Szent István University
Doctoral School of Economic and Regional Sciences

The Impact of Industry 4.0 on Supply Chain Integration and Performance: An Empirical Investigation in an Emerging Market

DOI: 10.54598/000230

The Ph.D. Dissertation

Gizem Erboz

Gödöllő, Hungary

2020

Szent István University, Hungary

Name of Doctoral School: Doctoral School of Economic and Regional Sciences

Discipline: Management and Business Administration Sciences

Head of Doctoral School: **Prof. Dr. H.c. Popp, József, DSC**

Corresponding member of the Hungarian Academy of Sciences
Szent István University
Faculty of Economics and Social Sciences
Institute of Agribusiness

Supervisor: **Prof. Dr. Szegedi, Zoltán, Ph.D.**

Széchenyi István University
Kautz G. Faculty of Economics
Department of Marketing and Management

Co-Supervisor: **Assoc. Prof. Dr. Yumurtacı Hüseyinoğlu, Işık Özge, Ph.D.**

Izmir University of Economics
Faculty of Business
Department of Logistics Management

Szegedi Zoltán

....

Approval of the Head of Doctoral School

....

Approval of the Supervisor

....

Approval of the Co-Supervisor

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

3DP: 3D Printing

ADVTECH: Advanced Technology

AI: Artificial Intelligence

AM: Additive Manufacturing

AVE: Average Variance Extracted

BI: Backward Integration

BSC: Balance Score Card

CAD: Computer-Aided Design

CB-SEM: Covariance Based Structural Equation Modelling

CEO: Chief Executive Officer

CFA: Confirmatory Factor Analysis

CInt: Customer Integration

CPS: Cyber Physical Systems

CRM: Customer Relationship Management

CS: Computer Science

E&C: Employee and Culture

EDI: Electronic Data Interchange

EFA: Exploratory Factor Analysis

ERP: Enterprise Resource Planning

FI: Forward Integration

FPERF: Flexibility Performance

I.4.0: Industry 4.0

IAI: Interfirm Activity Integration

ICT: Information and Communication Technologies

IFI: Information Flow Integration

IInt: Internal Integration

IoS: Internet of Services (IoS)

IoT: Internet of Things

ISI: Interfirm Systems Integration

ISO: Istanbul Chamber of Industry

IT: Information Technologies

JIT: Just in Time

KPI: Key Performance Indicator

MES: Manufacturing Execution System

MRP: Material Requirements Planning

MST: Manufacturing Science and Technology

OPC: Coordination of Operational Decisions

OPERF: Output Performance

PFI: Physical Flow Integration

PLS-SEM: Partial Least Squares Structural Equation Modelling

PM: Performance Management

PMS: Performance Management Systems

PPS: Production Planning Systems

RBV: Resource-Based View

RPERF: Resources Performance

ROI: Return on Investments

SC: Supply Chain

SCC: Supply Chain Council

SCI: Supply Chain Integration

SCM: Supply Chain Management

SCOR: Supply Chain Operations Reference

SCP: Supply Chain Performance

SEM: Structural Equation Modelling

SInt: Supplier Integration

SKU: Stock Keeping Unit

SME: Small and Medium Sized Enterprises

S&O: Strategy and Organisation

T: Technology

VIF: Variance Inflation Factor

VMI: Vendor Managed Inventory

UK: The United Kingdom

USA: The United States of America

ACKNOWLEDGEMENTS

I am really grateful to all individuals who helped me in completing this dissertation in several ways. First of all, I would like to thank my parents, Vural Erboz, Sükriye Erboz, Gözde Günestekin and Erdal Günestekin, for their invaluable support and for believing me to pursue my academic goals. I am so privileged to have such a family.

Secondly, I would like to express my sincerest gratitude to my supervisors, Prof. Dr. Zoltán Szegedi and Assoc. Prof. Dr. Işık Özge Yumurtacı Hüseyinoğlu for their guidance, patience and encouragement. I am also thankful to Prof. Dr. Mária Farkasné Fekete, Assoc. Prof Dr. Bengü Sevil Oflaç, Assist. Prof. Dr. Aysu Göçer for their assistance and presence. Additionally, I would like to extend my appreciation to the reviewers of this dissertation, Assis. Prof Dr. Zita Fodor, Assis. Prof Dr. Monika Gabriel and Assoc. Prof. Dr. Attila Kurucz for their precious and helpful suggestions.

Thirdly, I am so thankful to the professionals of the companies for helping me with my data collection. Also, several institutions such as Izmir Chamber of Industry, Izmir Chamber of Commerce, Izmir University of Economics and Yasar University helped me to approach the organisations. I have special thanks to the professionals, Tahir Özdemir, Ali Osman Kesgin, Emel Bıçak, Alparslan Kurtmen, Burak Babayiğit and Mehmet Sıdra for the data collection of this dissertation. I am also grateful to the professionals that I approach through LinkedIn. I appreciate that they gave their precious time to complete the questionnaire in this dissertation.

Additionally, I appreciate the supports of my friends, Don Dungan, Mert Paldrak, Serap Oztürk, Melek Aylin Ozoflu, Bedrettin Gürcan, Giray Gerim, Maral Jamalova and Sezen Korkulu. I am also grateful to Melis Salcı and Fahriye Salcı to encourage me on my academic journey and make my life meaningful in Budapest.

Finally, I dedicated this dissertation to my niece, Ada Güneştekin, who always motivate me with her presence since 2011.

1. INTRODUCTION

1.1. Research Background

The industry is a significant part of an economy that enables productivity and industrial growth (Rüßmann et al., 2015, p.1). Since the start of industrialisation, technological improvements have triggered to fundamental changes that today are called “industrial revolutions” (Lasi et al., 2014, p.239). Industrial revolutions have initiated with the conversion from one-off to mass production, involving division of employees and standardisation (Brettel et al., 2014, p.37). The combination of production processes and information and communication technologies (ICTs) known as “Industry 4.0”, commits the manifold potentials such as increasing operational effectiveness and improvements of new business models, products and services (Hermann et al., 2016, p.3928). A transformation driven by the fusion of advanced technologies spans the connecting systems, analysing data to forecast failures, reacting faster in processes so as to improve the value chain beyond a single company (Rüßmann et al., 2015, p.1).

The introduction of Industry 4.0 into industrial production and manufacturing has also had many influences on the structure of supply chains (SCs) (Tjahjono et al., 2017, p. 1176) in particular real-time tracking of material flows (Hofmann and Rüsch, 2017, p. 24), on-time adaptive decision-making (Zhong et al., 2017, p. 616), administrate predictive maintenance and preclude asset breakdowns (Ghobakhloo, 2018, p.920) and achievements in organisational-economic level such as lean management (Schumacher et al., 2016, p.161) with the integration of Internet of Things (IoT) and Cyber-Physical Systems (CPS). From the marketing perspective, Industry 4.0 supports the mechanisms on a communication channel, which would lead to information exchange and customer-oriented approaches on value-added services (Roblek et al., 2016, p.8). In addition, integrated IT infrastructures that are featured by integrated applications and agreed data standards facilitate information flows and coordination of activities among the partners in the supply chain network (Rai et al., 2006, p. 226). In order to accomplish the race in competitiveness in the global market, enterprises attempt to decentralise their value-adding activities by improving virtual enterprise; this highlights the significance of digital technologies in integrating suppliers, manufacturers, customers or other partnering firms, known as supply chain integration (Gunasekaran and Ngai, 2004, p. 269). Likewise, the targets of Industry 4.0 are to attain a higher efficiency in operations, productivity and automatization (Lu, 2017, p. 1; Haseeb et al., 2019, p. 1). The context of vertical and horizontal manufacturing processes integration supports organisations to obtain higher industrial performance (Dalenogare et al., 2018, p. 383). Moeuf et al. (2018, p. 1118) suggest that the future of enterprises is based on how well they respond to the expectations of their customers while sustaining their competitive advantage. To accomplish this, companies are required to enhance their industrial management processes such as planning and controlling production, utilising resources and measuring operational performance. Furthermore, Industry 4.0 enables analytical capabilities for decision making and flexible manufacturing processes by optimising performance in SCs (Lin et al., 2018, p. 593); thus, improving overall supply chain performance (Vaidya et al., 2018, p. 234).

Despite the potential benefits of Industry 4.0 on supply chain management (SCM), there is a deficiency of the literature in terms of practices of smart production and their influences on the performance, especially in emerging markets (Lin et al., 2018, p. 590). Industry 4.0 has recognised in developed markets, where preceding industrial phases are already mature concerning the implementation of ICT (Dalenogare et al., 2018, p. 385; Kagermann et al., 2013, p. 77). At this point countries with high cost skilled employees may be able to take advantage of a higher level of automation (Rüßmann et al., 2015, p. 11); therefore, a significant gap might occur between developed and emerging markets regarding Industry 4.0 adoption (Dalenogare et al., 2018, p. 385). However, many developing countries also obtain the opportunities for automation due to their young and technology shrewd workforce (Rüßmann et al., 2015, p. 11). In the case of Turkey, there is a rising attention in the utilisation of ICT components by companies because of ongoing changes in the telecommunication sector in recent years (Fındık and Tansel, 2016, p. 107). As indicated by Turkstat (2019), in the country the proportion of Internet usage in enterprises with at least 10 workers reached 94.9%, 66.6% of enterprises have their own website, and one out of two enterprises uses social media and digital tools in 2019. Another point is that the utilisation of advanced technologies leads to production at low cost, conceive new investment and then new occupations (Kılıçaslan and Töngür, 2018, p. 1). Teo et al. (2014, p. 1232) suggest that using technologies without any challenges and using the Internet as a primary source for reaching the adequate information could be used as the main indicators to analyse the level of digitalisation in nations. The results of Turkstat (2019) reveal that in Turkey internet access of households and the usage of internet of individuals aged between 16-74 reached 88.3% and 75.3% respectively in 2019. Therefore, the rising young generation in the country could be more familiar with digital tools and ways of working with them.

Given the above considerations, the main motivation of this dissertation is to investigate the current Industry 4.0 concept in an emerging market, in Turkey, and its impacts on SCM, specifically on supply chain integration (SCI) and supply chain performance (SCP). The rest of the sections, section 1.2, 1.3. and 1.4, explains the problem statement, research questions and hypotheses, and contribution and structure of the dissertation respectively.

1.2. Problem Statement

Digitalisation has a disruptive transformation impact on companies, creating potential influences on value and network perspectives of organisations (Büyüközkan and Göçer, 2018, p.157). Besides, the focus on digitalisation, Industry 4.0 highlights an advanced digitalisation of enterprises; initiating a number of technological advances rather than a sole technology (Glas and Kleemann, 2016, p.56). However, advanced features of Industry 4.0 such as real-time capability, usage of ICT systems through vertical and horizontal integration and interoperability are considered current challenges to stay competitive for enterprises. The process of digital transformation needs multidisciplinary activities; therefore, the current state of the consensus might be challenging to understand the idea of Industry 4.0, its comprehensive strategies and methodologies that help organisations operationalise this transformation (Colli et al., 2018, p. 1347). Therefore, a deeper understanding of the concept and its vision must be provided by academics and practitioners (Ibarra et al., 2018, p. 5). The technology architecture of Industry 4.0 could be viewed as complex; in this sense, an effective assessment of Industry 4.0 is a significant manner of research (Lee et al., 2015, p. 18). Hence, both academics and practitioners have emphasised the important winnings through the integration of digital systems and intelligent manufacturing processes; however, this integration must be taken in both "horizontal level" (integration of all value chain participants) and "vertical level" (integration of all spheres of automation) (Schumacher et al., 2016, p. 161). To address this issue, some scholars have proposed the frameworks, roadmaps, maturity or readiness assessments for effective implementation of Industry 4.0 (Ghobakhloo, 2018; Schumacher et al., 2016; Akdil et al., 2018; Sony and Naik, 2019; Castelo-Branco et al., 2019); however, there is still uncertainty of the effect of Industry 4.0 systems on the concept of operation management, and SCs (Ivanov et al., 2018, p. 137). For this reason, the effects of Industry 4.0 on SCM concept is an open question since there are only a few specified examples of its influences on SCM (Tjahjono et al., 2017, p.1178). Although some studies claim that Industry 4.0 improves the overall SCP (Lin et al., 2018, p. 590; Ardito et al., 2019, p. 339; Ivanov et al., 2018, p.140); however, the linkage between these two remains inexplicable because the number of empirical analyses has stayed limited to observe the clear effects of Industry 4.0 on SCP.

Another raised question for decades also is whether more integration improves the performance in supply chains. Many studies confirm the positive effect of SCI on SCP (Danese and Bortolotti, 2014, p.7079; Prajogo and Olhager, 2012, p.520; Zailani & Rajagopal, 2005, p.390; Zhao et al., 2015, p.170), while some studies argue that SCI does not always increase SCP (Fabbe-Costes and Jahre, 2008, p.130; Vickery et al., 2003, p.533; Cousins and Menguc, 2006, p.605). Another point is that even the assessment of IT or digital technologies sometimes does not have a direct effect on SCP; there could be an indirect effect via the influence of SCI (Li et al., 2009, p.126; Delic et al., 2019). This possibility has also taken less interest in the literature. Thus, it is significant to provide more research to explore the clear relationships between these concepts.

1.3. Research Questions and Hypotheses

Regarding the discussion in section 1.2, the main objective of this dissertation is to identify the links among the concepts of Industry 4.0, SCI and SCP. As previously mentioned, the lack of studies has been identified in that field; therefore, this dissertation attempts to identify whether the practices of Industry 4.0 positively affect the concepts of SCM, in particular SCI and SCP. In addition, the dissertation aims to observe the relevance between SCI and SCP since different perspectives are taken in the literature. For this reason, in this dissertation, the definitions, directions and elements of these three concepts have been analysed and, in the end, the linkages have been tested empirically. The arguments regarding the dissertation lead to improved research questions, as follows:

Research Question 1: *How does Industry 4.0 affect SCI?*

Using IT and advanced digital technologies the partners in a supply chain require to undergo system alterations to enrich the relationships between them (Birasnav and Bienstock, 2019, p. 150; Vickery et al., 2003). Thus, it is expected that advanced technological solutions drive manufacturing processes to integrate the partners in a supply chain with their production systems. Although the research is ambiguous yet related to assessment models on Industry 4.0, this dissertation seeks to answer whether there is an impact of Industry 4.0 on SCI. After reviewing the literature, the first hypothesis was formulated as followed:

H1: Industry 4.0 positively affects Supply Chain Integration.

Research Question 2: *How does SCI affect SCP?*

SCI can be seen as a key success of organisations and their SCs (Huo, 2012, p. 596; Fabbe Costes and Jahre, 2008; Flynn et al., 2010). For many years, the scholars (Narasimhan and Kim, 2002, p.303; Sezen, 2008, p. 233; Vickery et al., 2003, p.533) argue whether the capabilities of SCI are always beneficial for SCP. However, the effects of SCI on SCP are still unknown (Zhao et al., 2015, p.162). Thus, this dissertation investigates whether SCI has an effect on SCP. Based on the in-depth review analysis, it has been hypothesised that;

H2: Supply Chain Integration positively affects Supply Chain Performance.

Research Question 3: *How does Industry 4.0 affect SCP?*

As briefly mentioned in Section 1.1., Industry 4.0 stimulates production processes through integrating them horizontally and vertically, as a consequence of this, it is estimated that the concept will increase both firm performance and SCP (Dalenogare et al., 2018, p. 383; Buer et al., 2018, p. 2934; Frank et al., 2019, p. 20). Accordingly, this dissertation explores the effects of Industry 4.0 on SCP. Regarding the analysis of the literature, the third hypothesis was formulated as followed:

H3: Industry 4.0 positively affects Supply Chain Performance.

In addition to the arguments mentioned above, some authors believe that there is a mediating role of SCI between Industry 4.0 and SCP (Delic et al., 2019; Yu, 2015, p.955; Bruque-Cámara et al., 2016, p.149). Since the role of integration in supply chains has been taken lack of importance when the relationship is observed between digital technologies and performance aspects; this thesis also seeks the impact of SCI between Industry 4.0 and SCP. Based on the literature, the fourth hypothesis was created as followed:

H4: Supply Chain Integration mediates the relationship between Industry 4.0 and Supply Chain Performance.

Research Question 4: *How should organisations prioritise the indicators of Industry 4.0 and SCI strategically to achieve higher performance in the context of supply chain?*

The dissertation also deepens the nature of links between three constructs by analysing the prioritisation items of Industry 4.0 and SCI, which lead to higher performance. It is significant to investigate which items are important for SCP and how companies perform on these items based on the analysis of the Importance-Performance Matrix. Ghobakhloo (2018, p. 911) suggested that organisations require to formulate accurate plans and designing principles because the directions of Industry 4.0 are still challenging and uncertain. Akdil et al. (2018, p. 62) argued that the outcomes of Industry 4.0 are still ambiguous because organisations do not have expertise on the concept. Therefore, the current state and route for the assessment of Industry 4.0 are necessary.

1.4. Contribution and Structure of the Thesis

The main contribution of this dissertation is to introduce the effects of Industry 4.0 assessment on the SCM concept in manufacturing organisations. The results of the dissertation could be an example to observe the practices of Industry 4.0 as well as the activities in SCM in developing economies. Besides, the hypotheses developed are grounded by two well-known theories: resource-based view (RBV) and relational view; in this way, a more complete model could be achieved through theoretical support. Likewise, with the analysis of a comprehensive literature review, this dissertation contributes to conceptualising Industry 4.0, SCI and SCP; and identify the models proposed related to them. Noteworthily, only a little research has been empirically conducted in order to analyse the connections between Industry 4.0 and the concept of SC; therefore, this dissertation also aims to close the research gap in this field by providing the statistical modelling on the data taken from primary sources.

In light of the discussion in this chapter, this dissertation is structured as follows. Chapter 2 starts with the reviews of Industry 4.0, SCI and SCP; and the sections include the definitions and the elements of these three concepts. Chapter 3 indicates the methodology selected in this dissertation by addressing the research design and model as well as explaining the tools of the analysis. Chapter 4 displays the findings of the analysis by explaining descriptive statistics, the validity of the model and structural model analysis. Finally, in chapter 5, the main conclusions and recommendations about the dissertation have been highlighted.

2. LITERATURE REVIEW

2.1. Review of Industry 4.0

2.1.1. Towards Information Revolution: Industrial Revolutions at a Glance

In the sphere of the context of industrial manufacturing, the developments of science and technology underpin the advances in industrialisation around the globe (Liao et al., 2017, p. 3609). The first industrial revolution, the introduction of steam power and water usage in industrial places, covering the period between the second half of the 18th century and almost the whole 19th century (Hermann et al., 2016, p.3932). There was an increase in productivity in fabric production since that production transferred from private homes to central factories. The second industrial revolution which took place after the application of electrically powered technologies (Liao et al., 2017, p. 3609), supported the mass production model through the division of employees (Drath and Horch, 2014 p.56). Using continuous production lines and conveyor belts triggered in productivity infusion in manufacturing industries. Utilisation of electronics and information technology such as computers, networks, interfaces, etc. are the concepts of the third industrial revolution, supporting automation of manufacturing (Drath and Horch, 2014 p.56) and creating highly flexible and efficient systems (Barreto et al., 2017, p.1246). The term “Industry 4.0”, representing the fourth industrial revolution, connects physical devices and company’s assets via the Internet (Vaidya et al., 2018, p.234), increases a multifaceted system with the combination and coordination by computational abilities of Cyber-Physical Systems (CPS) (Colombo et al., 2017, p.6).

Blinder (2006, p.115) explains that “industrialising countries from farm to factory, societies were transformed beyond recognition”. After the first and second revolutions, the shifts were massive; the workers moved into factories from farms. Through the years, the potential benefits of industrial revolutions are immense such as massive influences on social life and in commerce with a new industrial class and new labour streams; alterations on production structures by promising delivery times (Chin et al., 2006, p.572) and productivity (Matsuyama, 1992, p.317; Schuh et al., 2014, p.51); in other words, creating complexity and variety for manufacturing industries.

According to Nuvolari (2019, p.34), during the 1980s, rapid growth and diffusion of innovation were characterised by the dispersion of ICT; however, the evolution of these technologies could be captured better in capitalist economies; therefore, the chronological scheme could be distinguished among countries in terms of industrial revolutions. Singh (2017, p. 15) emphasises that the sustainability of these industrial revolutions is also significant for industries with accurate economic analysis in each country. Popkova et al. (2019, p.23), the prior condition for the outbreaking of industrial revolutions is to enhance an adequate volume of industrial production thanks to new technologies. After these technologies access a sufficient number; the second part is to improve them; which occurs with necessary development for implementation; therefore, the transition process from quantity to quality could begin. However, in this case, there could be some challenges due to inadequate well-established infrastructure for these technologies.

As to preliminary points of all industrial revolutions, technological leaps create paradigm shifts (Lasi et al., 2014, p. 239); however, some structural changes in work environment increase creativity and productivity of employees as well as easing human work in business (Lorenz et al., 2015 p.14; Anon, 2016 p.120). Companies tend to be more responsive to the requirements of their customers and handling their complexities (Blinder, 2006, p.115). Development of skills and capabilities, the complexity of innovation, establishing infrastructure, value chain shifts, socio-economic changes and environmental changes are the main issues of transforming manufacturing businesses and the future of production through Industry 4.0 (Moavenzadeh, 2015, p.18).

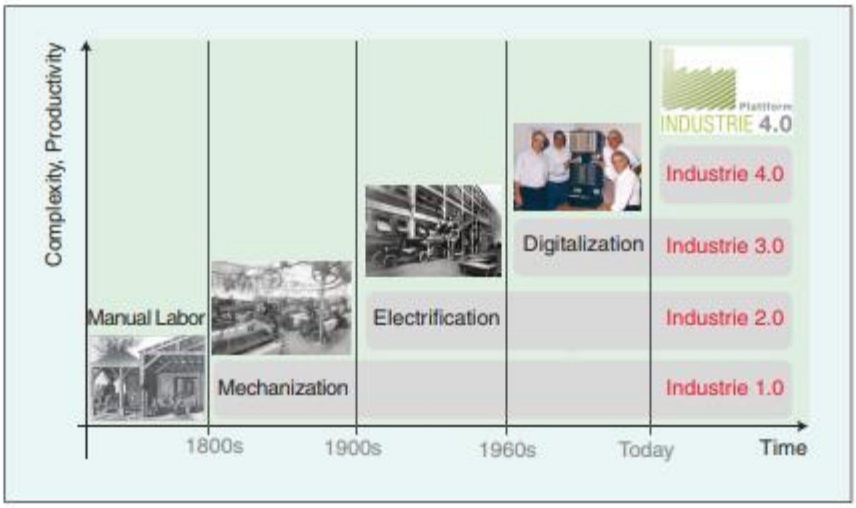


Figure 1. An Overview of the Industrial Revolutions
Source: Drath and Horch (2014, p.56)

Figure 1 displays an overview of the industrial revolutions in industries. As Figure 1 shows, these are the last 200 years of mankind which display us accelerated speed in revolutionising operations. Furthermore, the complexity and productivity of production have increased by each industrial revolution.

2.1.2. The Concept of the Fourth Industrial Revolution (Industry 4.0)

The concept of "Industry 4.0" received public attention in 2011; when a venture called "Industrie 4.0" through academia and practitioners, maintained the idea of enhancing the competitiveness of manufacturing industry (Hermann et al., 2016, p. 3932). Later, the idea was granted by the German federal government as "High Tech Strategy 2020", targeting the leadership on technological developments (Kagermann et al., 2013, p.77). There were also similar strategies put forward by other key industrial countries, for instance, "Industrial Internet from the USA and Internet + from China" (Wang et al., 2016, p.1).

According to the definition of the European Parliament (2016, p.20), Industry 4.0 is described as follows;

"*the organisation of production processes based on technology and devices autonomously communicating with each other along the value chain: a model of the smart factory of the future where computer-driven systems monitor physical processes, create a virtual copy of the physical world and make decentralised decisions based on self-organisation mechanisms."*

In this dissertation, various research papers have been analysed to identify the definition and dimensions of Industry 4.0. The systematic search was based on two well-known electronic databases, Web of Science (WoS) and SCOPUS. Through a comprehensive set of studies, the author categorised the descriptions of the term into two groups: the first one consists of the technical and technology-related definitions of Industry 4.0, while the second group covers the value chain integrated perspectives of the concept. Table 1 indicates the example definitions of the articles selected from high quality management journals such as "Journal of Manufacturing Technology Management", "Sustainability", "Technological Forecasting and Social Change", "International Journal of Production Research" and so on.

Accordingly, some scholars (Sanders et al., 2016, p. 816; Bortolini et al., 2017, p. 5702; Ghobakhloo, 2018, p. 910; Sung, 2018, p. 41; Vaidya et al., 2018, p. 237; Mariani and Borghi, 2019, p. 2) use the technology-oriented definitions to define the Industry 4.0 concept. These studies mostly mention the terms of "Cyber-Physical Systems (CPS), Internet of Things (IoT) or smart systems" to conceptualise the definition of Industry 4.0. Sanders et al. (2016, p. 816) argue that Industry 4.0 depends on the principles of smart technologies by enabling human-machine interaction. Bortolini et al. (2017) identify that Industry 4.0 transforms traditional production systems through the fusion of IoT and advanced technologies such as "big data, cloud and machine learning". Ghobakhloo (2018, p. 910) suggests that the application of CPS plays a key role to accomplish Industry 4.0. Sung (2018, p. 41) views that Industry 4.0 represents significant technological improvements that change the direction of designing, producing and commercialising products and services. Vaidya et al. (2018, p. 237) explain that Industry 4.0

provides smart production processes through smart communication of machines and products. Mariani and Borghi (2019, p. 2) also mention the technical side of Industry 4.0 by considering the three basic concepts of Industry 4.0 as “CPSs, IoT and smart factory”. Xu et al. (2018, p. 2942) propose that Industry 4.0 combines the integrated systems of digital technologies.

Some other research attempts to define Industry 4.0 from a broader perspective rather than only focusing on technological terms of the concept (Wang et al., 2016, p. 1; Hermann et al., 2016, p. 3930; Hofmann and Rüsch, 2017, p. 24; Ardito et al., 2018, p. 326; Müller et al., 2018a, p. 4; Nagy et al., 2018, p. 4; Nosalska et al., 2019, Forthcoming). These studies discussed that Industry 4.0 not only offers technological developments but also increases the integration of value chains. According to Wang et al. (2016, p.1), Industry 4.0 could be described as “Cyber-Physical Systems (CPS) that integrate production facilities, warehousing systems, logistics, and even social requirements to establish global value creation networks”. The study of Hermann et al. (2016, p.3930) describes the concept as both technologies and value chain concepts; however, the six design principles of Industry 4.0 need to be enforced accurately; (i) “interoperability” (integration of the systems such as human-human, machine-machine and human to machine) through IoT, (ii) “virtualisation” (fusion of physical aspects into the virtual world), (iii) “decentralised decisions”” (decision making of embedded computers on their own), (iv) real-time capability” (collection of data in real-time), (v) “service orientation” (a combination of transparency and interconnection from inside and outside of a company), and (vi) “modularity” (flexible modular systems that adapt to changing requirements). Hofmann and Rüsch (2017, p.25) define Industry 4.0 as basically with three concepts: “flexible products and services, digital connectivity and decentralised value networks”. Ardito et al. (2018, p. 326) explain that Industry 4.0 increases digitisation that leads to horizontal and vertical integration of companies’ processes. Müller et al. (2018a, p. 4) indicate that Industry 4.0 suggests the integration of different practices of supply chains by using digital technologies. Furthermore, Nagy et al. (2018, p. 4) acknowledged that Industry 4.0 is a networked-linked approach, integrating the value chain operations and supply chain activities. Finally, Nosalska et al. (2019, forthcoming) discussed that Industry 4.0 is a concept of value chain integration that supports customer requirements through the related technologies.

Although there are several definitions of Industry 4.0 as indicated above; however, the scholars argue that the literature lacks a well-agreed explanation of the concept (Hermann et al., 2016, p. 3928; Hofmann and Rüsch, 2017, p.24; Ghobakhloo, 2018, p.929, Brettel et al., 2014, p.43). As previously explained, the studies which approach the different perspectives about the definition of Industry 4.0, are displayed in Table 1.

Table 1. Example Definitions of Industry 4.0

Category	Authors	Definitions
Technology-oriented definitions of Industry 4.0	Sanders et al. (2016, p.816)	Industry 4.0 applies "the principles of cyber-physical systems (CPS), internet and future-oriented technologies and smart systems with enhanced human-machine interaction paradigms"
	Bortolini et al. (2017, p. 5702)	"Industry 4.0 can be defined as the comprehensive transformation of the entire industrial production through the merging of Internet and information & communication technologies (ICT) with traditional manufacturing processes"
	Ghobakhloo (2018, p. 910)	"In general, Industry 4.0 is interpreted as the application of the cyber physical systems within industrial production systems"
	Sung (2018, p.41)	"A smart factory, a key feature of Industry 4.0, adopts a so-called calm-system that deals with both the physical world and the virtual world"
	Vaidya et al. (2018, p.237)	"Industry 4.0 which allows smart, efficient, effective, individualised and customised production at a reasonable cost. With the help of faster computers, smarter machines, smaller sensors, cheaper data storage and transmission could make machines and products smarter to communicate with each and learn from each other"
	Xu et al. (2018, p.2942)	"Industry 4.0 focuses more on the end to end digitisation and the integration of digital industrial ecosystems by seeking completely integrated solutions"
	Mariani and Borghi (2019, p. 2)	"The three basic concepts underpinning the *Industrie* 4.0 phenomenon are: cyber-physical systems (CPSs), Internet of things (IoTs), and smart factories"
Value-Integration oriented definitions of Industry 4.0	Wang et al. (2016, p.1)	"Industry 4.0 is a production oriented Cyber-Physical Systems (CPS) that integrate production facilities, warehousing systems, logistics, and even social requirements to establish global value creation networks"
	Hermann et al. (2016, p.3930)	"Industrie 4.0 is a collective term for technologies and concepts of value chain organisation. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralised decisions"
	Hofmann and Rüsch (2017, p. 25)	"The value networks are controlled decentralised while system elements (like manufacturing facilities or transport vehicles) are making autonomous decisions (autonomous and decentralised decision making)"
	Ardito et al. (2018, p. 326)	"The main idea underlying the Industry 4.0 is running businesses by adopting digital technologies that can help firms to create connections between their machinery, supply systems, production facilities, final products, and customers in order to gather and share real-time market and operational information"
	Müller et al. (2018a, p. 4)	"Industry 4.0 leads to industrial value creation that is not only automated, mostly within single manufacturing plants, but also interconnected between objects, products, and humans, building on the concept of the Internet of Things"
	Nagy et al. (2018, p. 4)	"Industry 4.0 penetrates the entire value chain of the corporation—although most of the value chains are interpreted as production-based, possibly supplemented with the logistics operations"
	Nosalska et al., (2019, Forthcoming)	"Industry 4.0 is a concept of organisational and technological changes along with value chains integration and new business models development that are driven by customer needs and mass customisation requirements and enabled by innovative technologies, connectivity and IT integration"

Source: Compiled by the author

In this dissertation, it has been considered that the descriptions related to Industry 4.0 could be convergent although the scholars view the diverse approaches on the principles of Industry 4.0. Most of the authors define Industry 4.0 as the following terms; "integration of smart systems", "Internet standards", "CPS", "human-machine interaction"; which are the concepts of "smart factory". This dissertation considers the explanation of Industry 4.0 concerning both "technology-oriented" and "value-integration oriented" definitions. Therefore, this dissertation follows the definition of Müller et. al (2018a, p.4), which is that "Industry 4.0 leads to industrial value creation that is not only automated, mostly within single manufacturing plants, but also interconnected between objects, products, and humans, building on the concept of the Internet of Things”.

2.1.3. Assessment Models of Industry 4.0

Previous research has conceived that manufacturing companies have little understanding or ability to implement the full extent of Industry 4.0 (Bibby and Dehe, 2018, p. 1034; Schumacher et al., 2016, p.162). Mittal et al. (2018, p.199) state that the phrases “roadmaps, frameworks, readiness assessments or maturity models” have a slight distinction in their explanations.

(i)Roadmaps provide a prerequisite for the improvement of the successful transition with digital solutions (Ghobakhloo, 2018, p. 911) including both short term and long-term plans (Mittal et al., 2018, p.199).

(ii)Maturity Model is a stepwise approach to achieve continuous improvement for enterprises (Mittal et al., 2018, p.199) and to transform their businesses and operations with maturity levels -capabilities of companies- (Akdil et al., 2018, p.61).

(iii)Frameworks are architecting systems that provide consistent procedures, methods and tools (Mittal et al., 2018, p.199).

(iv)Readiness Assessments are measurement tools to identify the extent of preparedness and presence of adequate conditions, attitudes, resources and so on (Castelo-Branco et al., 2019, p.31; Mittal et al., 2018, p.199).

The previous studies employed the terms “readiness”, “maturity”, “framework” or “roadmap” jointly in order to evaluate their models of Industry 4.0 since the field is still in the emerging phase (Gökalp et al., 2017, p. 131; Akdil et al., 2018, p.63; Schumacher et al., 2016, p.162; Bibby and Dehe, 2018, p.1034; Mittal et al., 2018, p.199). Thus, in this dissertation, it has been adjusted the models which include these terms for evaluating the categories and items of Industry 4.0 assessment. The further measurement model has been called “the Industry 4.0 assessment model” in this dissertation.

