** Industry 4.0 maturity level by sub-dimension of product customisation = 2*

** Industry 4.0 maturity level by sub-dimension of digital features of product = 3*

** Industry 4.0 maturity level by sub-dimension of data-driven services = 3*

** Industry 4.0 maturity level by sub-dimension of product data usage = 1*

** Industry 4.0 maturity level by sub-dimension of share of revenue = 2*

Industry 4.0 maturity level by dimension = Average of maturity levels for all sub-dimensions

Industry 4.0 maturity level by dimension = (2+3+3+1+2)/5

Therefore, the Industry 4.0 maturity level by dimension = 2 (see Figure 22).

d. Overall Industry 4.0 readiness = *Average of Industry 4.0 maturity or readiness levels for all dimensions*

For example, if the maturity level for the dimensions of

** manufacturing and operations = 2;*

** products and services = 2;*

** supply chains = 1;*

** business model = 1;*

** and strategy and organisation = 3,*

then the overall Industry 4.0 readiness = (2+2+1+1+3)/5.

Therefore, the overall Industry 4.0 readiness = 2.

3.3.3. Data Input Interface and Assessment Guide for all Dimensions

Data collected from the organisations under assessment were inputted into the data input interface of the assessment model. These included data on all the dimensions to be assessed, as seen in the assessment guides (Tables 8–12), data on how the relevant elements were implemented across the organisation's value chain. The products and services data input interface is used to illustrate the data input process (see Figure 22).

	Readiness level	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions	I.40 Maturity Level by Dimension (Average)
1	Product customisation	No	No	Yes	No	No	No	2	2	2
2	Digital features of products	No	No	No	No	Yes	No	2	3	
3	Data-driven services	No	No	No	No	Yes	No	3	3	
4	Level of product data usage	No	Yes	No	No	No	No	3	1	
5	Share of revenue	No	No	Yes	No	No	No	3	2	

Additional Subdimensions

										I.40 Maturity Level by Dimension (Average) + Additional Subdimensions
1	Product Life Cycle Management (PLM)	No	No	No	Yes	No	No	1	2	2
2	Quality Management	No	No	No	No	Yes	No	4	4	
3	Technical Assistance	No	No	No	No	No	Yes	1	3	

Figure 22. Data Input Interface – Products and services

Figure 23 presents an example of how the data input interface was used to enter data on elements of SM and their constituent features. Using this interface, data on the relevance of these elements and their constituent features and the elements implemented by the organisation being assessed can be entered. The Industry 4.0 maturity level by element is also entered in this interface. The metrics used were discussed in the list of key terms and metrics presented in 3.3.1 above.

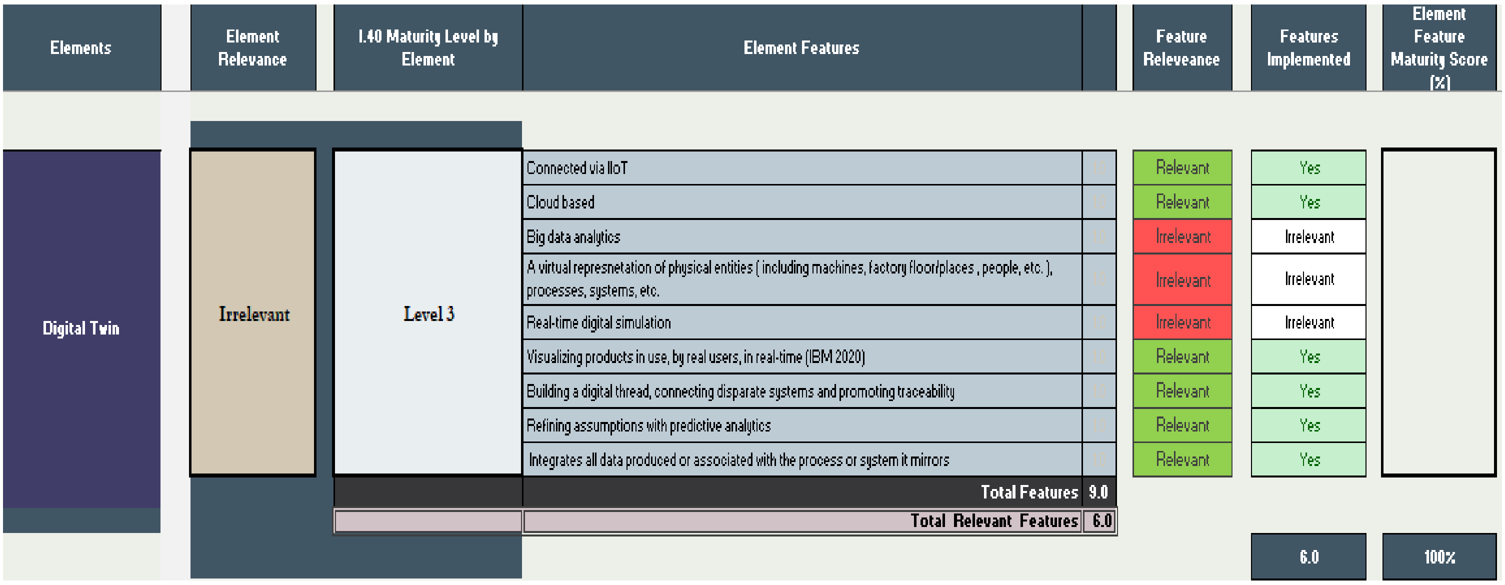

Figure 23. Data Input Interface – Elements of Smart Manufacturing and Their Constituent Features

Tables 8–12 contain the data input assessment guide, which covers all dimensions and categories and provides guidelines for entering data into the data input interface. This assessment guide is based on the WMG Industry 4.0 assessment model.

MANUFACTURING AND OPERATIONS						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
Automation	☐ Not relevant	Automation not in use	☐ Up to 25% of the manufacturer's relevant machines are controlled through automation.	☐ Up to 50% of the manufacturer's relevant machines can be controlled through automation.	☐ Up to 75% of the manufacturer's relevant machines can be controlled through automation.	☐ All of the manufacturer's relevant machines and systems can be completely controlled through automation.
	Elements of Industry 4.0 that contribute to automation. 1. Digital twins 2. Cyber-physical systems (CPS) 3. Industrial Internet of Things (IIoT) 4. Industrial communications 5. Big data analytics 6. Autonomous robots 7. Machine learning					

	8. Programmable logic controller (PLC) 9. Industrial cloud 10. Smart sensors 11. Human-robot collaboration (COBOTS) 12. Intelligent and individualised workstations 13. Artificial intelligence 14. SCADA					
Machine and operation system integration (M2M)	☐ Not relevant	☐ The manufacturer’s machines and systems do not have M2M capability.	☐ Up to 25% of the manufacturer’s relevant machines and systems are interoperable.	☐ Up to 50% of the manufacturer’s relevant machines and systems are integrated.	☐ Up to 75% of the manufacturer’s relevant machines and systems are integrated.	☐ All of the manufacturer’s relevant machines and systems are fully integrated.
	Elements of Industry 4.0 that contribute to M2M. 1. Digital twins 2. IIoT 3. Industrial communications 4. Open standards					
Equipment readiness for Industry 4.0	☐ Not relevant	☐ A complete overhaul is required to achieve Industry 4.0.	☐ Significant overhaul is required to achieve Industry 4.0 requirements (over 50% of machines and systems).	☐ Up to 50% of relevant machines and systems are upgradable.	☐ Over 50% of relevant machines have already met Industry 4.0 requirements and can be upgraded in areas where needed.	☐ All relevant machines and systems have already met all future requirements.
Autonomously guided workpieces	☐ Not relevant	☐ The manufacturer does not use autonomously guided workpieces.	☐ There is awareness of autonomously guided workpieces, and there are ongoing discussions about conducting a pilot program.	☐ The manufacturer does not use autonomously guided workpieces, but there are pilot programs underway.	☐ The manufacturer uses autonomously guided workpieces in selected areas.	☐ The manufacturer has widely adopted autonomously guided workpieces.
	Elements of Industry 4.0 that contribute to autonomously guided workpieces. 1. COBOT 2. Autonomous robots 3. Industrial communications 4. IIoT 5. Smart sensors					
Self-optimising processes	Not relevant	☐ There are no self-optimising processes.	☐ There are no self-optimising processes in use;	☐ There are no self-optimising processes in use;	☐ Self-optimisation processes have	☐ The manufacturer has widely

			however, there are ongoing conversations about conducting a pilot program in certain areas of the business.	however, there are pilot programs in advanced areas of the organisation.	been adopted in selected areas.	implemented self-optimising processes.
	Elements of Industry 4.0 that contribute to self-optimising processes. 1. CPS 2. Digital twins 3. Industrial communications 4. Machine learning 5. Smart sensors 6. Big data analytics 7. IIoT 8. Industrial cloud and AI					
Digital modelling	☐ Not relevant	☐ Digital modelling is not in use.	☐ Digital modelling is not in use; however, there are plans for its implementation.	☐ Digital modelling is used in up to 50% of relevant processes.	☐ Digital modelling is used in up to 70% of relevant processes.	☐ Digital modelling is used in all relevant processes.
Operations data collection	☐ Not relevant	☐ Operations data are not collected.	☐ Data collection is manually performed when required, such as in sampling for control.	☐ The manufacturer digitally collects data in certain areas.	☐ Digital data is comprehensively collected in multiple areas of the business.	☐ Digital data collection is automated In all required areas and processes.
	Elements of Industry 4.0 that contribute to operations data collection. 1. Enterprise resource planning (ERP) 2. SCADA 3. Manufacturing execution system (MES) 4. Enterprise manufacturing intelligence (EMI) 5. Advanced planning and scheduling (APS) 6. IIoT 7. Industrial communications 8. Smart sensors 9. Industrial cloud 10. PLC 11. Digital supply chain management 12. Digital inventory management 13. Quality 4.0 14. Digital product lifecycle management (DPLM) 15. Digital twins 16. Real-time remote monitoring 17. Predictive maintenance 18. Big data analytics					

Operations data usage	☐ Not relevant	☐ Operations data is not used.	☐ Collected data are only used for quality and regulatory purposes.	☐ Processes are controlled using some of the collected data.	☐ Over 50% of the relevant collected data are used to control and optimise processes (e.g., predictive maintenance).	☐ All of the relevant collected data are not only used to optimise processes but also to make decisions.
	Elements of Industry 4.0 that contribute to operations data usage. 1. CPS 2. Big data analytics 3. Machine learning 3. ERP 4. SCADA 5. MES 6. EMI 7. APS 9. IIoT 10. Industrial communications 14. Digital supply chain management 15. Digital inventory management 16. Quality 4.0 17. DPLM 18. Digital twins 19. Real-time remote monitoring 20. Predictive maintenance 21. AI					
Cloud solution usage	☐ Not relevant	☐ Cloud solutions are not implemented.	☐ Some discussions have been held amongst management about implementing cloud solutions. However, no initial solutions have been planned.	☐ Initial solutions have been planned for cloud-based software, data storage, and data analysis.	☐ In some areas of the business, pilot solutions have been implemented.	☐ Across the business, multiple solutions have been implemented.
	Elements of Industry 4.0 that are cloud-based. 1. Predictive maintenance 2. Digital supply chain management 3. Digital inventory management 3. Big data analytics 4. IIoT 5. Industrial communications 6. MES					

	7. APS 8. SCADA 9. DLPM 10. Quality 4.0 11. Digital customer relationship manager 12. DHRM 13. CPS 14. Digital twins					
Information technology (IT) and data security	☐ Not relevant	☐ No IT security solutions have been planned.	☐ IT security solutions have been planned.	☐ IT security solutions have been partially implemented.	☐ Plans have been developed to fill essential gaps in the implemented IT security solutions.	☐ In all relevant areas, IT security has been implemented, and frequent reviews are conducted to ensure compliance.
Additional sub-dimensions						
Asset maintenance and management	☐ Not relevant	☐ There is no awareness of the benefits of technologies such as predictive maintenance, remote maintenance, and augmented reality in asset maintenance.	☐ Discussions have been held amongst management on the benefits of technologies such as such as predictive maintenance, remote maintenance, and augmented reality in asset maintenance. However, plans have yet to be made towards their implementation.	☐ Plans have been initiated to implement technologies such as predictive maintenance, remote maintenance, and augmented reality in asset maintenance.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to asset maintenance and management. 1. Predictive maintenance 2. Remote monitoring 3. Remote maintenance 4. Augmented reality 5. Digital twins 6. Industrial communications					

Performance monitoring and management	☐ Not relevant	☐ There is no awareness of the benefits of advanced digital technologies such as digital twins, IIoT, and big data analytics in monitoring and managing performance.	☐ Discussions have been held amongst management on the benefits of advanced digital technologies such as digital twins, IIoT, and big data analytics in performance monitoring and management performance. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies in performance monitoring and management, and plans have been made towards their implementation.	☐ A pilot program is in underway.	The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to performance monitoring and management. 1. Digital twins 2. SCADA 3.PLC 4. Big data analytics 5. Smart sensors 6. Industrial communications 7. IIoT 8. Industrial cloud 9. MES 10. Real-time remote monitoring					
Virtualisation	☐ Not relevant	☐ There is no awareness of the benefits of advanced digital technologies such as digital twins, augmented reality, and IIoT in virtualisation.	☐ There are ongoing discussions amongst management on the benefits of advanced digital technologies such as digital twins, augmented reality, and IIoT in virtualisation. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies such as digital twins, augmented reality, and IIoT in virtualisation, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to virtualisation.					

	1. Digital twins 2. Augmented reality 3. Industrial communications					
Production planning and scheduling	☐ Not relevant	☐ There is no awareness of the benefits of advanced planning and scheduling software.	☐ There are ongoing discussions amongst management on the benefits of advanced planning and scheduling software. However, plans have yet to be made towards its implementation.	☐ All relevant management staff are aware of the benefits of advanced planning and scheduling software, and plans have been made towards its implementation.	☐ A pilot program is underway.	☐ The pilot program was successful and advanced planning and scheduling software has been fully implemented.
	Elements of Industry 4.0 that contribute to production planning and scheduling. Advanced planning and scheduling software					
Technical assistance	☐ Not relevant	☐ There is no awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers.	☐ There are ongoing discussions amongst management on the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to technical assistance. 1. IIoT 2. Industrial cloud 3. Big data analytics 4. Design to value 5. Product data utilisation 6. SCADA 7. Demand forecasting via predictive analytics 8. Digital customer relationship management (CRM) 9. EMI					

	10. MES 11. APS 12. Augmented reality 13. DHRM 14. Intelligent and Individualised Workstation 15. DPLM 16. Digital supply chain management 17. Digital inventory management

Table 8. Manufacturing and Operations Data Input Assessment Guide

PRODUCTS AND SERVICES						
Readiness level	Not relevant (NR)	Level 0 (Outsider)	Level 1 (Beginner)	Level 2 (Intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Product customisation	☐ Not relevant	☐ Product customisation is not a priority.	☐ Plans are being made to introduce product customisation. However, products do not allow individualisation. Standardised mass production is still employed.	☐ Products are manufactured in large batches, with limited late differentiation.	☐ Although products can be largely customised, production is still standardised.	☐ For the majority of made-to-order products, late differentiation is offered.
	Elements of Industry 4.0 that contribute to product customisation. 1. Digital customer co-creation 2. IIoT					
Digital features of products	☐ Not relevant	☐ There is no awareness of the benefits of product digitalisation.	☐ There is awareness of the benefits of product digitalisation. However, no plans have been made towards digitalising products.	☐ Plans have been made towards digitalising products. However, manufactured products only show physical value.	☐ Manufactured products have some digital features.	☐ Manufactured products have high digital features and show value from intellectual property licensing.
	Elements of Industry 4.0 that contribute to digital features of products. 1. Product digitalisation 2. IIoT					
Data-driven services	☐ Not relevant	☐ Data-driven services are not a priority.	☐ There is no customer integration for the data-driven services offered.	☐ There is little customer integration for the data-driven services offered.	☐ There is customer integration for the data-driven services offered.	☐ There is complete customer integration for the data-driven services offered.

Level of product data usage	☐ Not relevant	☐ There is no awareness of the benefits of product data usage.	☐ There is awareness of the benefits of product data usage. However, the collected data are not used.	☐ Up to 20% of the collected data are used.	☐ 20–50% of the collected data are used.	☐ Over 50% of the collected data are used.
	Elements of Industry 4.0 that contribute to level of product data usage. 1. Big data analytics 2. Industrial cloud 3. Product data utilisation 4. IIoT					
Share of revenue	☐ Not relevant	☐ Services are not data-driven.	☐ Data-driven services are responsible for less than 2.5% of revenue.	☐ Data-driven services are responsible for 2.5–7.5% of revenue.	☐ Data-driven services are responsible for 7.5–10% of revenue.	☐ Data-driven services are responsible for over 10% of revenue.
	Additional sub-dimensions					
Product lifecycle management (PLM)	☐ Not relevant	☐ There is little or no awareness of the benefits of digital product lifecycle manageme nt software.	☐ Discussions have been held amongst management on the benefits of product life cycle management . However, plans have yet to be made towards it implementat ion.	☐ There is awareness of the benefits of digital product lifecycle management software, and plans have been made towards its implementatio n.	☐ A pilot program is underway.	☐ The pilot program was successful, and product lifecycle management has been fully implemented.
	Elements of Industry 4.0 that contribute to product lifecycle management. 1. Digital product life cycle management					
Quality management	☐ Not relevant	☐ There is little or no awareness of the benefits of Quality 4.0.	☐ Discussions have been held amongst management on the	☐ There is awareness of the benefits of Quality 4.0, and plans have been made	☐ A pilot program is underway.	☐ The pilot program was successful, and Quality 4.0 has been fully implemented.

			potential implementation of Quality 4.0. However, plans have yet to be made towards it implementation.	towards its implementation.		
	Elements of Industry 4.0 that contribute to quality management. Quality 4.0					
Technical assistance	☐ Not relevant	☐ There is little or no awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers.	☐ Discussions have been held amongst management on advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to technical assistance 1. IIoT 2. Industrial cloud 3. Big data analytics 4. Design to value 5. Product data utilisation 6. SCADA 7. Demand forecasting via predictive analytics 8. Digital CRM 9. EMI 10. MES 11. APS 12. Augmented reality					

	13. DHRM 14. Intelligent and individualised workstation 15. DPLM 16. Digital supply chain management 17. Digital inventory management

Table 9. Products and Services Data Input Assessment Guide

SUPPLY CHAIN						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
Inventory control using a real-time data management database	☐ Not relevant	☐ Inventory levels are not understood.	☐ Inventory levels are understood.	☐ Inventory levels are manually updated using a computer database.	☐ Inventory levels are updated using a combination of smart devices and a computer database.	☐ A real-time database is updated using smart devices.
	Elements of Industry 4.0 that contribute to inventory control using a real-time data management database. Digital inventory management					
Supply chain integration	☐ Not relevant	☐ Supply chain integration is not a priority.	☐ There is awareness of the importance of supply chain integration. However, communications with suppliers and customers remain ad hoc and reactive.	☐ There is basic communication and data sharing with suppliers and customers when needed.	☐ There is data transfer between key strategic suppliers and customers (e.g. customer inventory levels).	☐ The systems employed are completely integrated with suppliers and customers for appropriate processes (e.g. real-time integrated planning).
Supply chain visibility	☐ Not relevant	☐ Supply chain visibility is not a priority.	☐ Supply chain visibility is deemed important. However, there is no visibility of site location, capacity, inventory, or operations between first-tier suppliers and customers.	☐ There is visibility of site location, capacity, inventory, and operations between first-tier suppliers and customers.	☐ There is visibility of site location, capacity, inventory, and operations across the supply chain.	☐ There is real-time visibility of site location, capacity, inventory, and operations across the supply chain. In addition, monitoring and optimisation can be achieved.
	Elements of Industry 4.0 that contribute to supply chain integration. Digital supply chain management					
Supply chain flexibility	☐ Not relevant	☐ There is no clear	☐ Plans are being made	☐ There is moderate	☐ There is moderate response to	☐ There is immediate

		understanding of measures that enable supply chain flexibility. Response to market changes is slow.	to improve supply chain flexibility and response to market changes.	response to market changes and general shifts in customer requirements.	changes in the market environment and individual customer requirements.	response to changes in the market environment and individual customer requirements.
	Elements of Industry 4.0 that contribute to supply chain flexibility. 1. Digital supply chain management					
Lead times	☐ Not relevant	☐ Lead time reduction is not a priority.	☐ There is awareness of the importance of lead time reduction. However, high inventory levels remain due to long material lead times.	☐ The organisation has identified improvements that can reduce lead times for some materials.	☐ The identified improvements have been implemented to reduce lead times for key materials.	☐ Stocking policies and lead times are differentiated to meet make-to-order efficiently.

Table 10. Supply Chain Data Input Assessment Guide

BUSINESS MODEL						
Readiness level	Not relevant (NR)	Level 0 (Outsider)	Level 1 (Beginner)	Level 2 (Intermediate)	Level 3 (Experienced)	Level 4 (Expert)
As a service business model	☐ Not relevant	☐ There is no awareness of the as a service business model.	☐ Discussions have been held amongst managements on the benefits of adopting an as a service business model, but plans have yet to be made towards its implementation.	☐ There is awareness of the concept and initial plans for development.	☐ There is high awareness, and plans for implementation are in development.	☐ The as a service business model has been adopted and offered to customers.
	Elements of Industry 4.0 that contribute to the as a service business model. 1. Cloud as a service 2. IIoT as a service 3. Big data analytics as a service (BDaaS)					
Data-driven decisions	☐ Not relevant	☐ Decision making is not data-driven.	☐ Up to 25% of the relevant collected data are analysed.	☐ Up to 50% of the relevant collected data are analysed and featured in key business reports to review performance.	☐ Up to 75% of the relevant collected data are analysed, and the results are used in business decision making.	☐ Over 70% of the relevant collected data are analysed, and the results are used in business decision making.
	Elements of Industry 4.0 that contribute to data-driven decisions. 1. IIoT 2. Industrial cloud 3. Big data analytics 4. Digital twins 5. DPLM 6. Digital CRM 7. EMI 8. MES 9. APS 10. ERP 11. SCADA * Only consider systems with analytics functions					

Real-time tracking	☐ Not relevant	☐ Products are not tracked.	☐ Product tracking is limited.	☐ Product movement between manufacturing and internal distribution sites can be tracked.	☐ Product movement through manufacturing and distribution and to the customer's distribution centre can be tracked.	☐ Product tracking is possible throughout the complete lifecycle.
	Elements of industry 4.0 that contribute to real-time tracking. 1. Digital supply chain management 2. Digital inventory management 3. Digital product life cycle management					
Real-time and automated scheduling	☐ Not relevant	☐ There is no awareness of the benefits of real-time automated scheduling. Equipment maintenance is manually performed according to a maintenance schedule.	☐ There is awareness of the benefits of real-time automated scheduling. However, equipment maintenance is still manually performed according to a maintenance schedule.	☐ Some machines can alert operators to performance issues to enable manual scheduling of maintenance tasks.	☐ Some machines can self-diagnose and automatically transfer information to the maintenance scheduling system.	☐ Generally, machines can self-diagnose, and the maintenance schedule automatically adjusts itself based on real-time data input from machines.
	Elements of Industry 4.0 that contribute to real-time and automated scheduling. 1. Predictive maintenance 2. Digital twins					
Integrated marketing channels	☐ Not relevant	☐ Integrated marketing channels are not a priority.	☐ There is awareness of the benefits of integrated marketing channels. However, online presence is separated from offline channels.	☐ There is integration within online and offline channels but not between them.	☐ There are integrated channels and an individualised customer approach.	☐ There is integrated customer experience management across all channels.
IT-supported business	☐ Not relevant	☐ Business processes are not	☐ The main business processes	☐ Some areas of the business are integrated	☐ Processes are completely supported by an IT	☐ All of the company's processes are

		supported by an IT system.	are supported by an IT system.	and supported by an IT system.	system; however, they are not fully integrated.	integrated and supported by an IT system.

Table 11. Business Model Data Input Assessment Guide

STRATEGY AND ORGANISATION						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
Degree of strategy implementation	☐ Not relevant	☐ Industry 4.0 is not recognised at all.	☐ Industry 4.0 is recognised at the departmental level but not integrated into strategy.	☐ Industry 4.0 is included in the business strategy.	☐ The Industry 4.0 strategy has been communicated to the business and is widely understood.	☐ The Industry 4.0 strategy has been implemented across the organisation's operations
Measurement	☐ Not relevant	☐ Industry 4.0 is not recognised at all.	☐ Industry 4.0 is recognised; however, key performance indicators (KPIs) do not focus on Industry 4.0.	☐ A structured set of business metrics exist, with some measurement of Industry 4.0 drivers.	☐ Industry 4.0 metrics are widely understood in the business and used in monthly reporting.	☐ Business metrics and personal development plans focus on Industry 4.0 objectives.
Investments	☐ Not relevant	☐ Industry 4.0 is not recognised at all.	☐ Initial Industry 4.0 investments have been made in one business area.	☐ Industry 4.0 investments have been made in more advanced business areas.	☐ Industry 4.0 investments have been made in multiple business areas.	☐ Industry 4.0 investments have been made across the entire business.
	Elements of Industry 4.0 that contribute to supply chain integration. Digital supply chain management					
People capabilities	☐ Not relevant	☐ Digitally upskilling employees is not a priority.	☐ There is awareness of the importance of upskilling employees, and plans have been made towards this goal.	☐ Technology-focused areas of the business employ people with some digital skills.	☐ Employees have digital and data analysis skills across most areas of the business (e.g., production).	☐ Employees have leading-edge digital and analytics skills across the business.
Collaboration	☐ Not relevant	☐ The organisation does not encourage collaboration .	☐ The organisation's operations are in functional silos.	☐ Interaction between departments is limited.	☐ Departments encourage cross-functional collaboration.	☐ Departments encourage cross-company collaboration to enable improvements.
Leadership	☐	☐	☐	☐	☐	☐

	Not relevant	Industry 4.0 is not recognised at all.	Leadership do not focus on Industry 4.0 investments.	Leadership are investigating the potential benefits of Industry 4.0.	Leadership recognise the financial benefits of Industry 4.0, and plans are being developed to promote widespread support within leadership and across the business.	There is widespread support for Industry 4.0 both amongst leadership and across the business.
Finance	☐ Not relevant	☐ Industry 4.0 is not recognised at all.	☐ No sizeable Industry 4.0 investments have been made.	☐ Cost-benefit analyses for Industry 4.0 investments are not being reviewed.	☐ A cost-benefit analysis of Industry 4.0 investments is performed annually.	☐ A cost-benefit Analysis of Industry 4.0 investments is performed quarterly.
Additional sub-dimensions						
People management	☐ Not relevant	☐ There is no awareness of the benefits of advanced digital technologies such as cloud computing, AI, and IIoT in human resource management.	☐ There is awareness of the benefits of advanced digital technologies such as cloud computing, AI, and IIoT in human resource management. However, plans have yet to be made towards their implement them.	☐ There is awareness of the benefits of advanced digital technologies such as cloud computing, AI, and IIoT in human resource management. management, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and digital HRM has been fully implemented.
	Elements of Industry 4.0 that contribute to Digital Features of Products 1. Digital human resource management					

Table 12. Strategy and Organisation Data Input Assessment Guide

3.3.4. Results Interface

The results interface displays the results obtained for the dimensions and sub-dimensions using the formulae presented in Sub-section 3.3.2; an example is shown in Figure 24. This allows the identification of strength and weaknesses.

Figure 24. Results Interface

3.3.5. Automated Gaps Identifier

The automated gaps identifier was used to identify relevant elements that have not been implemented. Figure 25 shows an example with the dimension of manufacturing and operations.

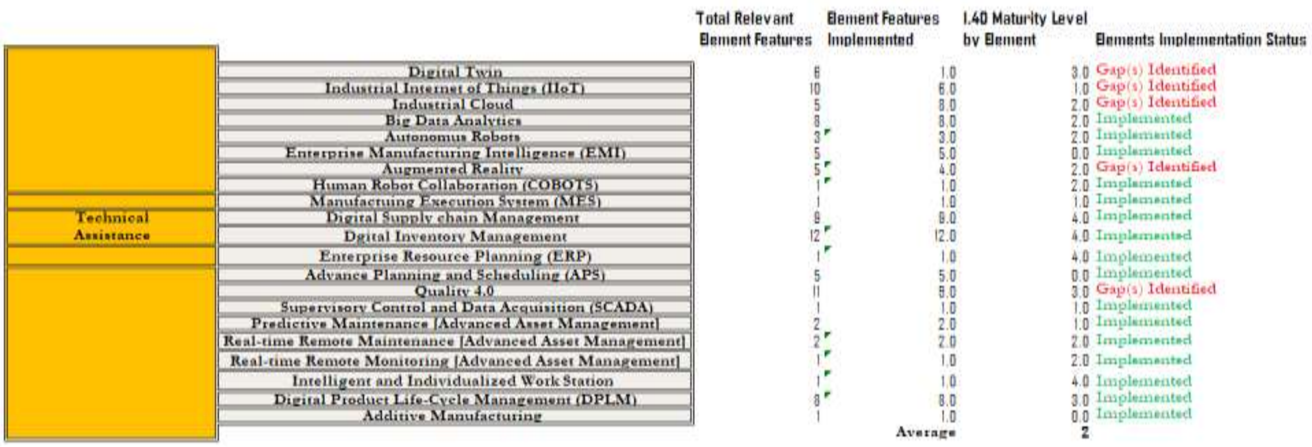

Figure 25. Automated Gaps identifier Interface (Manufacturing and Operations)

3.3.5. Support interface For Making Recommendations

This feature enabled deep investigation of elements that have not been fully implemented and their constituent features, which partially provided the basis for recommendations made in this thesis. Figure 26 shows an example of the support interface for making recommendations with the element of DCRM.

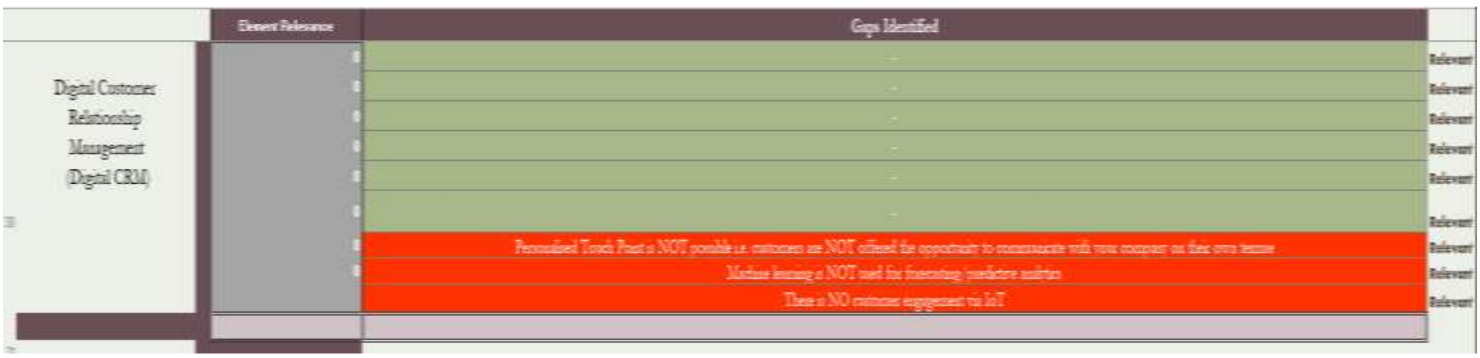

Figure 26. Support interface for making recommendations Interface (Digital CRM)

3.4. Summary

3.4.1. Model Calculations

The assessment model comprises five dimensions which form a manufacturer's value chain: manufacturing and operations, products and services, supply chain, business model, and strategy and organisation. These dimensions were further categorised into sub-dimensions and additional sub-dimensions (see Sub-section 3.2.3.), as shown in Tables 8–12. These tables also contain assessment criteria for all dimensions, sub-dimensions, and additional sub-dimensions, which were used to assess manufacturers. Furthermore, relevant elements were assigned to each dimension, sub-dimension, and additional sub-dimension, which allowed manufacturers to be assessed on the relevant elements of Industry 4.0, and element features implemented. Readiness levels for each sub-dimension and additional sub-dimension and Industry 4.0 elements were averaged to determine the readiness level for a given sub-dimension or additional sub-dimension. Then, the average readiness level of all sub-dimensions and additional sub-dimensions in a given dimension was determined to ascertain overall readiness level within this dimension. Lastly, the average readiness level of all dimensions was calculated to determine the manufacturer's overall readiness level (see Sub-section 3.3.2 for formulae used).

3.4.2. Key Components of the Model

The key components of the developed Industry 4.0 model include the data input interface, assessment guide, results interface, automated gaps identifier, and support interface for making recommendations . The assessment guide contains the assessment criteria, which provide information about a manufacturer's readiness level. Using the data input interface, the assessor can input the appropriate readiness level. The results interface displays the readiness level of the manufacturer being assessed, whilst the automated gaps identifier pinpoints gaps in the form of relevant SM elements that have not yet been implemented. Lastly, the support interface for making recommendations displays features of relevant SM element that have not yet been implemented. The support interface for making recommendations was used to support the recommendations process.

All of the model's facets are integrated and automated to enable streamlined assessments.

3.4.3. Model Design Phases

The design process for the assessment model comprised three phases. The first phase was the exploratory phase, whilst the second phase involves the modification of WMG's Industry 4.0 assessment model to address the identified gaps. The author identified and utilised important SM elements as key components of the new assessment model. Furthermore, the second phase of the design process also involved the addition of new sub-dimensions to the WMG assessment model. The final design phase involved the development of an integrated and automated Industry 4.0 maturity assessment model with multiple features to enable a robust level of assessment, identify gaps, and generate information to guide the recommendation process, amongst others.

3.4.4. Model Robustness

The WMG assessment model was modified to develop the novel model presented in this thesis. The modifications include an algorithmic approach to measuring manufacturer's Industry 4.0 readiness level. To achieve this, the focus of the assessment model developed for this project transcended the dimensions of the model to include the digital technologies, practices, and approaches encompassed by these dimensions and how they should be deployed across a manufacturer's value chain. Another key modification was the introduction of new sub-dimensions to the model to expand its assessment criteria. All modifications made to the WMG model enabled an additional layer of robustness and made the model developed for this thesis suitable for manufacturers of all sizes.

Chapter 4: Model Testing and Assessment Results

The current chapter covers the testing of the Industry 4.0 assessment model and results from the assessments. Testing was deemed necessary to validate the assessment model with real-world data from manufacturers in a developing region, where there is low awareness of Industry 4.0 and associated strategies.

4.1. Analysing the Participating Organisations

The names of participating organisations were anonymised and disclosed only to the author's supervisors and examiners. In this project, the participating organisations were referred to as 'Organisation A', 'Organisation B', 'Organisation C', and 'Organisation D'. These three organisations were sufficient for the project, as they covered the areas of focus specified for the research.

Organisation A

Organisation A are an SME located in the south of Nigeria. They are a fast-moving consumer goods manufacturer of alcoholic and non-alcoholic beverages.

The profile of Organisation B includes the employee count and revenue of Organisation B and its parent company, as seen below. These data were obtained from the financial time, February 2023.

- Number of employees (including parent company): 1.93k
- Revenue In Nigerian naira: 214.33.Bn
- Revenue in U.S. dollars: ~$465.27Bn

Organisation B

Organisation B are an SME located in the south of Nigeria. They manufacture multi-purpose aluminium sheets.

The profile of Organisation B includes the employee count and revenue of a single branch, (i.e. excluding its other branches in Nigeria).

- Number of employees: < 101
- Annual revenue in Nigerian naira (2018): N5.3 billion
- Annual revenue in U.S. dollars: ~$11.5M

Organisation C

Organisation C are an SME in western Nigeria. They are a fast-moving consumer goods manufacturer of table salt.

The profile of Organisation C includes their employee count and revenue and two other branches of the company, as seen below. These data were obtained from the financial time, February 2023.

- Number of employees (includes branches in Port Harcourt, Lagos, and Ogun State): 579
- Revenue In Nigerian naira: N48.94Bn
- Revenue in U.S. dollars: ~$106.29M

Organisation D

Organisation D are a micro manufacturer located in the south of Nigeria. They are a fast-moving consumer goods manufacturer of bottled water. Their exact employee count and annual revenue were not disclosed.

- Employees: < 50
- Revenue In Nigerian naira: Not disclosed.
- Revenue in U.S. dollars: Not disclosed.

4.1.1. Collaboration Matrix

A collaboration matrix was established to determine each participating manufacturer's level of collaboration. Organisations A, B, and C were found to collaborate at Level 2, whilst Organisation D was found to collaborate at Level 4 (see Figure 27)

	Level 1	Level 2	Level 3	Level 4
Data only collected through survey.	✓	X	X	X
Interested in data collection through face-to-face interviews, phone calls, or video calls.	X	✓	✓	✓
Interested in receiving the Industry 4.0 maturity assessment results at the end of the research.	✓	✓	✓	✓
Interested in collaborating with the author to design a holistic digital strategy to digitalise the organisation's value chain.	X	X	✓	✓
Interested in building digital business resilience using the Industry 4.0 maturity assessment model developed for this project.	X	X	X	✓

Figure 27. Collaboration Matrix

4.2. Assessment Results

The assessment model includes five dimensions: manufacturing and operations, products and services, supply chain, strategy and organisation, and business model. All four participating organisations were assessed across these five dimensions, including the relevant sub-dimensions introduced in this project.

4.2.1. Dimension of Manufacturing and Operations

Figures 28 and 29 illustrate the results of the assessments for all four organisations on the dimension of manufacturing and operations. Organisations A, B, C, and D were all determined to be at Level 1 (beginner).

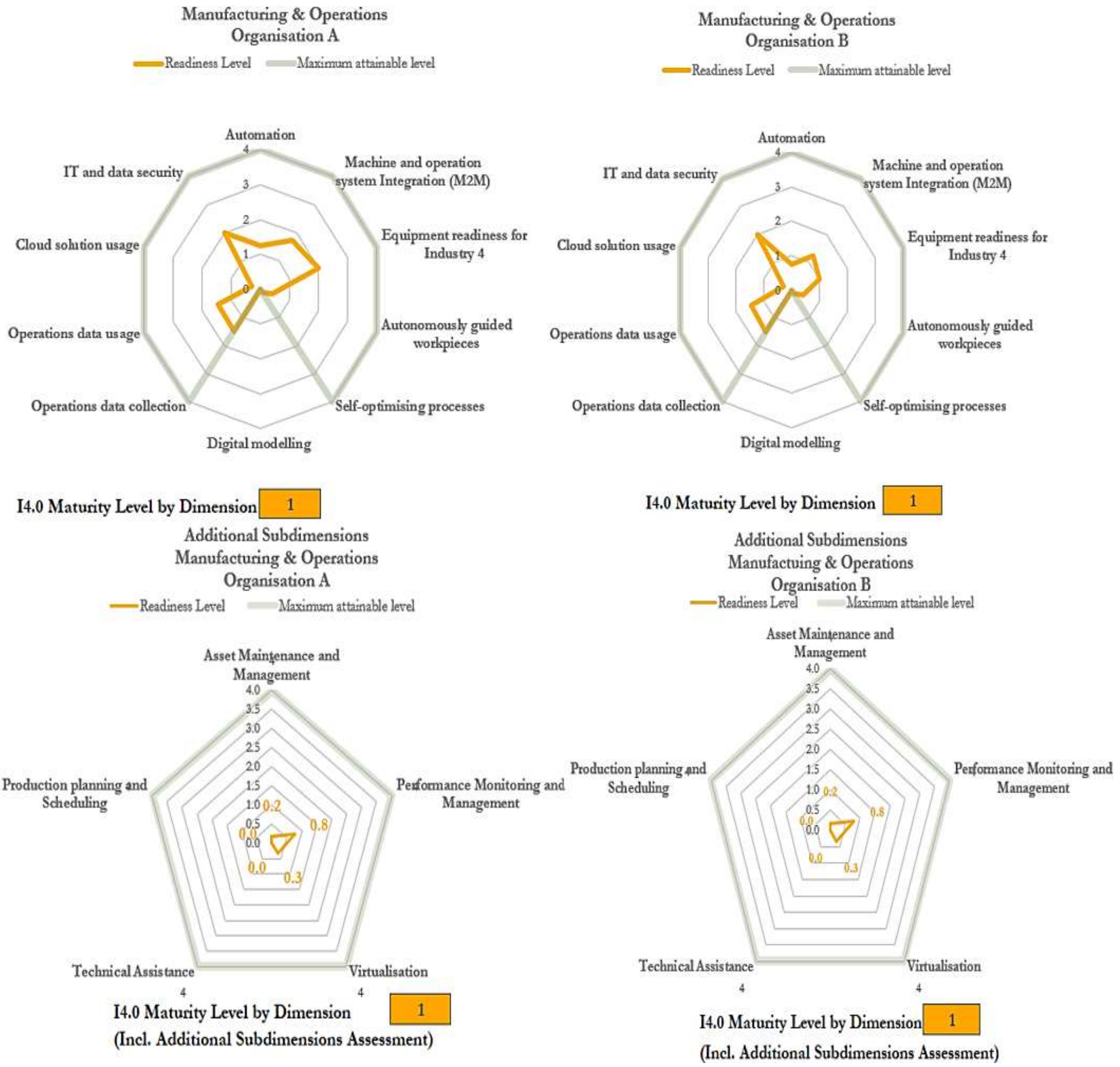

Figure 28. Dimension of Manufacturing and Operations – Results for Organisations A and B

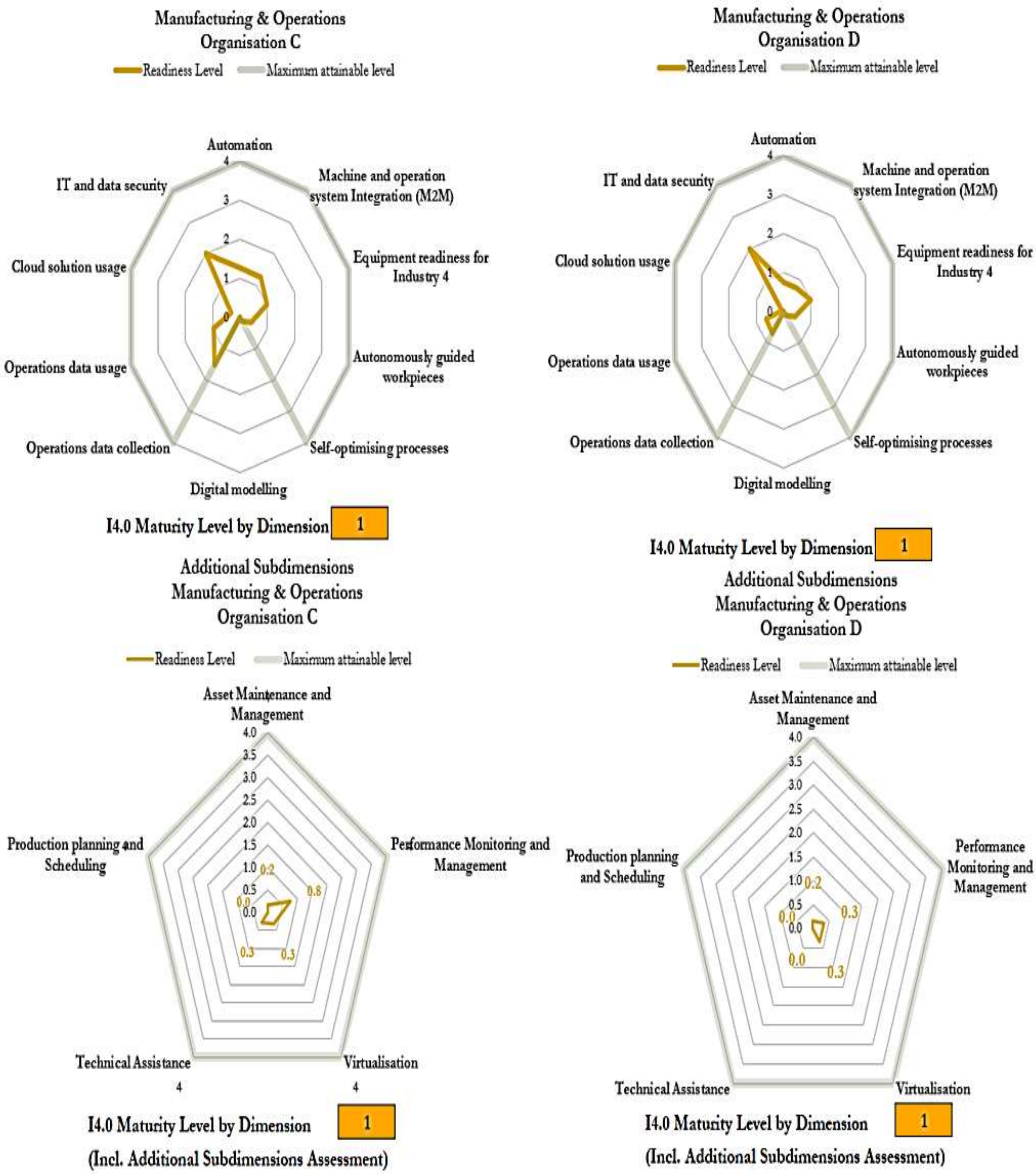

Figure 29. Dimension of Manufacturing and Operations – Results for Organisations B and C

Table 13 displays Readiness Levels on Sub-Dimensions within the dimension of manufacturing and operations.