Some researchers suggested the “readiness assessment” models to identify the dimensions of Industry 4.0 (Lichtblau et al., 2015, p.21; Jung et al., 2016, p.712; Castelo-Branco et al., 2019, p.27; Sony and Naik, 2019, forthcoming). The Industry 4.0 model of Lichtblau et al. (2015, p.21) encompasses six categories; “strategy and organisation” (implementing and reviewing Industry 4.0 strategy and investments), “smart factory” (including automated production, control and monitoring processes), “smart products” (ICT components such as sensors, communication interfaces), “smart operations” (integration of physical and virtual world, production planning systems -PPS-), “employees” (new skills and adaptability of workers, and “data driven services” (collection of data about processes, customers and suppliers). Jung et al. (2016, p.712) categorise their manufacturing system readiness assessment into four categories; “organisational” (comprehensiveness of the activities such as identifying activities for digital transformations and assigning responsible people for this), "IT" (availability of IT resources), "performance management" (which performance indices are used and monitored) and "information connectivity" (exchanging and sharing of necessary information). Castelo-Branco et al. (2019, p.27) measure the European countries' adaption level into Industry 4.0 by considering two categories; "Industry 4.0 infrastructure" (a combination of interconnectivity, interoperability, and virtualisation) and "Big Data Maturity" which refers to the ability of processing the information through Industry 4.0 implementation. The findings of the paper indicate that a huge dispersion among countries exists in terms of the adequate conditions for the readiness of Industry 4.0 and even the large economies in Europe such as France and Italy indicate lower than average values in both categories; while the UK is ranked in the top regarding "Big Data Maturity", the country has been positioned below average regarding "Industry 4.0 infrastructure". According to the systematic literature review analysis of Sony and Naik (2019), the key ingredients of Industry 4.0 readiness can be grouped into six categories: "top management involvement, the readiness of organisational strategy, level of digitalisation, the extent of digitalisation, smart products and services, and employee adaptability" with Industry 4.0. These categories are interconnected with each other; thus, companies should consider all these factors to assess Industry 4.0 successfully.

Some scholars also considered the maturity models for Industry 4.0 (Schumacher et al., 2016, p.164; Gökalp et al., 2017, p.139; Schuh et al., 2017, p.20; Akdil et al., 2018, p.68; Fettermann et al., 2018, p. 257; Colli et al., 2018, p.1349; Sjödin et al., 2018, p.24; Asdecker and Felch, 2018, p.850; Bibby and Dehe, 2018, p.1038; Mittal et al., 2018, p.207). Schumacher et al. (2016, p.164) develop empirically grounded models to assign Industry 4.0 maturity of manufacturing companies; they identify 9 overall categories; "(i) products, (ii) customers, (iii) technology, (iv) operations, (v) strategy, (vi) leadership, (vii) governance (viii) culture and (ix) people" and 62 items for measuring Industry 4.0 maturity. They note that assessing the maturity model of Industry 4.0 is not a simple task, which must reflect the current capabilities, respective strategies and action plans of companies. Gökalp et al. (2017, p.139) analyse seven maturity models/frameworks on Industry 4.0 in terms of "their scope, purpose, completeness, clearness and objectivity"; and their findings show that any of them does not meet the anticipated criteria; thus, they require to be developed. According to their proposed model, Industry 4.0 must be viewed as a holistic approach including "process transformation, application management, data governance, asset management and organisational alignment areas". Schuh et al. (2017, p.20) identify the capabilities that a manufacturing firm needs to adapt to achieve transformation into an agile organisation. These capabilities are explained as "structural areas including resources, information systems, culture and organisational structure". "Resources" explain tangible and physical resources such as human resources, equipment, materials, tools and so forth. Information systems include socio-technical systems, human-machine interaction, processes, store and transfer data and information to enhance real-time ability. Culture and organisational structure consist of both collaboration on internal organisation and dynamic relationships through value network. The framework of Akdil et al. (2018, p.68) has been grouped into three categories – “strategy and organisation, smart business processes and smart products and services”, with 13 regarded fields within these categories. The research was applied in a retail firm operated in Turkey. Fettermann et al. (2018, p. 257) analyse 38 successful cases based on the companies’ websites, publications and government reports about Industry 4.0 assessment. The study observes the “technology” category as the most commonly used term among the literature; therefore, their framework is mostly technology-oriented including “IoT, CPS, mobile devices, cloud computing, data analysis and processing, augmented reality and additive manufacturing”. However, they also add that some socio-cultural aspects such as “Leadership and Culture” could be considered in Industry 4.0 models. Colli et al. (2018, p.1349) introduce five clusters on the digital capabilities of organisations to evaluate the maturity level of them. These digital capabilities cover the indicators of “governance, technology, connectivity, value creation and competence”. “Governance” indicates the current state of the firm at organisational level such as strategy, resources, awareness of Industry 4.0. “Technology” includes the process of digital data through information systems such as MES, ERP systems, and business intelligence programs. “Connectivity” represents the infrastructural tools to transmit the data such as security systems, and data sharing capabilities. “Value creation” is the capability of capturing valuable data such as forecasting the data or monitoring the data for predictive maintenance purposes. Finally, “competence” represents the mindset and skills to create digital solutions such as a training and learning culture. Sjödin et al. (2018, p.24) develop the three categories; “people, technology and process” regarding the challenges mentioned through 31 in-depth interviews in Sweden on Industry 4.0 adoption. They emphasise that competencies and skills should be improved on employers’ side to handle fast technological transformations; and agile systems must be improved in a way of short development cycles and daily stand-ups to meet changing demands. Besides, these capabilities must be supported by technologies to cope with continuous innovation and the complexity of value chains. Asdecker and Felch (2018, p.850) develop a technology grounded model of “Industry 4.0 maturity for the delivery process” of companies. Their approach defines that Industry 4.0 covers “integrated database” (integrating different departments through a single database), “integrated interface” (using interfaces to eliminate media discontinues), “information flow” (using multiple sources for real time information), “mobile devices” (employee access to cloud services), “digital mapping” (using a digital twin of physical objects), "automated monitoring" (the ability to track and trace processes), "machine learning" (providing system via algorithms), "self-optimisation" (autonomously reacting to alterations on changing conditions and offering optimal solutions to solve them), and "partner integration" (integrating supply chain partners into digital ecosystems). Bibby and Dehe (2018, p.1038) propose a conceptual framework on Industry 4.0 maturity including three groups: "factory of the future" (advanced technologies on Industry 4.0), "people and culture" (skills on openness to innovation), and "strategy" (digital investments, agility and production strategy). The key findings of the study reveal that manufacturing companies are on the development phase of Industry 4.0 assessment; companies need to focus more on the allocation of resources, aiming at improvement, sharing knowledge with their main value chain members and detailed roadmap on digitalisation (Bibby and Dehe, 2018, p.1040). The research conducted by Mittal et al. (2018, p.207) acknowledged the requirements of SMEs in digital transformation. According to the study, the models should consist of the capabilities of SMEs in terms of "finance", "resource availability", "standardisation", "organisation culture", "employee participation", "alliance with academic/ research institutes" and "collaboration with their suppliers".

Some scholars also named their Industry 4.0 model as frameworks or roadmaps (Geissbauer et al., 2016, p.28; Ghobakhloo, 2018, p. 927; Bienhaus and Haddud, 2018, p. 971). Geissbauer et al. (2016, p.28) propose "an assessment model for Industry 4.0"; mainly concentrates on strategies and technological capabilities of companies. The model is based on seven categories; "digital business models (disruptive digital solutions to serve customers), "digitalisation of products and service" (implementing integrated solutions via smart sensors or communication devices), "vertical and horizontal value chains" (integration in both across the whole company and from suppliers to customers), "data analytics" (availability of data and data integrated systems), "agile IT architecture" (IT infrastructure to respond to demand quickly), "compliance security, legal and tax" (identifying risks and challenges in a digital network), "organisation, employees and culture" (digital culture and skills of employees). Geissbauer et al. (2016, p.14) emphasise that real-time update about products and services with value chain is adequate for digital transformation. Ghobakhloo (2018, p. 927) attempts to improve "a strategic roadmap for Industry 4.0 transition" by mainly using advanced technologies "big data, cloud computing, IoT, CPS" and so on as the items. They define the categories as the strategies in functional areas including "strategic management in general", "marketing strategy", "human resources strategy", "IT maturity strategy", "smart manufacturing strategy" and "smart supply chain management strategy" towards Industry 4.0 transition. However, they suggest that there are no well-agreed strategies that could be applicable for all businesses; because of the differences in their core competencies, motivations, abilities, priorities and capital (p.930). Bienhaus and Haddud (2018,

p. 971) attempt to examine the relationship between digital transformation and procurement activities in supply chain management. They develop three constructs on their empirical research from 414 manufacturing and service companies. The first construct includes the items about “Artificial Intelligence”, “Big Data” and “Internet of Things” towards procurement activities. The second construct covers “organisational structure and culture”, “organisational environment”, and “leadership and ‘employee”. The third construct also encompasses the tools and technologies for communication and collaboration. The study suggests that capacities and capabilities through digital transformation assist the companies’ vision and mission to become more sustainable and achieve long term profitability (p.981).

Asdecker and Felch (2018, p.850) ascertain that many maturity/readiness models in Industry 4.0 concentrate on the manufacturing processes of companies. However, in the long run, value creation activities, both upstream and downstream, must be exploited; otherwise, competitive advantage in industrial companies will be disregarded. Rajnai and Kocsis (2018, p.229) compared the different approaches on Industry 4.0 assessment and conclude that there is no well-accepted model of Industry 4.0 readiness in previous research due to the developing phase of the digital transformation phenomenon. However, there is an increase in research interest on readiness models of Industry 4.0 as well as the research gap; because the evaluation criteria consist of different categories and items in the proposed models (Akdil et al., 2018; Sony and Naik, 2019). For that reason, more models need to be developed to understand the main ingredients and to determine the readiness of Industry 4.0 holistically.

Table 2. Industry 4.0 Assessment Models

Category	Authors	Model Name	Method of the Study	Assessment Categories
The Readiness Models	Lichtblau et al. (2015)	“Industry 4.0 Readiness Model”	Questionnaire	Six categories are measured; “strategy and organisation”, “smart factory”, “smart products”, “smart operations”, “employees” and “data- driven services”
	Jung et al. (2016)	“Smart Manufacturing System Readiness Assessment”	Reference Activity Model	The assessment model is analysed with four categories; “organisational, IT, performance management and information connectivity”
	Castelo Branco et al. (2019)	“Adoption & Readiness Model of Industry 4.0”	Questionnaire	The adoption level of I.4.0 includes two categories; “Industry 4.0 infrastructure” and “Big Data Maturity”
	Sony and Naik (2019)	“Industry 4.0 Readiness Model”	Systematic Literature Review	Their readiness model is grouped in six categories: “top management involvement”, “organisational strategy”, “level of digitalisation”, “extent of digitalisation”, “smart product and services”, and “employee adaptability”
The Maturity Models	Schumacher et al. (2016)	“Industry 4.0 Maturity Model”	Questionnaire	Their model includes 9 categories; “products, customers, technology, operations, strategy, leadership, governance culture and people”
	Gökalp et al. (2017)	“Industry 4.0 Maturity Model”	Literature Review	The model applies in five holistic areas; “process transformation”, “application management”, “data governance”, “asset management” and “organisational alignment areas”
	Schuh et al. (2017)	“Industry 4.0 Maturity Index”	Multi-Case Study	Model was tested with three structural areas including “resources”, “information systems”, “culture and organisational structure”
	Akdil et al. (2018)	“Industry 4.0 Maturity and Readiness Model”	Case study	Three categories are determined; “strategy and organization”, “smart business processes” and “smart products and services”
	Fettermann et al. (2018)	“Industry 4.0 Maturity Model”	Multi-Case Study	Their technology-oriented model including “IoT”, “CPS”, “mobile devices”, “cloud computing”, “data analysis and processing”, “augmented reality” and “additive manufacturing”
	Colli et al. (2018)	“Maturity Assessment for Industry 4.0”	Problem Based Learning Model	The assessment model covers five clusters; “governance”, “technology”, “connectivity”, “value creation” and “competence”
	Sjödin et al. (2018)	“A Preliminary Maturity Model for Digitalisation”	Exploratory Case Study	The model includes three categories; “people”, “technology” and “process”
	Asdecker and Felch (2018)	“Development of Industry 4.0 Maturity Model”	Questionnaire	Their model is technology grounded with the categories; “integrated database”, “integrated interface”, “information flow”, “mobile devices”, “digital mapping”, “automated monitoring”, “machine learning”, “self-optimisation”, “partner integration”
	Bibby and Dehe (2018)	“Industry 4.0 Maturity Assessment”	Multi-Case Study	Three categories are evaluated; “factory of the future”, “people and culture” and “strategy”
	Mittal et al. (2018)	“Smart Manufacturing and Industry 4.0 Maturity Model”	Literature Review	The requirements are determined in maturity models; “finance” “resource availability”, “standards”, “culture”, “employee participation”, “alliances”, “collaboration”
The Frameworks and Roadmaps	Geissbauer et al. (2016)	“Digital Enterprise Model for Industry 4.0”	Questionnaire	The model focuses on strategies and technological categories; “digital business models”, “digitalisation of products and service”, “vertical and horizontal value chains”, “data analytics”, “agile IT architecture”, “compliance security”, “legal and tax”, “organisation, employees and culture”
	Ghobakhloo (2018)	“Strategic Roadmap Toward Industry 4.0”	Systematic Literature Review	The categories of the model include functional areas; “strategic management”, “marketing strategy”, “human resources strategy”, “IT maturity strategy”, “smart manufacturing strategy” and “smart supply chain management strategy”
	Bienhaus and Haddud (2018)	“Digitisation Framework for Procurement”	Questionnaire	The model covers three constructs; “AI, Big Data and IoT”, “organisational structure and culture, organisational environment leadership’ and ‘employee” and “the tools and technologies for communication and collaboration”

Source: Compiled by the author

Table 2 displays several assessment models of Industry 4.0 mentioned above. Based on the analysis of this dissertation, the author categorises the assessment models as “the readiness models”, “the maturity models” and “the frameworks and roadmaps”. Furthermore, it has been shown the key dimensions of each assessment model as well as the methods of their studies.

Table 3.Dimensions of Industry 4.0 Assessment Models

Study/Dimensions	**Strategy**	**Employee**	**Culture & Organisation**	**Technology**
Lichtblau et al. (2015)	X	X	X	X
Jung et al. (2016)			X	X
Schumacher et al. (2016)	X	X	X	X
Geissbauer et al. (2016)		X	X	X
Gökalp et al. (2017)			X	X
Schuh et al. (2017)			X	X
Akdil et al. (2018)	X			X
Fettermann et al. (2018)				X
Colli et al. (2018)			X	X
Sjödin et al. (2018)		X		X
Asdecker and Felch (2018)	X			X
Bibby and Dehe (2018)	X	X	X	X
Mittal et al. (2018)		X	X	X
Ghobakhloo (2018)	X	X		X
Bienhaus and Haddud (2018)	X	X	X	X
Castelo-Branco et al. (2019)				X
Sony and Naik (2019)	X	X	X	X
Total	8	9	11	17

Source: Compiled by the author

Table 3 also indicated the common dimensions used in the proposed models on Industry 4.0 explained above. Considering these models, the elements of Industry 4.0 assessment in this dissertation consist of three categories; including “technology”, “strategy and organisation” and “employee and culture”. Based on the results of Table 3, the dimension of “technology” was used in every proposed model, followed by “culture”, “employee factor” and “strategy”. All these categories will be explained in the following sections.

The concept of ‘Technology’ in Industry 4.0

Industry 4.0 is perceived as advanced automation and digitisation activities including the application of information technologies in manufacturing and services (Lu, 2017, p.6). The scholars draw slightly different classifications about the technologies of Industry 4.0. Lasi et al. (2014, p.241) outline the technologies concerning the field of business and system engineering such as “advanced methods of modelling”, “innovative Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) approaches”, “business intelligence”, “digital product memories” for the collection of data, “planning systems, intelligent platforms”, “data models and exchange formats” such as additive manufacturing. Zhou et al. (2015, p.2149) discuss the main applications as “CPS”, “IoT”, “big data”, “cloud technology” and “advanced analytical techniques”. Lu (2017, p.6) explains that the main technologies of Industry 4.0 are “mobile computing”, “cloud computing”, “big data” and “IoT”. Xu et al. (2018, p.2944) include “IoT related technologies” such as RFID, sensor networks, real-time monitoring; “cloud computing”, “CPS” and “enterprise architecture systems”. However, these explanations cover the general concepts related to Industry 4.0 rather than expressing individual technologies. Bibby and Dehe (2018, p.1038) express the eight technologies including “big data, autonomous robots, cloud, additive manufacturing, internet of things and CPS, manufacturing execution systems (MES), sensors and e-value chains” that are the concepts of the factories of the future. The brief descriptions of these technologies are as follows;

Big Data is defined as large, diverse and complex datasets that companies hold, process, analyse in order to enhance their decision-making processes. Data analytics give various opportunities to the organisations such as information on preferences of customers, new trends, decision-making capabilities for their processes, reducing errors, increasing predictive systems and so on (Ji and Wang, 2017 p.188; Seele, 2017 p. 675).

Autonomous Robots are used as a supportive role for humans on tasks that could not be solved easily by workers. They enhance in becoming more autonomous, flexible, and cooperative with humans (Rüßmann et al., 2015, p. 3; Hedelind and Jackson, 2011 p.895).

Cloud Computing includes an online platform based on the integration and storing facilities of the connected devices (Givehchi et al., 2013 p.2). Their computing abilities create agile information sharing among partners (Thames and Schaefer, 2016 p.13).

Additive Manufacturing (AM) also called as 3D printing, linked with producing customised products for customers (Rüßmann et al., 2015, p. 4). AM technologies take the information from the necessary software such as computer-aided design software (CAD) and create layer by layer a three-dimensional object. The major advancements of this technology are to develop products in less time at a cost reduction, less human interaction and the ability to create any shape that could be hard to produce with a machine (Wong and Hernandez, 2012 p.1).

Internet of Things (IoT) technically speaking, IoT covers the physical artefacts, having computing and communication capabilities via Internet. IoT gives solutions for computations and analytics using the Internet; the data collected from physical objects transfer into higher-level devices; and they make the decisions regarding operations. (Akhtar et al., 2017 p.2).

Manufacturing Execution Systems (MES) which has been improved by software firms to offer “data management abilities” and “common user interface” (Bibby and Dehe, 2018, p.1032) function between production abilities and ERP systems of the firms. They are used to maintain and to enhance material control, employee and machine capacity, trace materials and orders, inventory and so on (Helo et al., 2014, p.648).

Sensors consist of integration of processes and equipment to gather, control and report information to operators. They are one of the most promising Industry 4.0 technologies (Bibby and Dehe, 2018, p.1033). Smart sensors are a base for accessing the related information about products, materials and facilities within the internet and software (Babiceanu and Seker, 2015, p.168).

E-value Chains create optimisation of supply chains by enabling a combination of digital aspects such as big data, IoT, sensors and improving transparency in value chains (Rüßmann et al., 2015, p. 3). That also refers to the extent of connectivity and access to companies' suppliers and customers (Bibby and Dehe, 2018, p.1038). Platforms supported by information technologies through SCs will increase flexibility and agility as well as the availability of real-time data.

Besides, a similar framework with Bibby and Dehe (2018) has been put forward by Rüßmann et al. (2015, p.2), promoted by Boston Consulting Group (BCG); they identify nine technological trends which will form the future of Industry 4.0. Their model also consists of "big data and analytics", "cloud", "autonomous robots", "IoT", "additive manufacturing", "horizontal and vertical integration (e-value chains)". However, they also add "simulation" (an imitation of processes virtually to optimise production), "augmented reality" (the wearable aspects that are supported by mobile devices to ease human tasks) and "cyber-security" (the protective software against cyber-attacks).

The Concept of 'Strategy and Organisation' in Industry 4.0

The assessment of Industry 4.0 is about more than developing current products or activities through the implementation of digital technologies; because it essentially provides the potential to cultivate completely new business models. Thus, it highly emphasises strategic importance for organisations (Lichtblau et al., 2015, p. 29). Based on the workshops related to the strategic orientation of Industry 4.0, Schumacher et al. (2016, p. 162) advocate that enterprises have failed to determine concrete guidance to promote their business strategies regarding Industry 4.0. Akdil et al. (2018, p.69) describe that having a strategy is a backbone for Industry 4.0 which needs a guidance in terms of new business models, investments in certain technologies and collaboration with strategic partners.

According to the study of Sony and Naik (2019), the organisational strategy related to Industry 4.0 mainly encompasses long term relationships with partners, technical aspects such as ICT networks on manufacturing systems to stimulate information exchange and huge initial investments for strategic fields determined by companies through their action plans, KPIs or mission and vision. The successful implementation of Industry 4.0 needs a detailed strategic roadmap, envisioning all future steps on the path toward the digitalisation of a company (Ghobakhloo, 2018, p. 911). Asdecker and Felch (2018, p. 850) highlight that strategy could be supported by a roadmap and digital mapping where physical reality is displayed as a virtual image. That eases monitoring and diagnosing the processes before they occur.

Industry 4.0 provides radical alterations in manufacturing companies through augmenting complexity of the production process; therefore, naturally, strategy involves having larger investments in technology, IT infrastructure and capability of boosting agile production via customisation activities (Bibby and Dehe, 2018, p. 1032). Schumacher et al. (2016, p.164) indicate that implementation of a "roadmap, resource availability and adaption of business models" are the significant indicators of performing successfully an Industry 4.0 strategy. Ghobakhloo (2018, p. 927) explains a comprehensive model about a "strategic roadmap for Industry 4.0 transition", derived from the activities of "strategic management, marketing, human resources, IT, smart manufacturing and smart supply chain management". The study suggests that companies are required to provide a strategic roadmap to visualise and comprehend each step to progress toward Industry 4.0 (p.926). Also, Patrucco et al. (2020, forthcoming) advocated that organisations might recognise the different sources to increase their knowledge about technological improvements, particularly they could collaborate with external sources such as universities to create more unique ideas for their supply chain operations. External professionals help organisations to achieve best practices and serve significant motives toward companies' visions (Erol et al., 2016, p. 497).

Despite the importance of having a well fit strategy on Industry 4.0, many scholars (Schumacher et al., 2016, p. 165; Lichtblau et al., 2015, p. 29; Akdil et al., 2018, p.76) found that organisations do not perform well on Industry 4.0 strategy. The main reasons for that, many organisations have uncertainty about the economic benefits of Industry 4.0 and lack of an understanding of the concept (Lichtblau et al., 2015, p. 60).

The Concept of 'Employee and Culture' in Industry 4.0

Employees who usually work in factories might lack the vision for grasping smart factory implementation or they could need to improve their capabilities toward Industry 4.0 transformation (Sjödin et al., 2018, p. 24). The new skills in IT and critical thinking by employees will also be very significant for their success and improvements in operational efficiency for organisations (Sony and Naik, 2019; Geissbauer et al., 2016, p. 2; Fekete Farkas and Torok, 2011, p. 76). Consequently, digitalisation will force them to acquire new skills and qualifications; therefore, it is essential that enterprises must make their employees ready for these alters through accurate training (Lichtblau et al., 2015, p. 52).

Employees are an important factor in implementing Industry 4.0 because of their value and power for organisations (Bibby and Dehe, 2018, p.1035; Feher and Reich, 2016, p. 50). Schumacher et al. (2016, p. 164) observe that ICT competency and openness of employees to digital technologies must be considered in assessing the maturity level of Industry 4.0. Ghobakhloo (2018, p.927) believes that fundamental changes through Industry 4.0 lead to a division of work between humans and machines; thus, competency of employees will be one of the essential indicators in shaping the digital transformation, depending on their skills in automation technology, IT infrastructure, data analytics, data security, process knowledge and assistance systems or software knowledge (Sony and Naik, 2019). Industrial managers are mainly responsible for concentrating on hiring and empowering employees with such digital capabilities while simultaneously improving digital abilities in the existing workers (Sjödin et al., 2018, p.25).

Although digital transformation is highly dependent on the capabilities and training of employees, another important point is “corporate culture”, addressing the issue of willingness to change the entire workforce when new technologies are introduced within an organisation (Schuh et al., 2017, p. 32). However, factories usually have a lack of systematic ventures to internalise modern project models that offer more agile and flexible solutions, so in this rigid culture, it is hard to change (Sjödin et al., 2018, p. 25). A culture of innovation and continuous improvement provides new opportunities and helps enterprises assimilate changes (Bibby and Dehe, 2018, p.1035; Gyenge et al., 2015, p. 132). Otherwise, without a robust digital culture driven by clear leadership, digital investments and their implementation will be a big challenge for organisations (Geissbauer et al., 2016, p. 9).

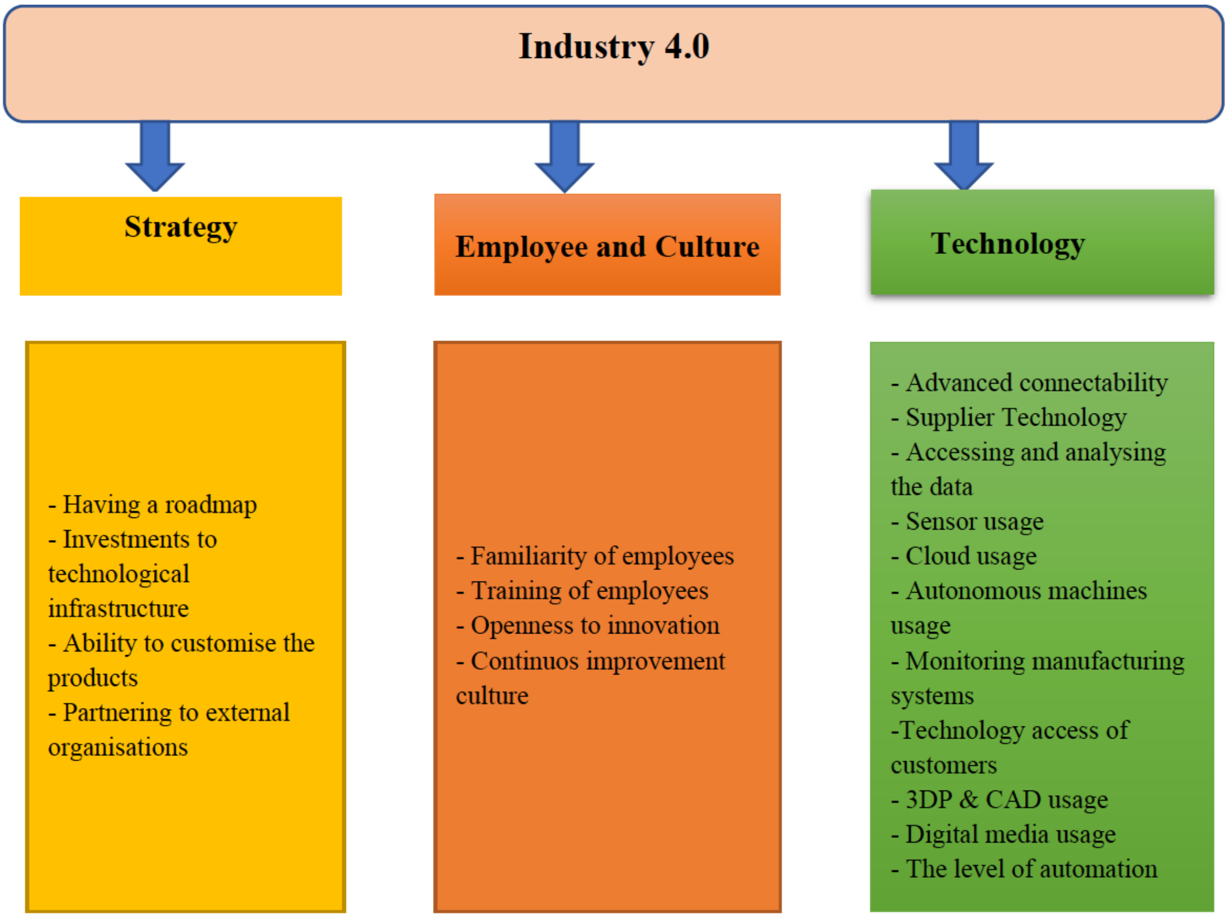


Figure 2. The Items and Dimensions of Industry 4.0
Source: Author's own elaboration

Based on the literature, the author adopted the scale of Bibby and Dehe (2018, p. 1038) for each concept explained above to measure Industry 4.0 assessment. Figure 2 demonstrates the dimensions and items used in this dissertation for the scale of Industry 4.0.

2.1.4. Supply Chain 4.0

The concept of supply chain mostly utilises the activities of marketing, production, and distribution; thus, the product is accessible for the final customer. Nevertheless, the digitisation of supply chains improves "a fully integrated ecosystem" as well as increasing transparency between the partners (Makris et al., 2019, p. 118). Basically, supply chain 4.0 encompasses the use of new technologies, new information systems, software tools, and connected factories for cultivating industry and supply chain (Dossou et al., 2018, p.453). Frederico et al. (2019, p.17) have grouped the core concepts of the framework of supply chain 4.0 and its elements. Their classification employs the four groups in the conceptual framework of Supply Chain 4.0; "managerial & capability supporters", "technology levers", "processes performance requirements", and "strategic outcomes". Tjahjono et al. (2017, p. 1176) argue the four main features of Industry 4.0 that will transform the supply chains although there is no conclusive description of the concept.

- *“Vertical networking of smart production systems”:* The stages of production processes based on CPSs are autonomous and smart factories are flexible and react faster to changes in customer demand. Therefore, manufacturing processes achieve accurate mass customisation (Dombrowski et al., 2017, p. 1061).
- *“Horizontal integration of global value chain networks”:* The application of CPSs needs strategies, networks, business models to fulfil horizontal integration. All the production stages from development to distribution are identified if there is any change in customer needs through the transparency within value chains (Wolf et al., 2013, p. 296).
- *“Engineering support across the entire value chain”:* The design, development, and manufacturing processes are supported via technical developments and deployed with the utilisation of big data (Nagy et al., 2018, p. 13).
- *“Acceleration through exponential technologies”:* The automated systems of Industry 4.0 create flexibility, rapid manufacturing, customisation, and reduced cost (Xu et al., 2018, p. 2946).

According to Min et al. (2019, p.8), data transparency and IT technologies related to agile decision-making processes could assist firms to build, develop and maintain relationships with a larger number of supply chain partners, this leads to improve their product and service diversity and reduce their costs. As an example of that, through an open platform-based supply chains, companies could ascertain trustworthy partners around the globe remotely by checking their delivery performance or whether they are complying with codes of conduct. Da Silva et al. (2019, p. 553) show that the reactions to changes in operational activities happen in real-time due to the synchronisation of data and information flow on all phases of the supply chain in the concept of supply chain 4.0. Recent online trends enable growing service expectations of customers combined with the trends on individualisation and customisation; therefore, constant changes occur in Stock Keeping Units (SKUs) of companies. Changes in requirements can be dealt with more precisely when they use a wide range of advanced technologies; also supply chains could react faster (Alicke et al., 2017, p.1).

Considering the discussions above, disruptive technologies and digitalised processes are changing the structures and business models of several industries as well as the supply chains to which they belong (Pfohl et al., 2015, p. 31, Da Silva et al., 2019, p. 546). According to Tjahjono et al. (2017, p. 1181), the most obvious benefits of supply chains through the implementation of Industry 4.0 are increased productivity, efficiency, flexibility, and quality standards. Ivanov et al. (2019, p. 840) advocate that the information flow in supply chains plays a supreme role in the operations; this, in turn, will decrease waste and risks in supply chains. By building on new trends and a broad range of new technologies, supply chains will become much faster and more accurate on information and physical flow, planning activities, performance and order management, inventory, supply chain service, and costs (Alicke et al., 2017, p.1). Although supply chain 4.0 could be accomplished after a progressive transformation process including environmental, social, and societal dimensions; however, the dimensions could be varied by the company which is being transformed (Dossou, 2018, p. 457).

Hofmann et al. (2019, p. 945) explain that supply chain 4.0 is a new phase of improvement in supply chains, in which the materials, information and financial flows are coordinated through automation and digital technologies. Accordingly, the digitalisation of company processes might simplify the integration of firm functions and supply chain partners (Ardito et al., 2019, p. 324). In this context, the effects of digital disruption entail a shift from traditional supply chain activities to digital supply chains to underpin new production models, shipping modes, customer feedbacks, and real-time information exchange (Queiroz et al., 2019, forthcoming). Despite improvements in digital technologies, understanding of digital supply chains is nevertheless in its initial stages (Büyüközkan and Göçer, 2018, p. 157). Consequently, the prior literature does not provide the structure of digital supply chains extensively to encourage organisations and their supply chain members on the way of their digital transformation. Thus, the following sections try to define the concepts of supply chain integration and performance and their dimensions, later, understand their relationships with Industry 4.0. Also, these relationships are grounded by two well-known theories in the strategic management; the resource-based view (RBV) and relational view (RV) theories.

2.2. Review of Supply Chain Integration

2.2.1. The Concept of Supply Chain Integration (SCI)

SCI is a significant field to enhance long-term competitiveness in supply chain practices (Kaliani Sundram et al., 2016, p. 1445). According to Zhu et al. (2018, p. 212), different definitions are considered to conceptualise SCI; “the locus of integration (which functional groups are integrated) and substance of integration (which information and organisational processes are integrated)”. In this thesis, the definitions of the scholars related to SCI were also divided into three categories by considering the study of Zhu et al. (2018). The first group includes the definitions concentrated on the locus of integration. The second group consists of the definitions of the substance of integration. Finally, the third group covers both locus and substance of integration in their definitions of SCI. The detailed descriptions are shown in Table 4.

Table 4. Key Definitions of SCI

Category	Authors	Definitions
The definitions related to locus of integration	Liu et al. (2016, p.14)	"SCI refers to the degree to which a firm collaboratively deploys its resources and capacities with channel partners"
	Ataseven and Nair (2017, p. 252)	"SCI manifests in terms of integration of internal operations within a firm as well as external integration with customers and suppliers"
	Wong et al. (2017, p. 554)	"The concept of SCI is defined as the inter- and intra- organisational coordination and collaboration among different partners in a supply chain"
The definitions related to substance of integration	Singh and Power (2013, p.6418)	"SCI includes cooperation, collaboration, information sharing, trust, partnerships, shared technology and a fundamental shift away from managing individual functional processes, to managing integrated chains of processes"
	Chang et al. (2016, p.283)	"SCI is a collaborative and coordinated management of intra and inter-organisational information, processes and behaviours to create maximum value"
	Kauremaa and Tanskanen (2016, p. 72)	"the SCI literature has mainly considered with the integration process, SCI and the performance, and the antecedents of SCI"
	Turkulainen et al. (2017, p. 290)	"In order to develop a deeper understanding of integration, research needs to move beyond performance outcomes to examine the context in which integration occurs. Such a focus would build greater insight into organisational designs and processes that enable effective and accurate processing of information"
The definitions related to both locus and substance of integration	Zhao et al. (2015, p.162)	"SCI refers to the degree to which a firm can strategically collaborate with its supply chain partners and collaboratively manage the internal and external processes to provide the maximum value to the customer at low cost and high speed"
	Yu et al. (2016, p. 4198)	"SCI involves a strategic collaboration between a focal firm and its customers and suppliers in managing boundary spanning business activities, including collaboration in purchasing, planning and forecasting, and joint product development"
	Manuel Maqueira et al. (2018, p. 2083)	"Supply Chain Integration (SCI) (integration of financial, physical and information flows) consists of cooperation, interaction and collaboration through all of the links that shape the supply chain"
	Jajja et al. (2018, p. 120)	"The strategic collaboration with key supply chain partners and effective and efficient management of intra- and inter-organisational activities related to the flow of products, services, information, finance and joint decision-making are identified as supply chain integration"
	Mora-Monge et al., (2019, p. 526)	"SCI is commonly associated with a firm's level of alignment of internal and external processes and strategic linkages with its trading partners"

Source: Compiled by the author

In order to conceptualise SCI, the author analysed several high-quality research papers selected from "Web of Science (WoS)" and "SCOPUS". Table 4 shows some example definitions of the articles gathered through well-known management and supply chain journals such as "International Journal of Production Economics", "Journal of Operations Management", "International Journal of Production Research", "European Management Journal", "The International Journal of Logistics Management", "Journal of Business Logistics", "Supply Chain: An International Journal" and so on.

The definitions corresponding to "locus of integration" describe the integration of supply chain partners, meaning that coordinative and collaborative activities of suppliers, customers, and other channel members. The definition of Liu et al. (2016, p. 14) emphasises that SCI is the extent to which a company can deploy its resources and capacities with its supply chain partners.

Ataseven and Nair (2017, p. 252) refer that "SCI manifests in terms of integration of internal operations within a firm as well as external integration with customers and suppliers". SCI has a major role in simplifying collaborations and coordination across supply chains (Wong et al., 2017, p. 554)

The definitions related to "substance of integration" focus on integrated processes of supply chains, meaning that functional internal and external processes such as information integration and operational processes in SCs. The definition of Singh and Power (2013, p.6418) is that SCI consists of "cooperation, collaboration, information sharing, trust, partnerships, shared technology and fundamental shifts away from individual functional processes". Chang et al. (2016, p.283) describe the concept as "a collaborative and coordinated management of intra and inter-organisational information, processes and behaviours to create maximum value". Kauremaa and Tanskanen (2016, p. 72) indicated that technological infrastructure and related information flows between activities are necessary for the usefulness of SCI. The study of Turkulainen et al. (2017, p. 301) addresses the information processing requirements in the context of SCI.

Finally, some scholars describe SCI by focusing on both "locus and substance of integration" (Zhao et al., 2015, p.162; Yu et al., 2016, p.4198; Maqueira et al., 2018, p.2083; Jajja et al., 2018, p. 120; Mora-Monge et al., 2019, p. 526). Zhao et al. (2015, p.162) define SCI as a degree of collaboration between a company and its partners to manage internal and external processes and effective and efficient flows of products, services and information to offer maximum value to customers at a low cost. SCI is comprised of strategic collaboration between a firm and its suppliers and customers including procurement, planning, forecasting and product development collectively (Yu et al., 2016, p.4198). Manuel Maqueira et al. (2018, p.2083) emphasise that recently the developments of IT increase the real-time information between processes as well as integration between partners. SCI is the level of building "inter-organisational strategies, processes, policies and actions" between partners (Jajja et al., 2018, p. 120). Mora-Monge et al., (2019, p. 526) define SCI as an "alignment of internal and external processes and strategic linkages with trading partners".

Beheshti et al. (2014, p.21) identify that "an effective supply chain requires organisations to form a partnership with their supply chain network and employ advanced technology to link with their business partners and customers". Briscoe and Dainty (2005, p.320) have shown that supply chains could vary in many different forms, complexities and diversities; therefore, although many authors argue that improving management practices lead to better integration; however, it is evident that in reality, it is difficult to achieve. SCI is strictly linked to coordination mechanisms and refers to business processes that facilitate inter-related within and outside the firm boundaries

(Cagliano et al., 2006, p.283). The vast focus on products and materials in the definitions of supply chain integration maintains the empirical studies are mostly based on the manufacturing context (Silvestro and Lustrato, 2014, p.299).

There is no doubt that one of the most ascendant concepts in supply chain management is integration; however, companies are not always accomplished in implementing high level of integration (Cagliano et al., 2006, p.295). The lack of integration among partners reduces operational efficiencies which compromise supply chain performance (Campbell & Sankaran, 2005, p.3325) The direct linkage with suppliers or customers reduces marketing costs and adds value to the production activities (Dunay et al., 2018, p. 201; Feher, 2012, p.353). SCI needs a comprehensive strategic plan and top management commitment. Moreover, it needs a carefully improved assessment strategy which analyses the significance of relationships among supply chain members (Beheshti et al., 2014, p.28). Patnayakuni et al. (2006, p.40) indicate the importance of information sharing with partners to improve value creation; therefore, relationship-specific assets must be learned and invested by managers for rich information exchange, learning and value creation in long term relationships. Szegedi et al. (2017, p. 266) show the significance of cooperation, information sharing and investing in partnerships in inter-organisational SCs. Zhou et al. (2018, p.62) stress that the concept of SCI applies in sharing information, trusting each other and shaping inter-organisational relationships; therefore, both buyers and suppliers should understand and plan the adoption strategies of SCI. The study also underlines that the main barrier to adapting SCI is an unwillingness to share some significant supply chain information between suppliers and buyers. Morvai (2014, p. 11) created the variables, which affect the supplier and buyer side integration for the Hungarian sample. The study showed that “applying modern supply chain methods”, “cooperation aspects” and “factors of trust” are the prerequisite concepts to accomplish high integration with suppliers and customers.

As explained previously, Table 4 presents the main representative definitions of SCI identified from literature, providing an exhibit in perceptions of the meaning and scope of the SCI concept. SCI is highly related to “coordination of value chain activities”, “integration of supply chain partners”, and “information sharing between the partners”. Therefore, this dissertation used the definition of Chang et al. (2016, p. 283), which is that “SCI is a collaborative and coordinated management of intra and inter-organisational information, processes and behaviours to create maximum value”. This dissertation follows the approach offered by this definition to understand the SCI concept and its relationships with the other concepts.

2.2.2. The Elements of Supply Chain Integration (SCI)

SCI has been a strongly researched theme during the last twenty years; however, no compromise has been taken on the measurement of the concept and operationalisation (Alfalla-Luque et al., 2015, p. 244). Besides, SCI could be conceptualised as a multidimensional construct since prior research examines the concept with different sub-elements (Liu et al., 2016, p. 14; Chang et al., 2016, p.283; Birasnav and Bienstock, 2019, p. 150).

Some scholars have categorised SCI into three elements: “supplier integration”, “internal integration” and “customer integration” to analyse the concept from a broader perspective (Zhao et al., 2015, p. 171; Beheshti et al., 2014, p.27; Ataseven and Nair, 2017, p.257; Birasnav and Bienstock, 2019, p. 150; Jajja et al., 2018, p.135; Lotfi et al., 2013, p.472). These studies mainly identify that the most successful firms are ones that couple their customers, suppliers and internal functions. Zhao et al. (2015, 163) state that the multifaceted nature of SCI is significant to perceive the relationships between SCI and performance. Beheshti et al. (2014, p.28) note that the supply chain strategy should consist of the internal integration activities within the company and structure for connecting these activities with supply chain partners to obtain extensive gains of integration. Ataseven and Nair (2017, p.257) explain the concept as a broader level, internal integration refers to intra-organisational aspects while customer integration and supplier integration evaluate relationships that companies enhance in their upstream and downstream activities. Jajja et al. (2018, p.135) show that sharing information, joint decision making and collaboration between partners as well as internal departments within organisations are important aspects to measure effective integration through SCs. Alternatively, some scholars argue only internal and external integration to elucidate the elements of SCI (Chaudhuri et al., 2018, p.699; Danese et al., 2013, p.126; Willis 2016, p. 767); however, integration with both suppliers and customers is generally regarded as external integration. Thus, this dissertation generally uses similar definitions of supplier and customer integration to explain external integration.

In addition, some authors only focus on particular dimensions of SCI such as only on customer integration (Enkel et al., 2005, p. 205, p. 203; Piller et al., 2004, p. 435) or only on supplier integration (Petersen et al., 2005, p. 371; Das et al., 2006, p. 563) or both (Zhou et al., 2018, p. 60; Frohlich and Westbrook, 2001, p.193) beyond internal integration. For instance, the analysis of Zhou et al. (2018, p. 60) measures the extent of supplier and customer e-supply chain integration through web-based implementation processes. The measurement also consists of some items such as “web-based usage on procurement”, “order scheduling and tracking”, “inventory planning” and “demand forecasting” activities for supplier integration; also, “customer profiling, online order taking, after sales support and demand forecasting” for customer integration. Another study conducted by Frohlich and Westbrook (2001, p.193) investigates the strategies of supplier and customer integration with 322 manufacturing companies. The five different strategies of integration, called “arcs of integration”, representing “inward, periphery, supplier, customer, and outward facing groups”.

Other studies also describe the elements of SCI with different approaches (Campbell and Sankaran, 2005, p. 3332; Cagliano et al., 2006, p.284; He and Lai, 2012, p.794; Kim and Cavusgil, 2009, p. 497; Tsanos et al., 2014, p.436). Campbell and Sankaran (2005, p. 3332) enhance their framework by grounding in companies’ experiences and perspectives about SCI; and they classify their SCI elements into three facets of integration; “internal integration”, “forward integration” and “backward integration”. Their inductive model concentrates on various items in integration internally, backward SC activities and forward SC activities on an organisational structure basis. Cagliano et al. (2006, p.283) investigate upstream supply chain mechanisms in particular aiming at the integration of production-logistics processes. The two main elements, “integration of information flows and physical flows”, were analysed through the adoption of a lean paradigm. He and Lai (2012, p.794) investigate different impacts of operational and strategic supply chain integration on firm performance, considering that the strategy of integration is also important as well as the integration scope for external, internal integration. Kim and Cavusgil (2009, p. 497) use two elements: “Interfirm Activity Integration (IAI)” and “Interfirm Systems Integration (ISI)” for measuring SCI. IAI refers to the extent of participation of SC partners in collaborative planning and forecasting whereas ISI is regarded as the readiness of the company’s SC communication system to support interfirm activities. Tsanos et al. (2014, p.436) highlight two elements: “Information Integration” and “Coordination of Operational Decisions (OPC)” to conceptualise SCI. According to their definitions, information integration stimulates information flows across SC participants while OPC activities refer to the integration of physical flows among partners.

Table 5. Elements of SCI used in the literature

SCI Elements	The Authors	Operationalisation/Most Common Items
(i) Supplier Integration (SInt) **(ii) Internal Integration (IInt)** **(iii) Customer Integration (CInt)**	Zhao et al. (2015, p.171); Beheshti et al. (2014, p.27); Ataseven and Nair (2017, p.257); Birasnav and Bienstock, (2019, p. 150); Jajja et al. (2018, p.135); Lotfi et al. (2013, p.472)	**SInt/CInt:** The level of information exchange, the establishment of quick ordering systems, the level of strategic partnership, monitoring collaborative activities, the participation of suppliers, adjustments in delivery with major suppliers/customers **IInt:** Real-time/data integration in internal functions, internal information sharing and decision making, usage of cross-functional teams in process improvement, new product development and strategic planning, etc.
(i) Internal Integration (IInt) **(ii)External Integration (EInt)**	Chaudhuri et al. (2018, p.699); Danese et al. (2013, p.126); Willis (2016, p. 767)	**IInt:** *same as the definition above* **EInt:** closer linkages, integrating processes and information exchange with customers and suppliers - *same definitions as SInt and CInt above*
(i) Operational Integration **(ii) Strategic Integration**	He and Lai (2012, p.794)	**Operational Integration:** all partners agree upon processes such as the physical, spatial, temporal and economic nature of SCI. On the customer side, the term refers to delivering products efficiently at competitive prices **Strategic Integration:** synchronising main competencies and abilities of SC partners together to maintain service capabilities at a low cost
(i) Interfirm Activity Integration (IAI) **(ii) Interfirm Systems Integration (ISI)**	Kim and Cavusgil (2009, p. 497)	**IAI:** The capability of a company to integrate activities with SC participants to achieve a competitive advantage such as adjusting business plans and strategies collaboratively **ISI:** This explains the level of a company's communication system whether it is ready or not, so it promotes interfirm activity integration.
(i) Information Integration **(ii) Coordination of Operational Decisions (OPC)**	Tsanos et al. (2014, p.436)	**Information Integration:** It refers to the capability of accessing information related to operations and important data for product and services flows in SC **OPC:** Coordination of OPC activities such as demand management, sales, operations, resource planning and material planning through SC.
(i) Internal Integration (IInt) **(ii) Backward Integration (BI)** **(iii) Forward Integration (FI)**	Campbell and Sankaran (2005, p. 3332)	**IInt:** multidivisional activities, cross-functionality, companies' business units related to supply chain, activity-based costing, supply chain segmentation **BI:** Supplier selection; management of suppliers (such as communication, collaborative planning, VMI, sharing demand information); performance of suppliers; the closeness of relationships; technological usage with suppliers **FI:** Relationship management such as level of connectivity with partners, performance rewards are given to customers, inventory management, collaborative planning with partners
(i) Physical Flow Integration (PFI) **(ii) Information Flow Integration (IFI)**	Cagliano et al. (2006, p.284)	**PFI:** It refers to purchasing activities such as supply base leveraging and rationalisation **IFI:** Leveraging information between partners to develop internal activities and operations management

Source: Compiled by author

Table 5 shows the elements of SCI and their explanations/items studied by different scholars. Additionally, Table 6 indicates the common dimensions used in the studies mentioned in Table 5.

Table 6. Dimensions of SCI

Studies	Internal Int*	Supplier Int*	Customer Int*	Operational Int*	Strategic Int*	Activity Int*	Systems Int*	Information Int*
Campbell and Sankaran (2005)	X	X	X					
Cagliano et al. (2006)		X						X
Kim and Cavusgil (2009)						X	X	
He and Lai (2012)				X	X			
Danese et al. (2013)	X	X	X					
Lotfi et al. (2013)	X	X	X					
Beheshti et al. (2014)	X	X	X					
Tsanos et al. (2014)				X				X
Zhao et al. (2015)	X	X	X					
Willis (2016)	X	X	X					
Ataseven and Nair (2017)	X	X	X					
Chaudhuri et al. (2018)	X	X	X					
Jajja et al. (2018)	X	X	X					
Birasnav and Bienstock (2019)	X	X	X					

Note: Int* denotes “Integration”

Source: Compiled by the author

In table 6, it has been shown that all dimensions used in the studies above. However, based on the analysis “internal integration”, “supplier integration” and “customer integration” were the most common elements used in the studies. Therefore, in this dissertation, SCI can be ultimately classified into three elements: “supplier integration” (SInt), “internal integration” (IInt) and “customer integration” (CInt). Although these elements are highly connected; however, they have different roles in SCI (Danese et al., 2013, p. 126). In the rest of the sections, each element will be explained in detail.

The Concept of Internal Integration in SCI

Chang et al. (2016, p.283) state that “internal integration” implies “a company’s coordination and collaboration of information, processes and behaviour within a company”. According to Danese et al. (2013, p.127), internal integration is the extent to where functions could be worked in a cooperative manner within a company in order to solve conflicts for the sake of acceptable outcomes. Qi et al. (2017, p.164) argue that the departments within a company must operate as part of an integrated system, and company structures, its organisational strategies, activities and operations should work collaboratively and synchronically to meet the requirements of its customers (Flynn et al., 2010, p. 59; Silvestro and Lustrato, 2014, p.300). Information sharing and joint decision making among departments within an organisation are two important factors to integrate the organisational activities internally (Chaudhuri et al., 2018, p. 696; Jajja et al., 2018, p. 135). Furthermore, Birasnav and Bienstock (2019, p. 153) explain that the united system of a company including information system structure between employees to deliver products and services strengthens the integration of production systems internally and improves dissemination of coordination and collaboration of internal entities.

The significance of “internal integration” is widely viewed by scholars in the fields of operation and performance management (Danese and Bortolotti, 2014, p.7077; Beheshti et al., 2014, p.27; Ellinger et al., 2015, p.480; Gimenez et al., 2012, p. 585; Huang et al., 2014, p. 65). As pointed out by Chang et al. (2016, p.292), internal integration has shown a stronger impact than external integration on firm performance. Chaudhuri et al. (2018, p. 705) show that internal integration highly influences the flexibility performance of enterprises. Boon-itt and Yew Wong (2011, p.268) found that internal integration positively affects customer delivery performance. The study also mentions that the relationship between internal integration and delivery performance could be reinforced when internal integration is supported by information technologies. Silvestro and Lustrato (2014, p.314) advocate that a lack of internal integration leads to lesser performance in supply chain activities.

It is also noteworthy that some studies suggest that organisations should first concentrate on internal integration rather than external integration because internal integration is viewed as the root of supplier and customer integration (Delic et al., 2019, p. 3; Cagliano et al., 2006, p.295; Chang et al., 2016, p. 292; Sacristán-Díaz et al., 2018, p. 702). The role of internal integration is vital for technical and social links through the activities of external integration due to increasing information, financial and physical flows between partners (Sacristán-Díaz et al., 2018, p.702).

Cagliano et al. (2006, p.295) believe that most enterprises have a failure on external integration because of a lack of their activities on internal integration. According to Glenn Richey et al. (2009, p. 829), it is sensible for companies to observe organisational barriers with an internal perspective which can be directly controlled. The study notes that internal planning failure occurs as a lack of effective planning mechanism whilst external monitoring failure happens as a lack of effectively monitoring the external environment.

Zailani and Rajagopal (2005, p.383) view that internal functions should be integrated on a system to system basis, and cross functional behaviour must be adapted rather than solely concerning about the functions of single departments within a firm; that is also important for successful supply chain activities. In addition, internal integration streamlines "collaboration within all functions in the company by breaking down functional barriers" (Kim and Chai, 2016, p. 468). Therefore, internal integration mostly converges the unified activities, practices and strategies within an organisation.

The Concept of Supplier Integration in SCI

Chaudhuri et al. (2018, p. 696) define "supplier integration" as information sharing, improving coordination approaches, joint decision making and system couplings such as "vendor managed inventory (VMI)", "just in time (JIT)" and "Kanban" activities, and continuous improvement with main suppliers. "Supplier integration" supports companies as a way of improving their production plans, providing their products and services on time and consequently, maintaining their delivery speed (Chen et al., 2018, p.207). Also, close integration with suppliers improves visibility in companies' upstream activities; therefore, it reduces the uncertainty of the focal firm's activities such as decreasing the bullwhip effect and transaction costs. In addition, it is significant to increase the extent of real-time information sharing with suppliers to respond better to customer orders, demand fluctuations and decrease lead time (Vanpoucke et al., 2017, p.514; Chen et al., 2018, p.207). Zailani and Rajagopal (2005, p.383) indicate that working closely with suppliers such as the degree of their involvement in decision-making of an organisation and the level of the strategic partnership with them through long-term relationships and alliances are in the context of supplier integration. As a result, a highly coordinated delivery system in upstream activities could be achieved through collaborative actions between suppliers and a focal company (Droge et al., 2012, p.251). Dainty et al. (2001, p.171) present that less integration with the supplier is the main barrier of hindering the activities of SC among other elements.

Studies also demonstrate that there is a strong relationship between supplier integration and different areas of performance management (Huo, 2012, p. 604; Wong et al., 2011, p. 612; Narasimhan and Kim, 2002, p. 320; Shou et al., 2018, p. 356). Boon-itt and Yew Wong (2011, p.269) analyse that supplier integration positively affects the delivery performance of SCs;

moreover, internal integration is not solely adequate without supplier integration in order to accomplish performance measures. Beheshti et al. (2014, p.28) reveal that the degree of supplier integration positively affects the financial performance of manufacturing companies; for this reason, managers need to improve strategies to maintain a higher level of integration with their suppliers. Flynn et al. (2010, p. 66) examine the effect of supplier integration on operational and business performance, and both are significantly related to the degree of supplier integration. However, the study explains that examination of the impact of the individual elements of SCI is not ample; all elements of SCI should be taken into account to examine the effects on performance fully. Ataseven and Nair (2017, p. 262) have found that the relationship between supplier integration and aggregate performance is moderated by financial and operational performance.

The Concept of Customer Integration in SCI

Vanpoucke et al. (2017, p.514) define customer integration as “flows of information, service and materials to customers; also includes information flowing back from customers to the focal firm”. Danese et al. (2013, p.126) view the concept as the extent of developing collaborative relationships and intimacy between manufacturer and customer such as highlighting the issues of exchanging information, collectively planning activities and partnerships of customers. There are several ways to embrace customer integration, including customer relationships, decreasing lead time and tracking the products (Droge et al., 2012, p.251). A higher extent of customer integration improves the competitive standing of the supply chain (Vanpoucke et al., 2017, p.514).

Furthermore, customer satisfaction is a business terminology to yield customer needs and expectations (Simon and Yaya, 2012, p. 1027). Some authors have found a close relationship between customer integration and customer satisfaction (Yu et al., 2013, p.355; Alfalla-Luque et al., 2015, p.261; Zailani and Rajagopal, 2005, p. 388; Droge et al., 2012, p.251). The companies which are likely to have closer customer relationships have higher customer satisfaction and a higher level of responsiveness through information obtained from their customers (Droge et al., 2012, p.251). In addition, decisions of customers increase the coordination of materials at the focal company (Vanpoucke et al., 2017, p.514). Zailani and Rajagopal (2005, p.383) explain that working closely with customers and following up on their feedback are the key issues of customer integration. The level of customer involvement could also increase the efficiency of delivering products to customers; thus, it is also associated with financial performance due to reducing costs and conceiving demand changes more quickly (Yu et al., 2013, p.355; Beheshti et al., 2014, p.28) and with firm performance such as quality, delivery and flexibility (Huo, 2012, 604; Flynn et al., 2010, p.66; Shou et al., 2018, p. 356; Alfalla-Luque et al., 2015, p.261).

In recent years, firms have also needed to focus on new customer integration techniques; therefore, they address them to achieve customisation techniques (Smith et al., 2013, p. 877; Matzler et al., 2011, p. 231; Lai et al., 2012, p. 443). This requires a company to establish a strategic collaboration with customers, to foresee their needs and to react to changing requirements easily (Droge et al., 2012, p.251). Therefore, industrial managers should share some information with their partners to guarantee the flow of materials; however, only a few companies are willing to have close links with their customers in strategic decisions due to concerns about sharing their business plans and competitive strategy (Bagchi et al., 2005, p.288). Companies should increase the level of implementation of usage of VMI, continuous replenishment or Kanban systems (Razmi et al., 2010, p. 773; Bagchi et al., 2005, p.287; Jajja et al., 2018, p. 135) to improve their strategic collaboration with their customers as well as using advanced manufacturing technologies to easily respond to customers' needs (Birasnav and Bienstock, 2019, p.153; Schumacher et al., 2016, p. 164).

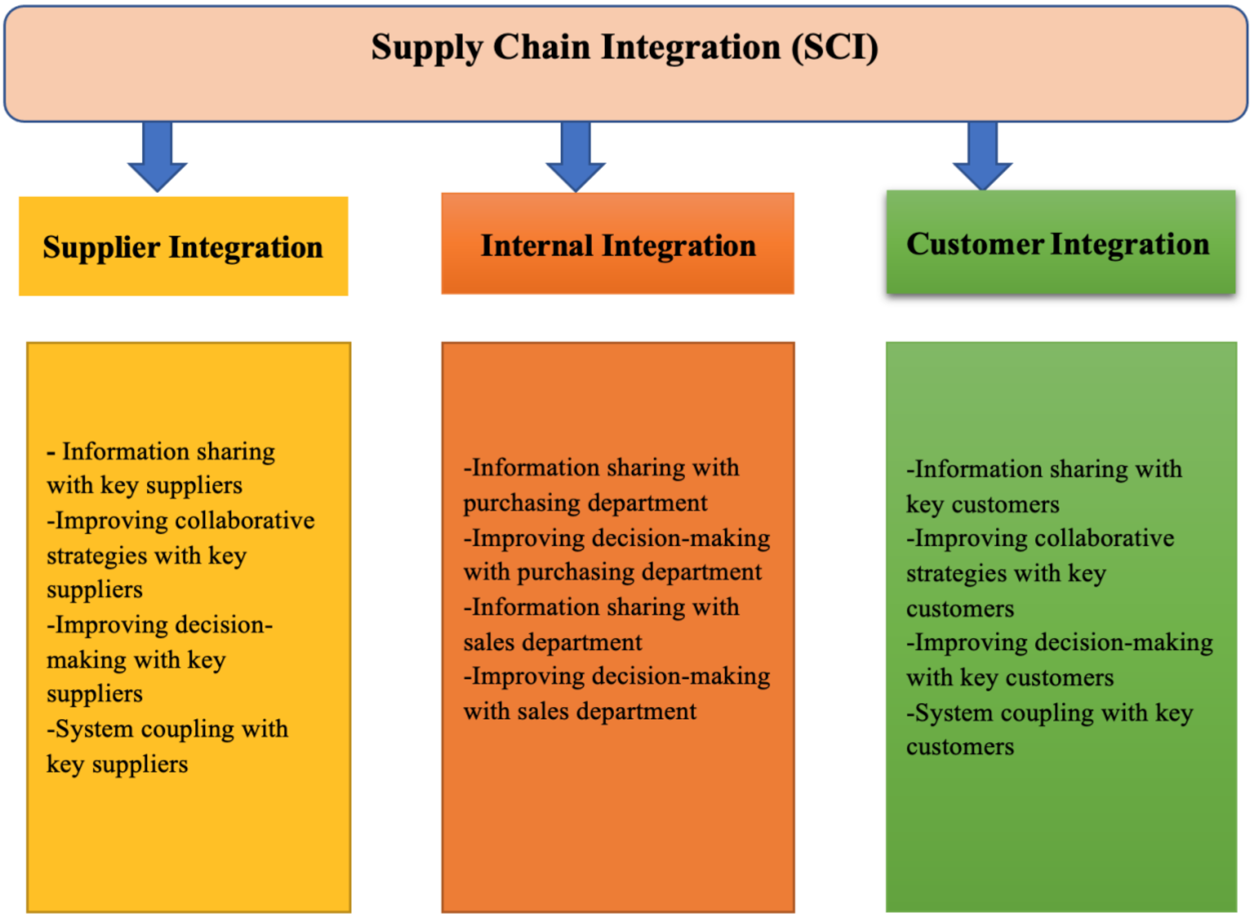


Figure 3. The Dimensions and Items of SCI
Source: Author's own elaboration

Based on the literature, the author adopted the scale of Jajja et al. (2018, p. 135) for each concept explained above to measure SCI. Figure 3 indicates the dimensions and items used in this dissertation for the scale of SCI.

2.3. Review of Supply Chain Performance

2.3.1. The Concept of Supply Chain Performance (SCP)

Analysing performance evaluation systems was the main concern during the 1990s (Estampe et al., 2013, p.249). Performance management (PM) attempts to explore measurement systems and their elements which would be compiled within the organisation strategy. Hausman (2004, p.66) believes that SCs are required to enforce the three main elements; “service, assets and speed”. Here, “service” reflects the capability to foresee, capture and fulfil customer demand and on-time delivery while “assets” cover the activities required commercial value, especially inventory and cash. “Speed” involves time-based metrics such as activities of quick response. Beamon (1999, p.276) defines the PM as “analysing performance measurement systems that are already in use, categorising performance measures and then studying the measures within a category and building rules of thumb or frameworks by which performance measurement systems can be developed for various types of systems”. Hervani et al. (2005, p.332) define performance measurement systems as “tangible or intangible measures with a balance of both types used to measure performance”. Their definition also comprises dynamic measures at multiple levels, including products and processes, a team approach based on a corporate strategy, both internal and external communications resulting in clear outcomes for decision-makers. Performance measurement must be viewed as performance management that helps companies improve their organisational structure and their abilities resulting in innovations in the companies. Fawcett et al. (2007, p.359) mention that the ability of companies to optimise SC performance gives them a unique competitive advantage.

To define SCP in this thesis, several high-quality research papers selected from “Web of Science (WoS)” and “SCOPUS” have been analysed. Table 7 demonstrates some examples of explanations of the articles gathered through well-known management and supply chain journals such as “International Journal of Production Economics”, “International Journal of Operations and Production Management”, “Benchmarking: An International Journal”, “Industrial Management & Data Systems”, “International Journal of Information Management” and so on. After reviewing the articles related to SCP, the definitions of SCP have been categorised into two groups. The first category consists of a systematic view of SCP while the second group explains SCP as a metric-based approach. The detailed definitions are shown in Table 7.

Some scholars define PM systems as a systematic approach; which refers to determine the procedures and steps to evaluate the outcomes and obtain optimum achievements

(Chithambaranathan et al., 2015, p. 310; Kaliani Sundram et al., 2016, p. 1448; Dossou and Nachidi, 2017, p. 839; Dweekat et al., 2017, p. 272; Hung Goh and Eldridge, 2019, p. 84). Chithambaranathan et al. (2015, p.310) define performance analysis as offering significant feedback information to SC managers "to monitor implementation, reveal progress, enhance communication and diagnose problems". Chithambaranathan et al. (2015, p.311) state that performance analysis could be observed as a multiple criteria tool from a global point perspective. Kaliani Sundram et al. (2016, p. 1448) describe the concept "as a systematic process of measuring the effectiveness and efficiency of supply chain operations". Dossou and Nachidi (2017, p. 839) claim that performance indicators help organisations to measure current and future activities of companies, and it is important to find the optimum by integrating criteria. Dweekat et al. (2017, p. 272) argue that efficient PM in supply chains needs some steps; (i) identifying business perspective, performance features, and choosing an accurate performance evaluation method; (ii) determining a way of gathering data; and (iii) identifying values and benefits behind them. Hung Goh and Eldridge (2019, p.84) view performance management as an "output control" which is "the evaluation of files, records and reports submitted by organisational units to senior management". The company adjusts some goals to be accomplished, determining independent tasks in the concept of project management and guide the responsible people towards these tasks (Galbraith, 1974; Malone and Crowston, 1994).

Some research papers explain the concept of PM with the metric-based approach, which defines that PM could be conceptualised with performance metrics, KPIs and capabilities of companies (Mishra et al., 2016, p. 186; Gawankar et al., 2016, p. 26; Zhang et al., 2016, p. 806; Maestrini et al., 2017, p. 301; Wu and Chiu, 2018, p. 8). Mishra et al. (2016, p. 186) highlight that SCP underlines a company's certain capabilities, involving "order fill capacity, delivery dependability, customer satisfaction and delivery speed". PM addresses the suitable key performance indicators (KPIs) of a company; therefore, it generally consists of cost efficiency and time responsiveness parameters of organisations (Gawankar et al., 2016, p. 26). SCP is conceptualised as "aggregate financial and operational performance measures and referring to buyers and/or suppliers" (Zhang et al., 2016, p. 806). Maestrini et al. (2017, p. 301) highlight that PM involves the processes and functions that serve the company's management interest; thus, it is developed within an individual company's boundaries. A set of metrics determined by a company improves the efficiency and effectiveness of supply chain activities. Wu and Chiu (2018, p. 8) consider the SCP as a formative construct that builds relationships with channel members with financial and non-financial items.