Sub-dimensions	**Org. A**	**Org. B**	**Org. C**	**Org. D**
Automation	Level 1	Level 1	Level 1	Level 1
Machine and operation system integration (M2M)	Level 2	Level 1	Level 1	Level 1
Equipment readiness for Industry 4.0	Level 2	Level 1	Level 1	Level 1
Autonomously guided workpieces	Level 0	Level 0	Level 0	Level 0
Self-optimising processes	Level 0	Level 0	Level 0	Level 0
Digital modelling	Not relevant	Level 1	Not relevant	Not relevant
Operations data collection	Level 2	Level 2	Level 2	Level 1
Operations data usage	Level 1	Level 1	Level 1	Level 1
Cloud solution usage	Level 0	Level 0	Level 0	Level 0
Information technology and data security	Level 2	Level 2	Level 2	Level 2

Additional sub-dimensions

Asset maintenance and management	Level 0	Level 0	Level 0	Level 0
Performance monitoring and management	Level 0	Level 0	Level 0	Level 0
Virtualisation	Level 0	Level 0	Level 0	Level 0
Technical assistance	Level 0	Level 0	Level 0	Level 0
Production planning and scheduling	Level 0	Level 0	Level 0	Level 0

Table 13. Dimension of Manufacturing and Operations – Readiness Levels on Sub-Dimensions

At Level 2, Organisation A was the most prepared on the sub-dimensions of M2M, equipment readiness for Industry 4.0, and IT and data security, whilst the other organisations achieved Level 1 status in these sub-dimensions. All four organisations achieved Level 2 status in the sub-dimension of IT and data security.

At Level 0 (outsider), all four organisations demonstrated the least preparation on the sub-dimensions of autonomously guided workpieces, self-optimising processes, cloud solutions usage, asset maintenance and management, technical assistance, production planning schedule, performance monitoring and management, and virtualisation.

4.2.2. Dimension of Products and services

Organisations A, B, C, and D were categorised as outsiders on the dimension of products and services (Level 0). This can be seen in Figures 30 and 31.

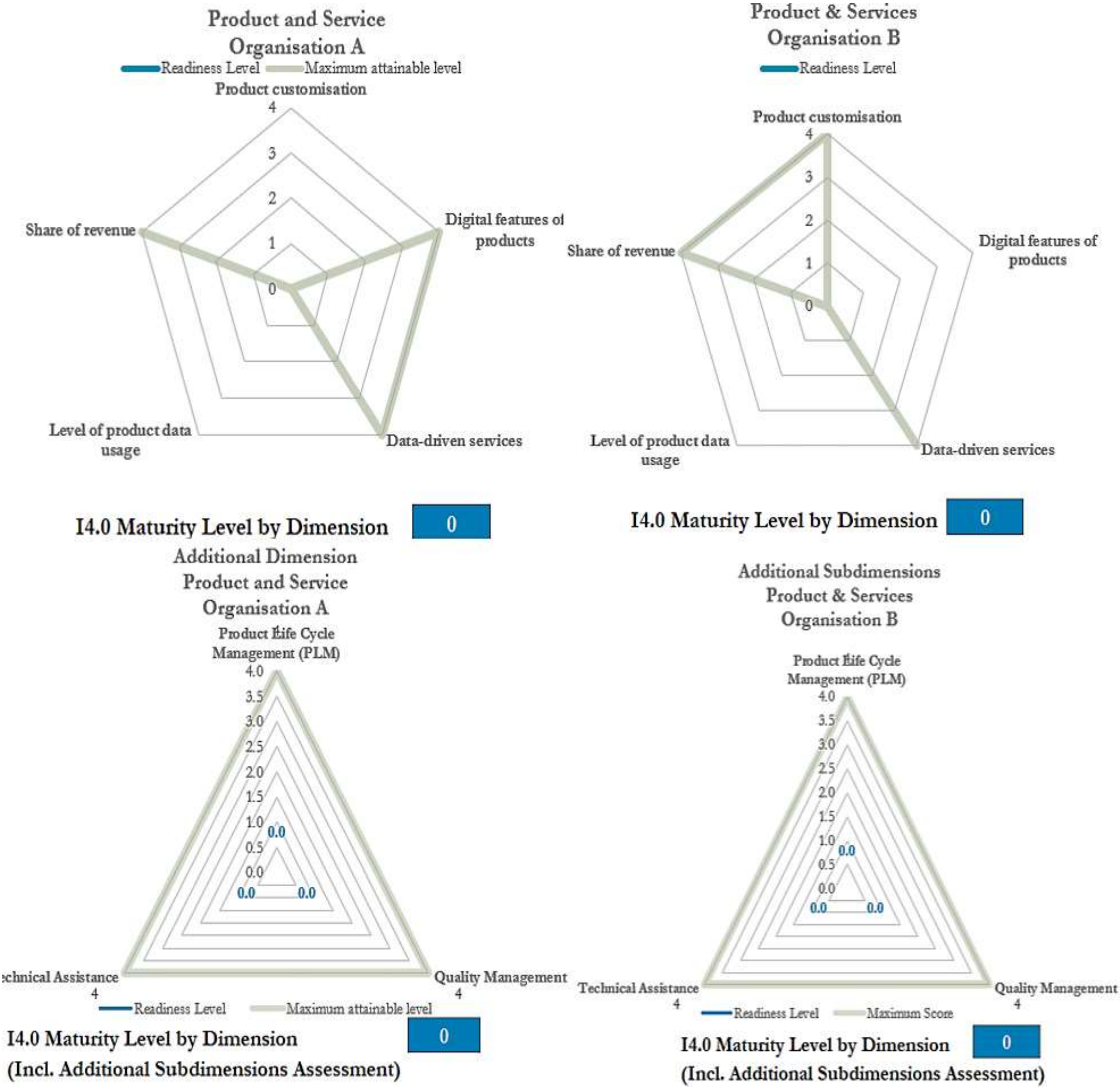

Figure 30. Dimension of Products and Services – Results for Organisations A and B

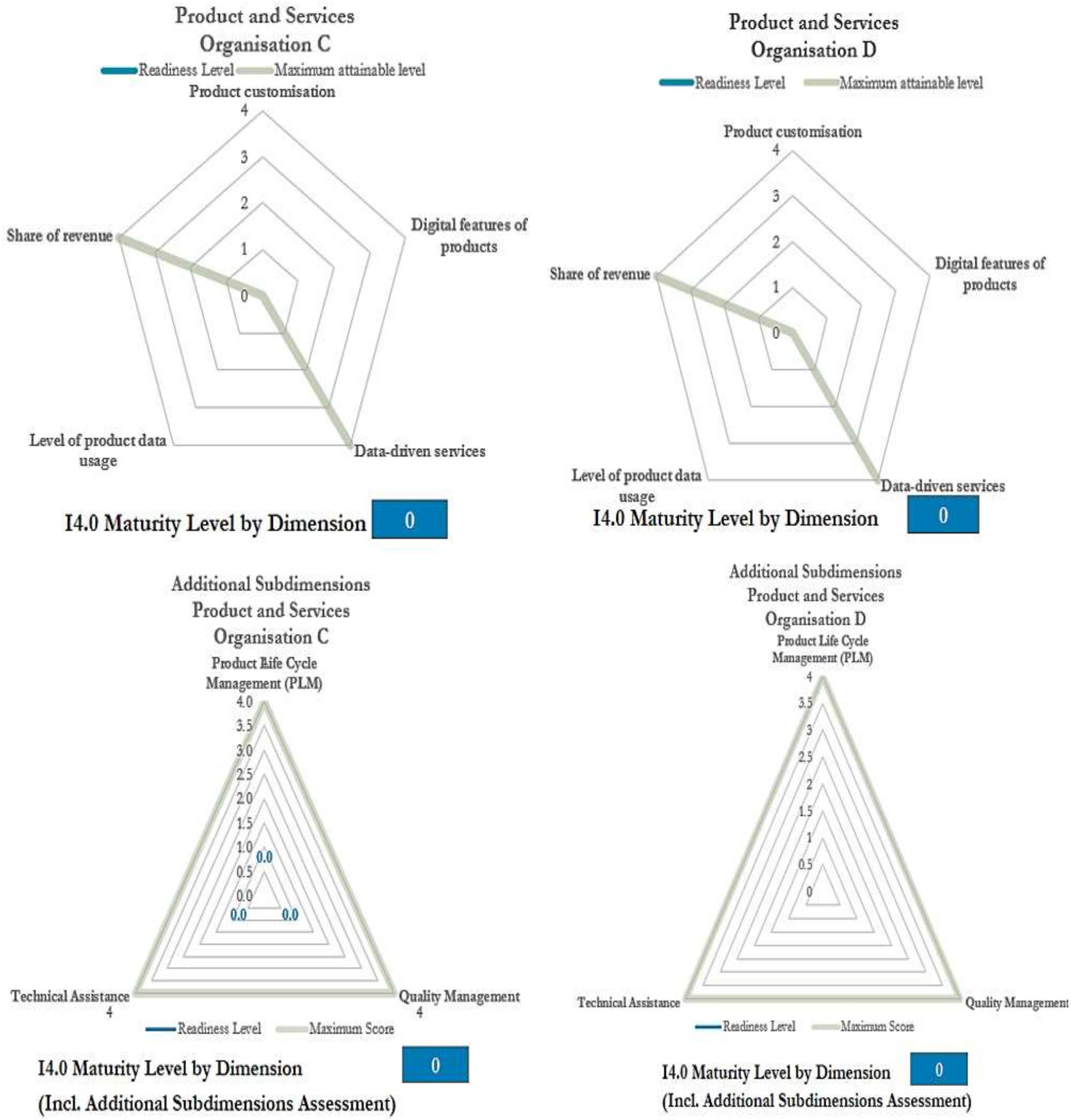

Figure 31. Dimension of Products and Services – Results for Organisations C and D

Table 14 displays readiness levels for the sub-dimensions of products and services. All four manufacturers were at Level 0 across all relevant sub-dimensions.

Sub-dimensions	Org. A	Org. B	Org. C	Org. D
Product customisation	Not relevant	Level 0	Not relevant	Not relevant
Digital features of products	Level 0	Not relevant	Not relevant	Not relevant
Data-driven services	Level 0	Level 0	Level 0	Level 0
Level of product data usage	Not relevant	Not relevant	Not relevant	Not relevant
Share of revenue	Level 0	Level 0	Level 0	Level 0
Additional sub-dimensions				
Product lifecycle management	Level 0	Level 0	Level 0	Level 0
Quality management	Level 0	Level 0	Level 0	Level 0
Technical assistance	Level 0	Level 0	Level 0	Level 0

Table 14. Dimension of Products and Services – Readiness Levels on Sub-Dimensions

4.2.3. Supply Chain

Organisations A and C achieved Level 1 (beginner) status in the dimension of supply chain, whilst Organisations B and D were at Level 0 (outsider). Figures 32 and 33 illustrate these findings.

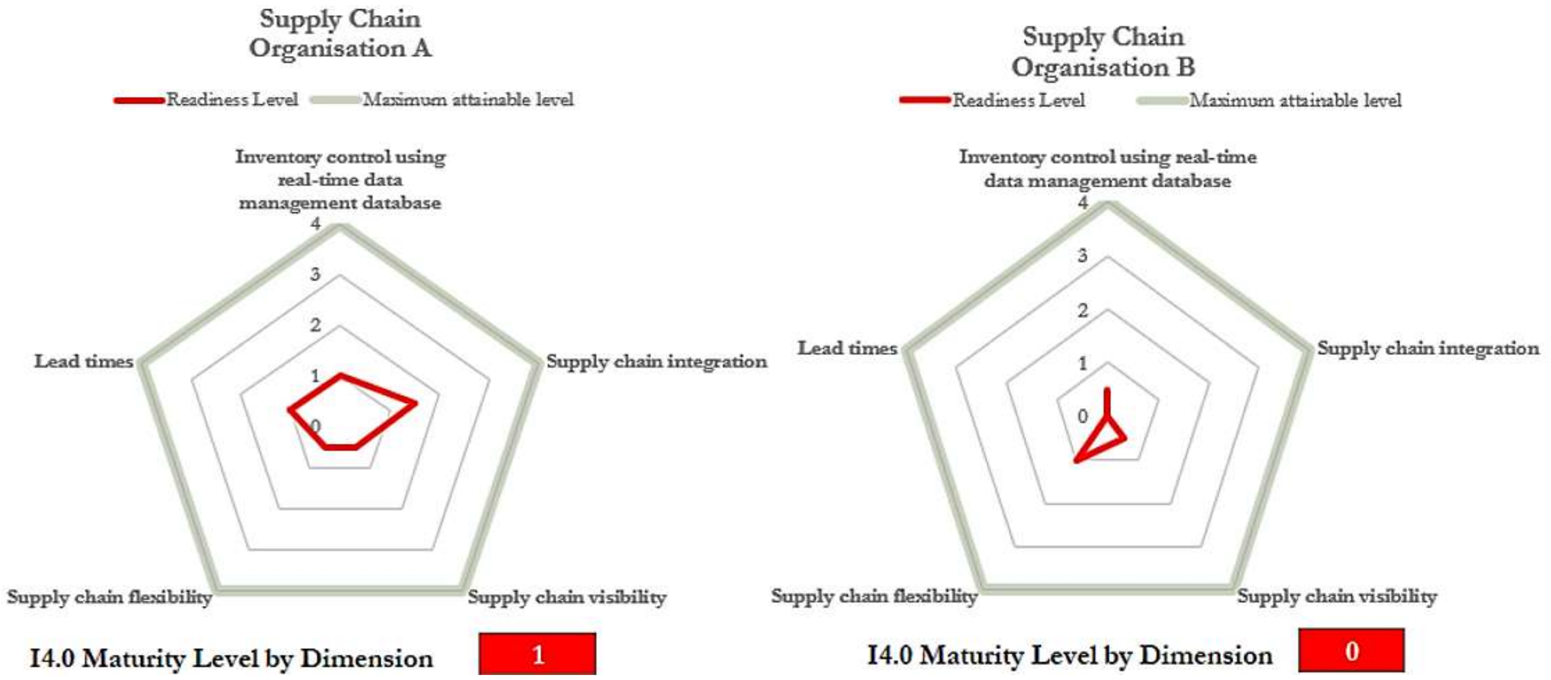

Figure 32. Dimension of Supply Chain – Results for Organisations A and B

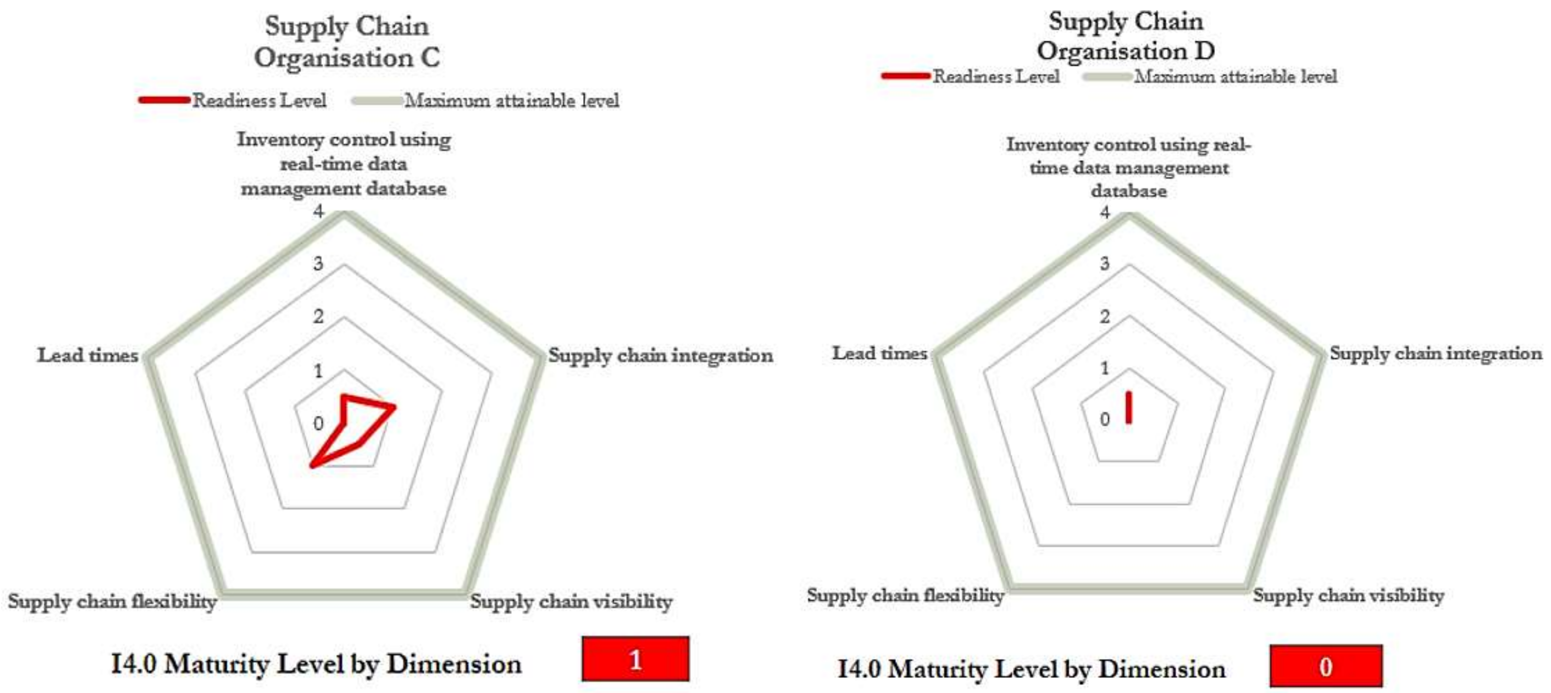

Figure 33. Dimension of Supply Chain – Results for Organisations C and D

Table 15 displays readiness levels for the sub-dimensions in the dimension of supply chain.

At Level 2 (intermediate), Organisation A demonstrated the highest readiness with regard to supply chain integration, and achieved beginner (Level 1) status across the sub-dimensions of supply chain.

At Level 0 (outsider), Organisation B demonstrated the lowest readiness with regard to the sub-dimensions of supply chain integration and lead times. However, they achieved beginner status across the other sub-dimensions of supply chain.

Organisation C achieved Level 1 status across all sub-dimensions of supply chain except for lead times.

Organisation D was deemed an outsider on the sub-dimensions of supply chain integration, supply chain visibility, supply chain flexibility, and lead times. However, it attained beginner status on the sub-dimensions of inventory control using a real-time data management database and supply chain flexibility.

Sub-dimensions	Org. A	Org. B	Org. C	Org. D
Inventory control using a real-time data management database	Level 1	Level 1	Level 1	Level 1
Supply chain integration	Level 2	Level 0	Level 1	Level 0
Supply chain visibility	Level 1	Level 1	Level 1	Level 0
Supply chain flexibility	Level 1	Level 1	Level 1	Level 0
Lead times	Level 1	Level 0	Level 0	Level 0

Table 15. Dimension of Supply Chain – Readiness Levels on Sub-Dimensions

4.2.4. Strategy and Organisation

Organisations A and C achieved Level 1 status on the dimension of strategy and organisation, whilst Organisations B and D were deemed outsiders. Figures 34 and 35 illustrate these findings.

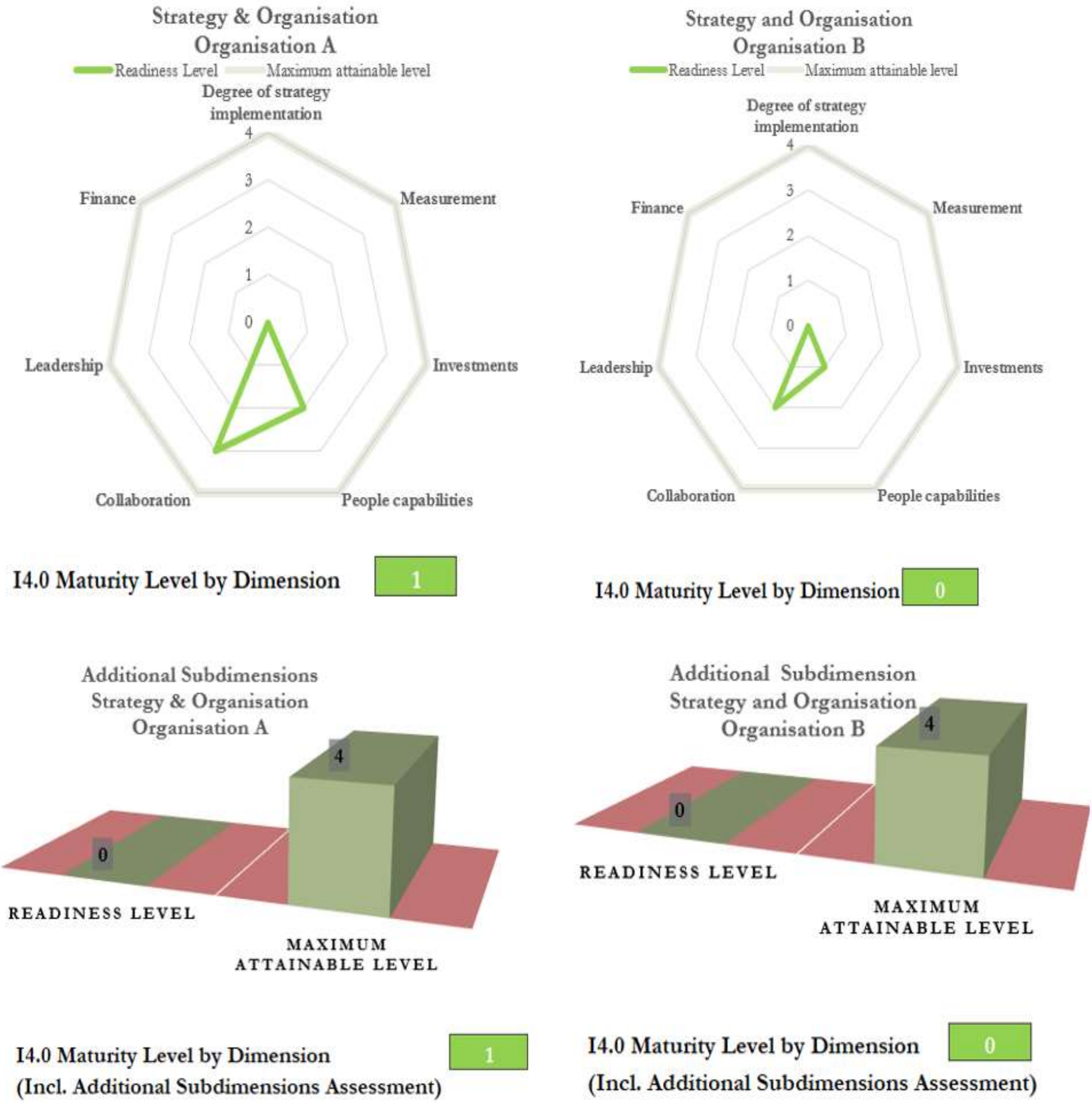

Figure 34. Dimension of Strategy and Organisation – Results for Organisations A and B