Performance measurement is a crucial concept and practice in SCM due to implementing both internal and external - involving SC partners - performance items. Besides, the determination of key performance indicators (KPIs) is a significant concern as their validity must be based on the validity of previous research (Lu et al., 2019, p.35). The gap between the planning and execution and unplanned events results in distortions in SCs; therefore, the partners in SCs are required to make adequate adaptations to close the gap. “Key Performance Indicators” (KPIs) enhance the entire visibility of the supply chain as well as planning activities of supply and demand. Also, supply chains need to apply an in-system approach, which is comprised of feedback and monitoring activities for the survival of the supply chain (Chae, 2009, p.423). Balfaqih et al. (2016, p.145) advocate that performance measurement in SC is a procreative research area due to the distinguished perceptions among scholars. The concept still needs to build specific needs of enterprises to be discovered as well as the assignation of KPIs and validation of empirical results.

Table 7. Key Definitions of SCP

Category	Authors	Explanations
The Systematic Approach	Chithambaranathan et al. (2015, p. 310)	“The evaluation regarded to monitor implementation, reveal progress, enhance communication and diagnose problems”
	Kaliani Sundram et al. (2016, p. 1448)	“SCP has been defined as a systematic process of measuring the effectiveness and efficiency of supply chain operations”
	Dossou and Nachidi (2017, p. 839)	“Performance criteria are used for measuring the existing and future systems. The performance of a system (supply chain) is improved by finding an optimum by combining criteria”
	Dweekat et al. (2017, p. 272)	PM requires “understanding the system’s business environment by analysing the SC from a business perspective, identifying its performance attributes, and selecting a suitable balanced scorecard for its performance evaluation; finding a way to collect data; and finding a reference to compare with in order to determine values or benefits”
	Hung Goh and Eldridge (2019, p. 84)	“SCP is an ‘output control’ which is the evaluation of files, records and reports submitted by organisational units to senior management”
The Metrics-based approach	Mishra et al. (2016, p. 186)	It “reflects upon certain capabilities of a firm namely; order fill capacity, delivery dependability, customer satisfaction and delivery speed”
	Gawankar et al. (2016, p. 26)	“Supply chain performance measurement (SCPM) is framed on the basis of appropriate key performance indicators (KPIs) of the firm”
	Zhang et al. (2016, p. 806)	“Supply chain performance has been conceptualised in numerous ways, as aggregate financial and/or single operational performance measures, and referring to buyers and/or suppliers”
	Maestrini et al. (2017, p. 301)	“a set of metrics used to quantify the efficiency and effectiveness of supply chain processes and relationships, spanning multiple organisational functions and multiple firms and enabling SC orchestration”.
	Wu and Chiu (2018, p. 8)	“Performance is conceptualised as a formative construct with financial and non-financial indicators. This is because the two indicators intend to define firm performance rather than manifest it, and firm performance is a composite of the two indicators that may be very different”

Source: Compiled by author

As mentioned before, Table 7 shows the various definitions and perspectives of the scholars about SCP. Considering the definitions above, in this thesis, SCP is defined as a "systematic process of measuring the effectiveness and efficiency of supply chain operations", which is the same definition of Kaliani Sundram et al. (2016, p. 1448).

2.3.2. The Performance Measurements and Metrics in SCM

Effective performance management (PM) systems have enormous potential for companies (Gunasekaran et al., 2001, p.72). However, only a few of them could comply with developing effective performance measures and metrics for integrated SCs; also, they lack revealing these measures and metrics with the concrete direction that is necessary for the strategies of their organisations (Bhagwat and Sharma, 2007, p. 44; Hudson et al., 2001, p. 805). Gunasekaran et al. (2004, p.335) suggest that targets of measurement exemplify organisational objectives; and metrics selected must represent a trade-off between financial and non-financial items to measure performance effectively. Moreover, companies should focus on the supply chain as a whole rather than concentrating on intra-company performance when they develop performance measurement tools (Shepherd and Günter, 2010, p.117; Hausman, 2004, p.63)

One of the well-known approaches to performance management provided by Kaplan and Norton (1992), is called a "balanced scorecard (BSC)". This measurement system identifies long term strategic objectives supported by short term actions rather than measuring short term financial metrics as the sole items. BSC is based on four main aspects: learning and growth, business processes, customers and finance. Another model, the "Supply Chain Operations Reference" (SCOR) was developed by the "Supply Chain Council" (SCC) to support companies in enhancing the effectiveness of their SCs and offering a process-based approach (Lockamy and McCormack, 2004, p.1192). The following areas; "Plan", "Source", "Make" and "Deliver" are the basis of the model to achieve communication between SC partners. Gunasekaran and Kobu (2007, p.2824) examine the most well-accepted approaches of PM. According to their research, performance measurement in logistics and supply chain systems could be categorised as follows:

- "*Balanced Score Card Perspective"*, which is a well-known model of Kaplan and Norton (1996) involves five perspectives ("financial", "customers", "internal processes", "innovation and improvement", and "employees").
- "*Components of a performance measure"*, which is a model of Beamon (1999), is viewed as performance measures in detail and characteristics of SC towards "resource utilisation", "output" and "flexibility".
- "*Location of measures in SC links*", where the model is based on the SCOR model, improved by the SCC. The model focuses on SC phases in the "plan, source, make and deliver".

- *Decision-making levels,* which were improved by Gunasekaran et al. (2001), highlighting a framework for evaluating “strategic”, “tactical” and “operational performance” in SCs.
- *Nature of measures,* which evaluates SCP using financial and non-financial items to evaluate performance at the operational level.
- *Measurement base,* which divides the main measurement bases into quantitative and qualitative measurement, changes in KPIs based on strategic objectives of the company.
- Traditional and modern measures identify the measurement systems as a function-based and value-based.

One of the well-known PM model, BSC, is strongly used in previous studies (Ferreira et al., 2016, p. 1420; Chung et al., 2016, p. 10; Mehralian et al., 2017, p. 119; Truong Quang and Hara, 2019, p. 1744). Ferreira et al. (2016, p. 1420) develop an assessment model of the environmental performance in supply chains, using the BSC approach. The four dimensions used in the research; financial indicators associated with the costs, supplier indicators such as suppliers’ degree of compliance with legislation and to meet customers’ needs, processes indicators such as level of quality of processes, percentage of waste generated, transportation of goods and raw materials and direct and indirect processes related to production, and learning and growth-related with the training of employees. Chung et al. (2016, p. 10) also improve a model on sustainable performance indicators based on BSC’s four dimensions; however, additionally, the study added a sustainable development dimension because of the relevance of the subject. Mehralian et al. (2017, p. 119) analyse the relationship between total quality management (TQM) and performance of the pharmaceutical companies, applying the BSC perspective. The study employs the basic indicators of the BSC approach; “financial, customer, internal and learning and growth items”. Truong Quang and Hara (2019, p. 1744) examine the relationship between supply chain risks and performance, based on the four balanced perspectives, market share growth and ROI counted as financial indicators while timeliness on delivery, product and service quality and response time to customer related to customers’ indicators. Also, the number of new product development and employee flexibility are innovation and learning indicators and production waste, costs of inventory and employee productivity are internal factors in the study.

On the other hand, the scholars adopted the model of Beamon (1999) to evaluate their PM models (Maghsoudi and Pazirandeh, 2016, p. 129; Um et al., 2017, p. 18; Wu and Chiu, 2018, p. 17). Maghsoudi and Pazirandeh (2016, p. 129) also adopted the items of Beamon (1999) to evaluate SCP. The study used total operational cost and cost-related items as resource utilisation; target fill rate achievement, minimum response time, and preventing stock-outs as output; and supply, production and demand flexibility items as the flexibility dimensions. Um et al. (2017, p. 18) used dynamic capabilities view to examine the linkages between product variety management and SCP. The study employed cost efficiency, customer service and flexibility items. The items selected for cost efficiency are similar to the items of resource utilisation, and customer service items were similar to output items considering the study of Beamon (1999). Wu and Chiu (2018, p. 17) examined the impact of supply chain collaboration on firm performance. The study employed the output and flexibility dimensions to evaluate the performance. The items of on-time delivery to customers, demand flexibility, new product development, product conformance and react to market change were seen as output and flexibility items. Wu and Chiu (2018, p. 17) also used financial items such as improving return on investment, return on assets, sales growth, reducing production and inventory cost, which are similar items of "resources" dimension based on the study of Beamon (1999), although these items were adopted from another study.

The already mentioned model, the SCOR model, also employed by scholars (Dissanayake and Cross, 2018, p. 108; Kottala and Kotzab, 2019, forthcoming; Lima Junior and Ribeiro Carpinetti, 2019, p.22). According to Dissanayake and Cross (2018, p. 107), responsiveness items evaluate the level of speed on the tasks, while agility items are the ability to respond and change, which also refers to production flexibility on the study. The items of reliability highlight the quality indicators which help organisations to perform their tasks. Finally, asset management evaluates the level of utilising assets of organisations; therefore, the items selected were inventory in hand, value at risk and outstanding sales. Kottala and Kotzab (2019, forthcoming) developed a scale measurement referencing the SCOR model between performance indicators. They argue that the efficiency and effectiveness indicators should be considered in the proposed models in order to measure SCP. The study categorised the related metrics in five dimensions; "plan, source, make, deliver and return". The metrics selected in the study were "quality of delivery goods", "cash to cash cycle time", "economic order quantity", "delivery reliability", "manufacturing lead-time", "total cash flow time", "inventory turnover ratio", "warranty/returns processing cost". The assessment of PM conducted by Lima Junior and Ribeiro Carpinetti (2019, p. 22), shows that PM requires the involvement of many member firms; therefore, it is a transversal process. The results of the business activities must be measured through leading and lagging metrics-based internally and externally. The proposed model of the study involves "order fulfilment metrics", "order cycle time", "upside and downside flexibility and adaptability", "overall value at risk", "return on working capital", "return on fixed assets", "cash to cash cycle time" and "total costs" to serve as the metrics of "reliability", "responsiveness", "agility", "assets" and "costs" dimensions.

Some studies also used decision-making levels, considering the strategical, operational and tactical measures (Petljak et al., 2018, p. 14; Khan et al., 2019, forthcoming). Petljak et al. (2018, p. 14) also attempt to investigate the indicators to achieve sustainable SCP. Improvements related to environmental goals and collaboration with suppliers were identified as a strategic level while transportation and purchasing functions were more based on an operational foundation in supply chains. The study used environmental indicators such as reducing waste items and collaboration with suppliers and economic items such as reducing transportation, warehousing and reverse logistics costs to measure SCP. Khan et al. (2019, forthcoming) state that supply chains need long and short-term decisions and criteria to measure SCP. Long term decisions refer to the long-lasting decisions that influence companies such as decisions related to warehouse or distribution locations and their capacities, and automation of the manufacturing processes. Short-term decisions involve the daily and weekly forecasting activities, or logistics processes for order fulfilment.

Finally, some scholars adopted the “measurement base” approach, employing KPI measures of companies in their models (Anand and Grover, 2015, p.157; Gardas et al., 2018, p. 268). Anand and Grover (2015, p.157) list the indicators in four aspects; “transport”, “information technology”, “inventory” and “resource optimisation”; and these aspects are divided into sub-categories such as “delivery, time, frequency, capacity, cost, quantity, service, IT implementation, and responsiveness” related performance indicators. Gardas et al. (2018, p. 268) developed 14 key essential indicators for the improvements of PM through experts’ opinions, these indicators include “organisational management”, “competitive and regulatory pressures”, “knowledge and training”, “brand image”, “economic”, “environmental”, “collaborative” and “reverse logistics” dimensions.

Gunasekaran et al. (2001, p.72) argue that scholars need to further explore the context of performance management for the following two reasons; the first one is due to a lack of understanding of companies about the significance of financial and non-financial performance measures. The second one is because of a lack of understanding of companies on the differences of the metrics at strategic, tactical and operational levels. For this reason, effective SC performance management deals with the idea of the whole supply chain goals and metrics to be used. The significant categories of PM are widely explained in the literature (Piotrowicz and Cuthbertson, 2015, p.1081; Beamon, 1999; Bullinger et al., 2002; Holmberg, 2000; Morgan, 2004; Shepherd and Gunter, 2006) by introducing the linkages between an organisation’s strategy and system of PM; however, still it can be observed that different approaches were used in the studies (Table 8).

Table 8. The studies and Metrics Used in SCP

Category	Authors	Evaluation Method	Performance Metrics
The BSC Perspective (“financial, customers, internal processes, learning and growth” indicators)	Ferreira et al. (2016, p. 1420)	Case Study	“Financial” (total costs of investments), “suppliers” (number of complaints, compliance with legislation), “processes” (wasting processes, transportation, packaging, direct and indirect process items) and “learning and innovation” (number of hours of employee training)
	Chung et al. (2016, p. 10)	Questionnaire	“Financial” (revenue growth, productivity, return on capital, cost management, risk management, investment strategy), “customer” (customer satisfaction, market share, customer profitability, customer retention rate) “Internal” (innovation and business processes, information system capabilities, products database management) “Learning and Growth” (employee factors, incentives and authorisation and supplier management capabilities)
	Mehralian et al. (2017, p. 119)	Questionnaire	“Financial indicators” (profitability, risk and growth); “customer indicators” (market share, customer satisfaction); “internal indicators” (internal process improvements) and “learning and growth indicators” (organisational change, innovation and growth)
	Truong Quang and Hara (2019, p. 1744)	Questionnaire	“Financial” (market share growth, ROI), “customer service” (delivery timeliness, product and service quality, response time to a customer), “internal” (amount of production waste, costs of inventory, employee productivity) and “innovation and learning” (employee flexibility, a number of products developed per year)
The Components of performance measures (“Resource utilisation, Output and Flexibility” indicators)	Maghsoudi and Pazirandeh (2016, p. 130)	Questionnaire	“Resources”: cost-related items, total operational cost “Output”: Target fill rate achievement, minimum response time and preventing stock-outs “Flexibility”: supply, production and demand flexibility items
	Um et al. (2017, p. 18)	Questionnaire	“Resources items” (total cost of distribution, manufacturing and inventory holding) have been named as “cost efficiency items”. Also, “output items” (order fill rate, on-time delivery, customer response time, order lead time and customer satisfaction and complaints reduction) have been named as “customer service items”. Finally, some “flexibility items” were selected (changes in supplier side, production volume, production, demand, etc.)
	Wu and Chiu (2018, p. 17)	Questionnaire	“Output” and “Flexibility”: on-time delivery to customers, demand flexibility, new product development, product conformance and react to market change also used financial items “Resources”: improving return on investment, return on assets, sales growth, reducing production and inventory cost
The Location of measures in SC links	Dissanayake and Cross (2018, p. 108)	Case study	The metrics related to “reliability, responsiveness, agility, and asset management” on supply chains
	Kottala and Kotzab (2019, forthcoming)	Questionnaire	The items are categorised in the “plan, source, make, deliver and return” dimensions. The metrics selected are the “quality of delivering goods”, “cash to cash cycle time”, “economic order quantity”, “delivery reliability”, “manufacturing lead-time”, “total cash flow time”, “inventory turnover ratio”, “warranty/returns processing cost”
	Lima Junior and Ribeiro Carpinetti (2019, p.22)	Fuzzy Logic/mathematical modelling	“Reliability”: Order fulfilment metrics “Responsiveness”: Order cycle time “Agility”: Upside and Downside flexibility, overall value at risk, upside SC adaptability “Assets”: Return on working capital, return on fixed assets, cash to cash cycle time “Costs”: Total costs to serve
The Decision-making levels (“Strategic, Operational and Tactical Level”)	Petljak et al. (2018, p. 14)	Questionnaire	Two dimensions used to measure SCP; “environmental and economic” indicators: “reducing waste” items and “cooperation with suppliers” as “environmental indicators” and “reducing transportation”, “warehousing and reverse logistics costs” were “economic indicators”
	Khan et al. (2019, forthcoming)	Fuzzy analytic hierarchy process	“Decision-making levels” are identified as a long and short-term basis. Short term metrics are “satisfying daily and weekly forecasting”, “short term relations with suppliers”, “logistics activities for order fulfilment”. Long term metrics are “warehouse location and capacity”, “manufacturing processes” such as automation, network design in SCs
The Measurement base	Anand and Grover (2015, p.157)	Literature Review	KPIs based approach – “transport, information technology, inventory and resource optimisation”
	Gardas et al. (2018, p. 268)	Case Study	14 essential KPIs were determined for SCP including, “organisational management”, “competitive and regulatory pressures”, “knowledge and training”, “brand image”, “economic”, “environmental”, “collaborative” and “reverse logistics” dimensions and so on

Source: Compiled by the author

As indicated in Table 8 and 9, authors approach the different perspectives and metrics to observe performance assessment; mostly they attempt to identify critical success factors which meet with organisational goals and KPIs. Therefore, it might be a challenge to accept a universal consensus-related to proper measures on examining performance on SCs (Akyuz and Erman Erkan, 2009, p.5150). The use of financial indicators such as cost related items heavily directs PM models due to their quantitative nature so they are easily measured (Sezen, 2008, p. 233).

Table 9. Dimensions of SCP

Studies	**Cost**	**Customer**	**Flexibility**	**Operational achievements**
Anand and Grover (2015)	X	X	X	X
Ferreira et al. (2016)	X			X
Chung et al. (2016, p. 10)	X	X		X
Maghsoudi and Pazirandeh (2016)	X	X	X	X
Fantazy et al. (2016)	X	X		X
Mehralian et al. (2017)	X	X		X
Um et al. (2017)	X	X	X	X
Wu and Chiu (2018)	X	X	X	X
Dissanayake and Cross (2018)				
Petljak et al. (2018)	X			X
Truong Quang and Hara (2019)	X	X		X
Kottala and Kotzab (2019)	X			X
Lima Junior and Ribeiro Carpinetti (2019)	X		X	X
Khan et al. (2019)		X		X

Source: Compiled by the author

However, today's SCs need to consider SC operational activities (Fantazy et al., 2016, p.1275; Fawcett et al., 2007, p.360; Kaplan and Norton, 2001, p.157) and customer-related factors (Anand and Grover, 2015, p. 153; Sezen, 2008, p. 234; Reddy et al., 2019, p.42) on the assessment of PM. Another point is that Kamble and Gunasekaran (2020, p. 70) argue that the lack of measures of flexibility has been found in previous PM models. Beamon (1999, p. 281) developed a framework that includes critical aspects of organisational goals and supply chain characteristics. According to research, “resources, output and flexibility” are the key elements to achieve strategic organisational goals. In the current dissertation, these three categories of SCP have been operationalised as followed. Based on Table 9, cost factors were identified as resource utilisation items, while customer and operational achievements were considered as output items.

The Concept of ‘Flexibility’ in SCP

Flexibility refers to “the functional ability to respond to a changing environment” (Um et al. (2017, p.7). Golden and Powell (2000, p.376) emphasise that “flexibility is the capacity to adapt” from numerous definitions in the literature. Here, “capacity” is used rather than “capability” because of multi-dimensional characteristics of the concept. Similarly, Cheng et al. (1997, p.147) adopt the basic definition of flexibility as “the ability to be bent or the ability to be reshaped”. Although flexibility refers to the reactive ability of companies; however, it also has a strategic role (Stevenson and Spring, 2007, p.701). Bernardes and Hanna (2009, p. 33) believe that the concept of flexibility is an enabler to offer superior value to customers rather than a direct influence on customers’ needs. Furthermore, the concept plays a role in handling uncertainty in SCs (Stevenson and Spring, 2007, p.701).

After the late nineties with the growing interest in supply chain issues, firms would like to go beyond the boundaries of intra activities and elaborate the activities with their supply chain partners; therefore, interchain competition from a raw material supplier to final customer was considered a significant issue. Therefore, value chain flexibility which includes purchasing, manufacturing and logistics within the network gives superior value to the final customer (Manders et al., 2017, p.973). In the supply chain context, companies are highly focused on the flexibility concept to accomplish a competitive advantage with low-cost competition and coordination of their partners; in this sense, they could respond to customer needs quickly, introduce new products using less effort and offer different types of products (Shuiabi et al., 2005, p.697). However, the notion of flexibility on SCs has arisen in the manufacturing flexibility literature; thus, it highly emphasises to a manufacturing context by omitting the role of other activities (Jafari et al., 2016, p.447; Cheng et al., 1997, p.147). According to Esmaeilikia et al. (2014, p.411), manufacturing flexibility could be regarded as process flexibility, manufacturing capacity flexibility and delivery flexibility; the initiatives of manufacturing flexibility is mostly practiced at the strategic level. Studies also indicate the four identifiable characteristics of the manufacturing flexibility including “new product flexibility”, “mix flexibility”, “volume flexibility” and “delivery flexibility” (Slack, 2005, p.1193; Chu et al., 2012, p.116; Oke, 2005, p.975).

Another point is that a higher level of supplier flexibility gives manufacturers much potentials over responsiveness against their competitors. Sreedevi and Saranga (2017, p. 334) define “supplier flexibility” as the level of flexibility within an upstream supplier network, supply contracts, and collaborative supplier relationships. Supplier flexibility mainly focuses on the ability of suppliers to respond to dynamic changes in production; however, suppliers often have a limited capability to react to customer needs (Christopher, 2000, Garavelli, 2003, p.151); therefore, manufacturers should manage a shared vision strategy with their suppliers to perform better in some production activities (Chu et al., 2012, p.124). Identically, responsiveness to changes in downstream activities is a part of marketing-based flexibility, also known as “demand flexibility”. This type of flexibility is the ability to respond to demand variations by managing ordering activities, customer service, price and discounts and promotions, which are also sometimes characterised by agility activities (Gunasekaran and Kobu, 2007, p. 2825; Yu et al., 2012, p.1208).

As discussed above, the concept of flexibility has been thoroughly analysed in the categories of the manufacturing flexibility including delivery performance (Sreedevi and Saranga, 2017, p. 334; Sezen, 2008, p. 235; Gerwin, 1993, p. 395; Sáenz et al., 2018, p. 238), supplier flexibility (Kamalahmadi and Mellat-Parast, 2016, p. 302; Saghiri and Barnes, 2016, p. 170; Avittathur and Swamidass, 2007, p. 717), demand flexibility (Sajjad et al., 2016, p. 2633; Finck et al., 2018, p. 409; Chen and Tseng, 2007, p. 596) or ability to respond to new products, markets or new competitors (Beamon, 1999, p. 284; Sezen, 2008, p. 235; Shuiabi et al., 2005, p.697). Therefore, these concepts will be used to examine the operations of manufacturing companies on flexibility performance in the current dissertation.

The Concept of ‘Output’ in SCP

According to Beamon (1999, p. 280), output measures customer responsiveness in general because, without acceptable output, customers could switch to other supply chains. Purbey et al. (2007 p.244) identify that output and processing measurement could be used for performance management to create better objectives and results for companies. In light of the growing attention to customer experience quality, outcomes also are counted as an important aspect of value creation (Kumar and Singh, 2019; Mccoll-Kennedy et al., 2017).

Numerous studies have viewed “output performance” as corresponding to customer satisfaction (Sezen, 2008, p.234; Deshpande, 2012, p. 18; Chan, 2003, p.538; Kasiri et al., 2017, p. 92; Chan et al., 2003, p.636). Sezen (2008, p.234) explains that output is generally related to customer satisfaction; thus, it includes the items consistent with organisations’ activities, operations, and services to meet customer expectations. These items were classified as on-time deliveries, sales, profit, lead time, order fill rate, customer response time, shipping errors and customer complaints (Sezen, 2008, p.234). Equivalently, the study of Deshpande (2012, p. 18) mentions “output” could be measured with the metrics of customer satisfaction such as product quality, the total time for producing the item, and on-time deliveries. Chan (2003, p.538) clarifies that evaluating the number of customer complaints registered is a direct measurement item for measuring the level of customer satisfaction. However, the study supplements time-related items to retain customers because unsatisfied customers might prefer another company as a consequence of the poor service level of the previous company. Chan et al. (2003, p.636) argue that customer satisfaction level could be counted as a qualitative measurement which is not shown with direct numerical measurement, despite the fact that some items could be quantified. Other studies (Cai et al., 2009, p.515; Khare et al., 2012, p. 27) also investigate the items of measuring “output” performance. Cai et al. (2009, p.515) use four categories: “sales or profits”, “rates of stockouts”, “fill rate” and “lead time of order fulfilment” whilst Khare et al. (2012, p. 27) employ the items such as “total revenues”, “percentage of the order filled”, “on-time deliveries”, “the lead time between order and delivery”, “backorder”, “customer complaints received”, and the “total amount of time to produce the products” in order to measure output performance.

The effects of globalization push companies to improve more sophisticated methods on productivity management; thus, quality control, reducing lead times, more outputs produced to meet demand were achieved at the expense of customer satisfaction (Bitici et al., 2012, p.313). Some studies (Kasiri et al., 2017, p. 92; Izogo and Ogba, 2015, p. 262) indicate that organisations’ service level is highly associated with customer satisfaction and output performance. For this reason, in the current dissertation, output performance corresponds to both organisation’s strategic goals and customers’ goals (Beamon, 1999, p. 283).

The Concept of ‘Resource Utilisation’ in SCP

Today’s supply chains are volatile in terms of demand; as volatility on-demand increases, manufacturing processes could lose their stability which leads to the source of their undeemed efficiency (Yin et al., 2017, p. 70; Fattahi et al., 2013, p.1095). Shepherd and Günter (2010, p.106) introduce a performance measurement system as quantifying the effectiveness and efficiency of an action. Here, efficiency indicates how economically companies’ resources are exploited when offering a pre-assigned extent of customer satisfaction. Szegedi and Illes (2006, p.840) state that minimising costs and maximising customer service levels are the main attributes for organisations to progress in SC performance. According to Angerhofer and Angelides (2006, p.284), the mission of competitiveness may be originated in two broad strategies; reducing cost production and product differentiation. Therefore, the objective of operations strategy is to maintain the positioning and evaluate the success of outcomes; which leads to utilising optimum usage of all company’s resources. Maghsoudi and Pazirandeh (2016, p.135) indicate that resource items are crucial for companies’ performance; if a company does not exploit resources well, they can lose their further funding from donors. The study used mainly operational cost-related items; “the total cost of resources used”, “ordering cost”, “general costs”, etc., to measure organisations’ resources performance. Alike, Adel El-Baz (2011, p.6682) expressed that resource measures are directed to achieve a high degree of efficiency. The measurement of resources offers goals related to cost efficiency such as “total cost of resources”, “inventory”, “manufacturing” and “distribution” costs existing in SCs (Um et al., 2017, p. 7).

Decreasing waste and increasing cost efficiency have been concentrated in determining the deficiencies in particular processes and at length maintaining profits (Dunuwila et al., 2018, p.588, Chaiwan et al., 2015, p.187). Some scholars argue that modern technologies such as IoT (Arnold et al., 2016, p.8), cloud (Wu et al., 2015, p.3), additive manufacturing (Elser et al., 2018, p. 1512; Ford et al., 2015, p.6) provide the optimisation of production systems in terms of costs, efficiency, reliability, time, and so forth. Another study conducted by Eguía et al. (2017, p.1033) shows reconfigurable manufacturing systems via advanced technologies could decrease the number of inputs consumed such as tools and models applied, material, and energy. Although technological advancements enhance organisations performance particularly in better resource utilisation, Shahbazi et al. (2017, p.113) stress that only a few companies still achieve resource efficiency on their KPIs, which occurs mainly in lacking productivity and material cost efficiency to accomplish fulfilling customer needs.

To be concluded that, measuring resource performance of organisations is commonly based on minimum requirements – quantity - or composite efficiency items (Beamon, 1999, p. 281). Thus, the present dissertation examines items such as “total cost”, “distribution cost”, “manufacturing cost”, “inventory” and “return on investment (ROI)” to measure the resource performance of enterprises.

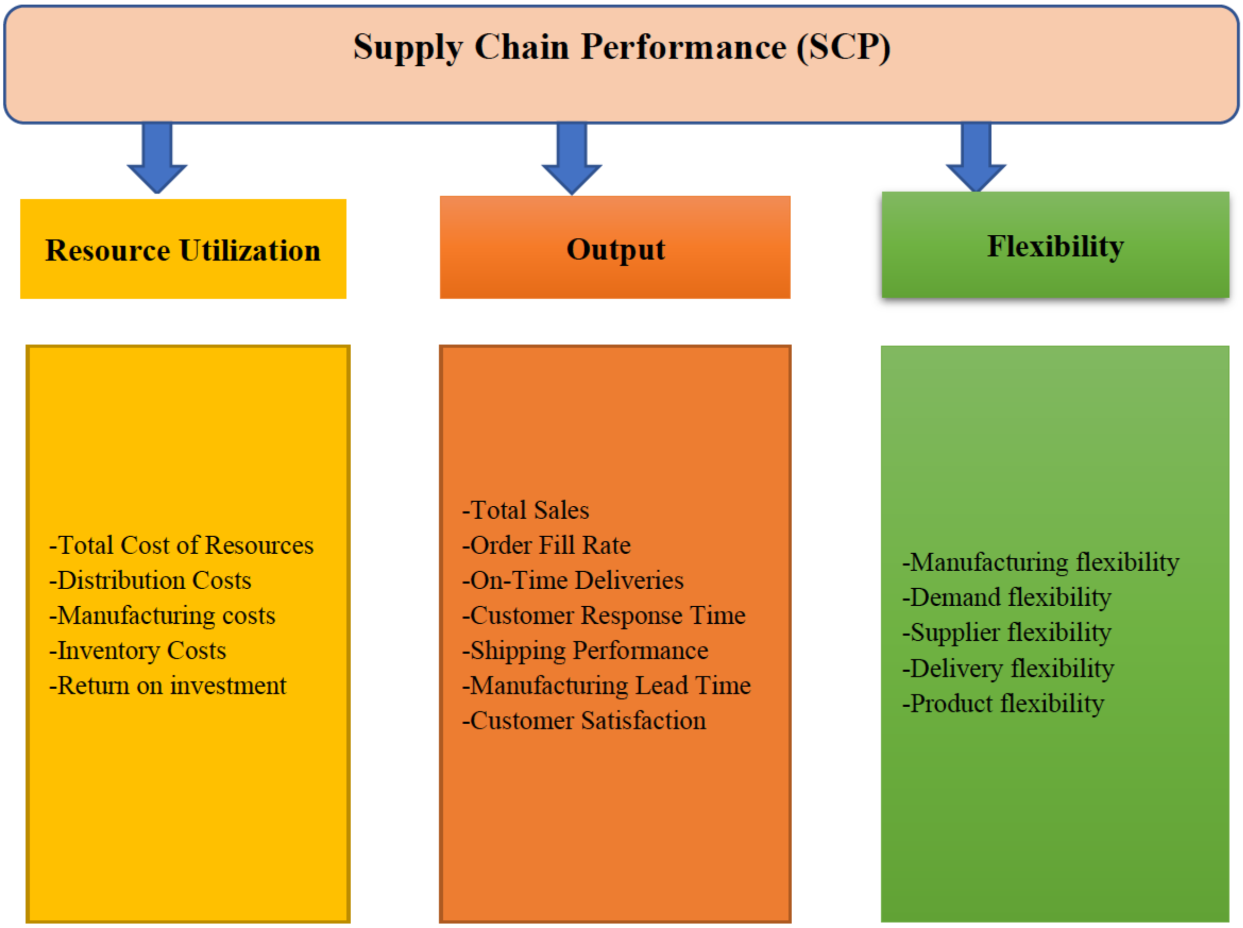


Figure 4. The Items and Dimensions of SCP
Source: Author's own elaboration

Based on the literature, the author adopted the scale of Beamon (1999, p. 281) for each concept explained above to measure SCP. Figure 4 indicates the dimensions and items used in this dissertation for the scale of SCP.

2.4. The Relationship Between Industry 4.0, SCI and SCP and Hypotheses Development

2.4.1. The Relationship between Industry 4.0 and SCI

According to Lasi et al. (2014, p.240), the production process via Industry 4.0 is actualised with dynamic networks; therefore, it is essential to develop concepts related to production with network partners. Through Industry 4.0, new strategies, networks and business models will be generated under the context of horizontal integration, which is one of the promises of Industry 4.0 (Tjahjono et al., 2017, p. 1177; Rüßmann et al., 2015, p. 1; Bibby and Dehe, 2018, p. 1038). As discussed previously, Industry 4.0 is described as recent technological advances that use Internet standards, therefore, the concept may lead to the integration of physical objects, employees, production lines and networked and agile SCs (Schumacher et al., 2016, p. 162).

Although there is a lack of empirical evidence for the relationship between Industry 4.0 and SCI; however, much research could be done regarding the exploitation of IT and digital technologies on SCI (Yu et al., 2016, p. 4203; Lee et al., 2016, p.2; Smart, 2008, p. 243; Frohlich and Westbrook, 2001, p.196; Crespo Marquez et al., 2004, p.362). Yu et al. (2016, p.4199) suggest that the capability of IT is viewed as an enabler of SCI due to streamlining relationships between partners such as sharing information in a timely manner. The results of the study reveal that a higher degree of IT capability increases SCI. The comprehensive model of Crespo Marquez et al. (2004, p.362) considers that the use of e-collaboration tools is significant for SCI; such as using Internet tools and installing an electronic payment system. The implementation of new technologies could begin with collaborative demand forecasting and sequenced by collaborative planning by sharing and assisting the inventory information in the supply chain. Gunasekaran and Ngai (2004, p.291) opt that IT implementation is an essential element for the competitiveness of companies and supply chains; well-developed IT-enabled integration improves strategic planning and infrastructure in SCM. Lee et al. (2016, p.2) claim that integrated IT systems increase rapid information exchange in supply chains as well as virtual integration by fostering collaboration. Smart (2008, p. 243) demonstrates the evidence of four case studies on the main issues of the usage of E-business and IT mechanisms on SCI. Only buy and sell applications used in companies would not lead to an integrated supply chain; if these systems are not confirmed within a structure of IT integration which assists the benefits at the supply chain level.

2.4.2. The Relationship between SCI and SCP

The basis of SCI is that smoothing core business processes gain an advantage over competitors through reducing costs and creating value related to superior company performance (Chang et al., 2016, p.282). Although most researchers recognise that SCI contributes to developing the different areas of performance (Beheshti et al., 2014, p.28; Aryee et al., 2008, p.571; Bagchi et al., 2005, p. 275); however, the literature indicates mixed findings on the SCI-SCP link; thus, discussions on this manner are still open (Danese and Bortolotti, 2014, p. 7062). Beheshti et al. (2014, p.28) found that SCI positively influences financial performance. The research conducted by Danese and Bortolotti (2014, p.7079) ascertains that full adopters in SCI perform better than non-adopters on operational performance categories, such as “quality”, “delivery”, “flexibility” and “efficiency”. Similarly, Bagchi et al. (2005, p. 275) found that SCI influences operational performance as well as reducing cost and increasing efficiency. Fantazy et al. (2016, p.1275) indicate that the extent of information sharing between partners positively influences firm performance. Birasnav and Bienstock (2019, p.155) state that SCI is a requirement for many companies to improve their competitive capabilities and accomplish superior performance.

On the other hand, there are a few studies, showing that SCI may not always improve performance (Fabbe-Costes and Jahre, 2008, p.145; Chaudhuri et al., 2018, p.699; Vickery et al., 2003, p. 533). The study of Fabbe-Costes and Jahre (2008, p.145) reinforces a clarification of the term SCI and a better comprehension of the phenomenon by offering a “state of the art” principle. However, the research observes an unclear link between SCI and either operational or financial performance. The core reason for this explained in the study is due to challenges and the complexity of measuring supply chain performance. Likely, Chaudhuri et al. (2018, p. 705) discover that there is no direct link observed between external integration -supplier and customer integration- and flexibility performance. Also, Vickery et al. (2003, p.533) found an indirect relationship between SCI and financial performance; however, customer service plays a fully mediating role between these two concepts.

2.4.3. The Relationship between Industry 4.0 and SCP

As mentioned earlier, Industry 4.0 supports industrial production processes by integrating vertical and horizontal activities; thus, it is expected to achieve higher industrial performance (Dalenogare et al., 2018, p. 383). However, we know little about the potential contribution of Industry 4.0 on performance-related issues, especially in emerging countries (Dalenogare et al., 2018, p. 383). Although some previous studies attempt to conceptualise Industry 4.0 and its related technologies by proposing maturity, readiness, or assessment models (as can be seen in section 2.1.3.); only a few studies can be identified on the effects of Industry 4.0 on performance (Dalenogare et al., 2018, p. 383; Buer et al., 2018, p. 2934; Frank et al., 2019, p. 20).

Dalenogare et al. (2018, p. 391) analyse the impacts of Industry 4.0 technologies on three performance dimensions: “product”, “operational” and “side effects”. The findings show that some of the technologies are positively related to industrial performance; however, the rest of them are still at an initial stage to adopt so the expected benefits are not obvious. Buer et al. (2018, p. 2937) state that implementation of Industry 4.0 and lean manufacturing jointly may have a positive impact on performance implications; however, they note that several studies solely examine on a conceptual level or gathering secondary data. Thus, more empirical studies need to be investigated for future research. Frank et al. (2019, p. 20) advocate that smart manufacturing processes have a direct influence on the operational performance of organisations.

Although there is scarce data in previous studies about the linkage between Industry 4.0 and performance; some authors consider particular technologies to observe their effects on PM (Delic et al., 2019; Aryee et al., 2008, p.571; Silvestro and Lustrato, 2014, p.318). Delic et al. (2019) found that the adoption of Additive Manufacturing (AM) contributes to the positive impacts on SCP whilst the empirical study of Aryee et al. (2008, p.571) concludes that both a combination of hard variables and soft variables via IT systems (MRP, ERP, EDI) will increase performance gains of the companies. Silvestro and Lustrato (2014, p.318) suggest a holistic perspective of the flow of physical and financial resources to improve supply chain performance across networks;

the findings of their case research also show the importance of developing payment systems and technologies which could reduce the dysfunctional impacts of SC information asymmetry.

In addition, some research concentrates on the effects of digital technologies on performance could be increased by the mediating role of SCI (Delic et al., 2019; Yu, 2015, p.955; Bruque-Cámara et al., 2016, p.149). Delic et al. (2019) stress that AM adoption positively influences supply chain performance, whereby SCI indirectly promotes performance developments enabled by the adoption of AM in automotive SCs. Yu (2015, p.955) shows that IT-enabled SCI is significantly associated with operational and financial performance. Bruque-Cámara et al. (2016, p.149) found that technological transformations such as cloud computing improve SC process integration which results in better operational performance.

After the discussion on section 2.4.1., 2.4.2, 2.4.3., the following hypotheses are formulated in the present dissertation:

H1: Industry 4.0 positively affects Supply Chain Integration.

H2: Supply Chain Integration positively affects Supply Chain Performance.

H3: Industry 4.0 positively affects Supply Chain Performance.

H4: Supply Chain Integration mediates the relationship between Industry 4.0 and Supply Chain Performance.

2.5. Underlying Theoretical Support

The discussion above by now provides for determining key characteristics and elements of three main constructs in the research model and relevant studies which show the possible relationship between them, whereas this section examines the relationships between Industry 4.0, SCI and SCP grounded on two theories: the resource-based view (RBV) and relational view.

2.5.1. Resource Based View (RBV): Identifying Firms' Resources and Performance Superiority

Strategic Management aims to gain a competitive advantage through companies' important assets (Richard, 2000, p. 165). Boyd et al. (2010, p. 593) define RBV as "aligning the determinants of perceived quality to competitive advantage, which is reflected in the firm's market prominence". In other words, the core of the theory underlines "superior firm performance is based on firm-specific resources and skills that cannot be easily imitated by competitors" (Nwankpa and Roumani, 2016, p. 3). Nath et al. (2010, p. 318) explain that RBV considers an organisation as a bundle of resources and capabilities. Specifically, the perspective of the RBV effectively states how companies accomplish competitive advantages and maintain them (Lin and Wu, 2014, p. 408). Thus, the RBV has emerged as a significant and potent theory of sustained superior performance in the strategic management field (Barney and Arikan, 2001, p. 174).

Several scholars have employed a resource-based perspective to address the issue of the assistance of IT on firm performance (Rivard et al., 2006, p. 29; Haseeb et al., 2019, p. 7; Wu et al., 2006, p. 493; Zhuang and Lederer, 2006, p. 251). With the characteristics of new technology and resource use, digital technologies could lead to radical and revolutionary changes (Han, 2017, p. 87). Wiengarten et al. (2012, p. 31) contend that the RBV sheds some light on the argumentative discussion about if IT resources could be used for long term performance development, providing that the RBV reveals a direct relationship between resources and competitive advantage with a well explained dependent construct and strategic value of particular resources. According to Wu and Chiu (2015, p. 27), IT resources, including tangible and intangible ones, could be realised as "valuable, rare, inimitable and non-substitutable" to achieve performance superiority; and these are counted as the four attributes of the RBV theory. On the other hand, Wu et al. (2006, p. 494) argue that when IT is solely implemented, it might not meet the RBV criteria due to relatively low obstructions to imitation by other companies, so the opportunities related to IT are likely to shorten fairly quickly.

Based on these explanations, the present dissertation seeks the implementation of Industry 4.0 in the concept of SCM; thus, it proposes that the assessment of Industry 4.0 could facilitate the improvements on SCM, in particular, SCI and SCP since it is organisation-specific and difficult to duplicate across enterprises. The RBV offers the underlying foundation for the improvement of Industry 4.0 construct in this dissertation because this construct designates a company's capability in IT exploitation. For this reason, the advantage of using sophisticated technologies achieved through system-based thinking, Industry 4.0, provides a sustained competitive advantage for an organisation (Wu et al., 2006, p. 494).

2.5.2. Relational View: Identifying Networks of Organisations and Performance Superiority

The foremost argument for the relational view is that distinctive inter-firm linkages might be a source of competitive advantage (Dyer and Singh, 1998, p. 660; Chen et al., 2013, p. 395). By presenting the relational view as a supplement to the RBV, competitive advantage could be accomplished by concentrating on dyads and networks of organisations as units of analysis (Wieland and Wallenburg, 2013, p. 303). Dyer and Singh (1998, p. 660) explain that organisations collaborate to perceive supernormal "relational rents", described as the basis of the relational view (Fawcett et al., 2015, p. 648). Notedly, the relational rents imply four attributes: "relation-specific assets", "knowledge sharing routines", "complementary resources/capabilities" and "effective governance" (Dyer and Singh, 1998, p. 660; He et al., 2013, p. 606), and it is defined that supernormal profits created in exchange relationships (Dyer and Singh, 1998, p. 662; Zacharia et al., 2011, p. 593). Consequently, organisations that focus on cooperation among SC partners may enhance higher economic benefits compared to ones that assimilate the traditional idea of competitive advantage (Paulraj et al., 2008, p. 46).

Prior studies investigated the impact of integration in SCs through using the firm's resources and capabilities on performance management (Lee et al., 2014, p. 285; Chen et al., 2013, p. 391; Prajogo et al., 2016, p. 220; Sanders et al., 2011, p. 179). Lee et al. (2014, p. 286) present that information systems are an inter-organisational source and pioneer to integrate SCs; therefore, it contributes to inter-organisational performances. Chen et al. (2013, p. 395) analyse whether IT integration of organisations and exchange of knowledge with their key suppliers influence SCP. Prajogo et al. (2016, p. 224) posit that the integration of supplier and buyer logistics processes including sharing information and coordinating the activities between these entities presents a source of competitive advantage for companies. Sanders et al. (2011, p. 179) assume that buyer to supplier information sharing, performance feedback and investments in inter-organisational IT plays a crucial role in performance improvement.

As discussed above, a company's competitive performance is connected to both internal resources and external resources of organisations as well as linkages of their partners in SC. Drawing upon the relational view theory, the present dissertation examines the integration of SCs (SCI) positively affect SCP because SCI is regarded as strategic alliances and long term relationships through information sharing, collaborative actions of partners or involving them in the decision making process as suggested in the relational view theory (Dyer and Singh, 1998, p. 660). Therefore, the current dissertation examines the network relationships in which organisations are embedded based on the relational view while it investigates their performance superiority from a resource perspective through the RBV.

3. MATERIALS AND METHODS

3.1. Quantitative Research Design and Research Method

Determination of research design such as using qualitative versus quantitative is significant for scholars to establish the guidelines for data collection and method of analysis (Han, 2017, p. 133). The discussions regarding the choice of qualitative or quantitative research depend on the differences in assumptions about what reality is and if data is measurable or not (Newman et al., 1998, p. 2). Generally speaking, quantitative research is represented with numerical and statistical data which reflects the objective of explaining the phenomena (Sukamolson, 2007, p. 2). Therefore, quantitative research is related to count occurrences, volumes, or size of entities (Gelo et al., 2008, p. 267). On the other hand, qualitative research-based data represent the analysis of text-based structure from interviews, focus groups, etc. (Clement et al., 2015, p. 12). In other words, this type of research seeks to use an interpretive and naturalistic way to deliver the meaning of research objectives (Han, 2017, p. 134).

Ercikan and Roth (2006, p. 14) demonstrate the difference between qualitative and quantitative research in terms of characteristics of data, objectivity and subjectivity in constructing data, and generalisability. The characteristics of data are described as the nature of data. In organisational research, researchers tend to show the data in written form with tables, regression graphs, or standardised notation systems to explain the analysis (Lee, 1992, p. 93). Objectivity and subjectivity of data are other concerns, which the former correlates with quantitative research while the latter is regarded as qualitative research. Whilst the subjective perspective of qualitative research supports the quality of the research, the objective nature of quantitative research is replicable by other researchers; however, many phases of data construction in quantitative research need “subjective” and “defensible” arguments by the scholars (Ercikan and Roth, 2006, p. 17). Another point is the level of generalisability, mainly associated with quantitative research rather than qualitative research due to its relevancy for statistically observed data (Ercikan and Roth, 2006, p. 18). The methods of quantitative research arise in the subjects of natural sciences which underline objectivity, measurement, reliability and validity of data (Lee, 1992, p. 87). Considering the characteristics, objectivity and generalisability of data, this research applies in quantitative research for the method and analysis.

One of the most used methods of quantitative research, the questionnaire method, investigates proof of patterns amongst large populations (Harris and Brown, 2010, p. 1). In very general terms, researchers think of conducting a questionnaire when it is intended to point out how a sample reacts to the world around them or how they may react to changes one may request to make (Sinclair, 1975, p. 73). This method is mostly applied by the authors in the field of SCM in order to collect information from respondents (Huo, 2012, p. 600; Prajogo and Olhager, 2012, p. 517; Wong et al., 2011, p. 608; Bruque-Cámara et al., 2016, p. 145). Therefore, this dissertation employs the questionnaire method to investigate the research questions and hypotheses formulated with the analysis of the data from primary sources.

3.2. Questionnaire Design

Although the quantitative method was selected for this dissertation, the background of the dissertation was also related to qualitative and exploratory research. A qualitative pilot-test is the main stage of the improvement of any questionnaire; that would lead to verify the questionnaire by target audiences who provide their understanding of the questions and propose some feedback on it (Perneger et al., 2015). Longhurst (2003) explains that applying semi-structured interviews in different locations helps researchers explore issues in a particular subject and develop alternative methodological methods coupled with higher reflexivity of the process of study. To address these concerns, the dissertation employed semi-structured interviews with some companies before developing the items of the questionnaire. However, selecting participants to interview is an important process since they are the representatives of shaping the research (Müller et al., 2018a). For this reason, first of all, we conduct online research about the companies, attempting to implement or already implemented Industry 4.0 activities. Later, it has been contacted with the industrial institutions, the chambers of commerce, the universities and the research institutes in the leading cities in Turkey (Istanbul, Ankara and Izmir) to determine successful firms regarding Industry 4.0 and to contact them. In total, 70 randomly selected companies were identified by checking their websites, initiatives on their activities in both Industry 4.0 and the supply chain. Later e-mails were sent to their production, operations, planning or supply chain managers, in addition to executives of these companies; 14 respondents were invited to attend to semi-structured interviews. Of the 14 companies, nine of them were large firms with higher than 250 employees and their annual revenue was more than 20 million dollars. Five of them were medium-sized companies with higher than 50 and less than 250 employees and their annual revenue was higher than 4 million dollars and less than 20 million dollars. The selected participants' experiences ranged from 1 year to 46 years and the duration of the interviews lasted from 30 to 90 minutes. The guideline of the interview contained three parts; firstly, the participant shortly stated the key operations of the enterprise and his/her position in the organisation. The second part was comprised of the questions related to Industry 4.0; main concepts and technologies of Industry 4.0 and the current state of its impact on their companies. The third section included supply chain-related questions; here the respondents explained what performance metrics were important for their companies, impacts of Industry 4.0 on these metrics and integration on the supply chain. Moreover, data gathered from the participants were compared to the firms' websites, and press interviews conducted by the companies. This offered more explicit understandings of the validity of the dissertation. The guideline of the interview and characteristics of the participants and the organisations are shown in Appendix 1 and Appendix 2.

A common aim of questionnaire research is to collect data, representing a population. Researchers gather information from the questionnaire to generalise their results supported by a sample from this population within the limits of random error (Kotrlik and Higgins, 2001). After the interview process, the next stage is to identify the items employed in the questionnaire. The scale items were adopted from prior research papers; however, the most appropriate scale was selected based on the findings of the interviews and conceptualisations of the constructs in the literature. The guideline of the questionnaire (see in Appendix 3) is comprised of four sections; (1) the questions linked to company information and profiles of the participants, including the position of the respondents in the organisation, employee numbers in the organisation, annual revenue turnover of the company and sector of the company. (2) the questions concerning Industry 4.0, including the extent to assessment of Industry 4.0 strategy of companies, the extent to assess the employee and culture in the activities of Industry 4.0 and the extent to assess technologies of Industry 4.0. (3) the questions related to Supply Chain Integration, including the degree of integration with suppliers, the extent to integrate internally, the extent to integrate with customers. (4) the questions related to Supply Chain Performance, including the extent to perform in items of resources, the extent to perform in output items and the extent to perform in flexibility items of organisations.

The first main construct measures the assessment of Industry 4.0; including three elements: strategy and organisation (S&O), employee and culture (E&C), and technology (T). A total of 24 items were selected to evaluate these elements. The scale items for the elements were improved considering the elements of Industry 4.0 previously mentioned in section 2.1.3. and the findings of the semi-structured interviews. Based on this, the most appropriate items were selected from the research of Bibby and Dehe (2018) to measure the elements of Industry 4.0 (Table 10). Through this dissertation, the first element – "strategy and organisation" (S&O)- was evaluated using four items; "availability of roadmap" (S&O1), "Industry 4.0 infrastructure" (S&O2), "customising products" (S&03), and "external collaborations" (S&O4). The second element – "Employee and Culture" (E&C) - was measured using four items; "employee familiarity" (E&C1), "employee training" (E&C2), "openness to innovation" (E&C3) and "continuous culture" (E&C4). The third element – "technology" - was evaluated using sixteen items; "advanced technology" (T1), "supplier technology" (T2), "data access" (T3), "data analysis" (T4), "sensor1" (T5), "cloud" (T6), "track and trace" (T7), "autonomous machines" (T8), "customer access" (T9), "CAD" (T10), "3D" (T11), "hard-soft resources" (T12), "digital media" (T13), "embracement of digitalisation" (T14), "sensor2" (T15) and "high level of automation" (T16). All items were evaluated on a 5-point Likert scale; where (1) represents "not at all"; (2) represents "slightly"; (3) represents "moderately"; (4) represents "very" and finally, (5) represents "extremely". Figure 5 displays the measurement model of Industry 4.0.

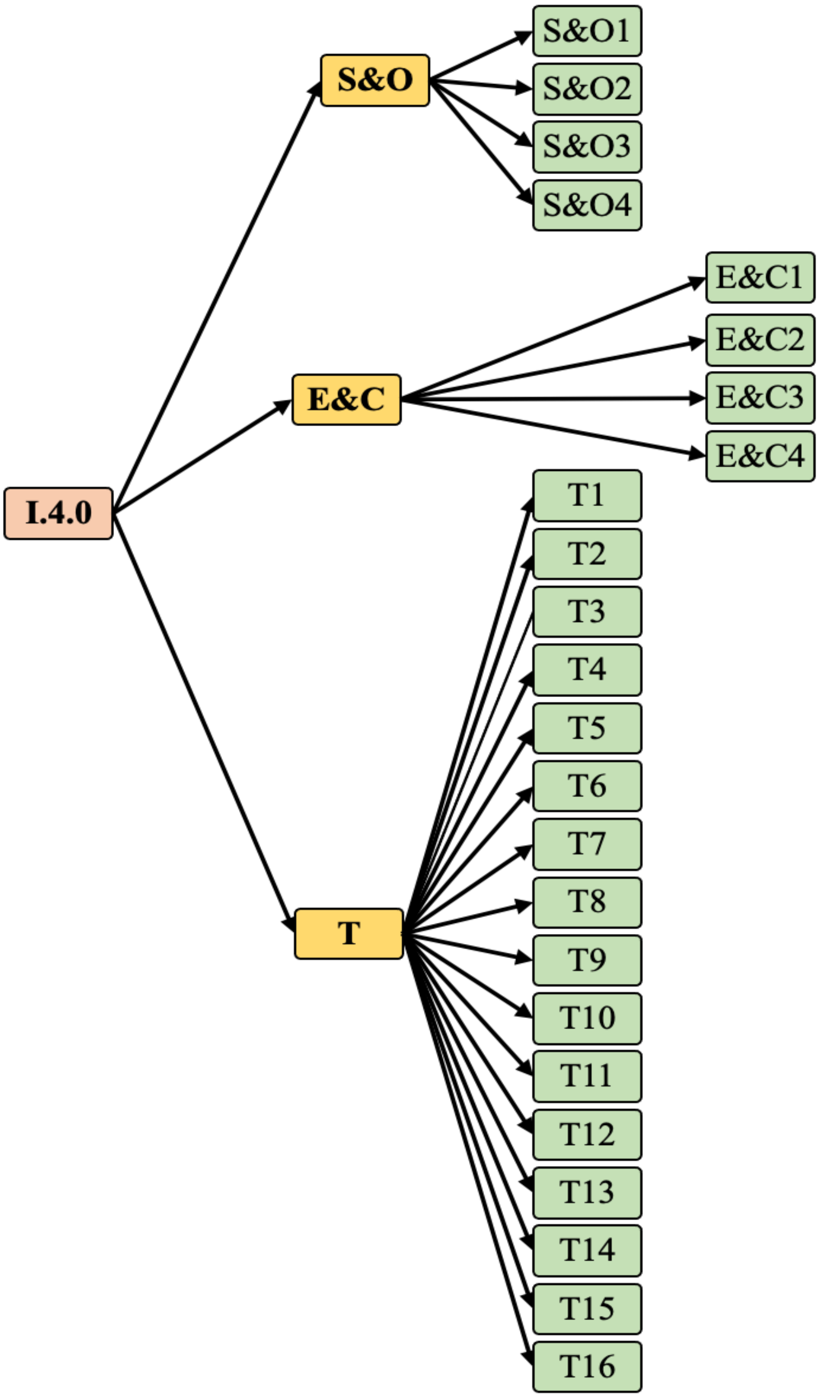
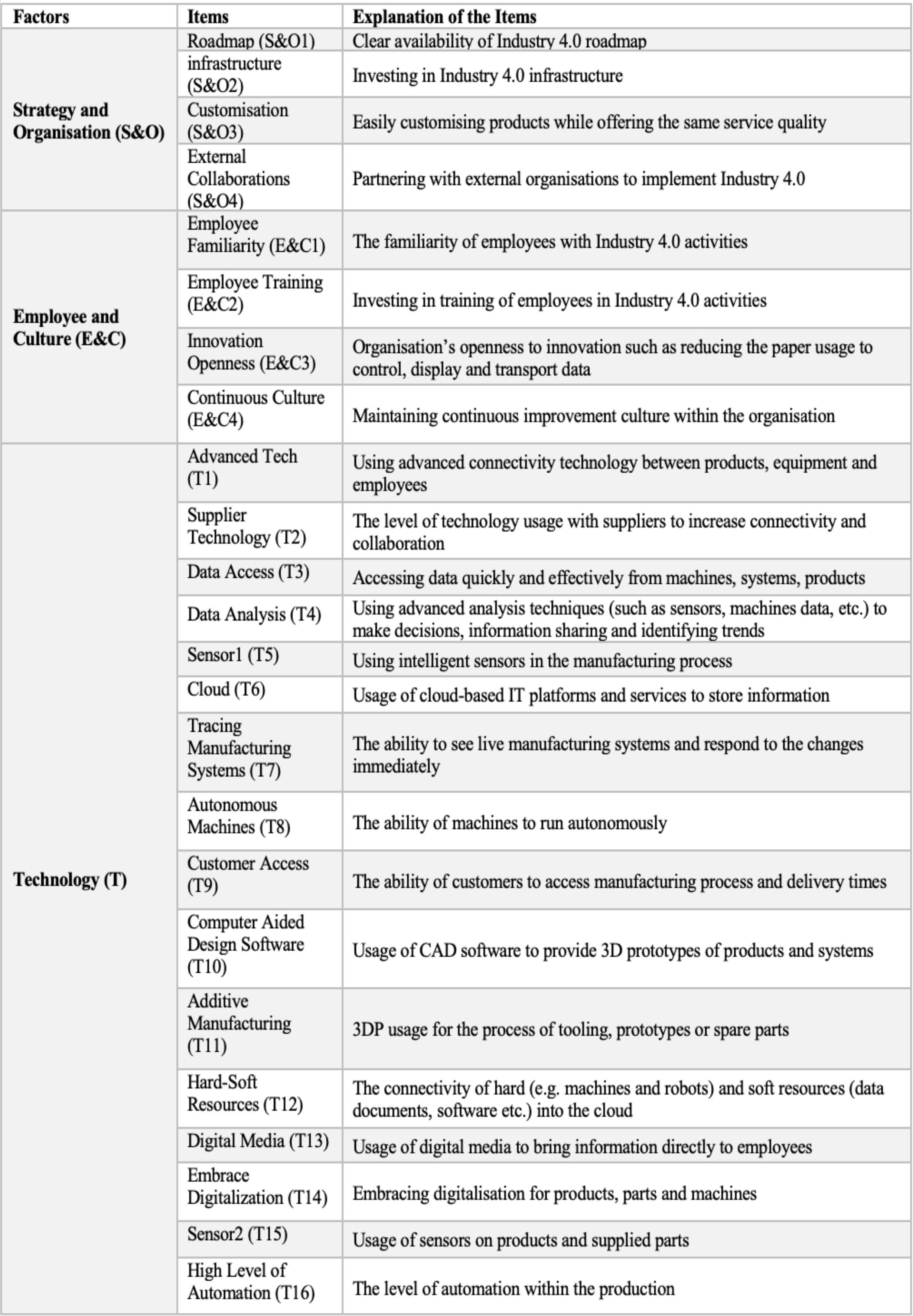


Figure 5. Measurement Model of Industry 4.0
Source: Author's own elaboration

Table 10.Construct Measures for Industry 4.0



Factors	Items	Explanation of the Items
Strategy and Organisation (S&O)	Roadmap (S&O1)	Clear availability of Industry 4.0 roadmap
	infrastructure (S&O2)	Investing in Industry 4.0 infrastructure
	Customisation (S&O3)	Easily customising products while offering the same service quality
	External Collaborations (S&O4)	Partnering with external organisations to implement Industry 4.0
Employee and Culture (E&C)	Employee Familiarity (E&C1)	The familiarity of employees with Industry 4.0 activities
	Employee Training (E&C2)	Investing in training of employees in Industry 4.0 activities
	Innovation Openness (E&C3)	Organisation's openness to innovation such as reducing the paper usage to control, display and transport data
	Continuous Culture (E&C4)	Maintaining continuous improvement culture within the organisation
Technology (T)	Advanced Tech (T1)	Using advanced connectivity technology between products, equipment and employees
	Supplier Technology (T2)	The level of technology usage with suppliers to increase connectivity and collaboration
	Data Access (T3)	Accessing data quickly and effectively from machines, systems, products
	Data Analysis (T4)	Using advanced analysis techniques (such as sensors, machines data, etc.) to make decisions, information sharing and identifying trends
	Sensor1 (T5)	Using intelligent sensors in the manufacturing process
	Cloud (T6)	Usage of cloud-based IT platforms and services to store information
	Tracing Manufacturing Systems (T7)	The ability to see live manufacturing systems and respond to the changes immediately
	Autonomous Machines (T8)	The ability of machines to run autonomously
	Customer Access (T9)	The ability of customers to access manufacturing process and delivery times
	Computer Aided Design Software (T10)	Usage of CAD software to provide 3D prototypes of products and systems
	Additive Manufacturing (T11)	3DP usage for the process of tooling, prototypes or spare parts
	Hard-Soft Resources (T12)	The connectivity of hard (e.g. machines and robots) and soft resources (data documents, software etc.) into the cloud
	Digital Media (T13)	Usage of digital media to bring information directly to employees
	Embrace Digitalization (T14)	Embracing digitalisation for products, parts and machines
	Sensor2 (T15)	Usage of sensors on products and supplied parts
	High Level of Automation (T16)	The level of automation within the production

Source: Adopted from Bibby and Dehe (2018)

Table 10 explains the measurement items for the selected element to measure Industry 4.0 assessment. As previously explained, to measure the Industry 4.0, three elements, “strategy and organisation”, “employee and culture” and “technology” elements were identified. These elements were measured with 4, 4 and 16 items respectively.

The second main construct, SCI, was measured using three elements: “supplier integration” (SInt), “internal integration” (IInt) and “customer integration” (CInt). A total of 12 items were created to measure these elements. The scale items used previously conducted by Jajja et al. (2018); which is close to the items provided by the interviews and the literature. Figure 6 indicates the measurement model of SCI.

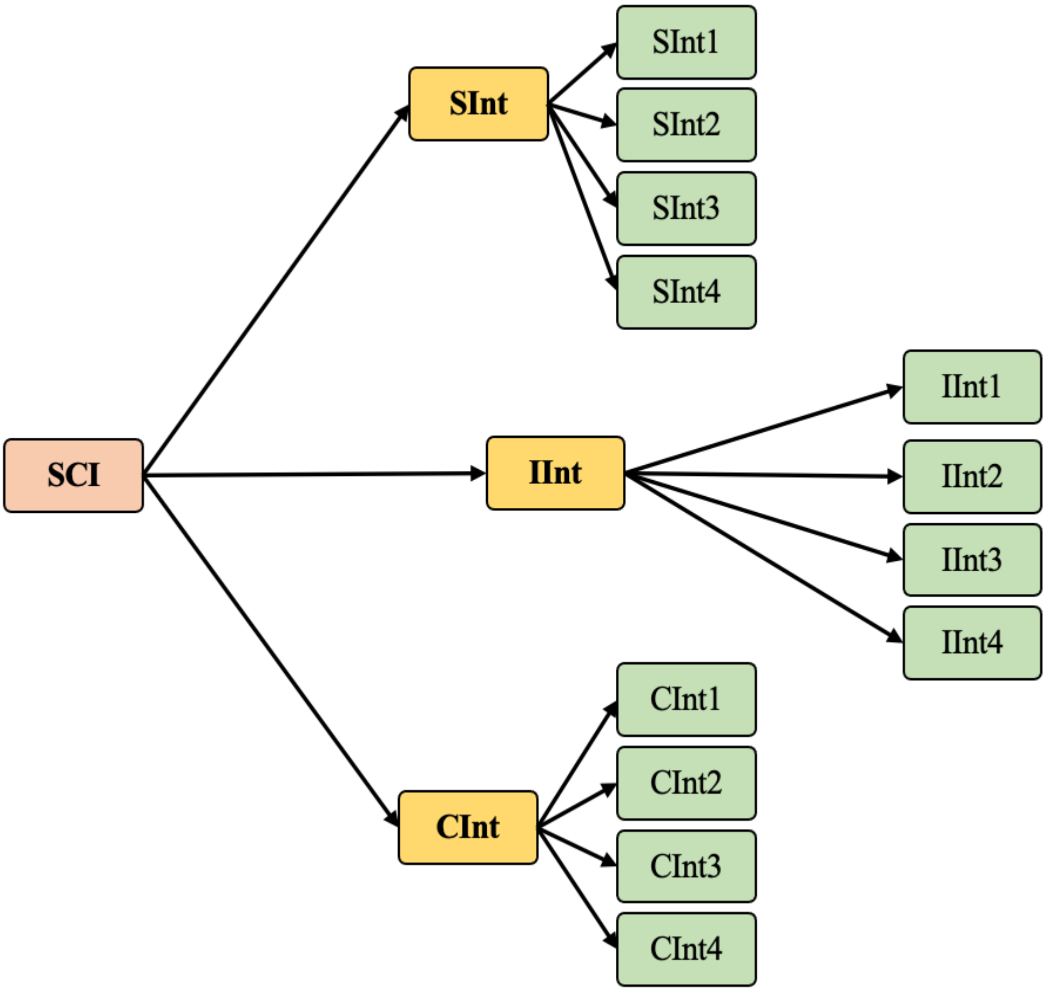


Figure 6. Measurement Model of SCI
Source: Author’s own elaboration

Table 11. Construct Measures for SCI

Factors	Items	Explanation of the Items
Supplier Integration (SInt)	Share Information (SInt1)	Information sharing with the main suppliers (about production plans, order management, delivery and inventory information)
	Collaboration (SInt2)	Improving collaborative strategies with the main suppliers (development of supplier, risk sharing, long term alliances)
	Decision Making (SInt3)	Improving decision making with the main suppliers (about product design/development, quality improvement, cost and process design)
	System Development (SInt4)	Developing a system with the main suppliers (VMI, JIT, Kanban, continuous replenishment)
Internal Integration (IInt)	Share Information with Purchasing (IInt1)	Information sharing with the purchasing department (about sales, production progress and inventory level)
	Decision Making with Purchasing (IInt2)	Improving decision making with the purchasing department (about sales, production plans and inventory level)
	Share Information with Sales (IInt3)	Information sharing with the sales department (about sales, production progress and inventory level)
	Decision Making with Sales (IInt4)	Improving decision making with the sales department (about sales, production plans and inventory level)
Customer Integration (CInt)	Share Information (CInt1)	Information sharing with the main customers (about production plans, order management, delivery and inventory information)
	Collaboration (CInt2)	Improving collaborative strategies with the main customers (risk-sharing, long-term agreements)
	System Development (CInt3)	Developing a system with the main customers (VMI, JIT, Kanban, continuous replenishment)
	Decision Making (CInt4)	Improving decision making with the main customers (about product design/development, quality improvement, and process design)

Source: Adopted from Jajja et al. (2018)

Table 11 demonstrates the items selected to measure SCI. “Supplier Integration” was measured using four items; “information sharing with main suppliers” (SInt1), “collaboration with main suppliers” (SInt2), “decision making with main suppliers” (SInt3) and “system development with main suppliers” (SInt4). “Internal Integration” was evaluated with four items; “information sharing with the purchasing department” (IInt1), “decision making with the purchasing department” (IInt2), “information sharing with the sales department” (IInt3) and “decision making with the sales department” (IInt4). Finally, “Customer Integration” was measured using four items; “information sharing with main customers” (CInt1), “collaboration with main customers” (CInt2), “decision making with main customers” (CInt3) and “system development with main customers” (CInt4). All of the items were evaluated using a 5-point Likert scale; where (1) represents “very low”; (2) presents “low”; (3) presents “moderate”; (4) presents “high” and finally, (5) represents “very high”.