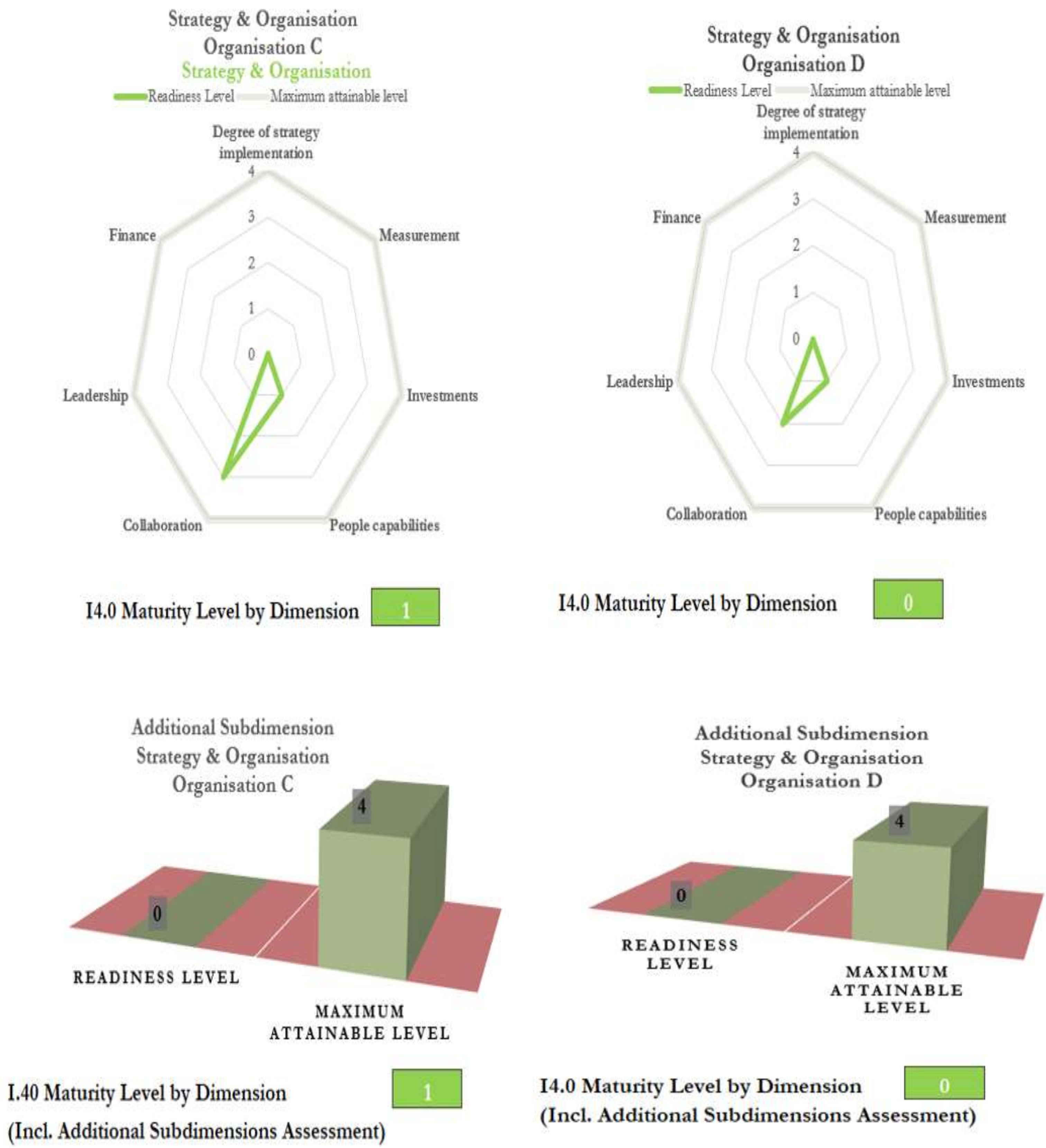

Figure 35. Dimension of Strategy and Organisation – Organisations C and D Results

Collaboration was the sub-dimension on which all four organisations demonstrated the highest readiness, followed by people management. However, all organisations were considered outsiders (Level 0) on the other sub-dimensions of strategy and organisation. Table 16 displays readiness levels for the sub-dimensions of strategy and organisation.

Readiness level	Org. A	Org. B	Org. C	Org. D
Degree of strategy implementation	Level 0	Level 0	Level 0	Level 0
Measurement	Level 0	Level 0	Level 0	Level 0
Investments	Level 0	Level 0	Level 0	Level 0
People capabilities	Level 2	Level 1	Level 1	Level 1
Collaboration	Level 3	Level 2	Level 3	Level 2
Leadership	Level 0	Level 0	Level 0	Level 0
Finance	Level 0	Level 0	Level 0	Level 0
Additional sub-dimensions				
People management	Level 0	Level 0	Level 0	Level 0

Table 16. Dimension of Strategy and Organisation – Readiness Levels on Sub-Dimensions

4.2.5. Business Model

All four organisations achieved beginner status on the dimension of business model. Figures 36 and 37 illustrate these findings.

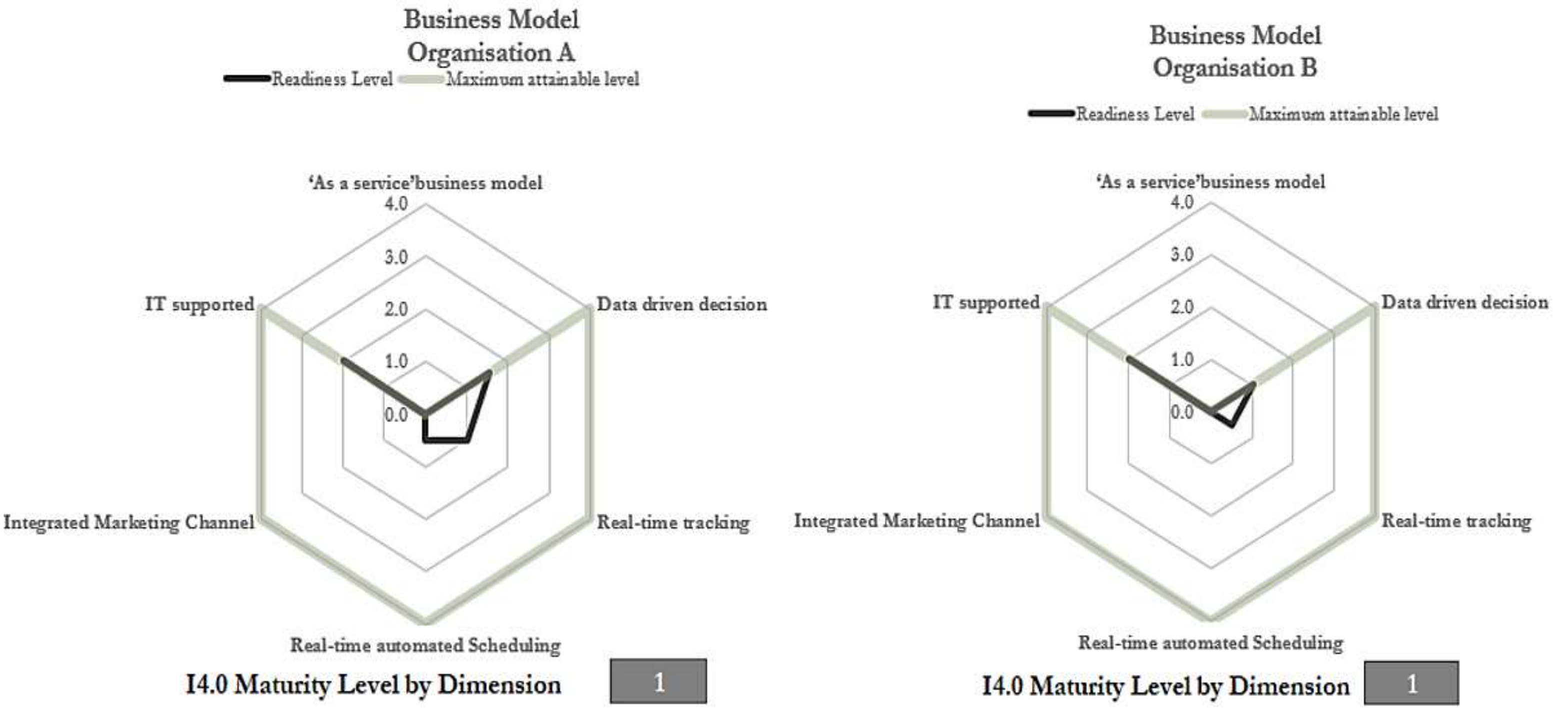

Figure 36. Dimension of Business Model – Results for Organisations A and B

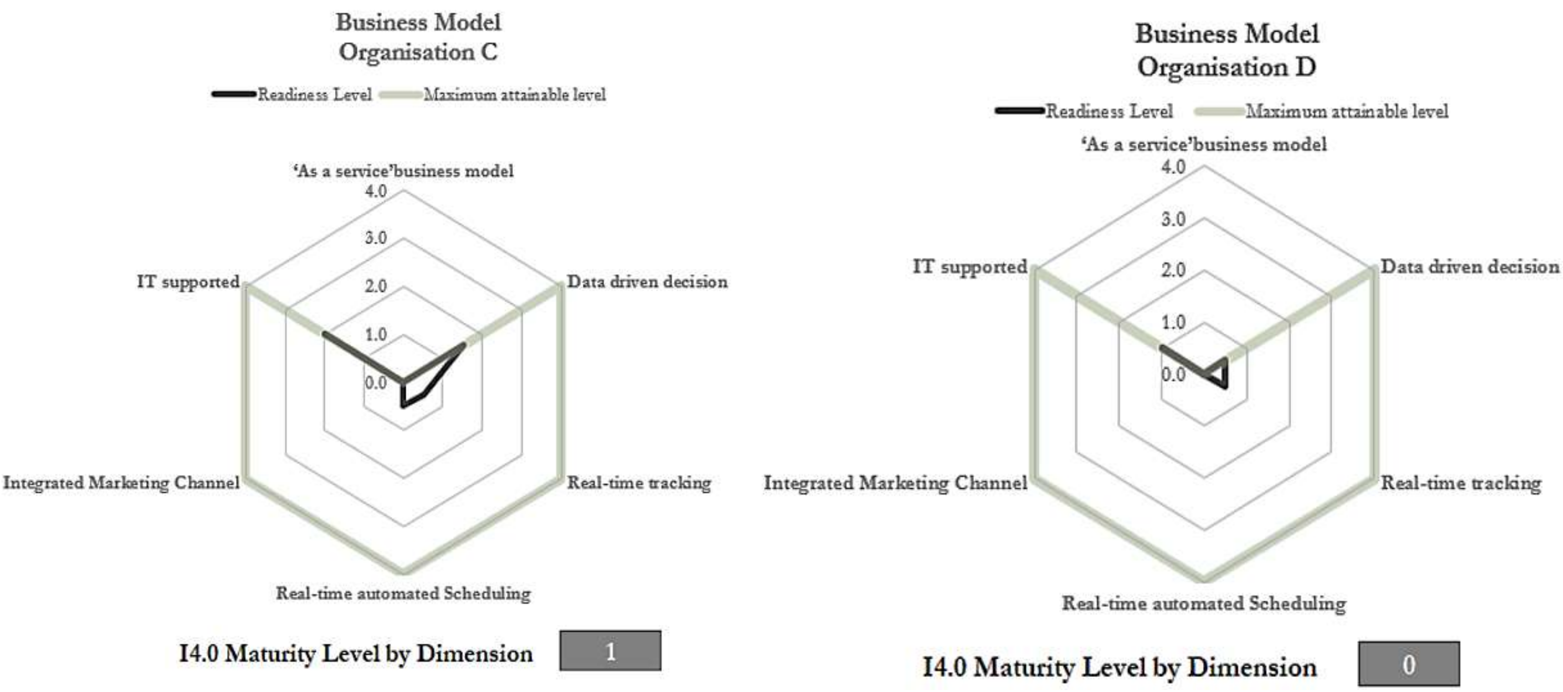

Figure 37. Dimension of Business Model – Results for Organisations C and D

Table 17 displays readiness levels for the sub-dimensions of business model. All organisations demonstrated the highest readiness on the sub-dimensions of data-driven decision and IT support and the lowest readiness on the sub-dimension of integrated marketing channels. Organisation B and D also had the lowest readiness on the sub-dimension of real-time and automated scheduling.

Readiness level	Org. A	Org. B	Org. C	Org. D
As a service business model	Not relevant	Not relevant	Not relevant	Not relevant
Data-driven decisions	Level 2	Level 1	Level 2	Level 1
Real-time tracking	Level 1	Level 1	Level 1	Level 1
Real-time and automated scheduling	Level 1	Level 0	Level 1	Level 0
Integrated marketing channels	Level 0	Level 0	Level 0	Level 0
IT support	Level 2	Level 2	Level 2	Level 1

Table 17. Dimension of Business Model – Readiness Levels on Sub-Dimensions

4.2.6. Overall Status – All Dimensions

None of the four organisations were assessed on the dimension of legal considerations, as no data were available for the assessment.

Organisations A and C achieved beginner status with regard to overall readiness level, whilst Organisation B and D were deemed outsiders. However, Organisation B achieved Level 1 status when the additional sub-dimensions introduced in this research were excluded from the assessment.

At Level 1, manufacturing and operations was the dimension on which all four manufacturers demonstrated the highest readiness. By contrast, at Level 0, products and services was the dimension on which they demonstrated the least preparation. Figures 38 and 39 illustrate these findings.

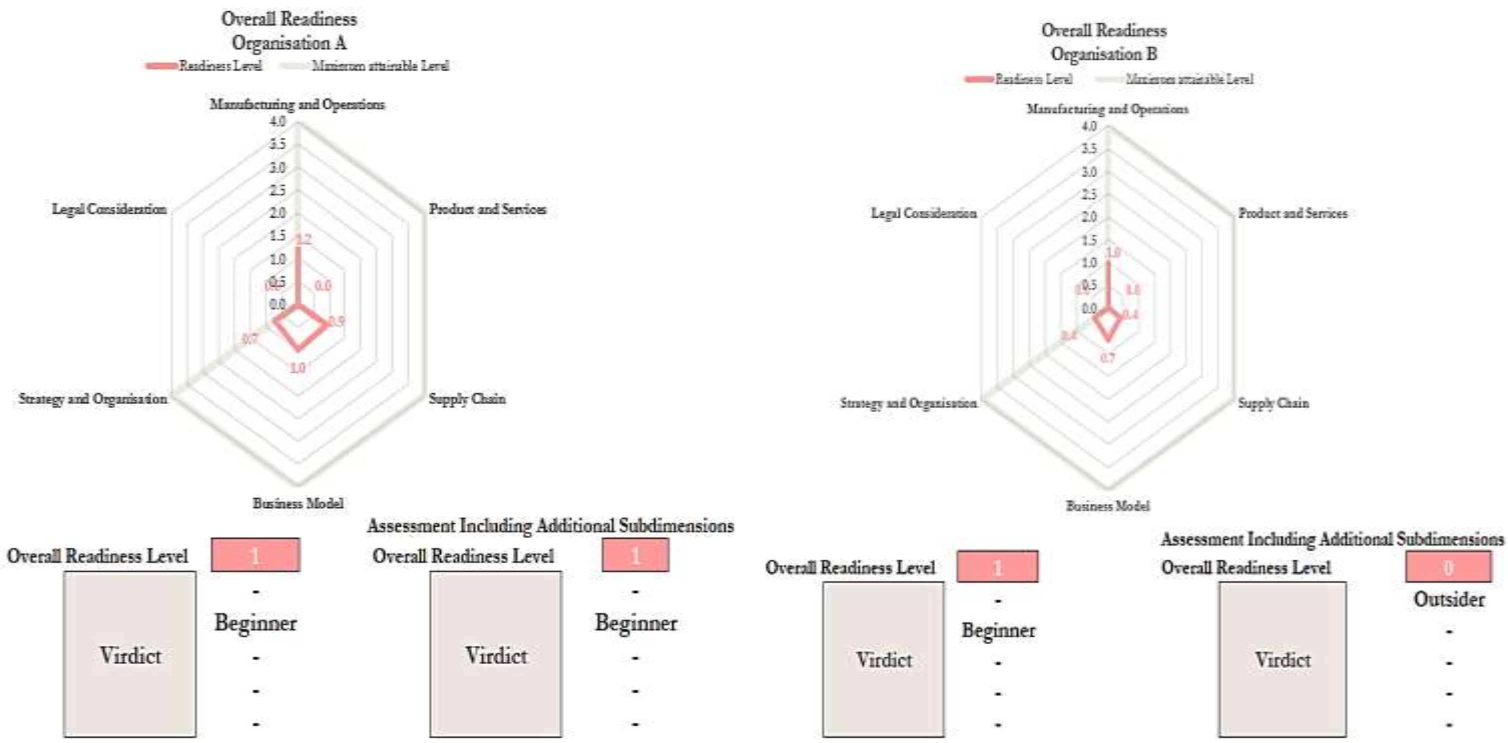

Figure 38. Overall Readiness Level – Results for Organisations A and B

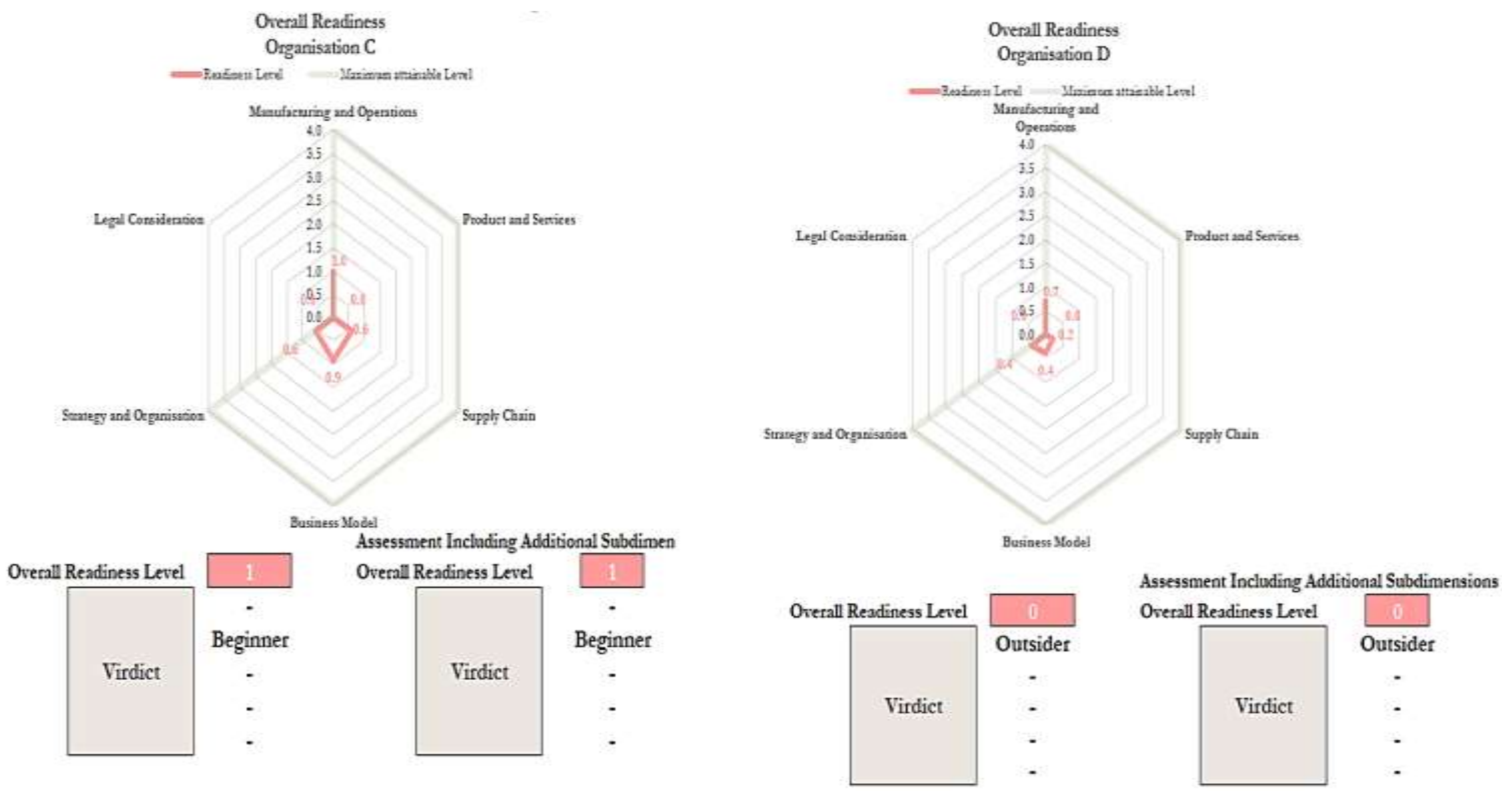

Figure 39. Overall Readiness Level – Results for Organisations C and D

4.3. Structure for Assessing Manufacturers

A structured approach was employed to enable recommendations to be made based on the features of the Industry 4.0 maturity assessment model, which are as follows:

a) **Assessment Guide**: The assessment guide was used to establish measures that can be taken to achieve expert status (Level 4) across all dimensions and sub-dimensions. Then, the automated gaps identifier and support interface for making recommendations interface can be used to obtain further insights on the SM elements employed and how they have been deployed across the organisation's value chain. The response manual is presented in Tables 8–12.

b) **Automated gaps identifier:** The automated gaps identifier is programmed to automatically identify elements that have not been fully implemented or not implemented at all. This feature is illustrated in the example in Figure 40, which shows SM elements that have been well-implemented and the areas in which they have been implemented for the dimension of products and services.

Figure 40. Automated Gaps Identifier Interface – Products and services

c) **Automated support interface for making recommendations :** This feature is programmed to automatically present constituent features of SM elements that have not been fully implemented or not implemented at all. It is used to provide recommendations to address identified gaps. Figure 41 shows how the automated support interface for making recommendations displays the missing features of an identified element.

Figure 41. Automated support interface for making recommendations

4.3.1. Identifying Gaps – Organisations A, B, C, and D

The author used the automated support interface for making recommendations and automatic gaps identifier to identify gaps at all three participating organisations. Organisations A, B, and C were all determined to be at Level 1 (beginner) across the five dimensions on which they were assessed.

<u>Organisation A</u>

The SM elements fully implemented in Organisation A were ERP, PLC, and design to value in the dimensions of manufacturing and operations and products and services. Industrial communications and security solutions were two elements that were partially implemented. The other 33 elements identified in this project were not implemented at all by Organisation A. Table 18 displays the SM elements that Organisation A did not implement.

Elements
CPS
Digital twins
Industrial Internet of Things (IIoT)
Industrial cloud
Big data analytics
Autonomous robots
Open standards
Enterprise manufacturing intelligence (EMI)
Product data utilisation
Open innovation
Augmented reality
Human-robot collaboration (COBOTS)
Digital customer co-creation
Digital human resource management
Digital supply chain management
Digital inventory management
Advance planning and scheduling (APS)
Quality 4.0
Supervisory control and data acquisition (SCADA)

Smart sensor
Advanced virtual self-services
Demand forecasting via predictive analytics
Predictive maintenance (advanced asset management)
Real-time remote maintenance (advanced asset management)
Real-time remote monitoring (advanced asset management)
Machine learning
Intelligent and individualised workstation
Digital product lifecycle management (DPLM)
Additive manufacturing
Product digitalisation
Digital customer relationship management (digital CRM)
MES
Artificial intelligence

Table 18. Smart Manufacturing Elements Not Implemented by Organisation A

Organisation B

Organisation B fully implemented the elements of SCADA, ERP, PLC, MES, and design to value in the dimensions of manufacturing and operations and products and services. Two elements that were partially implemented were industrial communications and industrial security solutions. The other 31 elements identified in this project were not implemented at all by Organisation B. Table 19 displays the SM elements that were not implemented.

Elements
CPS
Digital twins
Industrial Internet of Things (IIoT)
Industrial cloud
Big data analytics
Autonomous robots
Open standards
Enterprise manufacturing intelligence (EMI)

Product data utilisation
Open innovation
Augmented reality
Human-robot collaboration (COBOTS)
Digital customer co-creation
Digital human resource management
Digital supply chain management
Digital inventory management
Advance planning and scheduling (APS)
Quality 4.0
Smart sensor
Advanced virtual self-services
Demand forecasting via predictive analytics
Predictive maintenance (advanced asset management)
Real-time remote maintenance (advanced asset management)
Real-time remote monitoring (advanced asset management)
Machine learning
Intelligent and individualised workstation
Digital product lifecycle management (DPLM)
Additive manufacturing
Product digitalisation
Digital customer relationship management (digital CRM)
Artificial intelligence

Table 19. Smart Manufacturing Elements Not Implemented by Organisation B

Organisation C

Organisation C fully implemented ERP, PLC, and design to value and partially implemented industrial communications and industrial security solutions. Table 18 shows the 33 elements that were not implemented at all by Organisation C.

Organisation D

Organisation D fully implemented PLC and partially implemented industrial communications and industrial security solutions. ERP, design to value, or any of the elements displayed in Table 18 were implemented at all in Organisation D.

4.3.2. Examination of Missing or Partially Implemented Elements at Organisations A, B, C, and D

The automated support interface for making recommendations generated insights on the SM elements that were not fully implemented at Organisations A, B, C, and D:

Industrial Communications

Time-sensitive networking, which promotes the continuous exchange of data, was not implemented. There was no end-to-end network architecture that connected business systems with automation and control via IIoT.

Industrial Security Solutions

IIoT devices and embedded systems were not secured. IIoT was not implemented at the participating organisations.

People, processes, and technology used to ensure safe and secure industrial security were not assessed.

A detailed risk assessment of the organisations' industrial systems was not conducted.

No security controls (i.e. safeguards or countermeasures to avoid, detect, counteract, or minimize security risks to physical property, information, computer systems, or other assets) were in place.

Cyber threats were not incorporated into the design and development of industrial security.

There was no visibility for protocol-specific data on operational technology networks. Thus, it is not possible to alert a central command-and-control system about misconfigurations and cyber events.

No independent security assurance and penetration testing was provided.

The participating organisations could not manage cyber risks in a cost-effective manner.

They did not have regular access to professional cybersecurity engineers.

Thirty-one SM elements were not implemented by the three organisations that participated in this research. The automated support interface for making recommendations feature generated a detailed breakdown of the constituent features of SM elements that were not implemented at all. Upon completion of the research, the insights generated by the automated support interface for making recommendations will be made available to all three manufacturers that participated in the assessments.

4.4. Digital Strategy Recommendations for Organisation D

The author worked with Organisation D to design a five-year customised digital strategy, which is designed to help the manufacturer become a digital enterprise. It includes the following components.

4.4.1. Adopting Realistic Industry 4.0 Goals

It is important for Organisation D to avoid simultaneously pursuing too many goals. A proof of concept (pilot programs) must be in place, followed by smaller projects that can be scaled up into larger projects if the pilot programs are successful. Organisation D should consider starting with pilot projects that focus on particularly impactful elements of Industry 4.0, such as big data analytics, IIoT, and the industrial cloud.

4.4.2. Taking a Holistic Approach by Adopting IIoT and the Cloud as Services

Taking a holistic approach means implementing elements of Industry 4.0 and strategies across various facets of Organisation D's value chain, including manufacturing operations, products and services, supply chain, and business model. In particular, data and analytics must become a core capability within Organisation D.

Over time, Industry 4.0 has become more accessible to SMEs, as its elements are now offered as services by automation and cloud vendors. This can save significant time and costs, as organisations no longer need to buy specific hardware or employ people who know how to operate it.

Organisation D can benefit from implementing industrial cloud and IIoT as services, which can benefit their value chain in various ways (see Figure 42).

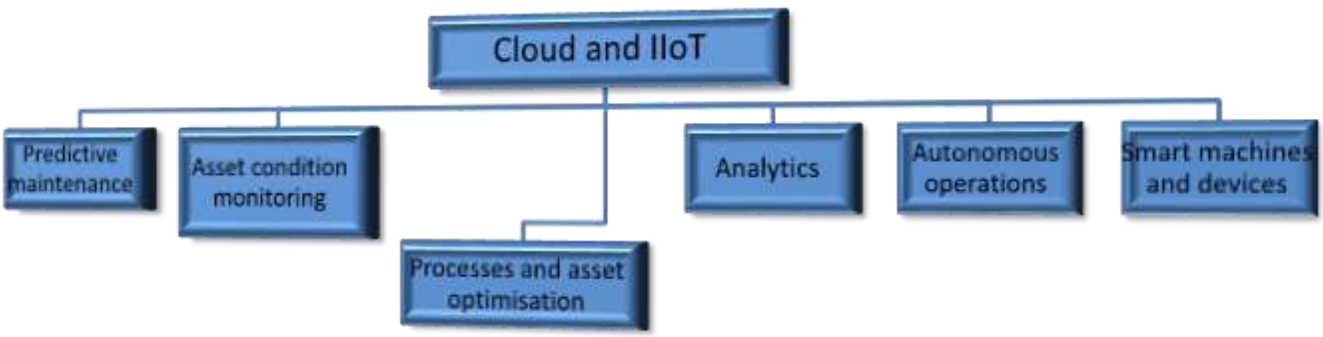

Figure 42. IIoT and Cloud as Services

When they are offered as services, Organisation D can benefit from the predictive maintenance capabilities of the industrial cloud and IIoT platforms. The manufacturer can also benefit from connecting machines and smart devices via IIoT, automating data collection, remote and onsite asset monitoring , optimising processes and assets on the shop floor, and utilising the advanced analytics functions of IIoT and cloud platforms.

Automation vendors that offer IIoT and cloud as services globally include the following:

a. Siemens
b. Amazon Web Service
c. General Electric (GE)
d. ASEA Brown Boveri (ABB)
e. Bosch Rexroth

4.4.3. Employing Analytics as a Service

Organisation D can benefit from subscription-based data analytics software and procedures through the cloud. Analytics as a service (AaaS) offers fully customisable business intelligence solutions with end-to-end capabilities; it can be used to analyse, organise, and present data in a manner that is easy to understand for non-technical professionals. AaaS is a cost-effective approach, compared to traditional onsite solutions. Organisation D would not need to employ data analysts or scientists to manage analytics. In addition, subscription-based data analytics software could result in cost savings for Organisation D and allow them to access various analytical software.

AaaS can be employed across various operational facets of Organisation D, including their business model, strategy and organisation, supply chain, and products and services. Moreover, the organisation can benefit from HR analytics, business analytics, CRM analytics, marketing analytics, etc.

Companies that offer AaaS in Nigeria include the following:

a. Weevil
b. Factual Analytics
c. Blacksentry
d. Bufiredd Economic Consultancy

4.4.4. Outsource Research to Companies that Offer Research as a Service (RaaS)

Organisation D can save significant costs by outsourcing their research to a company that offers research as a service. They can benefit immensely from the analytics provided by such companies, which include AI, machine learning, deep learning, and natural language processing. Areas that can be explored include the following:

a. Demand forecasting
b. Market insights
c. Consumer insights
d. Competitive insights
e. Supplier insights

Organisation D can outsource their research quarterly, every six months, or annually.

Potential benefits include lead time reduction, quicker response to market changes and customer requirements, stronger relationships with suppliers, and increased business resilience.

Companies that offer research as a service in Nigeria include the following:

a. Matog Consulting
b. Bufiredd Economic Consultancy
c. Leyhausen Research Africa
d. Consumer Idea Ltd.
e. Market Trend International

f. Market Research Consultancy Ltd.

4.4.5. Adopt a Digitalisation-Based Business Model

Industry 4.0 presents an opportunity for organisations to create new business models and explore new business opportunities, which may manifest as new products and service offerings, new types of relationships with customers and employees, and new forms of cooperation between companies.

Organisation D can explore the implementation of digital HR as a measure for digitalising human resource management. Advanced HR analytics through AaaS can improve the employee experience, future recruitment, employee development, etc.

Organisation D can also improve supply chain integration by developing stronger relationships with their partners, suppliers, and customers. This can be achieved by improving communication and sharing relevant insights generated through research and advanced analytics as a service offerings.

Lastly, Organisation D can explore new products through research provided as a service.

4.6. Analysing the Impact of the Proposed Digital Strategy for Organisation D and Five-Year Implementation Plan

The author analysed the impact of the digital strategy proposed for Organisation D. Figure 43 summarises the resulting five-year implementation plan.

Figure 43. Digital Strategy – Five-Year Plan for Organisation D

4.6.1. Dimension of Manufacturing and Operations

Organisation D can achieve experienced (Level 3) status on the dimension of manufacturing and operations by implementing the proposed digital strategy (i.e. two levels above their current Industry 4.0 readiness level). They are expected to demonstrate the highest readiness on the sub-dimensions of operations data collection, cloud solutions usage, performance monitoring and management, operations data usage, and technical assistance (see Figure 44).

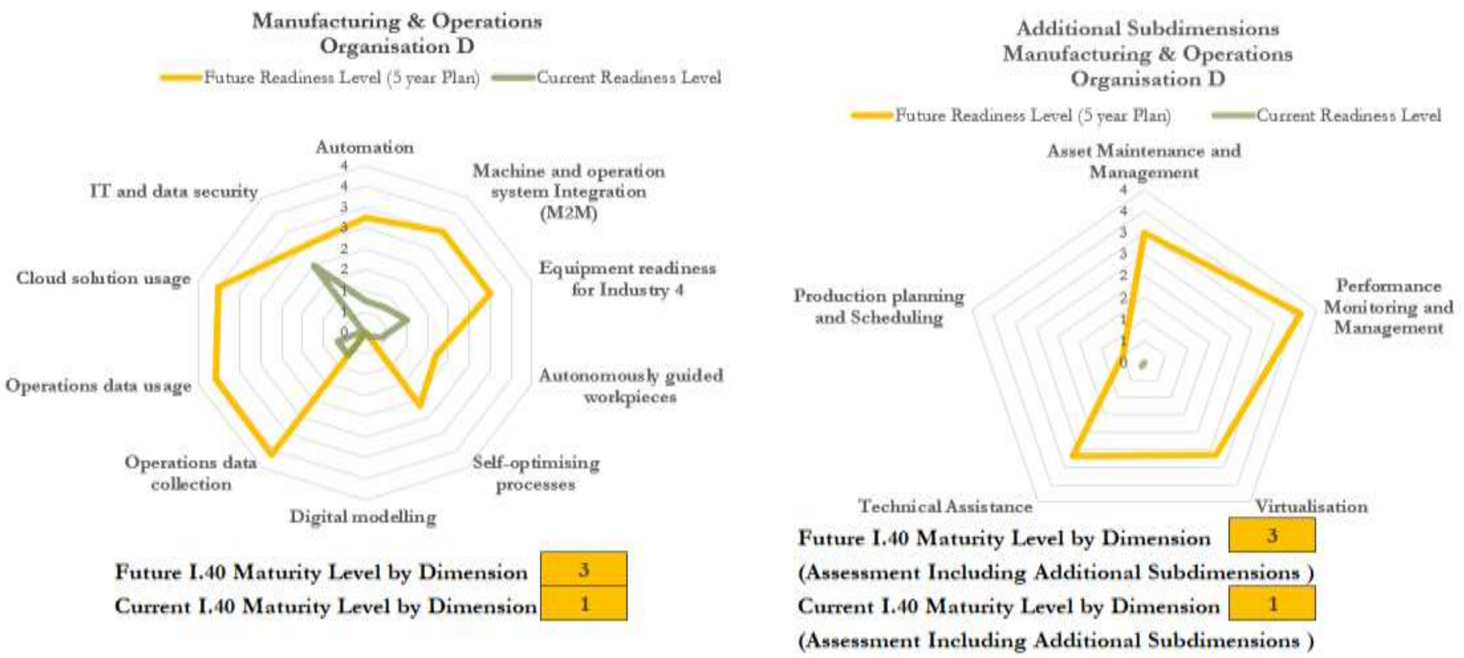

Figure 44. Impact of Proposed Digital Strategy on the Dimension of Manufacturing and Operations

4.6.2. Dimension of Products and services

Organisation D can achieve experienced (Level 3) status on the dimension of products and services by implementing the proposed digital strategy (i.e. three levels above their current Industry 4.0 readiness level). They are expected to demonstrate the highest readiness on the sub-dimensions of quality management, technical assistance, and data-driven services (see Figure 45).

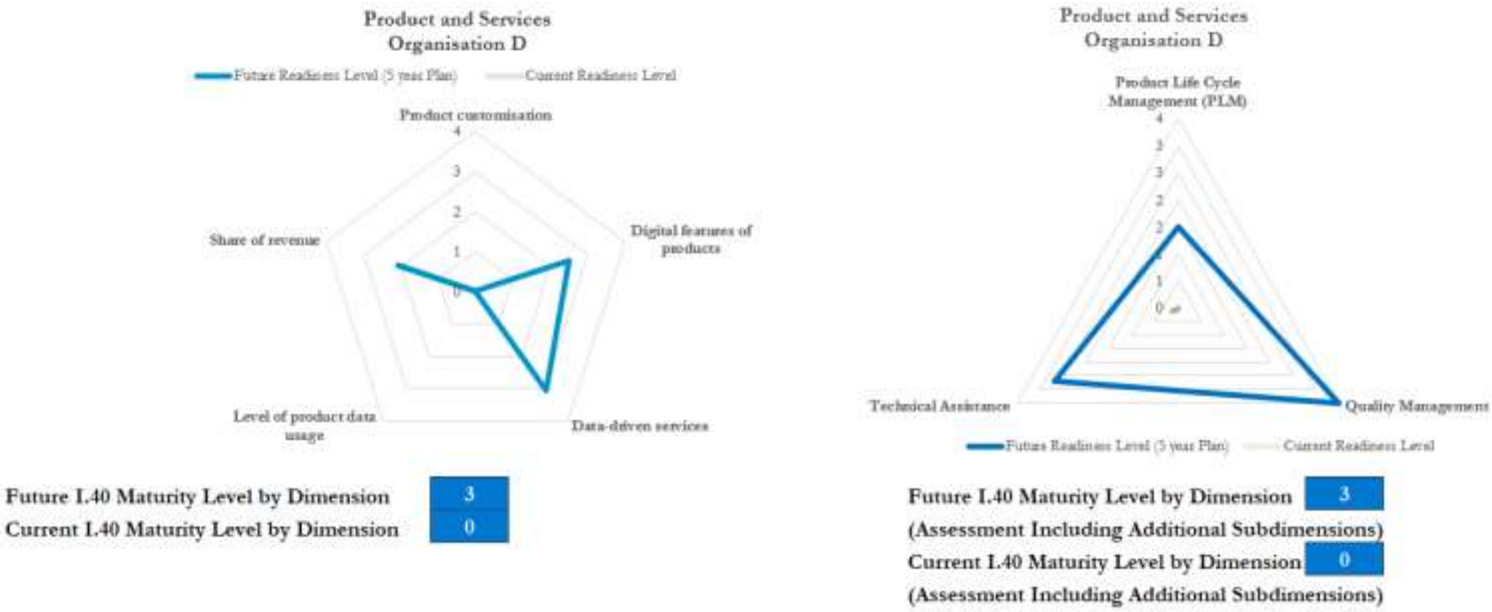

Figure 45. Impact of Proposed Digital Strategy on the Dimension of Products and Services

4.6.3. Dimension of Supply chain

Organisation D can achieve experienced (Level 3) status on the dimension of supply chain by implementing the proposed digital strategy (i.e. three levels above their current Industry 4.0 readiness level). They are expected to demonstrate the highest readiness on the sub-dimensions of supply chain integration, supply chain flexibility, and inventory control using a real-time data-management database (see Figure 46).

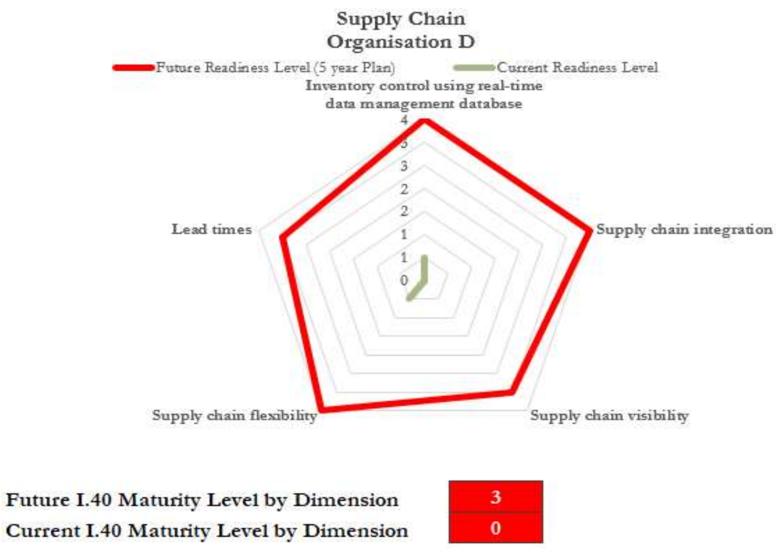

Figure 46. Impact of Proposed Digital Strategy on the Dimension of Supply Chain

4.6.4. Dimension of Business Model

Organisation D can achieve experienced (Level 3) status on the dimension of business model by implementing the proposed digital strategy (i.e. two levels above their current Industry 4.0 readiness level). They are expected to demonstrate the highest readiness on the sub-dimensions of real-time automated scheduling, data-driven services, and IT support (see Figure 47).

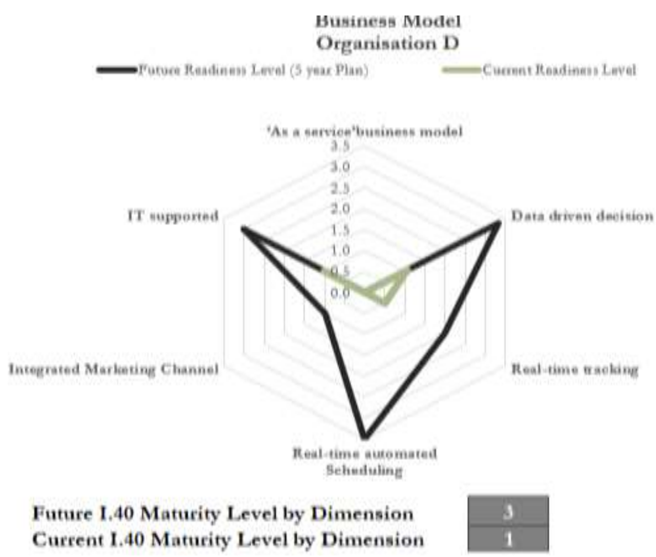

Figure 47. Impact of Proposed Digital Strategy on the Dimension of Business Model

4.6.5. Dimension of Strategy and Organisation

Organisation D can achieve experienced (Level 3) status on the dimension of strategy and organisation by implementing the proposed digital strategy (i.e. three levels above their current Industry 4.0 readiness level). They are expected to demonstrate the highest readiness on the sub-dimensions of degree of strategy implementation and leadership (see Figure 48).

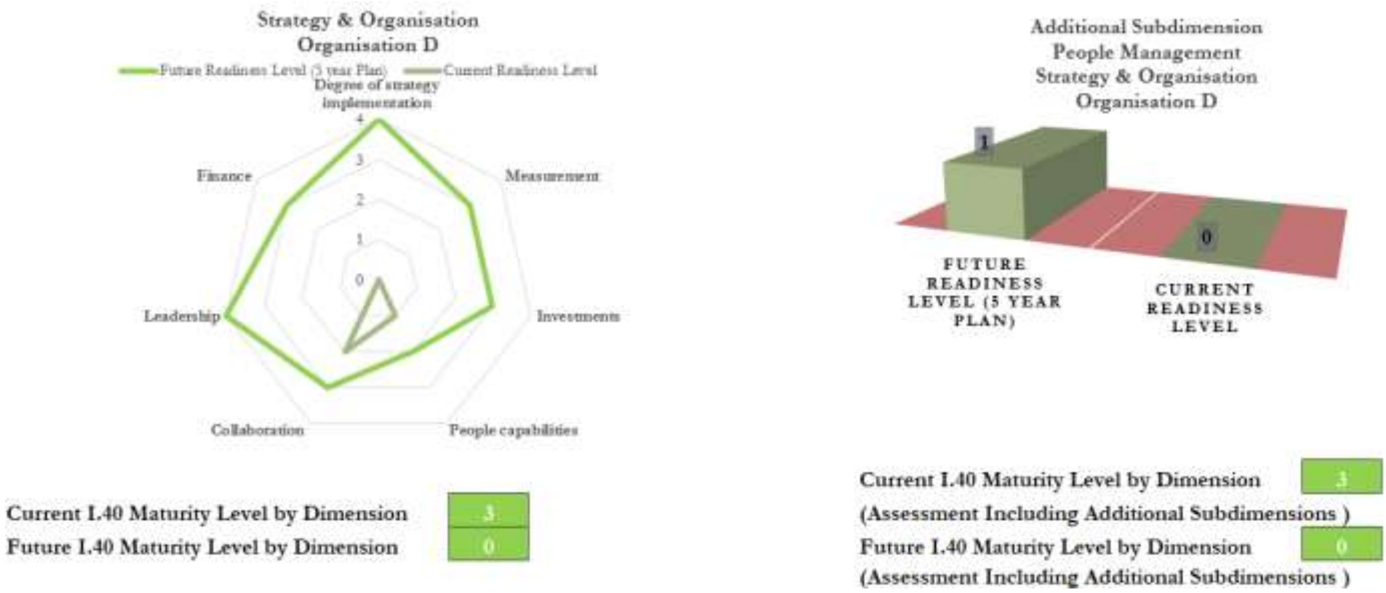

Figure 48. Impact of Proposed Digital Strategy on the Dimension of Strategy and Organisation

4.6.6. Overall Industry 4.0 Readiness Level

Organisation D is expected to move from a Level 0 (outsider) to a Level 3 (expert) overall readiness and to demonstrate the highest readiness on the dimensions of supply chain, strategy and organisation, and manufacturing and operations. They were not assessed on the dimension of legal considerations (see Figure 49).