The third main construct, SCP, was evaluated with three elements: “resources” (RPERF) “output” (OPERF) and “flexibility” (FPERF). A total of 17 items were created to measure SCP. The scale items used previously conducted by Beamon (1999) which is a well-known model in performance measurement. Figure 7 displays the measurement model of SCP.

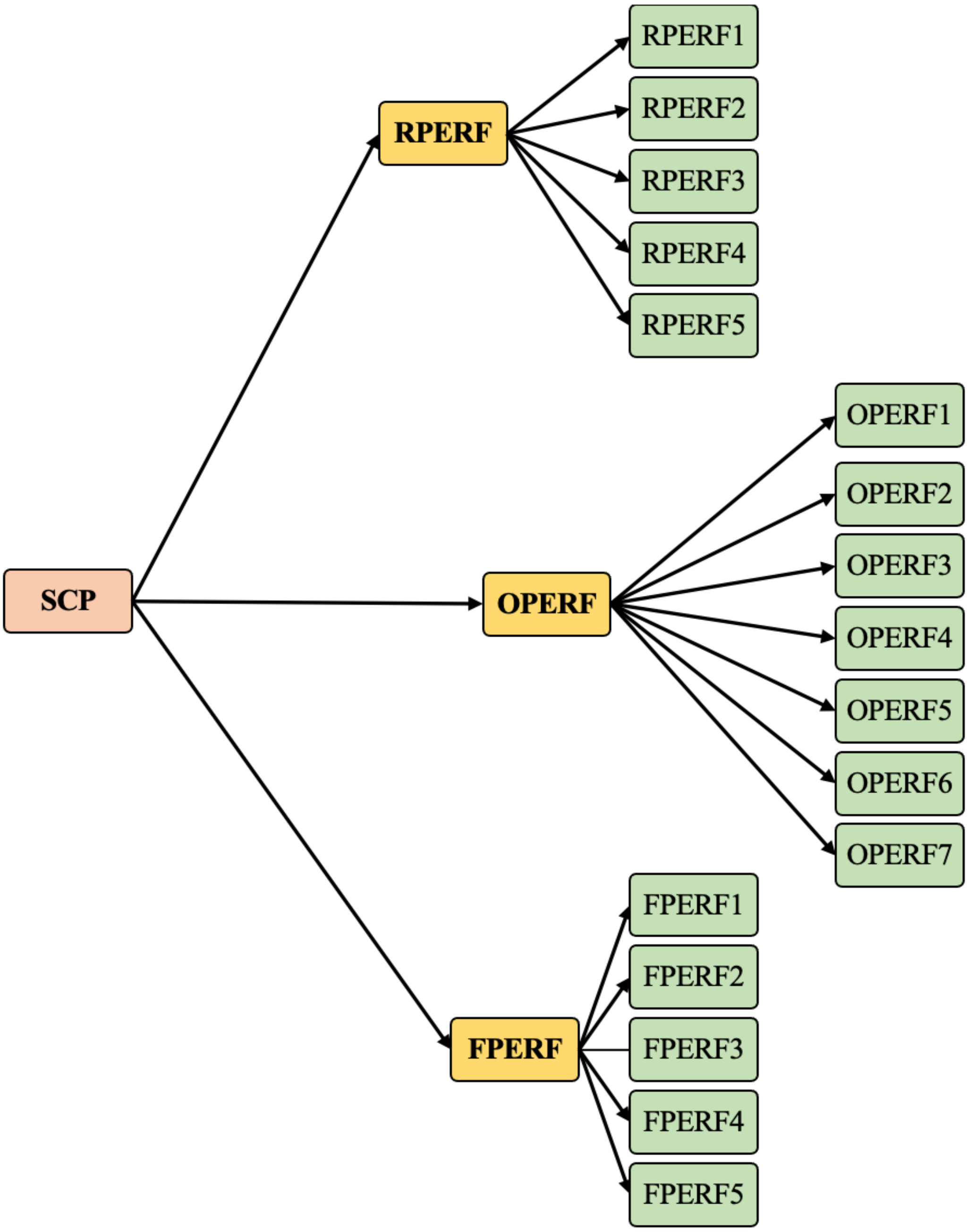
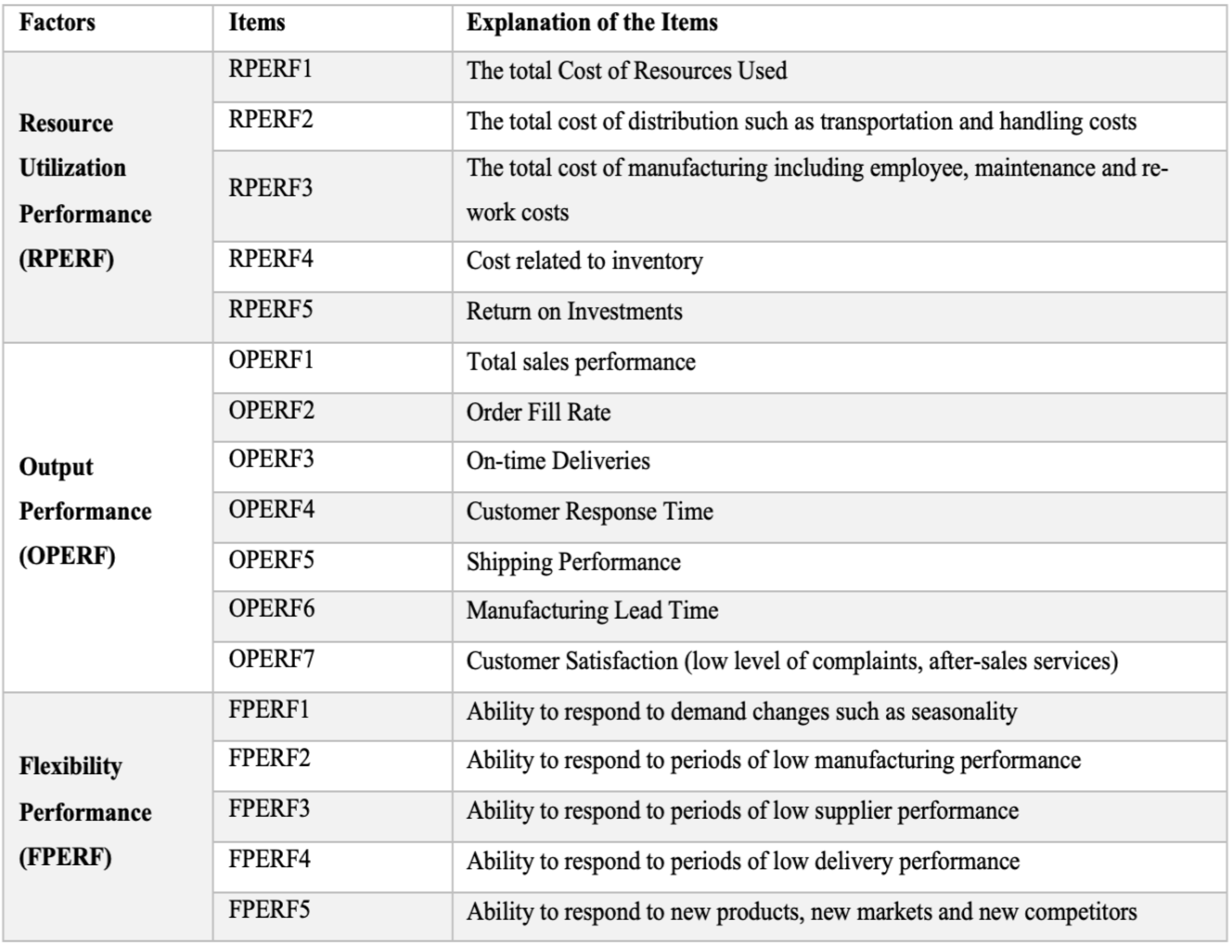


Figure 7. Measurement Model of SCP
Source: Author’s own elaboration

Table 12. Construct Measures for SCP



Factors	Items	Explanation of the Items
Resource Utilization Performance (RPERF)	RPERF1	The total Cost of Resources Used
	RPERF2	The total cost of distribution such as transportation and handling costs
	RPERF3	The total cost of manufacturing including employee, maintenance and re-work costs
	RPERF4	Cost related to inventory
	RPERF5	Return on Investments
Output Performance (OPERF)	OPERF1	Total sales performance
	OPERF2	Order Fill Rate
	OPERF3	On-time Deliveries
	OPERF4	Customer Response Time
	OPERF5	Shipping Performance
	OPERF6	Manufacturing Lead Time
	OPERF7	Customer Satisfaction (low level of complaints, after-sales services)
Flexibility Performance (FPERF)	FPERF1	Ability to respond to demand changes such as seasonality
	FPERF2	Ability to respond to periods of low manufacturing performance
	FPERF3	Ability to respond to periods of low supplier performance
	FPERF4	Ability to respond to periods of low delivery performance
	FPERF5	Ability to respond to new products, new markets and new competitors

Source: Adapted from Beamon (1999)

"Resources" were evaluated with five items: "the total cost of resources used" (RPERF1), "the total cost of distribution" (RPERF2), "the total cost of manufacturing" (RPERF3), "inventory costs" (RPERF4) and "return on investments" (RPERF5). "Output" was measured using seven items: "sales" (OPERF1), "order fill rate" (OPERF2), "on-time deliveries" (OPERF3), "customer response time" (OPERF4), "shipping errors" (OPERF5), "manufacturing lead time" (OPERF6) and "customer complaints" (OPERF7). Finally, "flexibility" was measured using five items: "the ability to respond to demand changes" (FPERF1), "ability to respond to periods of low manufacturing performance" (FPERF2), "ability to respond to periods of low supplier performance" (FPERF3), "ability to respond to periods of low delivery performance" (FPERF4) and "ability to respond to new products, new markets and new competitors" (FPERF5). All of the items were evaluated using a 5-point Likert scale; where (1) presents "very low"; (2) presents "low"; (3) presents "moderate"; (4) presents "high" and finally, (5) presents "excellent". Table 12 shows the items and elements used to evaluate SCP.

Before data collection, the questions used in a questionnaire must be precise; therefore, firstly, each question was reviewed by supervisors in terms of phrases describing each item, length, readability and avoiding ambiguity of the questionnaire. Later, the survey instrument was also pre-tested by ten practitioners and six academics from the field of supply chain, production and operations management to check if the indicators were susceptible for evaluating the models. Besides, they revise the questionnaire to adjust any necessary modifications regarding terminology, clarity of the phrases and format. A pre-test is significant for self-administered questionnaires to avoid confusion of the respondents while they complete the survey independently (Han, 2017, p. 177). After the results of the pre-test, small changes were made in the questionnaire. Only one question was removed from the Industry 4.0 scale, which was "the company's 3D machines use metal alloys as its raw material", as an item of technology element. This question was found to be very technical and vague by 11 academics/practitioners; for this reason, it may cause some distortions on the final results. Also, the 3DP applications in developing countries still lag behind those of developed countries (Long et al., 2017, p. 1494); therefore, this question may be irrelevant for the respondents. Instead of this item, the question which was added based on the recommendations of interviewees and literature, was that "the company applies in Computer Aided Design (CAD) software tools to design the 3D models of products". CAD has seen an important enabler of 3DP applications in the literature (Galantucci et al., 2006, p. 102; Chlebus and Krot, 2016, p. 20; Tiede and Blaschke, 2005, p. 26). Additionally, "employee training toward Industry 4.0" was highlighted through the interviews and literature (Lichtblau et al., 2015, p.9; Sjödin et al., 2018, p. 27) in Industry 4.0 assessment; for this reason, another question was added into the questionnaire as an item of "employee and culture element", which was "my company supports the training of employees toward Industry 4.0". Except this, some of the questions were explained more with examples in brackets to improve the explicitness of the questionnaire. As for the scale of SCI and SCP, no questions were added to or removed from the questionnaire, only some explanations in brackets were added to the items to make them clearer for the respondents.

One could raise a question about the length of the questionnaire, which may affect the response quality; however, many supply chain studies involves a similar number of metrics in the last years, particularly to explain the complex relationships between the constructs (Świerczek, 2014, p. 99; Wu and Chiu, 2018, p. 16; Wiengarten et al., 2019, p. 557; Ganbold et al., 2020, forthcoming). Therefore, this dissertation does not consider the length of the questionnaire as an issue.

The original language of the questions derived from the literature was English. Therefore, the questionnaire was translated into the Turkish language by a native speaker in the area of the supply chain; and later, it was checked by two other native speakers in the same field for its accuracy.

3.3. Sampling and Data Collection

For this dissertation, the data for hypotheses testing were gathered from the participants who were involved in the operational, production, or supply chain activities of the companies. To elaborate this, the questionnaire in this dissertation seeks for the respondents’ positions on the following: 1) the extent of assessment of Industry 4.0 in their companies, 2) the extent of supply chain integration activities in their companies, 3) the extent of supply chain performance metrics in their companies. For this reason, the target respondents are CEOs, general managers, department heads and professional experts who are familiar with the activities of Industry 4.0 as well as understand its impacts on supply chain integration and performance.

Data for this dissertation were collected from Turkish manufacturing companies listed on 1000 largest manufacturing companies operating in Turkey according to the Istanbul Chamber of Industry (ISO). The term of “supply chain management” which has taken great focus on the manufacturing industry (Burgess et al., 2006; Yumurtacı Hüseyinoğlu et al., 2020) also has propelled continuous improvement in manufacturing (Zolait et al., 2010). Therefore, manufacturing industry has been considered in a sample frame in this dissertation. In a first step, we identified the enterprises on the list. Next, it approached the target respondents - such as production, operations, supply chain managers, executives, heads- within each of the enterprises selected. The questionnaire was sent to the key informants via online channels such as emails, their profiles on LinkedIn or via on-site visits made to some of the companies. After sending the questionnaire, it was followed up by email. Out of 1000 respondents, a total of 212 usable responses were collected. The response rate is 21.2% among the targeted sample. Accordingly, all reported analysis is based on a sample of 212 manufacturing firms.

3.4. Data Analysis

This section mainly explains the research approach to analyse the data gathered. Section 3.4.1. gives some insights about the PLS-SEM technique used in this dissertation to test the hypotheses. Section 3.4.2 examines the procedures of measurement model evaluation, which is crucial to analyse the reliability and validity of the measurement constructs and to explain the results of Confirmatory Factor Analysis (CFA) for each endogenous variable in the model. Finally, section 3.4.3. explains the criterion of structural model analysis for examining the complex relationships between the variables and evaluating the final model.

The measurement model and structural model assessments were measured using SMARTPLS 3 software programme, which is the latest version of SMARTPLS while data preparation tests such as normality, common method bias, collinearity tests and descriptive statistics of the data were conducted in IBM SPSS Statistics 25.0 software programme.

3.4.1. Overview-PLS-SEM

Structural equation modelling (SEM) is equivalent to analyse the cause effect relationships between latent constructs in management research (Hair et al., 2011, p.139). By using the SEM method, latent variables which are hard to measure and unobservable could be analysed to overcome business research challenges (Wong, 2013, p.1). Although the prior application of this modelling is based on a "covariance-based approach (CB-SEM)"; however, in the last years, scholars have also adapted another technique of this approach, variance based "partial least square technique (PLS-SEM)" (Hair et al., 2014, p. 107).

Ringle et al. (2012, p.4) discuss the comprehensive reasoning of choosing PLS-SEM among researchers. The majority of the researchers employs PLS-SEM technique due to small sample size. The second reason is non normally distributed data while the third is to use formative latent variables. Other substantive reasons suggested by Hair et al. (2011) to prefer PLS-SEM have been found so rare in the research. In the present dissertation, small sample size and non-normal distributed data are considered as two reasons for choosing PLS-SEM technique. Several researchers show that required sample size for CB-SEM is more than 250 (Rigdon et al., 2017, p. 6; Reinartz et al., 2009, p. 332; Roberts et al., 2010, p. 4345); therefore, in this dissertation, the sample size - 212 samples - is not suitable to use CB-SEM technique. On the other hand, PLS-SEM also applies in rule of thumb of 10 cases per predictor, known as 10 times rule, whereby total sample size must be 10 times higher than the largest number of reflective items used to measure one latent variable (Marcoulides and Saunders, 2006, p. 4; Ringle et al., 2012, p. 9; Hair et al., 2011, p. 144). In this dissertation, the largest number of indicators observed to measure one construct is 16; therefore, the minimum required threshold for the sample size must be 160. Since this dissertation employs 212 samples, it is quite acceptable for PLS-SEM analysis.

Another point is that, the data used in this dissertation is non normal distributed which will be explained in Section 4.1.1. In this case, using non-parametric tests for further analysis is suggested (Ringle et al., 2012, p.4; Hair et al., 2019, p.5). PLS-SEM works well to predict non-normal distributed data for complex models, nevertheless CB-SEM estimates the linkages well for normal distributed data.

Before moving to the measurement and structural evaluation part, Figure 8 indicates the research model which outlines the relationship between Industry 4.0, SCI and SCP. Addressing the research questions, more specifically, the research model examines whether *"Industry 4.0 affects SCI", "SCI affects SCP", "Industry 4.0 affects SCP"* and *"SCI mediates the relationship between Industry 4.0 and SCP".*

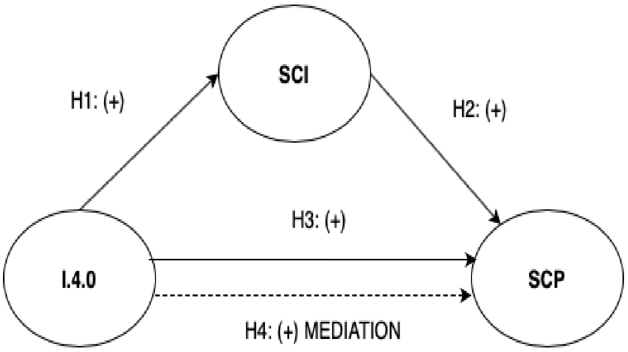


Figure 8. The Proposed Conceptual Model
Source: Author's own figure

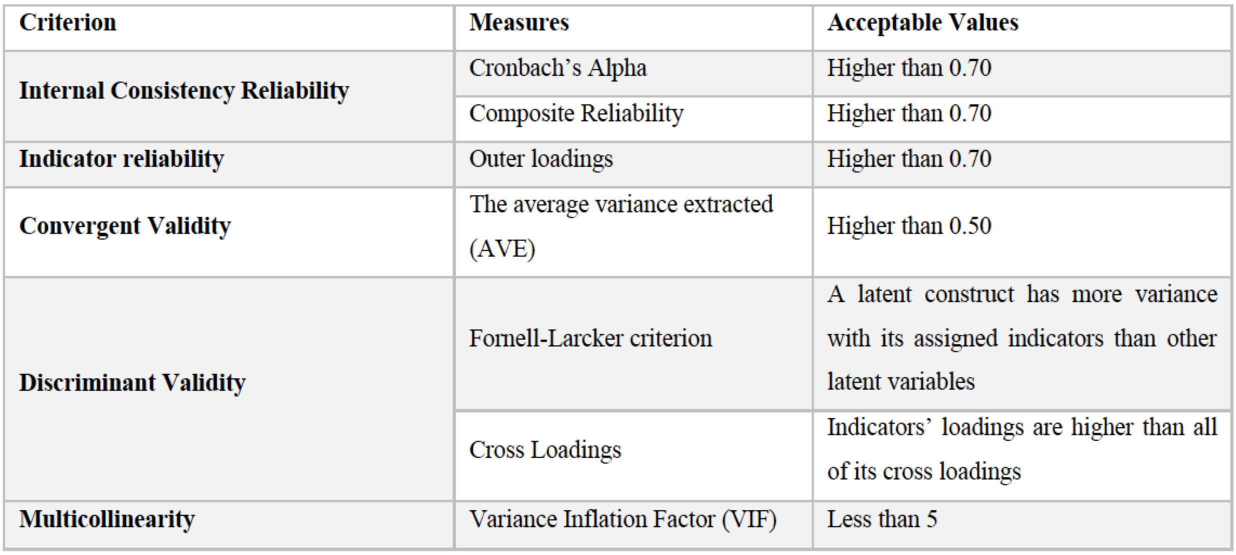
All items and elements previously mentioned are analysed as the reflective constructs, which are described as the measures that are interchangeable, and eliminating any of the measures would not highly affect the meaning and interpretation of the construct (Lee and Cadogan, 2013, p. 243). In this research, it has been observed that all previous studies used for the scale development (Industry 4.0, SCI, and SCP) in the questionnaire of this dissertation have exerted the reflective models for interpreting a particular construct. Besides, Coltman et al. (2008, p. 1254) suggest that the items need a common theme related to the construct, and the latent construct exists independent of the measure used. As an example of this, the measurement of Industry 4.0 assessment is evaluated by many scholars (Section 2.1.3.) that they are mostly using technology items rather than using strategy and employee and culture. The latent variable, Industry 4.0 assessment, in this case, is not measured by the combination of the indicators. The same explanations could be done for SCI and SCP. Regarding the theoretical considerations, removing one or two items may not make any change to measure the latent variables in our model. As an empirical investigation, the items could be checked by correlation analysis. If items are highly correlated, that means the framework should be conducted as reflective. In order to evaluate that, a non-parametric test, Spearmen Rank Correlation, was conducted. Appendices 4, 5 and 6 indicate the items which represent each construct do not reflect low correlations with each other. Therefore, the model was carried out as a reflective like the previous studies which applied the same frameworks.

In the structural model, the elements of Industry 4.0, SCI and SCP are set as endogenous variables. In addition, the main constructs, Industry 4.0, SCI and SCP, measured as the endogenous variables. The items which explain the elements are conducted as the exogenous variables because they can be directly evaluated through the questionnaire.

3.4.2. Measurement Model Assessment

Although both “Exploratory Factor Analysis (EFA)” and “Confirmatory Factor Analysis (CFA)” investigate the underlying relationships as a set of latent constructs that explain the measured variable, many studies mention that EFA is used for scale development, conversely CFA is used for verifying the factor structure of a set of latent variables used in prior studies (Hayton et al., 2004, p. 192; Williams et al., 2010, p. 3; Lorenzo-Seva and Ferrando, 2006, p. 88). Therefore, the current dissertation only applies the CFA technique in order to observe the outer loadings of the latent indicators on measured variables as reflecting the measurement of indicator reliability. CFA indicates the procedures of reliability and validity assessment criteria of measurement construct by explaining “internal consistency reliability”, “convergent validity”, “discriminant validity” and “Variance Inflation Factor (VIF) values”, which explain under the context of multicollinearity assessment.

Table 13.Rules of Thumb for Measurement Model Evaluation



Criterion	Measures	Acceptable Values
Internal Consistency Reliability	Cronbach’s Alpha	Higher than 0.70
	Composite Reliability	Higher than 0.70
Indicator reliability	Outer loadings	Higher than 0.70
Convergent Validity	The average variance extracted (AVE)	Higher than 0.50
Discriminant Validity	Fornell-Larcker criterion	A latent construct has more variance with its assigned indicators than other latent variables
	Cross Loadings	Indicators’ loadings are higher than all of its cross loadings
Multicollinearity	Variance Inflation Factor (VIF)	Less than 5

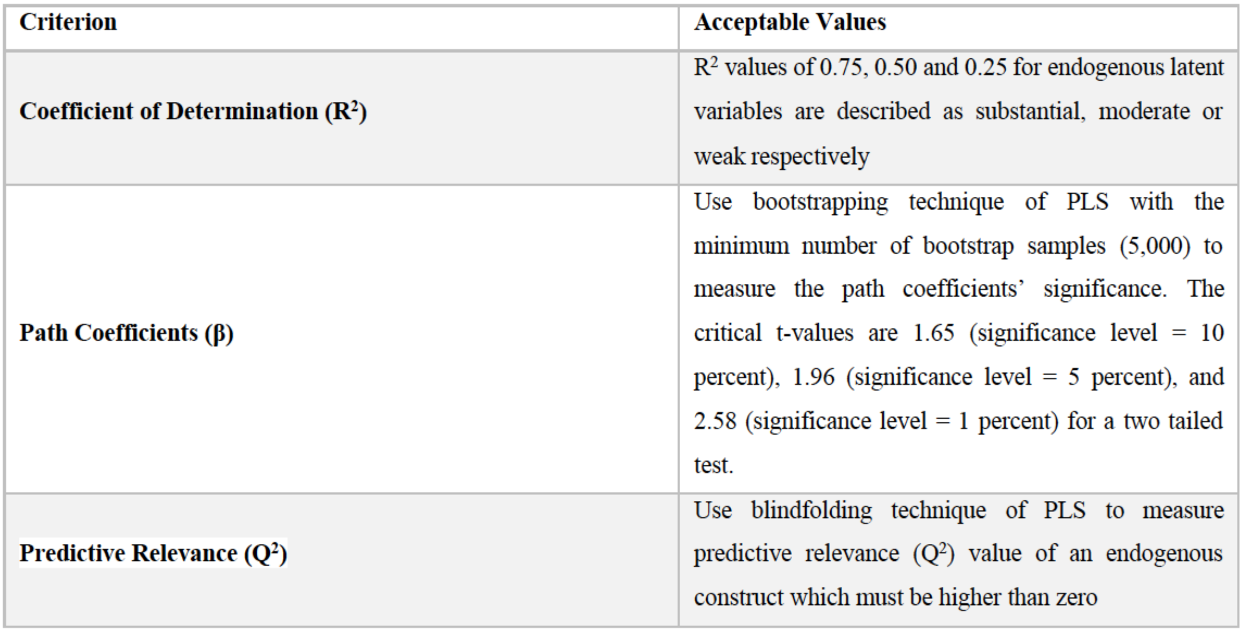
Source: Adopted from Hair et al. (2011, p. 145)

In exploratory research, the values of Cronbach’s alpha and composite reliability must be higher than 0.70 - however, 0.60 is also considered acceptable-, while higher values show higher levels of reliability (Hair et al., 2012). For convergent validity test, scholars are required to analyse the average variance extracted (AVE). An AVE value of 0.50 or more displays a certain threshold of convergent validity which states that the latent variable describes more than half of the variance of its indicators (Hair et al., 2011, p.146). Indicator reliability explains outer loadings of reflective constructs, whereby their standardised loading is more than 0.708 (Hair et al., 2019, p.8). Outer loadings represent the contribution of an item into its assigned construct. In reflective models, loadings are used rather than outer weights. The PLS algorithm calculates each item’s loading to make accurate estimations on the structural models (Hair et al., 2011, p. 141). Since our model is reflective, loadings were calculated rather than weights. Discriminant validity could be accepted when the latent variables and other latent variables' correlations are less than a value of communality among the latent variable indicators (Kock, 2017, p. 251). Typically, the values of the items in the diagonal cell for each column should be higher than the other values in the same column. Finally, VIF values should be less than 5 thresholds because higher values than 5 imply multicollinearity problems; therefore, it must be removed from the model (Hair et al., 2011, p. 145). Table 13 shows the summary of the rules of thumb for measurement model evaluation.

3.4.3. Structural Model Assessment

PLS-SEM measures the predictive capabilities of the structural model, principally it assesses how well the endogenous constructs are estimated, in contrast, CB-SEM applies in the measures on the goodness of fit of the model. Before starting to measure the metrics, Hair et al. (2011, p.145) also suggest that collinearity assessment must be done among predictor constructs. In section 3.4.2., it has been shown that the VIF values of indicators must be lower than 5 for a certain endogenous variable. In our model, all items have a lower value than 5 (will be shown in Section 4.2), collinearity is not an issue in the structural model.

Table 14.Rule of Thumb for Structural Model Evaluation



Criterion	Acceptable Values
Coefficient of Determination (R^2)	R^2 values of 0.75, 0.50 and 0.25 for endogenous latent variables are described as substantial, moderate or weak respectively
Path Coefficients (β)	Use bootstrapping technique of PLS with the minimum number of bootstrap samples (5,000) to measure the path coefficients' significance. The critical t-values are 1.65 (significance level = 10 percent), 1.96 (significance level = 5 percent), and 2.58 (significance level = 1 percent) for a two tailed test.
Predictive Relevance (Q^2)	Use blindfolding technique of PLS to measure predictive relevance (Q^2) value of an endogenous construct which must be higher than zero

Source: Adopted from Hair et al. (2011, p. 145)

Table 14 indicates a summary of the rules of thumb for structural model evaluation. In order to evaluate the structural model, the primary criteria are to explain the "coefficient of determination (R^2)" and "path coefficients (β)" of the model in PLS-SEM (Hair et al., 2011, p.145). Furthermore, "predictive relevance (Q^2)" and "effect size (f^2)" could be analysed in the structural model analysis. R^2 which demonstrates the predictive accuracy of the model also represents the fraction of the variance explained by each indicator. Although Hair et al. (2011, p.

147) state that the level of R^2 depends on the specific research discipline, nonetheless "R^2 values of 0.75, 0.50 and 0.25 are described as substantial, moderate, or weak", consecutively as a rule of thumb (Hair et al., 2011, p. 147). Path coefficients (β) are also used to examine the direct and indirect effects of the variables, and calculated by the bootstrapping technique in PLS-SEM. Here, also the critical t-values, "1.65 (significance level = 10 percent), 1.96 (significance level = 5 percent), and 2.58 (significance level = 1 percent)" for a two-tailed test should be considered. 5.000 is commonly suggested as the minimum number of bootstrap samples for assessing the test (Hair et al., 2011, p. 147). As for the effect size (f^2), the critical thresholds are "0.02, 0.15, and 0.35 which represent small, medium, and large effects" respectively, to determine the effect size value of construct for a specific endogenous construct of the model (Hair et al., 2014, p. 114). Also, the value of predictive relevance (Q^2) of an endogenous construct should be higher than zero; thus, latent constructs that explain this endogenous variable show predictive relevance (Hair et al., 2011, p. 147).

4. RESULTS AND DISCUSSION

4.1. Descriptive Analysis

This part provides an overview of the respondents by addressing three themes. First, section 4.1.1. indicates the findings of common method bias and normality tests. In section 4.1.2., demographic profiles of the respondents and the companies are discussed. Finally, section 4.1.3. shows the descriptive analysis of the research constructs.

4.1.1. Common Method Bias and Normality Tests

Common method bias is an issue because it is the root of measurement error and threatens the validity of the results (Podsakoff et al., 2003). Although there are many statistical methods in order to analyse a potential impact of common method bias, "Harman's one factor analysis" is often employed to identify if the variance in the data is highly explained by a single factor (Chang et al., 2010). Following this approach, all the constructs used in this dissertation were observed in the unrotated solution Exploratory Factor Analysis (EFA). The findings reveal that several factors were extracted with an eigenvalue above 1 and they account for 70 percent of the total variance. Also, the first factor accounted for 37 percent of total variance which is less than a majority of the variance among measures. Therefore, common method bias is not an issue in this dissertation. (Appendix 7).

The normality test is also carried out as can be seen in Appendix 8, although PLS-SEM does not require that the data should be normally distributed. Two tests have been applied for this: the Shapiro-Wilk test and Kolmogorov-Smirnov test. In both tests, as a rule of thumb, the null hypothesis is rejected when p-value is lower than 0.05. Since our findings show statistically significant results, it is summarised that the data is non-normal in this dissertation.

4.1.2. Demographic Profiles of the Respondents and Companies

In order to analyse the demographic profiles, four questions were formed in the questionnaire. These questions are about the position of the respondent in the organisation, the number of employees working in the organisation, the annual revenue of the company and the related sector of the organisation.

The first question, representing the position of the respondent in the firm, includes four classifications: CEOs, general managers, department heads and professional experts engaged in the companies (Figure 9). Of 212 respondents, only 5.7 percent (n=12) accounted for CEOs of the companies, while 26.4 percent of them (n=56) indicate general managers. Among the categories, department heads hold the majority of the respondents, which accounted for 40.1 percent total (n=85). Finally, professional experts represent 27.8 percent of the respondents (n=59). The position of the target respondents such as department heads and professional experts is mainly related to the fields of manufacturing planning and control, production, or supply chain operations. Furthermore, Appendix 9 displays the demographic profiles of the respondents and companies in detail.