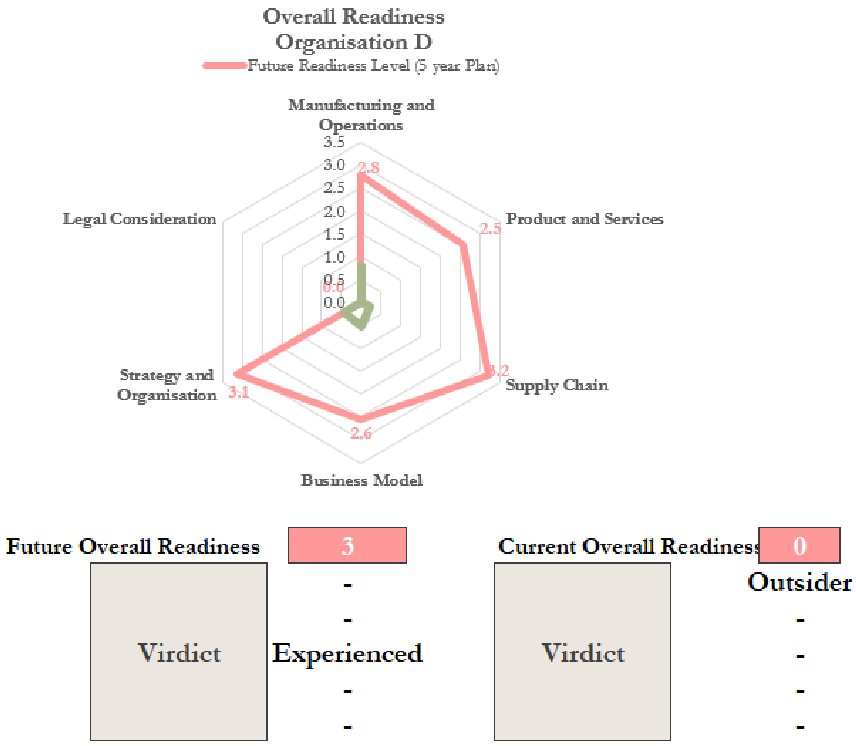

Figure 49. Impact of Proposed Digital Strategy on Overall Readiness Level

Chapter 5: Conclusion, Limitations of Study, and Recommendations for Future Work

The current chapter summarises and evaluates the thesis. To this end, key areas of the thesis are evaluated to ensure that its aims, objectives, and deliverables have been sufficiently met.

5.1. Research Focus

This project focuses on the development of an Industry 4.0 assessment model for small and medium manufacturers in Africa, a region in which there is low awareness of Industry 4.0. An Industry 4.0 maturity assessment model was developed to assess manufacturers' Industry 4.0 readiness and identify gaps that may hinder them from becoming digital enterprises. The assessment model is intended to serve as a tool for improving digital business resilience.

5.2. Research Contributions

The research contributions of this thesis are as follows:

a. Development of an Industry 4.0 maturity assessment model suitable for micro, small and medium manufacturers in Africa and other regions where there is low awareness of Industry 4.0. Modifications made to WMG's existing assessment model resulted in an algorithmic and more robust approach to measuring the Industry 4.0 readiness of manufacturers of all sizes and products.

b. Development of an Industry 4.0 maturity assessment model that can provide customised industry- and company-specific assessments. The model is designed to account for the manufacturer's size, manufactured products, the relevance of digital technologies employed, redundancies, etc. This enables deeper insights and more robust assessments.

c. Development of a tool to raise awareness of Industry 4.0, its technologies, and strategies for manufacturers in Africa. If the model developed for this project is implemented on a large scale, it is expected to raise awareness of Industry 4.0, its technologies, and strategies in manufacturers in Africa and other developing regions where there is low awareness of Industry 4.0.

d. Development of a tool to that would foster a level of independence that would enable African manufactures to self-assess their Industry 4.0 maturity level and make necessary changes to address gaps identified in their value chain.

e. Development of a tool that can be used to promote digital business resilience amongst manufacturers in Africa. The assessment model developed is designed to identify key gaps that hinder manufacturers from becoming digital enterprises.

f. This research contributes to the discourse on the benefits of Industry 4.0 in Africa and how manufacturers in the region can leverage the opportunities associated with Industry 4.0 to foster growth in the manufacturing industry.

5.3. Project Objectives Achieved

The following objectives were achieved in this project:

a. Development of a multi-faceted Industry 4.0 maturity assessment model with automated capabilities (see Chapter 3)

b. Establishment of industry contacts with manufacturers in Nigeria and collection of primary data through face-to-face interviews, phone or video calls, and a survey (see Chapter 1)

c. Testing and validation of the Industry 4.0 maturity assessment model using data obtained from participating manufacturers (see Chapter 4)

d. Assessment of participating manufacturers' SM readiness level of and identification of gaps that may hinder them from becoming digital enterprises (see Chapter 4)

5.4. Project Deliverables Achieved

The project deliverables were discussed in Chapter 3, which also presented all key features of the model. In Chapter 4, the structure for assessing manufacturers and the use of the Industry 4.0 maturity assessment model to evaluate four Nigerian manufacturers was discussed, as well as the digital strategy developed for Organisation D and its impacts.

5.5. Model Validation and Reliability

Organisation D endorsed the assessment model, which was used to assess their Industry 4.0 readiness level and ascertain the impact of the five-year digital strategy developed for the manufacturer.

The assessment model developed in this research can be relied upon to evaluate the industry 4.0 readiness of manufacturers of all sizes, as it is based on the tried-and-tested WMG Industry 4.0 assessment model. The latter has been used by Tata Steel and endorsed by Catapult, amongst other reputable organisations. The modifications made to the WMG assessment model made it more robust and suitable for manufacturers in regions where there is low awareness of Industry 4.0. Therefore, the conclusions derived from use of the model developed for this project are reliable.

5.6. Limitations of the Study

There are some limitations associated with the findings from this study. These limitations can be categorised into limitations related to the research methodology and limitations related to the model design.

5.6.1. Limitations of Research Methodology

5.6.1.1. Limited Access to Manufacturers

It was challenging to identify manufacturers that were willing to collaborate extensively on this project. Many of the approached manufacturers were unwilling to allow their manufacturing data to be utilised in an academic project, whilst others only worked with students that they sponsored. This limited the number of organisations that the author had access to for the project.

Despite this challenge, the author was able to collaborate with four manufacturers in Nigeria. All participating manufacturers allowed the author to use their data to test and validate the model by assessing their readiness level. These organisations were sufficient as they enabled the model to be tested and validated using real-world data.

To address this limitation, future research should involve collaboration with more African organisations to improve the Industry 4.0 maturity assessment model by enhancing its accuracy and versatility.

5.6.1.2. Limited Research on the Elements of Industry 4.0

Industry 4.0 is still in its infancy. Therefore, little research has covered a wide range of Industry 4.0 elements. Most studies focus on the key elements of IIoT, big data analytics, CPS, etc. Moreover, some research is available on individual elements of Industry 4.0 and their impacts.

To address this challenge, the author not only examined academic journals but also obtained information on manufacturers of Industry 4.0 technologies and automation vendors (including Siemens, Bosch, and ABB, etc.) through an extensive literature review. The author also obtained information on manufacturers with smart factories around the world, including data on the Industry 4.0 technologies employed in these factories and how they are deployed across value chains.

This limitation was addressed in the recommendations for future work.

5.6.1.3. Lack of Buy-In at the Departmental Level

There was a lack of Industry 4.0 buy-in at the departmental level for all of the manufacturers involved in this research. This had an impact on the depth of information gathered on the business' operations.

5.6.2. Limitations of Model Design

All dimensions in the novel Industry 4.0 assessment model are equally weighted, similar to the existing WMG, PWC, and IMPULS Industry 4.0 assessment models investigated as part of this research. Furthermore, the constituent features of each element are equally weighted.

This limitation was addressed in the recommendations for future work.

5.7. Recommendations for Future Study

The limitations identified in the previous sections provided the basis for the following recommendations for future study.

a. The Industry 4.0 maturity assessment model developed for this project may be expanded by examining the technical features of the various SM elements. This endeavour would increase the maturity of the model and expand its assessment criteria, but it requires a high level of collaboration with automation vendors and manufacturers of various SM technologies.

b. A viable approach should be established to assign weights to the dimensions of the model and the constituent features of each element in the model.

c. It would be beneficial to collaborate with an established digital enterprise with one or more smart factories. This level of access could contribute immensely to the maturity of the Industry 4.0 assessment model.

d. Conducting extensive research and collaborating with a significant number of manufacturers in Africa could shed light on the readiness level of Industry 4.0 in the region. In addition, this would contribute to raising awareness of Industry 4.0 technologies and strategies and the discourse on its implementation in the region to ensure that organisations leverage the opportunities presented by the Fourth Industrial Revolution.

e. Developing an application for the Industry 4.0 assessment model would allow African manufacturers to utilise it on a large scale. However, this would require collaboration with data engineers, developers, and data scientists.

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Appendices

Appendix A: Completed Industry 4.0 Questionnaire – Organisation D

Industry 4.0 Questionnaire

Select the relevancy or Industry 4.0 readiness level of your company across all 5 dimensions and 40+ sub-dimensions.

Please tick the appropriate responses from the options below.

Enyinna Okam

Kingston University London

MANUFACTURING AND OPERATIONS						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
Automation	☐ Not relevant	☐ Automation not in use	☒ Up to 25% of the manufacturer's relevant machines are controlled through automation.	☐ Up to 50% of the manufacturer's relevant machines can be controlled through automation.	☐ Up to 75% of the manufacturer's relevant machines can be controlled through automation.	☐ All of the manufacturer's relevant machines and systems can be completely controlled through automation.
	Elements of Industry 4.0 that contribute to automation. 1. Digital twins 2. Cyber-physical systems (CPS) 3. Industrial Internet of Things (IIoT) 4. Industrial communications 5. Big data analytics 6. Autonomous robots 7. Machine learning					

	8. Programmable logic controller (PLC) 9. Industrial cloud 10. Smart sensors 11. Human-robot collaboration (COBOTS) 12. Intelligent and individualised workstations 13. Artificial intelligence 14. SCADA					
Machine and operation system integration (M2M)	☐ Not relevant	☐ The manufacturer's machines and systems do not have M2M capability.	☒ Up to 25% of the manufacturer's relevant machines and systems are interoperable.	☐ Up to 50% of the manufacturer's relevant machines and systems are integrated.	☐ Up to 75% of the manufacturer's relevant machines and systems are integrated.	☐ All of the manufacturer's relevant machines and systems are fully integrated.
	Elements of Industry 4.0 that contribute to M2M. 1. Digital twins 2. IIoT 3. Industrial communications 4. Open standards					
Equipment readiness for Industry 4.0	☐ Not relevant	☐ A complete overhaul is required to achieve Industry 4.0.	☒ Significant overhaul is required to achieve Industry 4.0 requirements (over 50% of machines and systems).	☐ Up to 50% of relevant machines and systems are upgradable.	☐ Over 50% of relevant machines have already met Industry 4.0 requirements and can be upgraded in areas where needed.	☐ All relevant machines and systems have already met all future requirements.
Autonomously guided workpieces	☐ Not relevant	☒ The manufacturer does not use autonomously guided workpieces.	☐ There is awareness of autonomously guided workpieces, and there are ongoing discussions about conducting a pilot program.	☐ The manufacturer does not use autonomously guided workpieces, but there are pilot programs underway.	☐ The manufacturer uses autonomously guided workpieces in selected areas.	☐ The manufacturer has widely adopted autonomously guided workpieces.
	Elements of Industry 4.0 that contribute to autonomously guided workpieces. 1. COBOT 2. Autonomous robots 3. Industrial communications 4. IIoT 5. Smart sensors					
Self-optimising processes	Not relevant	☒ There are no self-optimising processes.	☐ There are no self-optimising processes in use;	☐ There are no self-optimising processes in use;	☐ Self-optimisation processes have	☐ The manufacturer has widely

			however, there are ongoing conversations about conducting a pilot program in certain areas of the business.	however, there are pilot programs in advanced areas of the organisation.	been adopted in selected areas.	implemented self-optimising processes.
	Elements of Industry 4.0 that contribute to self-optimising processes. 1. CPS 2. Digital twins 3. Industrial communications 4. Machine learning 5. Smart sensors 6. Big data analytics 7. IIoT 8. Industrial cloud and AI					
Digital modelling	☒ Not relevant	☐ Digital modelling is not in use.	☐ Digital modelling is not in use; however, there are plans for its implementation.	☐ Digital modelling is used in up to 50% of relevant processes.	☐ Digital modelling is used in up to 70% of relevant processes.	☐ Digital modelling is used in all relevant processes.
Operations data collection	☐ Not relevant	☐ Operations data are not collected.	☒ Data collection is manually performed when required, such as in sampling for control.	☐ The manufacturer digitally collects data in certain areas.	☐ Digital data is comprehensively collected in multiple areas of the business.	☐ Digital data collection is automated In all required areas and processes.
	Elements of Industry 4.0 that contribute to operations data collection. 1. Enterprise resource planning (ERP) 2. SCADA 3. Manufacturing execution system (MES) 4. Enterprise manufacturing intelligence (EMI) 5. Advanced planning and scheduling (APS) 6. IIoT 7. Industrial communications 8. Smart sensors 9. Industrial cloud 10. PLC 11. Digital supply chain management 12. Digital inventory management 13. Quality 4.0 14. Digital product lifecycle management (DPLM) 15. Digital twins 16. Real-time remote monitoring 17. Predictive maintenance 18. Big data analytics					

Operations data usage	☐ Not relevant	☐ Operations data is not used.	☒ Collected data are only used for quality and regulatory purposes.	☐ Processes are controlled using some of the collected data.	☐ Over 50% of the relevant collected data are used to control and optimise processes (e.g., predictive maintenance).	☐ All of the relevant collected data are not only used to optimise processes but also to make decisions.
	Elements of Industry 4.0 that contribute to operations data usage. 1. CPS 2. Big data analytics 3. Machine learning 3. ERP 4. SCADA 5. MES 6. EMI 7. APS 9. IIoT 10. Industrial communications 14. Digital supply chain management 15. Digital inventory management 16. Quality 4.0 17. DPLM 18. Digital twins 19. Real-time remote monitoring 20. Predictive maintenance 21. AI					
Cloud solution usage	☐ Not relevant	☒ Cloud solutions are not implemented.	☐ Some discussions have been held amongst management about implementing cloud solutions. However, no initial solutions have been planned.	☐ Initial solutions have been planned for cloud-based software, data storage, and data analysis.	☐ In some areas of the business, pilot solutions have been implemented.	☐ Across the business, multiple solutions have been implemented.
	Elements of Industry 4.0 that are cloud-based. 1. Predictive maintenance 2. Digital supply chain management 3. Digital inventory management 3. Big data analytics 4. IIoT 5. Industrial communications 6. MES					

	7. APS 8. SCADA 9. DLPM 10. Quality 4.0 11. Digital customer relationship manager 12. DHRM 13. CPS 14. Digital twins					
Information technology (IT) and data security	☐ Not relevant	☐ No IT security solutions have been planned.	☐ IT security solutions have been planned.	☒ IT security solutions have been partially implemented.	☐ Plans have been developed to fill essential gaps in the implemented IT security solutions.	☐ In all relevant areas, IT security has been implemented, and frequent reviews are conducted to ensure compliance.
Additional sub-dimensions						
Asset maintenance and management	☐ Not relevant	☒ There is no awareness of the benefits of technologies such as predictive maintenance, remote maintenance, and augmented reality in asset maintenance.	☐ Discussions have been held amongst management on the benefits of technologies such as such as predictive maintenance, remote maintenance, and augmented reality in asset maintenance. However, plans have yet to be made towards their implementation.	☐ Plans have been initiated to implement technologies such as predictive maintenance, remote maintenance, and augmented reality in asset maintenance.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to asset maintenance and management. 1. Predictive maintenance 2. Remote monitoring 3. Remote maintenance 4. Augmented reality 5. Digital twins 6. Industrial communications					

Performance monitoring and management	☐ Not relevant	☒ There is no awareness of the benefits of advanced digital technologies such as digital twins, IIoT, and big data analytics in monitoring and managing performance.	☐ Discussions have been held amongst management on the benefits of advanced digital technologies such as digital twins, IIoT, and big data analytics in performance monitoring and management performance. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies in performance monitoring and management, and plans have been made towards their implementation.	☐ A pilot program is in underway.	The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to performance monitoring and management. 1. Digital twins 2. SCADA 3.PLC 4. Big data analytics 5. Smart sensors 6. Industrial communications 7. IIoT 8. Industrial cloud 9. MES 10. Real-time remote monitoring					
Virtualisation	☐ Not relevant	☒ There is no awareness of the benefits of advanced digital technologies such as digital twins, augmented reality, and IIoT in virtualisation.	☐ There are ongoing discussions amongst management on the benefits of advanced digital technologies such as digital twins, augmented reality, and IIoT in virtualisation. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies such as digital twins, augmented reality, and IIoT in virtualisation, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to virtualisation.					

	1. Digital twins 2. Augmented reality 3. Industrial communications					
Production planning and scheduling	☐ Not relevant	☒ There is no awareness of the benefits of advanced planning and scheduling software.	☐ There are ongoing discussions amongst management on the benefits of advanced planning and scheduling software. However, plans have yet to be made towards its implementation.	☐ All relevant management staff are aware of the benefits of advanced planning and scheduling software, and plans have been made towards its implementation.	☐ A pilot program is underway.	☐ The pilot program was successful and advanced planning and scheduling software has been fully implemented.
	Elements of Industry 4.0 that contribute to production planning and scheduling. Advanced planning and scheduling software					
Technical assistance	☐ Not relevant	☒ There is no awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers.	☐ There are ongoing discussions amongst management on the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to technical assistance. 1. IIoT 2. Industrial cloud 3. Big data analytics 4. Design to value 5. Product data utilisation 6. SCADA 7. Demand forecasting via predictive analytics 8. Digital customer relationship management (CRM) 9. EMI					

	10. MES 11. APS 12. Augmented reality 13. DHRM 14. Intelligent and Individualised Workstation 15. DPLM 16. Digital supply chain management 17. Digital inventory management

PRODUCTS AND SERVICES						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
Product customisation	☒ Not relevant	☐ Product customisation is not a priority.	☐ Plans are being made to introduce product customisation. However, products do not allow individualisation. Standardised mass production is still employed.	☐ Products are manufactured in large batches, with limited late differentiation.	☐ Although products can be largely customised, production is still standardised.	☐ For the majority of made-to-order products, late differentiation is offered.
	Elements of Industry 4.0 that contribute to product customisation. 1. Digital customer co-creation 2. IIoT					
Digital features of products	☒ Not relevant	☐ There is no awareness of the benefits of product digitalisation.	☐ There is awareness of the benefits of product digitalisation. However, no plans have been made towards digitalising products.	☐ Plans have been made towards digitalising products. However, manufactured products only show physical value.	☐ Manufactured products have some digital features.	☐ Manufactured products have high digital features and show value from intellectual property licensing.
	Elements of Industry 4.0 that contribute to digital features of products. 1. Product digitalisation 2. IIoT					
Data-driven services	☐ Not relevant	☒ Data-driven services are not a priority.	☐ There is no customer integration for the data-driven services offered.	☐ There is little customer integration for the data-driven services offered.	☐ There is customer integration for the data-driven services offered.	☐ There is complete customer integration for the data-driven services offered.

Level of product data usage	☒ Not relevant	☐ There is no awareness of the benefits of product data usage.	☐ There is awareness of the benefits of product data usage. However, the collected data are not used.	☐ Up to 20% of the collected data are used.	☐ 20–50% of the collected data are used.	☐ Over 50% of the collected data are used.
	Elements of Industry 4.0 that contribute to level of product data usage. 1. Big data analytics 2. Industrial cloud 3. Product data utilisation 4. IIoT					
Share of revenue	☐ Not relevant	☐ Services are not data-driven.	☒ Data-driven services are responsible for less than 2.5% of revenue.	☐ Data-driven services are responsible for 2.5–7.5% of revenue.	☐ Data-driven services are responsible for 7.5–10% of revenue.	☐ Data-driven services are responsible for over 10% of revenue.
	Additional sub-dimensions					
Product lifecycle management (PLM)	☐ Not relevant	☒ There is little or no awareness of the benefits of digital product lifecycle manageme nt software.	☐ Discussions have been held amongst management on the benefits of product life cycle management . However, plans have yet to be made towards it implementat ion.	☐ There is awareness of the benefits of digital product lifecycle management software, and plans have been made towards its implementatio n.	☐ A pilot program is underway.	☐ The pilot program was successful, and product lifecycle management has been fully implemented.
	Elements of Industry 4.0 that contribute to product lifecycle management. 1. Digital product life cycle management					
Quality management	☐ Not relevant	☒ There is little or no awareness of the benefits of Quality 4.0.	☐ Discussions have been held amongst management on the	☐ There is awareness of the benefits of Quality 4.0, and plans have been made	☐ A pilot program is underway.	☐ The pilot program was successful, and Quality 4.0 has been fully implemented.

			potential implementation of Quality 4.0. However, plans have yet to be made towards it implementation.	towards its implementation.		
	Elements of Industry 4.0 that contribute to quality management. Quality 4.0					
Technical assistance	☐ Not relevant	☒ There is little or no awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers.	☐ Discussions have been held amongst management on advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers. However, plans have yet to be made towards their implementation.	☐ There is awareness of the benefits of advanced digital technologies such as IIoT, augmented reality, and big data analytics in technical assistance for workers, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and all relevant elements have been fully implemented.
	Elements of Industry 4.0 that contribute to technical assistance. 1. IIoT 2. Industrial cloud 3. Big data analytics 4. Design to value 5. Product data utilisation 6. SCADA 7. Demand forecasting via predictive analytics 8. Digital CRM 9. EMI 10. MES 11. APS 12. Augmented reality					

	13. DHRM 14. Intelligent and individualised workstation 15. DPLM 16. Digital supply chain management 17. Digital inventory management

SUPPLY CHAIN						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
Inventory control using a real-time data management database	☐ Not relevant	☐ Inventory levels are not understood.	☒ Inventory levels are understood.	☐ Inventory levels are manually updated using a computer database.	☐ Inventory levels are updated using a combination of smart devices and a computer database.	☐ A real-time database is updated using smart devices.
	Elements of Industry 4.0 that contribute to inventory control using a real-time data management database. Digital inventory management					
Supply chain integration	☐ Not relevant	☒ Supply chain integration is not a priority.	☐ There is awareness of the importance of supply chain integration. However, communications with suppliers and customers remain ad hoc and reactive.	☐ There is basic communication and data sharing with suppliers and customers when needed.	☐ There is data transfer between key strategic suppliers and customers (e.g. customer inventory levels).	☐ The systems employed are completely integrated with suppliers and customers for appropriate processes (e.g. real-time integrated planning).
Supply chain visibility	☐ Not relevant	☒ Supply chain visibility is not a priority.	☐ Supply chain visibility is deemed important. However, there is no visibility of site location, capacity, inventory, or operations between first-tier suppliers and customers.	☐ There is visibility of site location, capacity, inventory, and operations between first-tier suppliers and customers.	☐ There is visibility of site location, capacity, inventory, and operations across the supply chain.	☐ There is real-time visibility of site location, capacity, inventory, and operations across the supply chain. In addition, monitoring and optimisation can be achieved.
	Elements of Industry 4.0 that contribute to supply chain integration. Digital supply chain management					
Supply chain flexibility	☐	☒ There is no clear	☐ Plans are being made	☐ There is moderate	☐ There is moderate response to	☐ There is immediate

	Not relevant	understanding of measures that enable supply chain flexibility. Response to market changes is slow.	to improve supply chain flexibility and response to market changes.	response to market changes and general shifts in customer requirements.	changes in the market environment and individual customer requirements.	response to changes in the market environment and individual customer requirements.
	Elements of Industry 4.0 that contribute to supply chain flexibility. 1. Digital supply chain management					
Lead times	☐ Not relevant	☒ Lead time reduction is not a priority.	☐ There is awareness of the importance of lead time reduction. However, high inventory levels remain due to long material lead times.	☐ The organisation has identified improvements that can reduce lead times for some materials.	☐ The identified improvements have been implemented to reduce lead times for key materials.	☐ Stocking policies and lead times are differentiated to meet make-to-order efficiently.

BUSINESS MODEL						
Readiness level	**Not relevant (NR)**	**Level 0 (Outsider)**	**Level 1 (Beginner)**	**Level 2 (Intermediate)**	**Level 3 (Experienced)**	**Level 4 (Expert)**
As a service business model	☒ Not relevant	☐ There is no awareness of the as a service business model.	☐ Discussions have been held amongst managements on the benefits of adopting an as a service business model, but plans have yet to be made towards its implementation.	☐ There is awareness of the concept and initial plans for development.	☐ There is high awareness, and plans for implementation are in development.	☐ The as a service business model has been adopted and offered to customers.
	Elements of Industry 4.0 that contribute to the as a service business model. 1. Cloud as a service 2. IIoT as a service 3. Big data analytics as a service (BDaaS)					
Data-driven decisions	☐ Not relevant	☐ Decision making is not data-driven.	☒ Up to 25% of the relevant collected data are analysed.	☐ Up to 50% of the relevant collected data are analysed and featured in key business reports to review performance.	☐ Up to 75% of the relevant collected data are analysed, and the results are used in business decision making.	☐ Over 70% of the relevant collected data are analysed, and the results are used in business decision making.
	Elements of Industry 4.0 that contribute to data-driven decisions. 1. IIoT 2. Industrial cloud 3. Big data analytics 4. Digital twins 5. DPLM 6. Digital CRM 7. EMI 8. MES 9. APS 10. ERP 11. SCADA *Only consider systems with analytics functions					

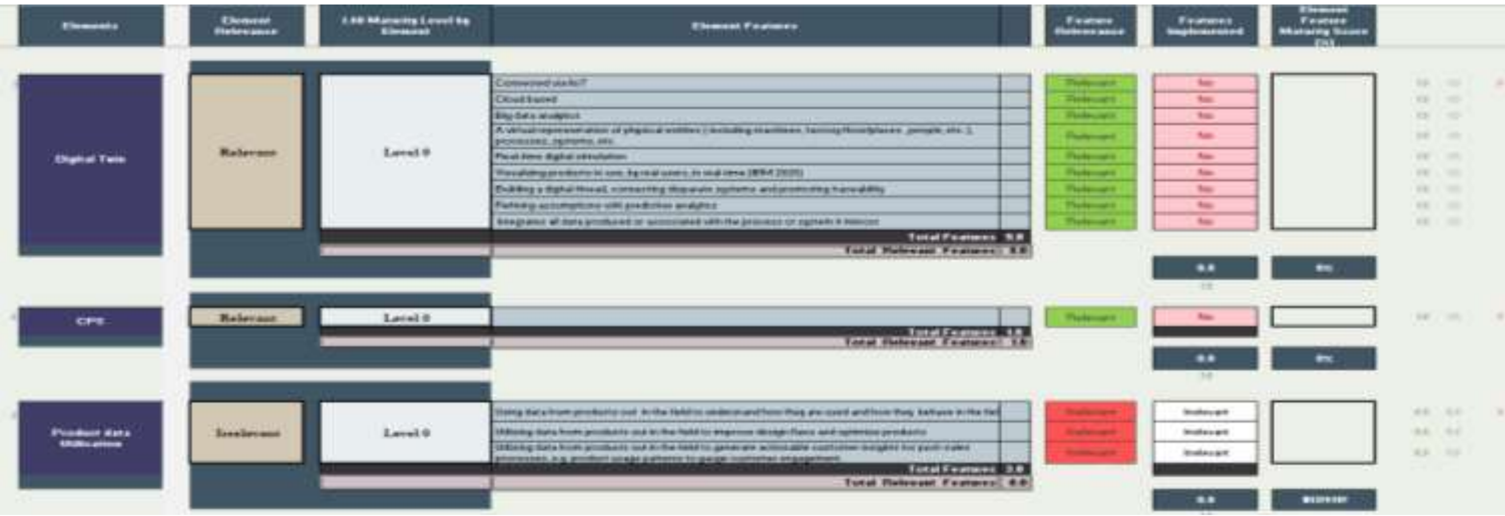
Real-time tracking	☐ Not relevant	☐ Products are not tracked.	☒ Product tracking is limited.	☐ Product movement between manufacturing and internal distribution sites can be tracked.	☐ Product movement through manufacturing and distribution and to the customer's distribution centre can be tracked.	☐ Product tracking is possible throughout the complete lifecycle.
	Elements of industry 4.0 that contribute to real-time tracking. 1. Digital supply chain management 2. Digital inventory management 3. Digital product life cycle management					
Real-time and automated scheduling	☐ Not relevant	☒ There is no awareness of the benefits of real-time automated scheduling. Equipment maintenance is manually performed according to a maintenance schedule.	☐ There is awareness of the benefits of real-time automated scheduling. However, equipment maintenance is still manually performed according to a maintenance schedule.	☐ Some machines can alert operators to performance issues to enable manual scheduling of maintenance tasks.	☐ Some machines can self-diagnose and automatically transfer information to the maintenance scheduling system.	☐ Generally, machines can self-diagnose, and the maintenance schedule automatically adjusts itself based on real-time data input from machines.
	Elements of Industry 4.0 that contribute to real-time and automated scheduling. 1. Predictive maintenance 2. Digital twins					
Integrated marketing channels	☐ Not relevant	☒ Integrated marketing channels are not a priority.	☐ There is awareness of the benefits of integrated marketing channels. However, online presence is separated from offline channels.	☐ There is integration within online and offline channels but not between them.	☐ There are integrated channels and an individualised customer approach.	☐ There is integrated customer experience management across all channels.
IT-supported business	☐ Not relevant	☐ Business processes are not	☒ The main business processes	☐ Some areas of the business are integrated	☐ Processes are completely supported by an IT	☐ All of the company's processes are

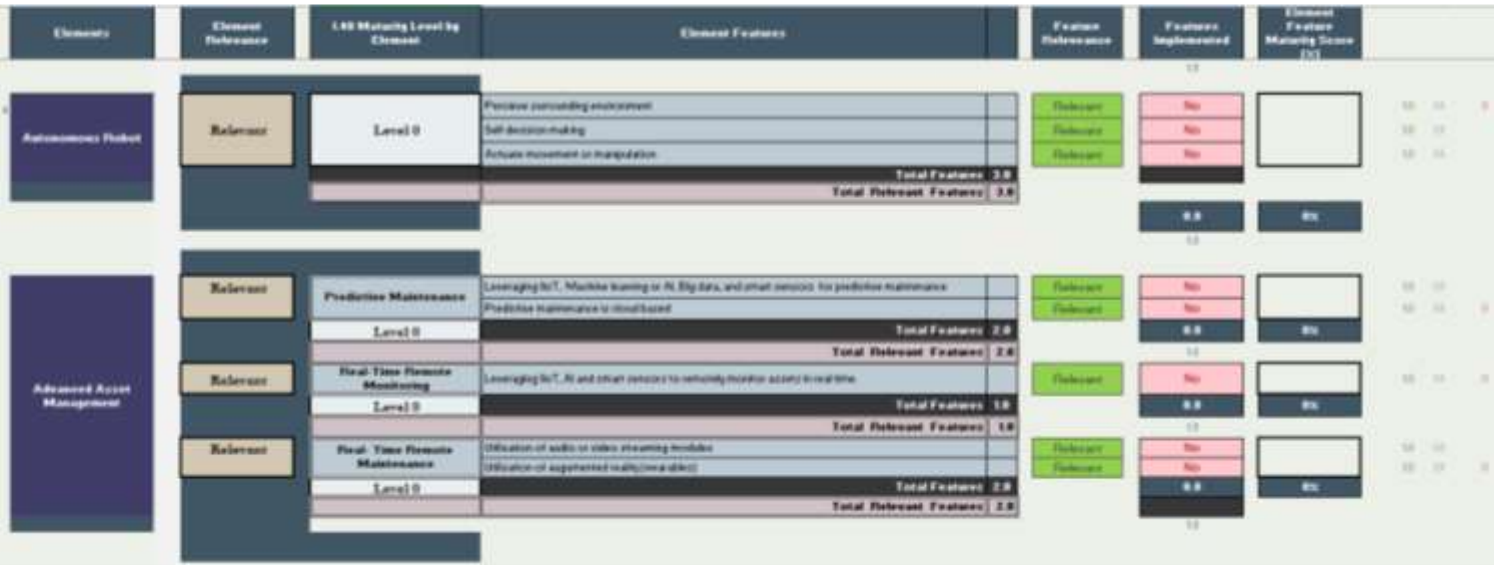
		supported by an IT system.	are supported by an IT system.	and supported by an IT system.	system; however, they are not fully integrated.	integrated and supported by an IT system.

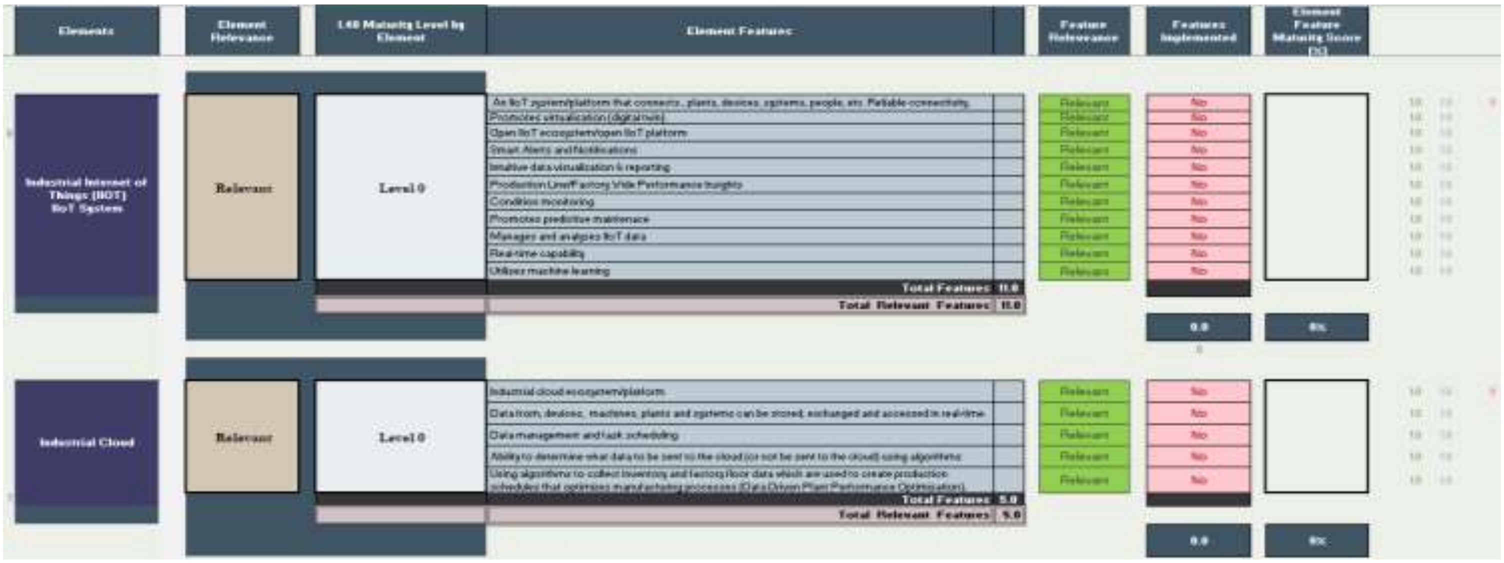
STRATEGY AND ORGANISATION						
Readiness level	Not relevant (NR)	Level 0 (Outsider)	Level 1 (Beginner)	Level 2 (Intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Degree of strategy implementation	☐ Not relevant	☒ Industry 4.0 is not recognised at all.	☐ Industry 4.0 is recognised at the departmental level but not integrated into strategy.	☐ Industry 4.0 is included in the business strategy.	☐ The Industry 4.0 strategy has been communicated to the business and is widely understood.	☐ The Industry 4.0 strategy has been implemented across the organisation's operations
Measurement	☐ Not relevant	☒ Industry 4.0 is not recognised at all.	☐ Industry 4.0 is recognised; however, key performance indicators (KPIs) do not focus on Industry 4.0.	☐ A structured set of business metrics exist, with some measurement of Industry 4.0 drivers.	☐ Industry 4.0 metrics are widely understood in the business and used in monthly reporting.	☐ Business metrics and personal development plans focus on Industry 4.0 objectives.
Investments	☐ Not relevant	☒ Industry 4.0 is not recognised at all.	☐ Initial Industry 4.0 investments have been made in one business area.	☐ Industry 4.0 investments have been made in more advanced business areas.	☐ Industry 4.0 investments have been made in multiple business areas.	☐ Industry 4.0 investments have been made across the entire business.
	Elements of Industry 4.0 that contribute to supply chain integration. Digital supply chain management					
People capabilities	☐ Not relevant	☐ Digitally upskilling employees is not a priority.	☐ There is awareness of the importance of upskilling employees, and plans have been made towards this goal.	☒ Technology-focused areas of the business employ people with some digital skills.	☐ Employees have digital and data analysis skills across most areas of the business (e.g., production).	☐ Employees have leading-edge digital and analytics skills across the business.
Collaboration	☐ Not relevant	☐ The organisation does not encourage collaboration .	☐ The organisation's operations are in functional silos.	☐ Interaction between departments is limited.	☒ Departments encourage cross-functional collaboration.	☐ Departments encourage cross-company collaboration to enable improvements.
Leadership	☐	☒	☐	☐	☐	☐

	Not relevant	Industry 4.0 is not recognised at all.	Leadership do not focus on Industry 4.0 investments.	Leadership are investigating the potential benefits of Industry 4.0.	Leadership recognise the financial benefits of Industry 4.0, and plans are being developed to promote widespread support within leadership and across the business.	There is widespread support for Industry 4.0 both amongst leadership and across the business.
Finance	☐ Not relevant	☒ Industry 4.0 is not recognised at all.	☐ No sizeable Industry 4.0 investments have been made.	☐ Cost-benefit analyses for Industry 4.0 investments are not being reviewed.	☐ A cost-benefit analysis of Industry 4.0 investments is performed annually.	☐ A cost-benefit Analysis of Industry 4.0 investments is performed quarterly.
Additional sub-dimensions						
People management	☐ Not relevant	☒ There is no awareness of the benefits of advanced digital technologies such as cloud computing, AI, and IIoT in human resource management.	☐ There is awareness of the benefits of advanced digital technologies such as cloud computing, AI, and IIoT in human resource management. However, plans have yet to be made towards their implement them.	☐ There is awareness of the benefits of advanced digital technologies such as cloud computing, AI, and IIoT in human resource management. management, and plans have been made towards their implementation.	☐ A pilot program is underway.	☐ The pilot program was successful, and digital HRM has been fully implemented.
	Elements of Industry 4.0 that contribute to Digital Features of Products 1. Digital human resource management					

Appendix B: Data Input Interface (Elements) – Organisation D







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Elements	Element Relevance	I4.0 Maturity Level by Element	Element Features	Feature Relevance	Features Implemented	Element Feature Maturity Score (S)
Open Standard	Relevant	Level 0	Standardized language that is comprehensible by various components of a production system and production IT	Relevant	No	
			Data is rationalized into similar formats and communicated across standard protocols, thereby promoting digital collaboration	Relevant	No	
			Total Features 2.0			
			Total Relevant Features 2.0		0.0	0%
Industrial Security Solution	Relevant	Level 2	Secured industrial control systems (different types of control systems and associated instrumentation, which include the devices, systems, networks, and controls used to operate and/or automate industrial processes)	Relevant	Yes	
			Secured IIoT devices and embedded systems	Relevant	No	
			Secured confidential information and intellectual property	Relevant	Yes	
			Security diagnostic – assessing the people, processes and technology used to ensure safe and secure industrial security	Relevant	No	
			Risk assessment – a detailed risk assessment of an organization's industrial systems	Relevant	No	
			Security architecture – development of designs, including recommended security controls (security control, safeguards or countermeasures to avoid, detect, counteract, or minimize security risks to physical property, information, computer systems, or other assets)	Relevant	No	
			Security cases – incorporate the cyber threat in the design and development of industrial security	Relevant	No	
			Network monitoring – provide visibility of protocol specific data on operational technology networks, alerting misconfigurations and cyber events to a central command and control system	Relevant	No	
			Security assurance – provide independent security assurance and penetration testing	Relevant	No	
			Security training – enable an organisation to manage its own cyber risks in the most cost effective way	Relevant	No	
			Security advisory – regular access to professional cyber security engineers	Relevant	No	
			Total Features 11.0			
			Total Relevant Features 11.0		2.0	18%
Industrial Communication	Relevant	Level 2	Allows for communications between people, devices, machines, systems, plants, etc.	Relevant	Yes	
			Continuous exchange of information carried out in real time through Time Sensitive Networking (TSN)	Relevant	No	
			End to end network architecture (Connecting business systems with automation and control via IIoT)	Relevant	No	
			Total Features 3.0			
			Total Relevant Features 3.0		1.0	33%

Elements	Element Relevance	I4.0 Maturity Level by Element	Element Features	Feature Relevance	Features Implemented	Element Feature Maturity Score (S)
Big Data Analytics	Relevant	Level 0	**Automated Production management** – [illegible]	Relevant	No	
			Cloud based big data analytics	Relevant	No	
			Used for Predictive maintenance	Relevant	No	
			Big Data Analytics through Self Service Systems – [illegible]	Relevant	No	
			[illegible]	Relevant	No	
			Real time capability	Relevant	No	
			[illegible]	Relevant	No	
			[illegible]	Relevant	No	
			Total Features 8.0			
			Total Relevant Features 8.0		0.0	0%
Design to Value	Relevant	Level 0	**Applying advanced analytics in product development covering the following areas:**			
			Market Research	Relevant	No	
			Consumer Insight	Relevant	No	
			Competitive Insight	Relevant	No	
			Supplier Insight	Relevant	No	
			Total Features 4.0			
			Total Relevant Features 4.0		0.0	0%
Open Innovation	Relevant	Level 0	Augment R&D through open innovation	Relevant	No	
			Implementing open innovation using a digital ecosystem	Relevant	No	
			Total Features 2.0			
			Total Relevant Features 2.0		0.0	0%

Elements	Element Relevance	I4.0 Maturity Level by Element	Element Features	Feature Relevance	Features Implemented	Element Feature Maturity Score (S)
Augmented Reality	Relevant	Level 0	Used for assembling production components	Relevant	No	
			Used to assist maintenance (including remote maintenance)	Relevant	No	
			Used to identify flaws (Quality assurance)	Relevant	No	
			Used for training	Relevant	No	
			Used in inventory management	Relevant	No	
			Total Features 5.0			
			Total Relevant Features 5.0		0.0	0%
Human Robot Collaboration/ Collaborative Robots (Cobots)	Relevant	Level 0	Robots intended for direct human robot interaction within a shared space. Humans and robots collaborate	Relevant	No	
			Total Features 1.0			
			Total Relevant Features 1.0		0.0	0%
Digital Product Life-Cycle Management (DPLM)	Relevant	Level 0	Use of digital ecosystem/platform	Relevant	No	
			Connected and cloud based DPLM	Relevant	No	
			Use of IIoT	Relevant	No	
			Complete most of the product lifecycle steps from product planning, research, development, production and risk analysis in one system	Relevant	No	
			Harness the power of data analytics to speed up time to market, generate actionable insights, etc. (Enabling element: Big data analytics)	Relevant	No	
			Leverage real-time data access from across interconnected devices, sensors, external systems, open portals for consumer inputs and feedback and other departments to drive product innovation decisions. (Enabling elements: IIoT, Big data analytics, Industrial cloud, Industrial communications, open innovation, customer co-creation, smart sensors)	Relevant	No	
			DPLM is integrated with other systems e.g. ERP. (Enabling element: IIoT, Industrial communications)	Relevant	No	
			Product traceability throughout its entire lifecycle	Irrelevant	Irrelevant	
			Total Features 8.0			
			Total Relevant Features 7.0		0.0	0%

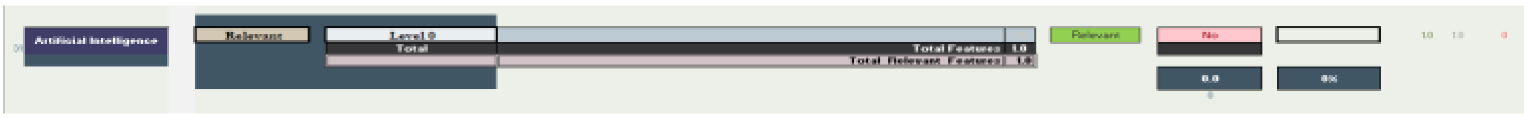
Elements	Element Relevance	I40 Maturity Level by Element	Element Features	Feature Relevance	Features Implemented	Element Feature Maturity Score (%)
Digital Human Resource Management (DHRM)	Relevant	Level 0	Cloud based HR system	Relevant	No	
			Utilisation of digital technologies including IoT, Big data analytics, AI and Machine learning	Relevant	No	
			Integrated digital HR platform (e.g. polling process, systems, operations, etc.)	Relevant	No	
			Real-time capability	Relevant	No	
			Real-time interactive dashboard	Relevant	No	
			HR Analytics	Relevant	No	
			Total Features 6.0			
			Total Relevant Features 6.0		0.0	0%
Machine Learning	Relevant	Level 0		Relevant	No	
			Total Features 1.0			
			Total Relevant Features 1.0		0.0	0%
Intelligent and individualized workstation.	Relevant	Level 0	Intelligent workstations automatically adapt to the needs, skills and preferences of operators (Bosch rexroth 2020)	Relevant	No	
			Total Features 1.0			
			Total Relevant Features 1.0		0.0	0%
Smart Sensor	Relevant	Level 0	Connected via IIoT	Relevant	No	
			Performs data conversion and digital processing	Relevant	No	
			Capable of bidirectional communication (Send and receive data). Communicate with external devices and the cloud	Relevant	No	
			Perform self assessment and self calibration	Relevant	No	
			Can detect issues such as sensor contamination, switch failures, and open coils	Relevant	No	
			Can perform logical operations (Logical operations are the function of logic gates in digital circuits)	Relevant	No	
			Total Features 6.0			
			Total Relevant Features 6.0		0.0	0%