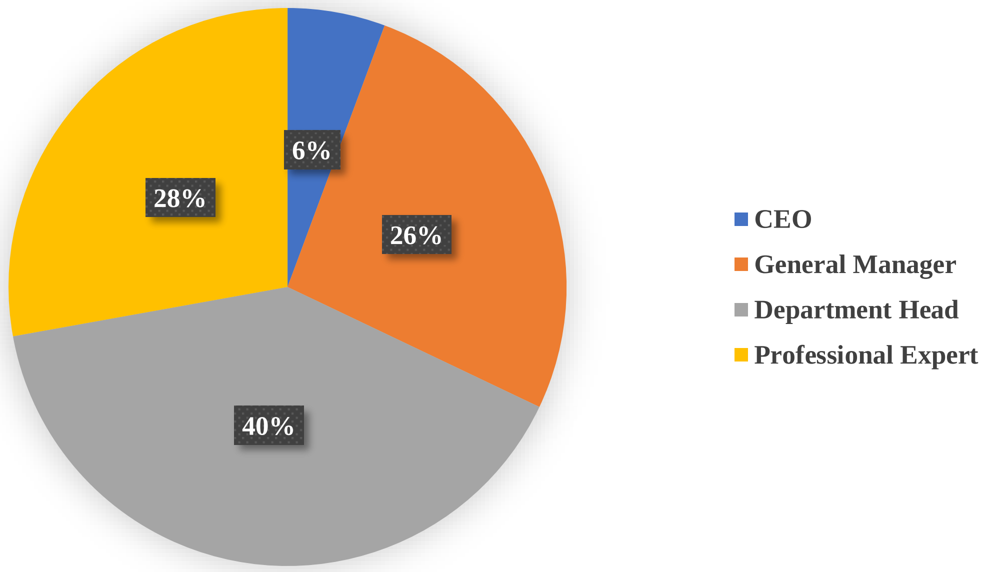


Figure 9. Positions of the respondents
Source: Author's own figure

The second question asked to the respondents was related to determining the number of employees who are working in the particular company (Figure 10). This also provides the background of the company size. The findings indicate that 14.2 percent of the companies employed higher than 10; but less than 50 employees (n=30), 20.3 percent had 50-249 employees (n=43). These organisations also represent small and medium-sized companies according to employee numbers. 16 percent of the companies demonstrate that the companies which have a number of employees between 250-499 (n=34); and 49.5 percent represent the companies that have more than 500 employees (n=105). These companies also are counted as big companies according to their employee numbers.

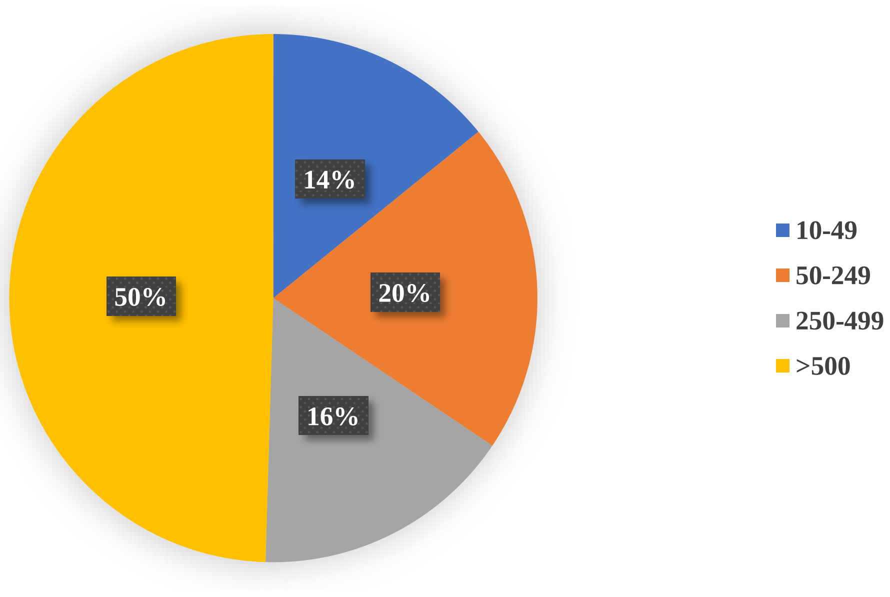
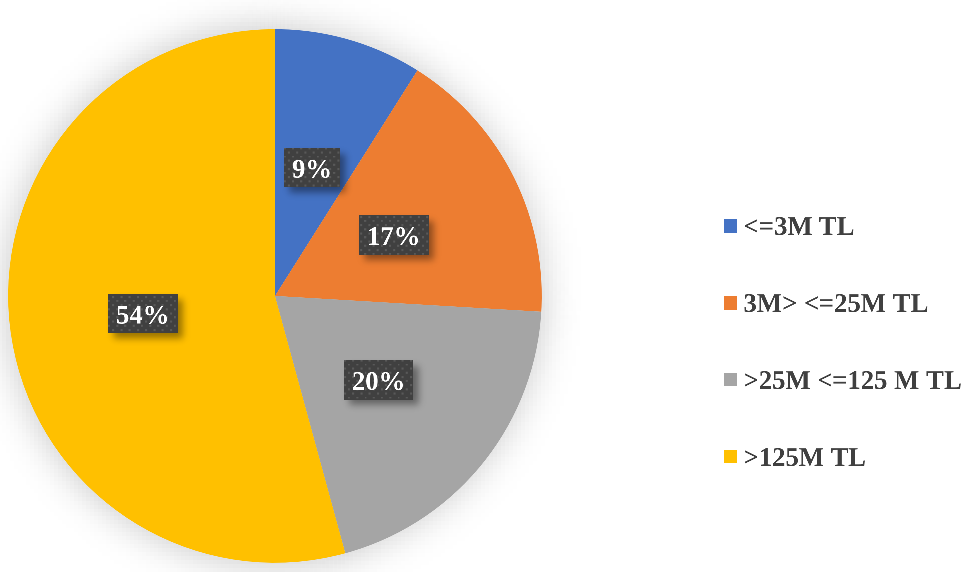


Figure 10. Number of Employees of the Companies
Source: Author’s own figure

The third question also involves the annual revenue turnover of the companies that attended this dissertation (Figure 11). The firms which have annual revenue turnover of less than 3 M TL accounted for 9 percent (n=19) while 17 percent (n=36) of them are with more than 3 M and less than 25 M TL. 19.8 percent of them (n=42) display more than 25 M TL and less than 125 M TL annual revenue. Finally, the companies with more than 125 M TL annual revenue turnover accounted for 54.2 percent (n=115). Considering the employee size and annual revenue turnover, this research involves predominantly large companies.



Note: *1 dollar is approximately 7.60 Turkish Lira (Date: September 24th, 2020)*
Figure 11. Annual Revenue Turnover of the Companies
Source: Author’s own figure

The final question also includes the sector of the companies involved in this dissertation, classified into four broad industries; textile including leather, carpet, clothing, etc. sub-sectors; automotive and electronic including automotive parts, machinery, electronic household appliances, metals, etc.; food and beverage; and chemicals/ pharmaceuticals (Figure 12). The majority of the companies are mainly from the automotive-electronic industry with 51.4 percent (n=109). The textile industry represents 22.6 percent of the companies (n=48), while 13.7 percent of the firms (n=29) are from the food and beverage industry. Chemicals/ pharmaceuticals industry only accounts for 12.3 percent (n=26).

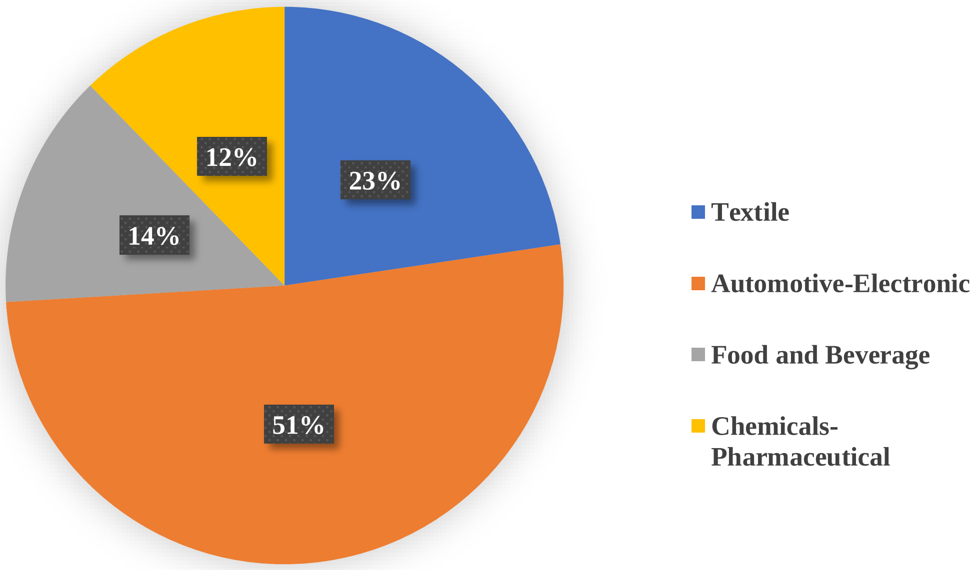


Figure 12. Sector of the Companies
Source: Author's own figure

4.1.3. Descriptive Statistics of the Elements

After exploring the demographic profiles of the respondents and the firms, the rest of the questions contained in the survey are used to evaluate the three main measurement constructs, namely Industry 4.0 assessment, Supply Chain Integration and Supply Chain Performance. The items of the main constructs and their abbreviations have been described previously in Section 3.2.

In order to assign Industry 4.0 assessment, three subsections were determined – "strategy and organisation", "employee and culture", and "technology". These subsections were measured using 4, 4 and 16 items consecutively by using a 5-point Likert scale ranging from "not at all" (1) to "extremely" (5). Appendix 10 presents the frequencies of the response scale (%) as well as means and standard deviations of the indicators used to assess Industry 4.0.

Figure 13 shows the distribution of strategy and organisation (S&0) items. The element of "Strategy and Organisation" was measured using four items; "roadmap" (S&01), "infrastructure" (S&O2), "customisation" (S&03) and "external collaborations" (S&04). The participants were asked to rate how their organisations perform to assess the Industry 4.0 strategy. The assessment of "Industry 4.0 strategy" indicated the following:

- 39.6% of the respondents observed have a clear Industry 4.0 roadmap (Mean=3; SD=1.20)

-46.7% of the respondents reported that their organisations are investing in Industry 4.0 infrastructure effectively (Mean=3.13; SD=1.24)

-79.7% of the respondents agreed that their organisations could quickly customise products while maintaining service quality effectively (Mean=4.02; SD=0.81)

- 36.4% of the respondents reported that their organisations effectively collaborate with external organisations to assess Industry 4.0 (Mean=2.92; SD=1.31

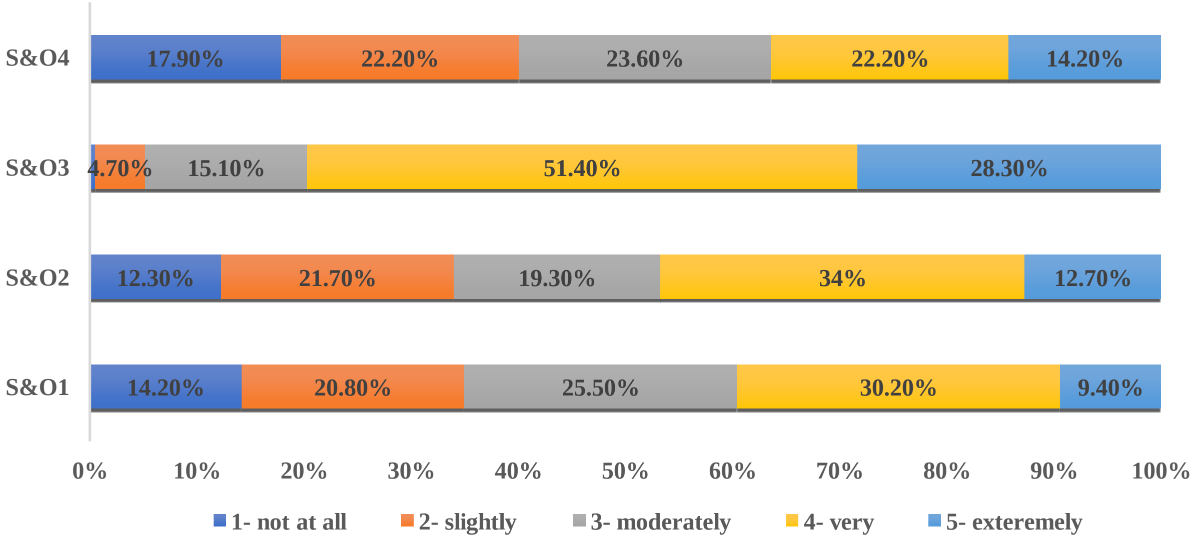


Figure 13. Distribution of Strategy and Organisation (S&O) Items
Source: Author's own figure

Figure 14 shows the distribution of employee and culture (E&C) items. The element of "Employee and Culture" was measured using four items; "Employee Familiarity" (E&C1), "Employee Training" (E&C2), "Openness to Innovation" (E&C3), and "Continuous Improvement" (E&C4). The participants were asked to rate how their organisations perform to invest their employees and improve their culture about Industry 4.0 assessment. The assessment of "employee and culture" indicated the following:

-37.7% of the respondents acknowledged that the majority of the employees of their organisations are quite familiar with the concepts of Industry 4.0 (Mean=3.04; SD=1.19)

- 35.3% of the respondents acknowledged that their organisations invest in training their employees in Industry 4.0 effectively (Mean=2.96; SD=1.26)

- 51% of the respondents acknowledged that their organisations are open to innovation (Mean=3.37; SD=1.14)

- 62.3% of the respondents acknowledged that their organisations participate in continuous improvement culture effectively (Mean=3.70; SD=0.98)

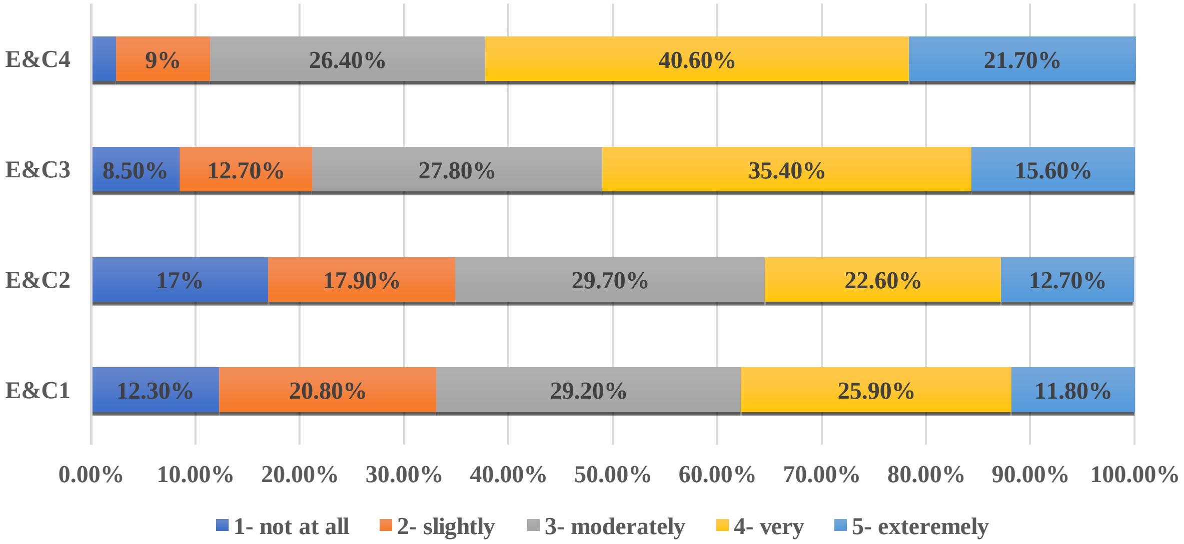


Figure 14. Distribution of Employee and Culture (E&C) Items
Source: Author's own figure

Figure 15 indicates the distribution of "technology" (T) items. The element of "technology" was measured using sixteen items; "Advanced Technology" (T1), "supplier technology" (T2), "data access" (T3), "data analysis" (T4), "sensor1" (T5), "cloud" (T6), "track and trace" (T7), "autonomous machines" (T8), "customer access" (T9), "CAD" (T10), "3D" (T11), "hard and soft resources" (T12), "digital media" (T13), "embracing technology" (T14), "sensor2" (T15) and "high automation" (T16). The participants were asked to rate how their organisations perform in implementing advanced technologies regarding Industry 4.0 assessment. The assessment of "technology" indicated the following:

- 48.6% of the respondents indicated that their organisations apply advanced connectivity technology between equipment, products and employees effectively (Mean=3.32; SD=1.11)

- 48.1% of the respondents indicated that their organisations use highly connected technologies with their suppliers (Mean=3.30; SD=1.09)

- 69.3% of the respondents indicated that their organisations easily and quickly access data from production, facilities and systems (Mean=3.76; SD=1.21)

- 64.1% of the respondents indicated that their organisations analyse data effectively to make decisions, information sharing and analyse trends (Mean=3.77; SD=1.06)

- 55.1% of the respondents indicated that their organisations use intelligent sensors effectively to support automation (Mean=3.47; SD=1.22)

- 43.9% of the respondents indicated that their organisations store information within a cloud network effectively (Mean=3.14; SD=1.35)

- 51% of the respondents indicated that their organisations have an ability to trace manufacturing systems and respond to changes immediately (Mean=3.40; SD=1.17)

- 26.4% of the respondents indicated that their organisations use machines that run autonomously (without human interaction) - (Mean=2.61; SD=1.24)

- 26.4% of the respondents indicated that their customers have access to the companies' systems to view manufacturing progress and delivery dates effectively (Mean=2.46; SD=1.37)

- 60.9% of the respondents indicated that their organisations use CADs effectively to draw 3D prototypes of their products (Mean=3.51; SD=1.53)

- 23.1% of the respondents indicated that their organisations use 3D printing machines effectively for tools, prototypes and spare parts (Mean=2.23; SD=1.48)

- 20.7% of the respondents indicated that the hard and soft resources in their organisations are well connected to a cloud (Mean=2.41; SD=1.31)

- 48.2% of the respondents indicated that their organisations use digital media effectively to bring information directly to their employees (Mean=3.29; SD=1.21)

- 38.2% of the respondents indicated that their organisations embrace digitalisation well for products, parts and machinery (Mean=3.08; SD=1.16)

- 33.5% of the respondents indicated that their organisations use sensors effectively on products and supplied parts (Mean=2.68; SD=1.35)

- 37.3% of the respondents indicated that the level of automation in their organisation is satisfactory (Mean=3.11; SD=1.16)

The second main construct was to evaluate Supply Chain Integration (SCI); three subsections were classified for evaluating this construct; "Supplier Integration (SInt)", "Internal Integration (IInt)", and "Customer Integration (CInt)". Each of the subsections was measured with four items using a 5-point Likert scale ranging from "very low" (1) to "very high" (5). Appendix 11 indicates the frequencies of the response scale (%) as well as means and standard deviations of the items used to evaluate SCI. Figure 16 displays the distribution of SCI items.

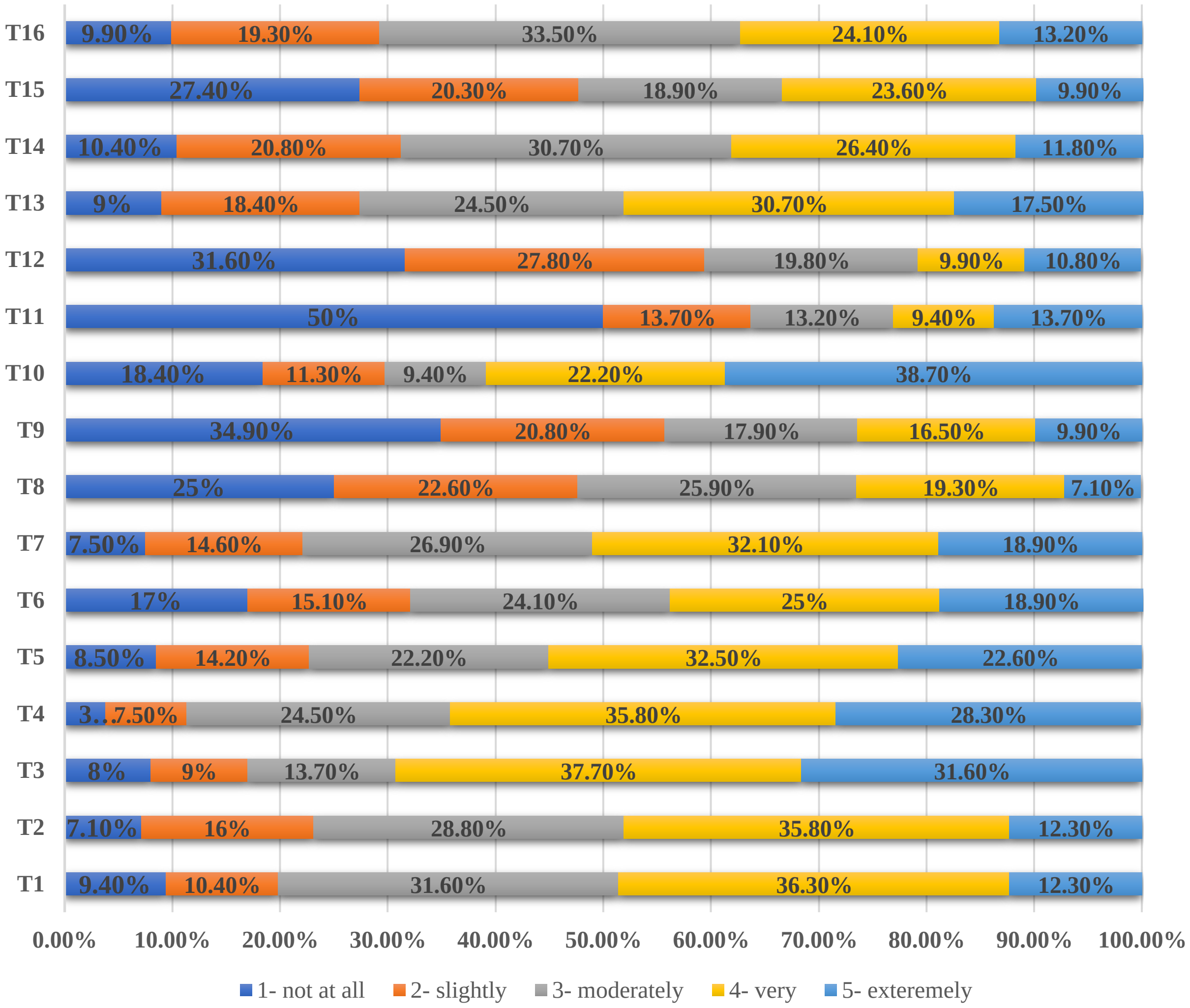


Figure 15. Distribution of Technology (T) Items
Source: Author's own figure

The element of SInt was measured using four items: "sharing info (SInt1)", "collaboration (SInt2)", "decision making (SInt3)", and "system development (SInt4) with main suppliers". The participants were asked to rate how their organisations integrate with their main suppliers. The element of SInt indicated the following:

-53.8% of the respondents stated that their organisations highly share the information with their main suppliers (Mean=3.51; SD=0.99)

-59.5% of the respondents stated that their organisations highly collaborate with their main suppliers (Mean=3.56; SD=0.95)

-54.7% of the respondents stated that their organisations highly involve their main suppliers in the decision-making process (Mean=3.53; SD=0.96)

-57.1% of the respondents stated that their organisations highly develop system (continuous improvement, Kanban etc.) with their main suppliers (Mean=3.34; SD=1.07)

The element of IInt was measured using four items: “information sharing with the purchasing department (IInt1)”, “decision making with the purchasing department (IInt2)”, “information sharing with the sales department (IInt3)”, and “decision making with the sales department (IInt4)”. The participants were asked to rate how their organisations integrate internally. The element of IInt indicated the following:

-63.7% of the respondents stated that their organisations often share the information with their purchasing departments (Mean=3.76; SD=0.90)

-68.4% of the respondents stated that their organisations often apply in joint decision making with their purchasing departments (Mean=3.81; SD=0.89)

-65.5% of the respondents stated that their organisations often share the information with their sales departments (Mean=3.80; SD=0.89)

-66.0% of the respondents stated that their organisations often apply in joint decision making with their sales departments (Mean=3.81; SD=0.89)

The element of CInt was measured using four items: “sharing info (CInt1)”, “collaboration (CInt2)”, “decision making (CInt3)”, and “system development (CInt4) with main customers”. The participants were asked to rate how their organisations integrate with their main customers. The element of CInt indicated the following:

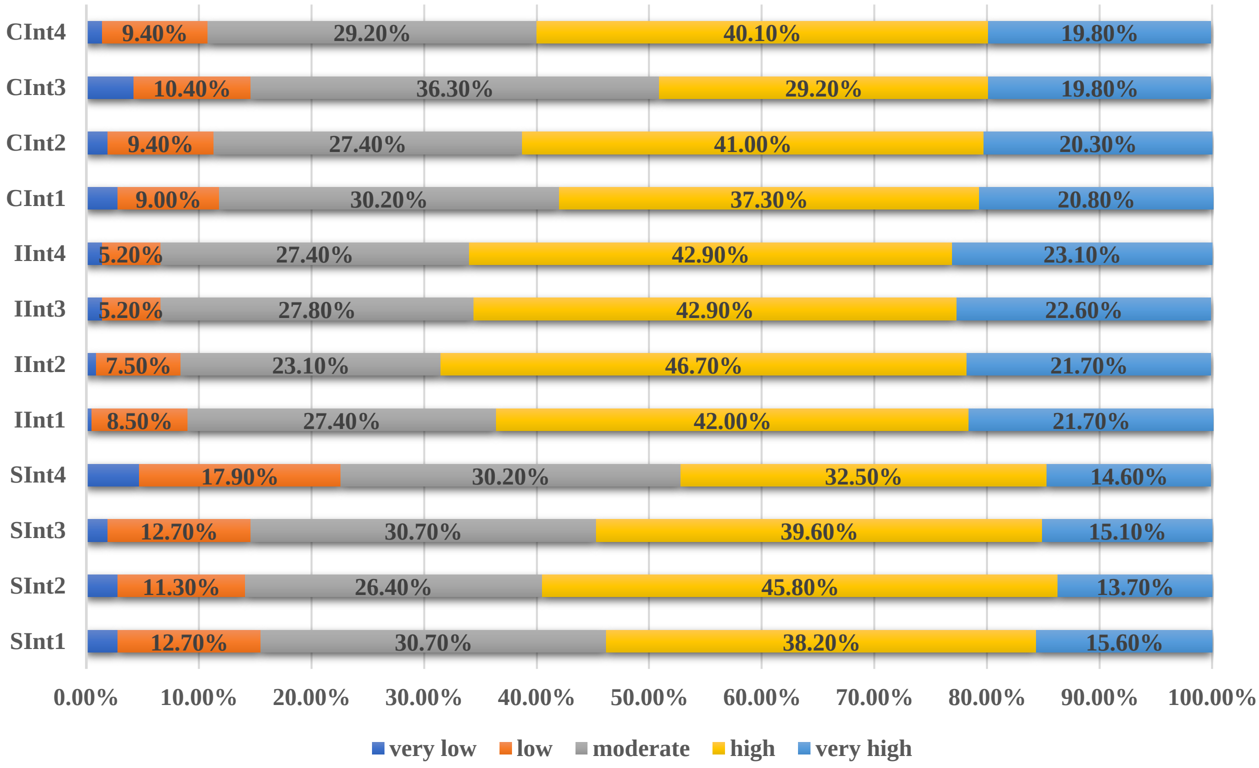
-58.1% of the respondents stated that their organisations often share the information with their main customers (Mean=3.64; SD=0.99)

-61.3% of the respondents stated that their organisations often collaborate with their main customers (Mean=3.68; SD=0.96)

-49.0% of the respondents stated that their organisations often develop a system (continuous improvement, Kanban, VMI, etc.) with their main customers (Mean=3.50; SD=1.05)

-59.9% of the respondents stated that their organisations often involve their main customers in the decision-making process (Mean=3.67; SD=0.94)

The third main construct, Supply Chain Performance (SCP), was divided into three sub-sections; “resources” (RPERF), “output” (OPERF) and “flexibility” (FPERF). These sub-sections were measured with 5, 7 and 5 items respectively by using a 5-point Likert scale ranging from “very poor” (1) to “excellent” (5). Appendix 12 presents the frequencies of the response scale (%) as well as means and standard deviations of the items used to assess SCP.



Note: SInt, IInt and CInt denote Supplier, Internal and Customer Integration

Figure 16. Distribution of SCI Items

Source: Author's own figure

Figure 17 shows the distribution of resources performance (RPERF) items. The element of 'RPERF' was measured using 5 items: "total cost of resources used (RPERF1)", "the total cost of distribution (RPERF2)", "the total cost of manufacturing (RPERF3"), "costs related to inventory (RPERF4)" and "return on investments (RPERF5)". The participants were asked to rate how their organisations use their resources associated items. The element of 'RPERF' indicated the following:

-43.8% of the respondents acknowledged that their organisations perform effectively on the total cost of resources used (Mean=3.42; SD=0.86)

-46.7% of the respondents acknowledged that their organisations perform effectively on the total cost of distribution including transportation and handling costs (Mean=3.47; SD=0.82)

-51.4% of the respondents acknowledged that their organisations perform effectively on the total cost of manufacturing including labor, maintenance and re-work costs (Mean=3.52; SD=0.89)

-45.8% of the respondents acknowledged that their organisations perform effectively on costs related to withheld inventory (Mean=3.38; SD=0.92)

-62.8% of the respondents acknowledged that their organisations perform effectively on return on investments (Mean=3.73; SD=0.89)

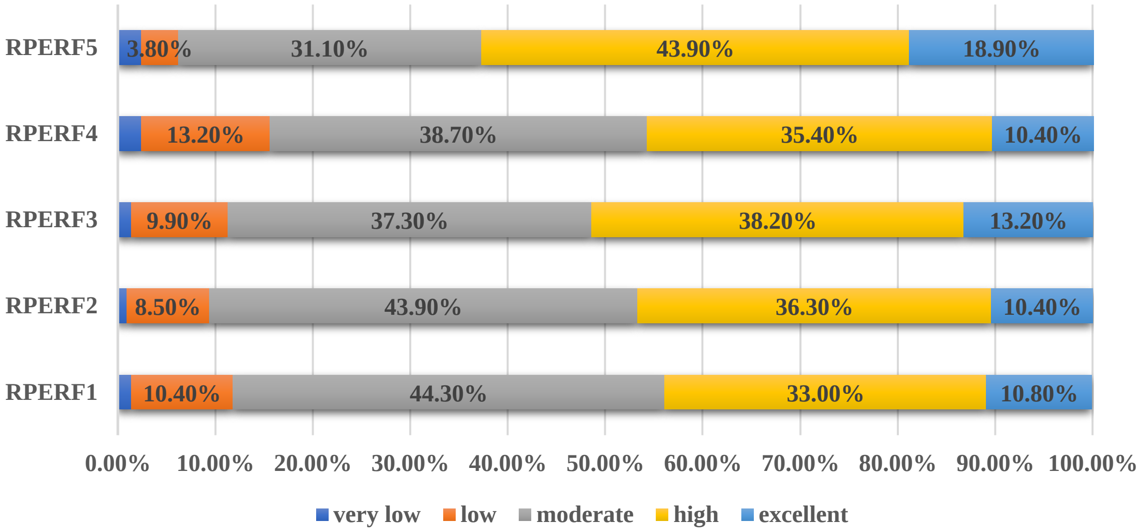


Figure 17. Distribution of Resources Performance (RPERF)Items
Source: Author's own figure

Figure 18 demonstrates the distribution of "output performance (OPERF)" items. The element of 'OPERF' was measured using 7 items: "sales (OPERF1)", "order fill rate (OPERF2)", "on-time deliveries (OPERF3)", "customer response time (OPERF4)", "shipping errors (OPERF5)", "manufacturing lead time (OPERF6)" and "customer complaints (OPERF7)". The participants were asked to rate how their organisations perform on their output items. The element of "OPERF" indicated the following:

-68.4% of the respondents stated that their organisations perform effectively on sales (Mean=3.76; SD=0.83)

-81.6% of the respondents stated that their organisations perform effectively on order fill rate (Mean=4.13; SD=0.81)

-84.4% of the respondents stated that their organisations perform effectively on-time deliveries (Mean=4.17; SD=0.78)

-74.1% of the respondents stated that their organisations perform effectively on customer response time (Mean=3.91; SD=0.84)

-77.8% of the respondents stated that their organisations perform effectively on shipping errors (Mean=4.01; SD=0.83)

-78.8% of the respondents stated that their organisations perform effectively on manufacturing lead time (Mean=4.05; SD=0.79)

-85.3% of the respondents stated that their organisations perform effectively on customer complaints (Mean=4.16; SD=0.72)