Elements	Element Relevance	I40 Maturity Level by Element	Element Features	Feature Relevance	Features Implemented	Element Feature Maturity Score (%)
Digital Supply Chain Management	Relevant	Level 0	Connected via IIoT	Relevant	No	
			Supply chain system is cloud based	Relevant	No	
			E2E (End to end) Visibility	Relevant	No	
			Real time capability	Relevant	No	
			Big data analytics	Relevant	No	
			Use of robotics (Autonomous robots)	Relevant	No	
			Supply chain system is automated (Automated Workflows)	Relevant	No	
			Predictive analytics	Relevant	No	
			Use of smart sensors	Relevant	No	
			Total Features 9.0			
			Total Relevant Features 9.0		0.0	0%
Digital Inventory Management System	Relevant	Level 0	Connected via IIoT (Enabling element: IIoT)	Relevant	No	
			Inventory management is cloud based (Enabling element: Industrial cloud)	Relevant	No	
			Big data analytics	Relevant	No	
			Allows for real time visibility (Enabling elements: IIoT, Industrial communications, Industrial cloud, smart sensors)	Relevant	No	
			Inventory alert/notification (Enabling element: IIoT)	Relevant	No	
			Inventory forecasting (Analytics) (Enabling element: Big data analytics)	Relevant	No	
			Inventory tracking (Enabling elements: IIoT, Industrial communications, smart sensors)	Relevant	No	
			Reporting tool	Relevant	No	
			Inventory application is integrated with other systems eg ERP (Enabling elements: IIoT, Industrial communications)	Relevant	No	
			Real-time updates (Enabling elements: IIoT, Industrial communications, smart sensors)	Relevant	No	
			Use of historical data and analytics (Enabling elements: Industrial cloud, Big data analytics, IIoT)	Relevant	No	
			Multi location management (Only applicable in cases where multiple warehouses or locations are involved)	Irrelevant	Irrelevant	
			Total Features [illegible]			
			Total Relevant Features [illegible]			

Elements	Element Relevance	I40 Maturity Level by Element	Element Features	Feature Relevance	Features Implemented	Element Feature Maturity Score (%)
Digital Manufacturing Operations Management	Relevant	Manufacturing Execution System (MES), Level 0		Relevant	No	
			Total Features 1.0			
			Total Relevant Features 1.0		0.0	0%
	Relevant	Enterprise Resource Planning (ERP), Level 0		Relevant	No	
			Total Features 1.0			
			Total Relevant Features 1.0		0.0	0%
	Relevant	Advance Planning and Scheduling (APS), Level 0	Use of algorithms to calculate the optimal production schedules	Relevant	No	
			Generate multiple scenarios	Relevant	No	
			Data visualization	Relevant	No	
			Real time schedule change	Relevant	No	
			Integration with other systems e.g. ERP, MES, etc.	Relevant	No	
			Total Features 5.0			
			Total Relevant Features 5.0		0.0	0%
	Relevant	Supervisory Control and Data Acquisition SCADA, Level 0		Relevant	No	
			Total Features 1.0			
			Total Relevant Features 1.0		0.0	0%
	Relevant	Enterprise Manufacturing Intelligence (EMI), Level 0	Gather manufacturing data from all systems and locations involved in production (Integrated with multiple systems)	Relevant	No	
			Provide features to clean and structure manufacturing data to make easier to use	Relevant	No	
			Deliver relevant information to the employees and managers involved in production	Relevant	No	
			Analyze production data in real time and alert users based on predefined rules	Relevant	No	
			Monitor KPIs and metrics for quality management, productivity, and cost control	Relevant	No	
			Total Features 5.0			
			Total Relevant Features 5.0		0.0	0%

Elements
Element Relevance
I4.0 Maturity Level by Element
Element Features
Feature Relevance
Features Implemented
Element Feature Maturity Score (%)
Quality 4.0
Relevant
Level 0
Quality 4.0 Ecosystem
Cloud based Quality 4.0
Predictive analysis
Big data analytics
Artificial Intelligence
Blockchain
IoT
Augmented Reality
Smart Sensors
Machine learning
Can be integrated with MES and ERP
Total Features
Total Relevant Features
Relevant
No
Additive Manufacturing
Irrelevant
Advanced Virtual Self-Services
#DIV/0!
Demand Forecasting via Predictive Analytics
0%

Elements
Element Relevance
I4.0 Maturity Level by Element
Element Features
Feature Relevance
Features Implemented
Element Feature Maturity Score (%)
Programme Logic Controller
Relevant
Level 4
Yes
Total Features
Total Relevant Features
100%
Product Digitalisation
Irrelevant
Level 0
Connectivity:
Control:
Context:
Digital Customer Relationship Management (Digital CRM)
Cloud based CRM
Automated CRM
Personalized Touch Point:
No
0%



Artificial Intelligence
Relevant
Level 0
Total
Total Features
Total Relevant Features
No
0.0
0%

Appendix C: Data Input Interface (Dimensions) – Organisation D

Instructions

Use the drop-down menu to input data

Manually Input type in NR (NOT Relevant) in I4.0 Maturity Level by Sub Dimensions has been established to be Irrelevant

Key equations

I4.0 Maturity level by sub-dimension = average of I4.0 maturity level by elements and sub-dimension readiness level

I4.0 Maturity Level by Dimension = average of I4.0 maturity level by sub dimensions

N/A = No elements associated with the sub dimension

	Sub-Dimension Readiness level	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions
1	Automation	No	No	Yes	No	No	No	0.5	1
2	Machine and operation system integration (M2M)	No	No	Yes	No	No	No	0.5	1
3	Equipment readiness for Industry 4	No	No	Yes	No	No	No	N/A	1
4	Autonomously guided workpieces	No	Yes	No	No	No	No	0.8	0
5	Self-optimising processes	No	Yes	No	No	No	No	0.3	0
6	Digital modelling	Yes	No	No	No	No	No	N/A	NR
7	Operations data collection	No	No	Yes	No	No	No	0.3	1
8	Operations data usage	No	No	Yes	No	No	No	0.3	1
9	Cloud solution usage	No	Yes	No	No	No	No	0.1	0
10	IT and data security Comprehensive	No	No	No	Yes	No	No	2.0	2

I.40 Maturity Level by Dimension (Average)

Additional Subdimensions

	Additional Subdimensions	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions
1	Asset Maintenance and Management	No	Yes	No	No	No	No	0.3	0
2	Performance Monitoring and Management	No	Yes	No	No	No	No	0.7	0
3	Virtualisation	No	Yes	No	No	No	No	0.7	0
4	Technical Assistance	No	Yes	No	No	No	No	0.0	0
5	Production planning and Scheduling	No	Yes	No	No	No	No	0.0	0

I.40 Maturity Level by Dimension (Average) + Additional Subdimensions

Product and Services

	Readiness level	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions
1	Product customisation	Yes	No	No	No	No	No	0	NR
2	Digital features of products	Yes	No	No	No	No	No	0	NR
3	Data-driven services	No	Yes	No	No	No	No	0	0
4	Level of product data usage	Yes	No	No	No	No	No	0	NR
5	Share of revenue	No	Yes	No	No	No	No	0	0

I.40 Maturity Level by Dimension (Average)

Additional Subdimensions

	Additional Subdimensions	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions
1	Product Life Cycle Management (PLM)	No	Yes	No	No	No	No	0	0
2	Quality Management	No	Yes	No	No	No	No	0	0
3	Technical Assistance	No	Yes	No	No	No	No	0	0

I.40 Maturity Level by Dimension (Average) + Additional Subdimensions

Supply Chain

Readiness level	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions	I.40 Maturity Level by Dimension (Average)
Inventory control using real-time data management database	No	No	Yes	No	No	No	0.0	1	0
Supply Chain Integration	No	Yes	No	No	No	No	0.0	0	
Supply chain visibility	No	Yes	No	No	No	No	0.0	0	
Supply chain flexibility	No	Yes	No	No	No	No	0.0	0	
Lead times	No	Yes	No	No	No	No	0.0	0	

Additional Subdimensions

I.40 Maturity Level by Dimension (Average) + Proposed Subdimensions

N/A

Business Model

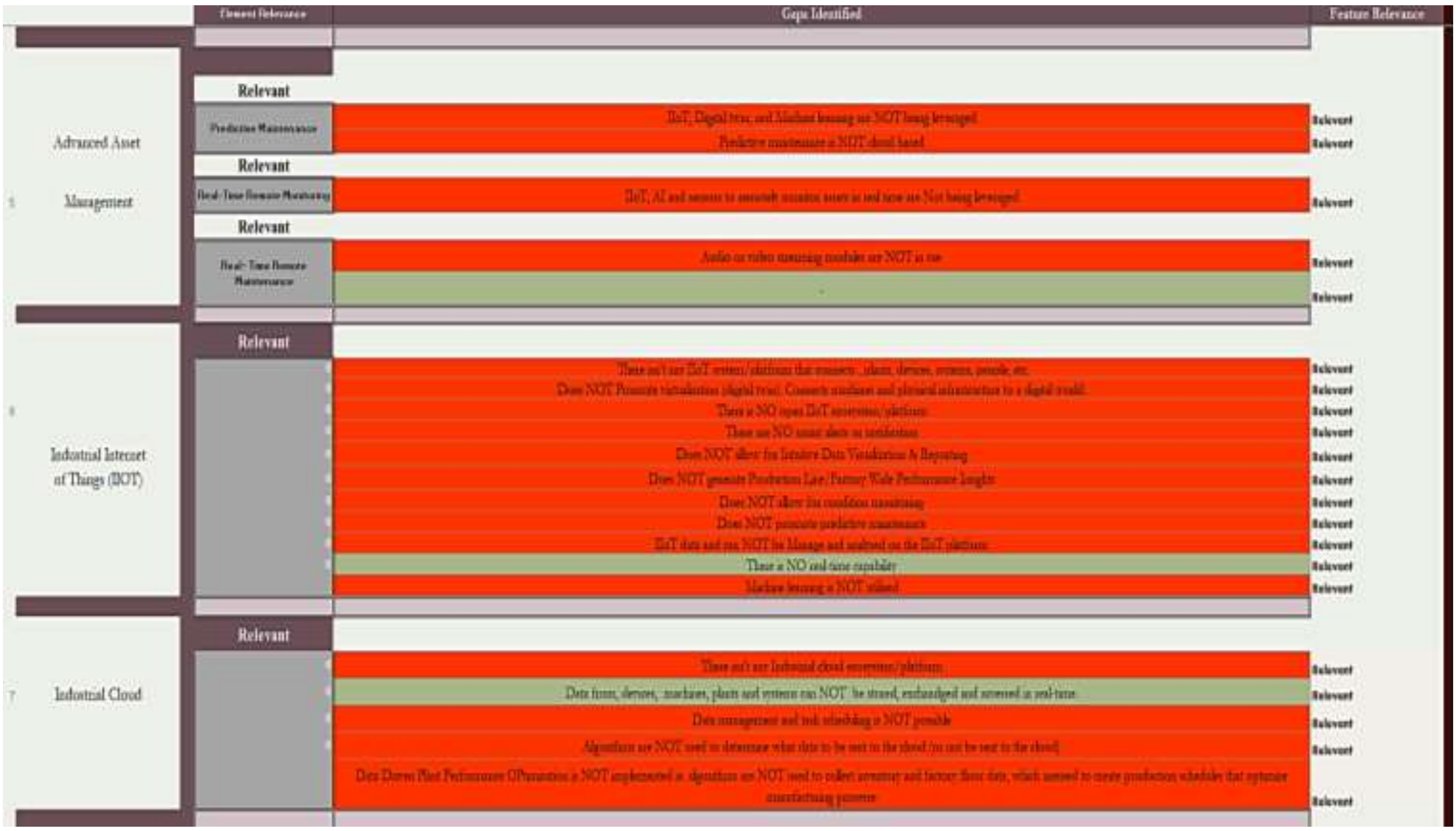
	Readiness level	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions	I.40 Maturity Level by Dimension (Average)
1	'As a service' business model	Yes	No	No	No	No	No	0.0	NR	0
2	Data driven decision	No	No	Yes	No	No	No	0.0	1	
3	Real-time tracking	No	No	Yes	No	No	No	0.0	1	
4	Real-time and automated Scheduling	No	Yes	No	No	No	No	0.0	0	
6	Integrated Marketing Channel	No	Yes	No	No	No	No	0.0	0	
	IT supported	No	No	Yes	No	No	No	N/A	1	

Starategy and Organisation

	Readiness level	Not Relevant (NR)	Level 0	Level 1 Beginner	Level 2 Intermediate	Level 3 Experienced	Level 4 Expert	I.40 Maturity Level by Elements (Average)	I.40 Maturity Level by Sub Dimensions	I.40 Maturity Level by Dimension (Average)
1	Degree of strategy implementation	No	Yes	No	No	No	No	N/A	0	0
2	Measurement	No	Yes	No	No	No	No	N/A	0	
3	Investments	No	Yes	No	No	No	No	N/A	0	
4	People capabilities	No	No	Yes	No	No	No	N/A	1	
5	Collaboration	No	No	No	Yes	No	No	N/A	2	
6	Leadership	No	Yes	No	No	No	No	N/A	0	
7	Finance	No	Yes	No	No	No	No	N/A	0	
	Additional Subdimensions									**I.40 Maturity Level by Dimension (Average) + Proposed Subdimensions**
1	People Management	No	Yes	No	No	No	No	0	0.0	0

Appendix D: Automated Support interface for making recommendations

– Organisation D



	Element Relevance	Gaps Identified	Feature Relevance
Industrial Communications	Relevant	-	Relevant
		Time Sensitive Networking (TSN) is NOT in use	Relevant
		NO End to end network architecture (Connect business systems with automation and control via IIoT)	Relevant
Big Data Analytics	Relevant	Does NOT allow Automated Production Management	Relevant
		Big Data Analytics is NOT cloud based	Relevant
		Does NOT promote Predictive Maintenance	Relevant
		Self-Service Analytics is NOT adopted	Relevant
		Not Used for operational monitoring	Relevant
		No real time capability	Relevant
		Data collection and analytics are NOT facilitated	Relevant
		Does NOT promote system integration	
Design to Value	Relevant	Market research is NOT carried out and/or utilised	Relevant
		Consumer insights are NOT generated and/or utilised	Relevant
		Competitive insight is NOT generated and/or utilised	Relevant
		Supplier insights are NOT generated and/or utilised	Relevant
Open Innovation	Relevant	R&D Needs to be Augmented through open innovation	Relevant
		A digital ecosystem for open innovation will prove beneficial	Relevant

	Element Relevance	Gaps Identified	Gaps Identified
Augmeneted Reality	Relevant	Augmented reality Is NOT used in assembling product components	Relevant
		Augmented reality is NOT used in asset maintenance	Relevant
		Augmented reality is NOT used to identify flaws (Quality Assurance)	Relevant
		Augmented reality is NOT used in training	Relevant
		Augmented reality is NOT used in inventory management	Relevant
COBOTS	Relevant	Augmented reality is NOT used in inventory management	Relevant
Digital Product Life-Cycle Management (DPLM)	Relevant	Digital ecosystem/platform is NOT in use	Relevant
		DPLM is Not cloud based	Relevant
		IIoT is NOT in use	Relevant
		Big data analytics is NOT implemented	Relevant
		Real-time data access from across interconnected devices, sensors, external systems, open portals for consumer inputs and feedback and other departments can be leveraged to drive innovation decisions	Relevant
		DPLM is NOT integrated with other systems	Relevant
		Products can NOT be traced through out their lifecycle	Relevant
Digital Customer Co-Creation	Irrelevant	-	Irrelevant
		-	Irrelevant
		-	Irrelevant

	Element Relevance	Gaps Identified	Gaps Identified
Digital Human Resource Management (DHRM)	Relevant		
		HR system is NOT cloud based	Relevant
		digital technologies including IoT, Big data analytics, AI, Cloud computing and Machine learning are NOT in use	Relevant
		Digital HR platform is NOT Integrated (policies, systems, operations, etc.)	Relevant
		Digital HR has NO real time capability	Relevant
		Real-time interactive dashboard is NOT present	Relevant
		HR analytics NOT implemented	Relevant
Machine learning	Relevant		
		Machine learning NOT implemented	Relevant
Intelligent and Individualised Workstations	Relevant		
		Having an intelligent workstation that automatically adapt to the needs, skills and preferences of operators might can help to increase productivity	Relevant
Smart Sensors	Relevant		
		NOT connected via IIOT	Relevant
		Lacks the ability to Perform data processing and digital processing	Relevant
		Incapable of bi-directional communication	Relevant
		Lacks the ability to self-assess and self calibrate	Relevant
		Lacks the ability to detect issues such as sensor contamination, switch failures, and open coils	Relevant
		Can NOT perform logical operations	Relevant

	Element Relevance	Gaps Identified	Gaps Identified
Digital Supply Chain Management	Relevant		
		Connected via IIoT	Relevant
		NOT cloud based	Relevant
		NO end to end visibility	Relevant
		No Real time capability	Relevant
		Big data analytics is NOT utilised	Relevant
		Autonomous robots are NOT utilised	Relevant
		Supply chain system is NOT automated	Relevant
		Predictive analytics is NOT utilised	Relevant
		Smart sensors are NOT utilised	Relevant
Digital Inventory Management System	Relevant		
		IIoT is NOT in use	Relevant
		Inventory Management is NOT cloud based	Relevant
		Big data analytics is NOT cloud based	Relevant
		Real time visibility is NOT possible	Relevant
		Inventory alerts and Notifications are NOT used	Relevant
		Inventory forecasting (analytics) is NOT possible	Relevant
		Inventory tracking is NOT possible	Relevant
		There is NO Inventory reporting tools	Relevant
		Digital inventory system is NOT implemented with other systems, e.g. ERP	Relevant
		Real time updates are NOT made possible	Relevant
		Historical data is NOT harnessed in inventory analytics	Relevant
		...	Irrelevant

	Element Relevance	Gaps Identified	Gaps Identified
Digital Manufacturing Operations Management	Relevant		
	Manufacturing Execution System (MES)	MES NOT in use	Relevant
	Relevant		
	Enterprise Resource Planning (ERP)	ERP NOT in use	Relevant
	Relevant		
	Advance Planning and Scheduling (APS)	The use of algorithms to calculate the optimal production schedules can prove beneficial	Relevant
		APS system can NOT generate multiple scenarios	Relevant
		There isn't any data visualising tool	Relevant
		Real time schedule change is NOT possible	Relevant
		APS is NOT integrated with other systems e.g. MES, ERP, etc	Relevant
	Relevant		
	SCADA	SCADA is NOT in use	Relevant
	Relevant		
	Enterprise Manufacturing Intelligence (EMI)	Lacks the ability to gather manufacturing data from all systems and locations involved in production	Relevant
		There isn't any feature that allows the manufacturing data to be cleaned and structured for easy usage	Relevant
		Relevant information can NOT be delivered to employees and managers involved in production	Relevant
		Production data can NOT be analysed in real time, neither can users be alerted based on predefined rules	Relevant
		KPIs and metrics for quality management can NOT be monitored	Relevant

		Element Relevance	Gaps Identified	Gaps Identified
25	Quality 4.0	Relevant	Digital Ecosystem NOT in use	
			Quality 4.0 is NOT cloud based	Relevant
			Predictive analytics is NOT in use	Relevant
			Big data analytics is NOT in use	Relevant
			Artificial intelligence is NOT in use	Relevant
			Blockchain is NOT in use	Relevant
			IIoT is NOT in use	Relevant
			Augmented reality is NOT in use	Relevant
			Smart sensors are NOT in use	Relevant
			Machine learning is NOT in use	Relevant
			Can NOT be integrated with MES and EMI	Relevant
25	Additive Manufacturing	Relevant	-	Irrelevant
26	Advanced Virtual Self-Services	Irrelevant	-	Irrelevant
27	Demand Forecasting via Predictive Analytics	Relevant	Demand forecasting via predictive analytics is NOT in use	Relevant
28	Program Logic Controller	Relevant	-	Relevant

		Element Relevance	Gaps Identified	Gaps Identified
29	Product Digitalisation	Irrelevant	-	Irrelevant
			Products can NOT be tracked through out its supply chain journey	Relevant
			Lack of connectivity makes it impossible to deliver customized, contextually relevant content and experiences to your customers	Relevant
30	Digital Customer Relationship Management (Digital CRM)	Relevant	Digital CRM is NOT cloud based	Relevant
			IIoT is NOT in use	Relevant
			Digital CRM is NOT automated	Relevant
			No Real time capability	Relevant
			Can NOT be integrated with other systems like shipping applications, billing systems, order status systems, ERP, point of sale system (POS)	Relevant
			Analytics for strategic decision making and operational journey enhancement is NOT in use	Relevant
			Personalised Touch Point is NOT possible i.e. customers are NOT offered the opportunity to communicate with your company on their own terms	Relevant
			Machine learning is NOT used for forecasting/ predictive analytics	Relevant
			There is NO customer engagement via IoT	Relevant
31	Artificial Intelligence	Relevant	Artificial intelligence is NOT in use	Relevant

Appendix E – Letter of Endorsement

This letter has been redacted for anonymity. The unredacted will be made available to the author's supervisory team and examiners.

[redacted]

To whom it many concern

I am writing to attest that Mr Enyinna Okam collaborated with [redacted] who are Operators [redacted] in Nigeria on his PhD research.

He obtained data for his research through phone interview and a survey.

He has made available to the company findings from his research alongside recommendations on how the company can digitalise its value chain.

We found the results obtained through the Industry 4.0 maturity assessment model he developed and the recommendations he provided very informative. We believe his Industry 4.0 maturity assessment model to be a tool that can assist SMEs digitalise their value chain and develop digital business resilience.

Yours Sincerely,

Name: [redacted]

Position: MD

Signature: [redacted]

Digitally signed by ifeanyi.uzor[redacted]
DN: cn=ifeanyi.uzor[redacted]
Date: 2022.03.02 15:32:20 +01'00'

Date: 3rd March 2022

Okam (2023, p.175 - p.183) These pages have been redacted for copyright reasons.

Conference – Oral Presentation

Kingston University Science Engineering and Computing Conference 2018

The significance of Industry 4.0 at organisational, sectoral and national levels

Enyinna Okam (School of Engineering)
Supervisor: Dr Andy Lung

Industry 4.0 is no longer a thing for the future as it is slowly becoming a reality. Organisations around the world are gradually integrating Industry 4.0 initiatives in their strategies. The implementation of Iot, big data analytics, cloud computing, sensors, 3D printing, advanced automation amongst others allows for a level of transformation in businesses towards significant gains with respect to cost reduction, efficiency as well as revenue generation. Organisations around the world are already beginning to reap the benefits of implementing advance levels of digitization and integration (PWC, 2016). According to a survey carried out by Pwc in 2016 involving over 2000 companies from 9 major industrial sectors and 26 countries across the world, the implementation of Industry 4.0 initiatives would allow for a 3.6% p.a. reduction in operational costs and also an annual increase in efficiency of 4.1%. 3.6% p.a. reduction in operational cost in monetary value amounts up $52 bn, $78 bnand $28 bn for the Industrial manufacturing, engineering construction and automotive sectors respectively. Industry 4.0 can contribute significantly towards organisational growth as well as sectoral growth, which in turn allows for the prospect of Industry 4.0 contributing significantly to growing the economy of a nation. The intended session would cover the significance of Industry 4.0 at organisational, sectoral and national level. Furthermore, the intended session would cover global statistics of Industry 4.0 by region and industries as well as industry 4.0 in a selected developing region of the world.