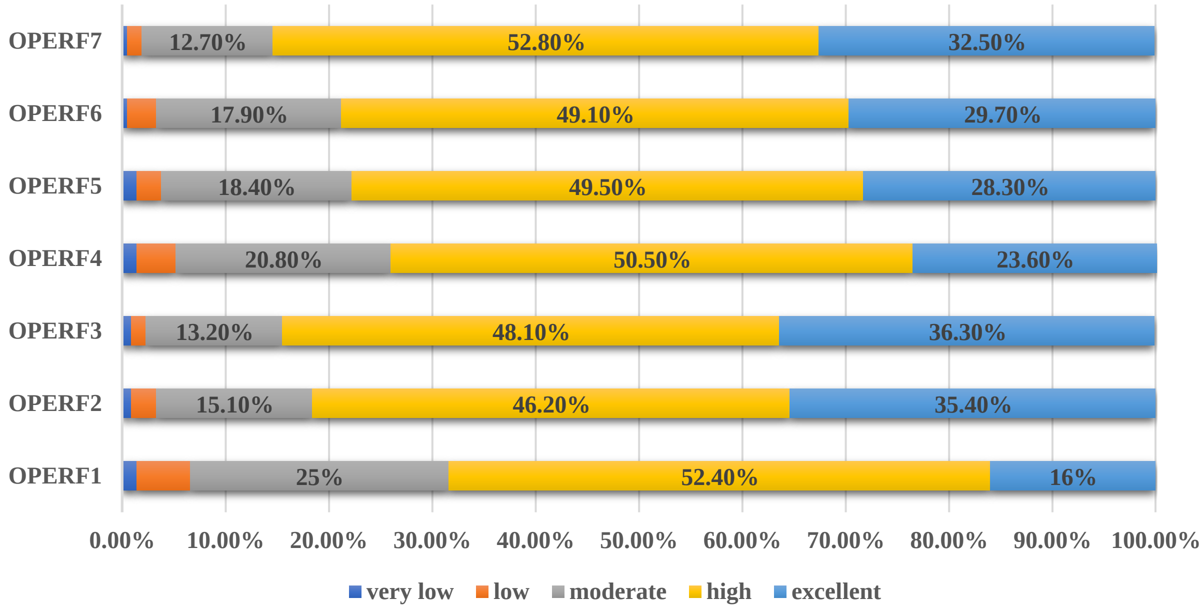


Figure 18. Distribution of Output Performance (OPERF) Items
Source: Author’s own figure

Figure 19 displays the distribution of “flexibility performance (FPERF)” items. The element of “FPERF” was measured using 5 items: “the ability to respond to demand changes (FPERF1)”, “ability to respond to periods of poor manufacturing performance (FPERF2)”, “ability to respond to periods of poor supplier performance (FPERF3)”, “ability to respond to periods of poor delivery performance (FPERF4)” and “ability to respond to new markets, products or new competitors (FPERF5)”. The participants were asked to rate how their organisations perform on their flexibility performance. The element of “FPERF” indicated the following:

-80.6% of the respondents stated that their organisations perform effectively on responding to demand changes (Mean=4.08; SD=0.84)

-69.8% of the respondents stated that their organisations perform effectively on responding to periods of poor manufacturing performance (Mean=3.89; SD=0.88)

-61.3% of the respondents stated that their organisations perform effectively on responding to periods of poor supplier performance (Mean=3.66; SD=0.92)

-64.6% of the respondents stated that their organisations perform effectively on responding to periods of poor delivery performance (Mean=3.76; SD=0.84)

-68.9% of the respondents stated that their organisations perform effectively on responding to new markets, products or new competitors (Mean=3.87; SD=0.92)

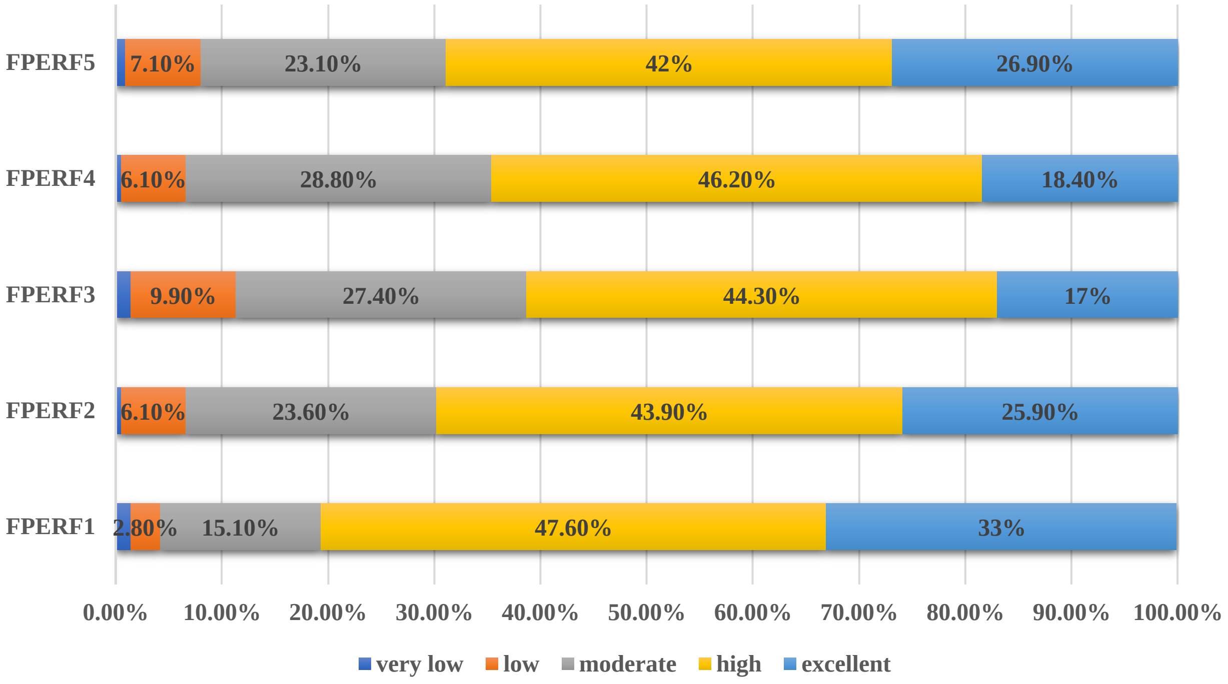


Figure 19. Distribution of Flexibility Performance (FPERF) Items
Source: Author's own figure

4.2. Measurement Model Evaluation

To validate the specified model, confirmatory factor analysis was implemented with the observed variables as discussed in Chapter 3. In our model, since the main endogenous variables were determined as Industry 4.0, SCI and SCP, reliability and validity tests must be evaluated for each variable. In order to conduct the reliability and validity tests, the measurement model needs to assess "internal consistency (composite reliability), indicator reliability (outer loadings)", "convergent validity (average variance extracted -AVE-)" and "discriminant validity tests" (Ainin et al., 2015). Therefore, in this section, the outer loadings, construct reliability and validity tests, discriminant validity tests, collinearity statistics (VIF) of the items for each element will be discussed.

4.2.1. Reliability and Validity Tests for the Items of Industry 4.0

Firstly, the measurement model for the indicators of Industry 4.0 has been conducted. Indicator reliability displays the number of variations in an indicator explained by the variables. Therefore, the factor loading of each item presents its contribution to the assigned variables in the model. As previously explained in Section 3.4.2, the items' outer loadings must be higher than 0.70 to have a sufficient threshold. Table 15 indicates the outer loadings of each of the items of Industry 4.0, a total of 15 items shows a value higher than 0.70. For this reason, a total of nine indicators were eliminated from the measurement model: "S&O3, T6, T8, T9, T10, T11, T12, T13, T15" because they have less than 0.70 outer loadings' value to explain their assigned variables. Although these indicators are extracted from the model one by one - starting from the lowest value -, none of them did exceed the sufficient threshold. The rest of the indicators retained in the model, "S&O1, S&O2, S&O4, E&C1, E&C2, E&C3, E&C4, T1, T2, T3, T4, T5, T7, T14, T16". Their outer loading values range from 0.737 to 0.941.

Table 15. Outer Loadings of the items of Industry 4.0

Items	Strategy	Employee and Culture	Technology
S&O1	0.94		
S&O2	0.941		
S&O3	**0.559***		
S&O4	0.859		
E&C1		0.859	
E&C2		0.887	
E&C3		0.737	
E&C4		0.737	
T1			0.745
T2			0.770
T3			0.826
T4			0.787
T5			0.775
T6			**0.499***
T7			0.795
T8			**0.668***
T9			**0.637***
T10			**0.430***
T11			**0.478***
T12			**0.591***
T13			**0.686***
T14			0.820
T15			**0.682***
T16			0.791

Note 1: S&O, E&C and T denote Strategy and Organisation, Employee and Culture and Technology Elements
Note 2: numbers marked with * excluded from the model
Source: Author's own analysis

"Internal consistency" is generally calculated using "Cronbach's alpha value" (Conway et al., 1995), which shows how closely linked a set of items as a group and a measurement of scale reliability. The composite reliability and convergent validity (AVE), are the measurement tests to evaluate the reliability and validity of the measurement models. All of these values are shown in Table 16 for the elements of Industry 4.0. In exploratory research, the acceptable values for Cronbach's alpha and composite reliability are higher than 0.70 - which is highly recommended for a reliable construct rather than 0.60 -; therefore, as can be seen in Table 16, the element of 'S&O' was measured with the values of 0.902 and 0.928 for Cronbach's alpha and composite reliability consecutively; the element of 'E&C' was observed with the values of 0.817 and 0.884 for Cronbach's alpha and composite reliability respectively; and the element of 'T' was measured with the values of 0.908 and 0.925 for Cronbach's alpha and composite reliability consecutively. These values are well accepted for the measurement model. As we checked the values of convergent validity -AVE-, indicating the level to which a measure has a positive correlation with alternative measures of the same construct; the accepted values determined for AVE as 0.50 or higher. The values of AVE for the measurement model were observed as 0.829, 0.647 and 0.618 consecutively for the elements of 'S&O', 'E&C' and 'T', thereby satisfying the threshold.

Table 16. Construct Reliability and Validity of the items of Industry 4.0

Elements	**No. of Indicators**	**Internal consistency reliability**		**Convergent Validity**	**Indicator Reliability**
		Cronbach's Alfa	Composite Reliability	AVE	Outer Loadings
S&O	3	0.902	0.928	0.829	0.859 to 0.941
E&C	4	0.817	0.884	0.647	0.737 to 0.887
T	8	0.908	0.925	0.618	0.745 to 0.826

Note: S&O, E&C and T denote Strategy and Organisation, Employee and Culture and Technology Elements

Source: Author's own analysis

"Discriminant validity" is also confirmed; this shows the level to which a variable is correctly distinguished from other variables. The findings of the "Fornell-Larcker criterion" indicated that (Table 17) the square root of AVE for the variables must be higher than other variables' correlation value. In the table, the findings shown in bold revealed that all of the square roots of AVE were higher than the correlation values of the other constructs for Industry 4.0.

Table 17. Discriminant Validity Test (Fornell Larcker Criterion) of the elements of Industry 4.0

Elements	**S&O**	**E&C**	**T**
S&O	**0.92**		
E&C	0.782	**0.811**	
T	0.751	0.779	**0.79**

Note: S&O, E&C and T denote Strategy and Organisation, Employee and Culture and Technology Elements

Source: Author's own analysis

Variance Inflation Factor (VIF) values also must be conceived in order to identify the multicollinearity between the variables. Highly correlated items adversely affect the results of the measurement model; therefore, these values must be at an acceptable level (lower than 5). Table 18 indicates the VIF values of the items used in the assessment of Industry 4.0. The values of all of the items were determined in acceptable levels, below 5, ranging between 1.601 to 4.204.

Table 18. Collinearity Statistics (VIF) of the items of Industry 4.0

Items	VIF Values
S&O1	4.204
S&O2	4.116
S&O4	2.075
E&C1	2.519
E&C2	2.694
E&C3	1.617
E&C4	1.601
T1	1.995
T2	2.126
T3	2.541
T4	2.228
T5	2.237
T7	2.239
T14	2.290
T16	2.314

Note: S&O, E&C and T denote Strategy and Organisation, Employee and Culture and Technology Elements
Source: Author's own analysis

4.2.2. Reliability and Validity Tests for the Items of SCI

In this section, reliability and validity tests for the indicators of SCI have been discussed. As a first step, factor loadings were calculated. Table 19 indicates the outer loadings for each item of SInt, IInt, and CInt, which are the elements of SCI. As discussed in section 3.4.2, the minimum threshold required is 0.70 or higher. In Table 19, the factor loading's value of each indicator is between 0.85 to 0.91; therefore, none of the indicators is extracted from the model.

Table 19. Outer Loadings of the items of SCI

Items	SInt	IInt	CInt
SInt1	0.852		
SInt2	0.883		
SInt3	0.88		
SInt4	0.854		
IInt1		0.881	
IInt2		0.914	
IInt3		0.919	
IInt4		0.872	
CInt1			0.858
CInt2			0.907
CInt3			0.906
CInt4			0.886

Note: SInt, IInt, CInt denote Supplier, Internal and Customer Integration
Source: Author's own analysis

As a second step, construct reliability and validity of the items of SCI have been shown in Table 20. The values of Cronbach's Alfa and Composite Reliability were calculated as 0.89 and 0.92 for SInt, 0.92 and 0.94 for IInt, and 0.91 and 0.94 for CInt respectively. Considering the accepted values, which must be higher than 0.70 for both tests, these measures are well accepted for the elements. Also, AVE values were observed as 0.75, 0.81 and 0.79 for SInt, IInt and CInt consecutively; therefore, all they are at a satisfactory level since the values are higher than 0.50.

Table 20. Construct Reliability and Validity of the items of SCI

Elements	**No. of Indicators**	**Internal consistency reliability**		**Convergent Validity**	**Indicator Reliability**
		Cronbach's Alfa	Composite Reliability	AVE	Outer Loadings
SInt	4	0.89	0.92	0.75	0.852 to 0.883
IInt	4	0.92	0.94	0.81	0.872 to 0.919
CInt	4	0.91	0.94	0.79	0.858 to 0.907

Note: SInt, IInt, CInt denote Supplier, Internal and Customer Integration
Source: Author's own analysis

Thirdly, a discriminant validity test - Fornell Larcker Criterion - has been employed for the elements of SCI, Table 21 shows the findings of the discriminant validity test for SInt, IInt and CInt. In the table, the results indicated in bold displayed higher values than the rest of the correlation values of the constructs; therefore, discriminant validity is accepted for SCI elements.

Table 21. Discriminant Validity Test (Fornell Larcker Criterion) of the elements of SCI

Elements	**SInt**	**IInt**	**CInt**
SInt	**0.871**		
IInt	0.639	**0.90**	
CInt	0.701	0.585	**0.89**

Note: SInt, IInt, CInt denote Supplier, Internal and Customer Integration
Source: Author's own analysis

Table 22. Collinearity Statistics (VIF) of the items of SCI

Items	**VIF Values**
SInt1	2.191
SInt2	2.674
SInt3	2.609
SInt4	2.192
IInt1	2.905
IInt2	3.528
IInt3	5.168
IInt4	3.994
CInt1	2.553
CInt2	3.369
CInt3	3.046
CInt4	2.754

Note: SInt, IInt, CInt denote Supplier, Internal and Customer Integration
Source: Author's own analysis

As a final step in this section, collinearity statistics (VIF) values have been checked for each item (Table 22). The accepted VIF value of each item must be lower than 5, as previously explained. As can be seen in Table 22, all the items, except II3, have lower values than 5. However, this item also has been observed as very close to the threshold; therefore, it was held in the model.

4.2.3. Reliability and Validity Tests for the Items of SCP

Similarly, the reliability and validity tests of SCP have been calculated. First of all, the outer loadings of the indicators of SCP have been observed, and all items show values higher than 0.70, except the 'OPERF1' item, as indicated in Table 23. Therefore, this item has been removed for further analysis, while the rest of the items were retained in the model.

Secondly, internal consistency reliability and convergent validity tests were conducted for the elements of SCP: RPERF, OPERF and FPERF. The values of Cronbach's Alfa and Composite Reliability were measured as 0.867 and 0.91 for RPERF, 0.87 and 0.89 for OPERF, and 0.90 and 0.92 for FPERF respectively; thus, these values are accepted for the model (> 0.70).

Table 23. Outer Loadings of the items of SCP

Items	Resources	Output	Flexibility
RPERF1	0.781		
RPERF2	0.854		
RPERF3	0.837		
RPERF4	0.848		
RPERF4	0.734		
OPERF1		**0.569***	
OPERF2		0.774	
OPERF3		0.834	
OPERF4		0.779	
OPERF5		0.768	
OPERF6		0.802	
OPERF7		0.712	
FPERF1			0.757
FPERF2			0.885
FPERF3			0.869
FPERF4			0.881
FPERF5			0.868

Note 1: RPERF, OPERF and FPERF denote Resources, Output and Flexibility Performance
Note 2: numbers marked with * excluded from the model
Source: Author’s own analysis

As for the convergent validity, AVE values were calculated as 0.66, 0.61 and 0.70 for RPERF, OPERF and FPERF consecutively. Since the values are higher than 0.50 threshold, convergent validity for the elements of SCP meets the criteria. Table 24 indicates the findings of “internal consistency reliability, convergent validity and indicator reliability” of SCP elements.

Table 24. Construct Reliability and Validity of the items of SCP

Elements	No. of Indicators	Internal consistency reliability		Convergent Validity	Indicator Reliability
		Cronbach’s Alfa	Composite Reliability	AVE	Outer Loadings
RPERF	5	0.867	0.91	0.66	0.734 to 0.854
OPERF	6	0.87	0.89	0.61	0.712 to 0.834
FPERF	5	0.90	0.92	0.70	0.757 to 0.885

Note: RPERF, OPERF and FPERF denote Resources, Output and Flexibility Performance
Source: Author’s own analysis

Table 25. Discriminant Validity Test (Fornell Larcker Criterion) of the elements of SCP

Elements	Resources	Output	Flexibility
RPERF	**0.812**		
OPERF	0.635	**0.778**	
FPERF	0.64	0.748	**0.841**

Note: RPERF, OPERF and FPERF denote Resources, Output and Flexibility Performance
Source: Author's own analysis

The results of the discriminant validity test also have been shown in Table 25 for the elements of SCP. Table 25 explains that the bold numbers are higher than the rest of the values for each element. Therefore, since all elements square roots of AVE are larger than the correlation values of the other constructs for SCP, discriminant values of the elements are accepted for the model.

Table 26. Collinearity Statistics (VIF) of the items of SCP

Items	VIF Values
RPERF1	2.125
RPERF2	2.687
RPERF3	2.216
RPERF4	2.281
RPERF5	1.561
OPERF2	2.039
OPERF3	2.534
OPERF4	1.880
OPERF5	1.884
OPERF6	1.956
OPERF7	1.550
FPERF1	1.769
FPERF2	2.998
FPERF3	3.152
FPERF4	3.174
FPERF5	1.757

Note: RPERF, OPERF and FPERF denote Resources, Output and Flexibility Performance
Source: Author's own analysis

Finally, the collinearity statistics (VIF) values were calculated for each item. Table 26 demonstrates that the VIF value of each item lower than 5; thus, the collinearity is not an issue between the items of SCP.

4.3. Structural Model Analysis and Hypotheses Testing

As the validity and reliability of the model were verified in Section 4.2, the next stage is to evaluate the structural model analysis, testing the hypotheses put forth in Section 1.3. Considering the findings of reliability and validity tests, the structural model has been measured with a total of 15 items for Industry 4.0, including 3 items for S&O, 4 items for E&C and 8 items for T elements. For SCI, none of the items was removed from the structural model so a total of 12 items were evaluated, including 4 items each for SInt, IInt and CInt. For SCP, only OPERF1 item was eliminated from the model; therefore, 5, 6, and 5 items were included in representing RPERF, OPERF and FPERF respectively.

Two sets of techniques, PLS and Bootstrapping, in the PLS-SEM framework were adopted in testing the relationships between the measurement variables as presented in section 3.4.1. In addition, the mediating effect of SCI between I.4.0 and SCP was analysed.

Table 27 displays the results of the coefficients of determination (R^2) to examine the predictive power of the model, estimated path coefficients and their significance level (p-values) and t-values for the three endogenous variables.

Table 27. Hypotheses and Main Research Model Results

Relationship	**Path coefficients (*β*)**	**t-values**	**P values**
H1: Industry 4.0 → Integration	0.630	12.135	**
H2: Integration→ Performance	0.635	9.964	**
H3: Industry 4.0 → Performance	0.17	2.670	*
H4: Industry 4.0 → Integration → Performance	0.395	7.838	**
Coefficients of determination (R^2)			
	R^2		**Adjusted** R^2
Integration	0.398		0.395
Performance	0.566		0.56

**$p < 0.001$ *$p < 0.05$ (all two-tailed)
Source: Author’s own analysis

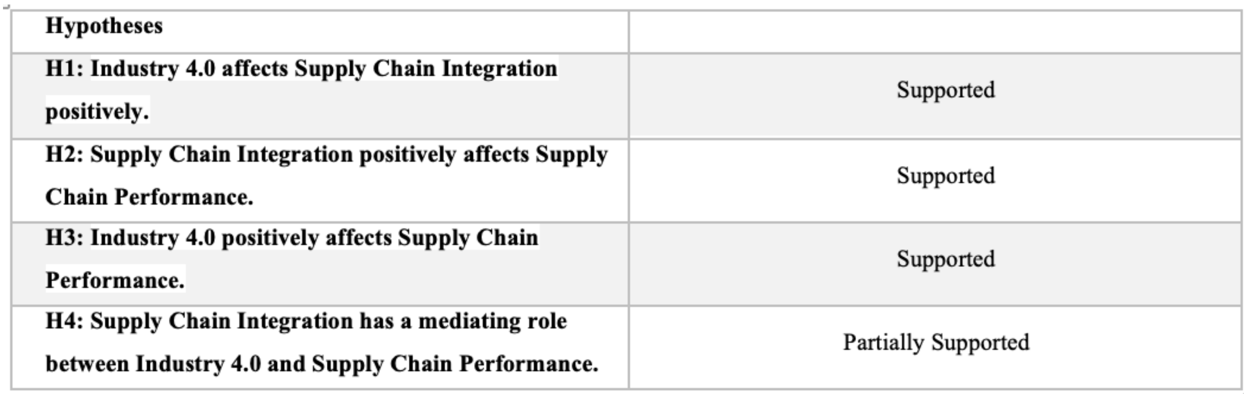
-H1: The effect of Industry 4.0 on SCI: As shown in Section 1.3, the first hypothesis proposed is that the higher degree of assessment of Industry 4.0 positively affects the degree of SCI. The findings of the structural model show that the assessment of Industry 4.0 has a positive and significant impact on SCI ($\beta=0.63$, $p < 0.001$), explaining 39.8% (R^2) of the variance of SCI. Also, t-value is acceptable since it is higher than 2.58 in $p < 0.001$. Therefore, the test results supported the hypothesis H1.

-H2: The effect of SCI on SCP: The second hypothesis is that the higher degree of SCI positively affects the degree of SCP. It has been found that SCI has a positive and significant influence on SCP ($\beta=0.635$, $p < 0.001$), where t value is greater than 2.58 in $p < 0.001$. Therefore, the test results supported hypothesis H2.

-H3: The effect of Industry 4.0 on SCP: The third hypothesis of the dissertation is that the higher degree of assessment of Industry 4.0 positively affects the degree of SCP. The results of the structural model indicate that Industry 4.0 has a positive and statistically influence on SCP; however, the relationship between these two has been observed as very weak ($\beta=0.17$, $p < 0.05$), where t value is accepted (higher than 1.96 in $p < 0.05$). Industry 4.0 and SCI have an influence on SCP, explaining 56.6% (R^2) of the variance of SCP. Therefore, H3 is also supported statistically.

-H4: Mediating Effect of SCI Between Industry 4.0 and SCP: According to the path results, 56.6% of the variance of SCP was explained by Industry 4.0 and SCI as shown in Figure 21. This also shows a significant prediction accuracy (Hair et al., 2014, p.116). Based on the findings of the structural model, there are significant relationships between Industry 4.0 and SCI, and SCI and SCP, although the relationship between Industry 4.0 and SCP is significant but weak. In this case, it could be checked the specific indirect effect of SCI between Industry 4.0 and SCP because there could be a partial mediation among observed variables as suggested in Hair et al. (2017).

Table 28. Summary of The Hypotheses



Hypotheses	
H1: Industry 4.0 affects Supply Chain Integration positively.	Supported
H2: Supply Chain Integration positively affects Supply Chain Performance.	Supported
H3: Industry 4.0 positively affects Supply Chain Performance.	Supported
H4: Supply Chain Integration has a mediating role between Industry 4.0 and Supply Chain Performance.	Partially Supported

Source: Author’s own findings

In this sense, the indirect effect of SCI was observed between Industry 4.0 and SCP. The results show that SCI is partially mediating the relationship between Industry 4.0 and SCP ($\beta=0.395$, $p < 0.001$ and t value= 7.838) since it is statistically positive and significant. The magnitude of the effect observed higher than the direct relationship between Industry 4.0 and SCP. Therefore, the test results partially supported the hypothesis H4. Table 28 and Figure 20 indicate the findings of the hypotheses put forth in this dissertation. In addition, all statistical findings of the path analysis used in this dissertation have been shown in Figure 21.

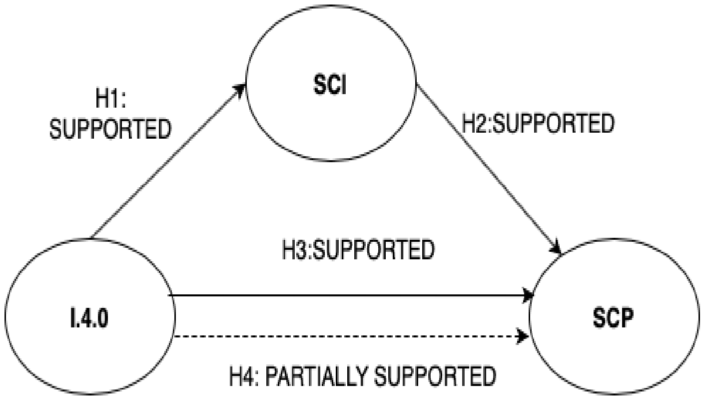


Figure 20. Hypotheses between Main Endogenous Variables
Source: Author's own figure

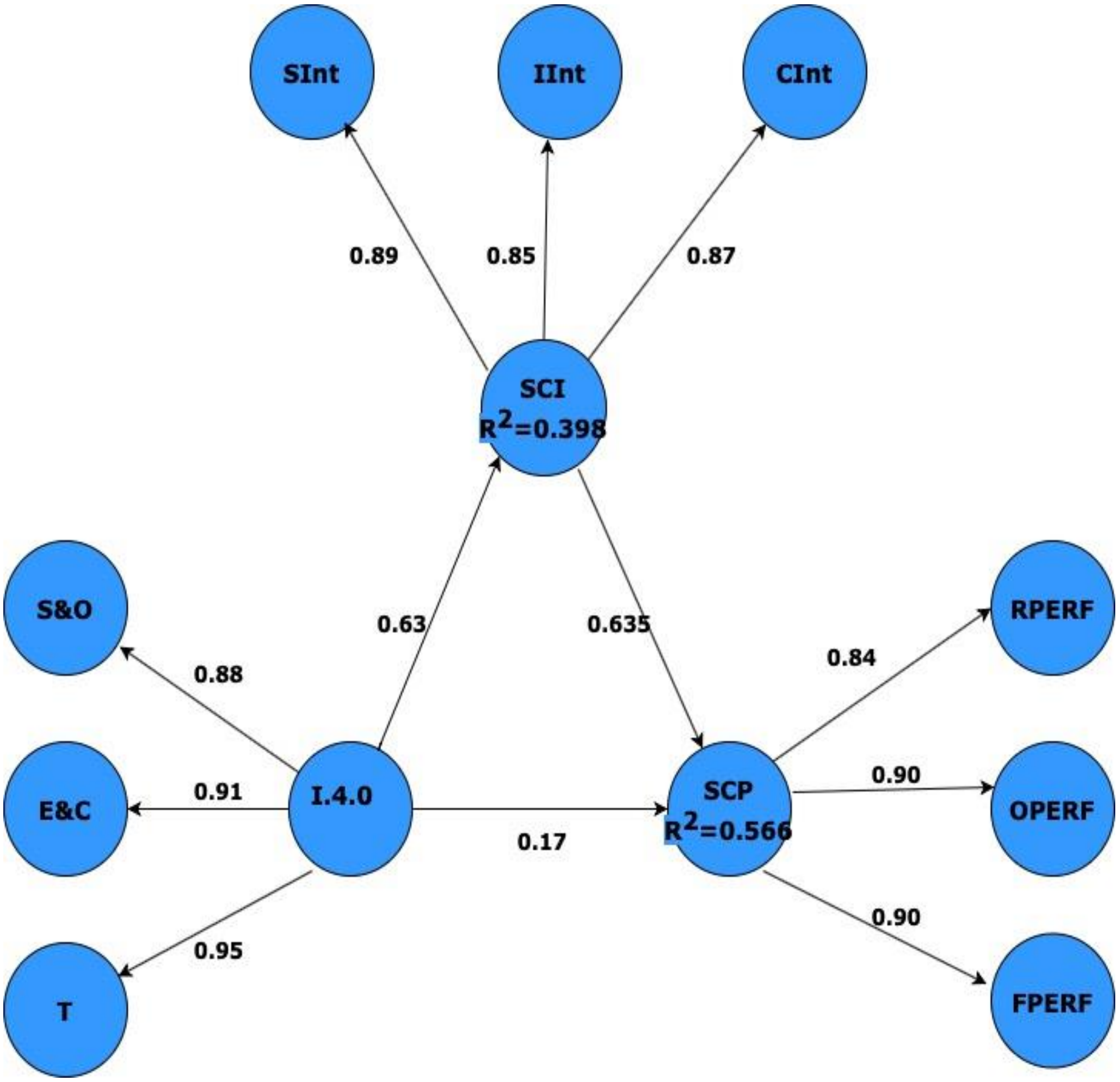


Figure 21. Results of path analysis
Source: Author's own figure

<u>-Effect Size and Predictive Relevance of The Variables:</u> The effect sizes (f^2) were also examined to assess the impact of constructs on each other. As noted by Henseler et al. (2015), the threshold values are “0.02, 0.15 and 0.35”, regarding “small, medium and large effect sizes”. The findings also show that Industry 4.0 has a strong impact on SCI ($f^2=0.65$) and SCI has a strong effect on SCP ($f^2= 0.55$). However, considering the impact of Industry 4.0 on SCP, the effect size is small ($f^2= 0.04$); so, Industry 4.0 has a small effect on SCP.

Finally, predictive relevance *(Q2)* of the structural model was analysed. If the values of Q^2 of the endogenous variables are higher than 0, then the model has a predictive significance, meaning that the variables are well constructed (Delic et al., 2019). The values of predictive relevance for Industry 4.0, SCI and SCP are 0.49, 0.493 and 0.417 respectively; so, the model has a predictive significance.

<u>-Control Variables:</u> Control variables were also considered in the dissertation; three variables, firm size - number of employees, annual revenue - and sector of the companies were added into the structural model to check their impacts on the endogenous variables. Following the measurement method of Jabbour et al. (2015, p.446), the number of employees, annual revenues of the firms and sector of the firms were created. The number of employees was classified into four categories: the number of employees ranges between 10-49; 50-249; 250-499; and more than 500 employees. The annual revenues of the firms are measured in four categories; less than 3 M TL, with more than 3 M and less than 25 M TL, more than 25 M TL and less than 125 M TL, more than 125 M TL. Finally, the sector of the companies was evaluated in four categories: textile, automotive and electronic, food and beverage; and chemicals/ pharmaceuticals.

Regarding the results, Industry 4.0 is affected by the number of employees ($p<0.05$) and annual revenue ($p<0.001$); SCI by only annual revenue ($p<0.05$) and SCP by the only number of employees ($p<0.05$). The impact of the sector is not accounted for as significant in any of the variables. The findings show that firm size appears to be the most significant control variable in all of the variables; however, as checked the impacts of the endogenous variables with each other, the final results observed are still the same except for the direct relationship between Industry 4.0 and SCP. Therefore, when control variables are added into the structural model, the results are still supported for the direct effects of Industry 4.0 on SCI ($\beta=0.659$, $p < 0.001$), SCI on SCP ($\beta=0.631$, $p < 0.001$); however, the results for the direct effect of Industry 4.0 on SCP show an insignificant impact ($p > 0.05$), while mediating the role of SCI is still significant ($p< 0.001$) between Industry 4.0 and SCP.

4.4. The Importance -Performance Matrix Analysis (IPMA)

In order to extend the findings of PLS, it is also useful to analyse the performance-importance matrix analysis (IPMA), which explains the performance and relative importance of each item on a target construct. IPMA is significant to identify the items that must be prioritised to improve a target construct for managerial actions. The framework of IPMA was originally developed by Martilla and James (1977) to investigate the perceptions of customers on the importance and performance of attributes (Deng and Pierskalla, 2018, p. 2). The horizontal axis (X-axis) displays the importance of the constructs from low importance to high importance. The vertical axis (Y-axis) stands for the performance of the constructs from low performance to high performance. Martilla and James (1977, p. 78) illustrated four quadrants for the importance-performance analysis of attributes, which can be important in developing company strategies. Figure 22 demonstrates these four quadrants: “keep up the good work”, “potential overkill”, “low priority” and “concentrate here”. “Quadrant I” denotes “keep up the good work”, where attributes are rated as high importance and performance; therefore, a company should maintain to its performance for these important attributes. “Quadrant II” relates to “concentrate here”, where the performance does not meet importance; therefore, these attributes need to be improved by a company. “Quadrant III” pertains to “low priority”, where the levels of performance and importance are low. Thus, when attributes are less important, they do not require priority by an organisation. “Quadrant IV” suggests “possible overkill” because the attributes are rated as low important, while the performance is high. Companies could reallocate their resources to other areas and deprioritise the attributes lying on this quadrant.

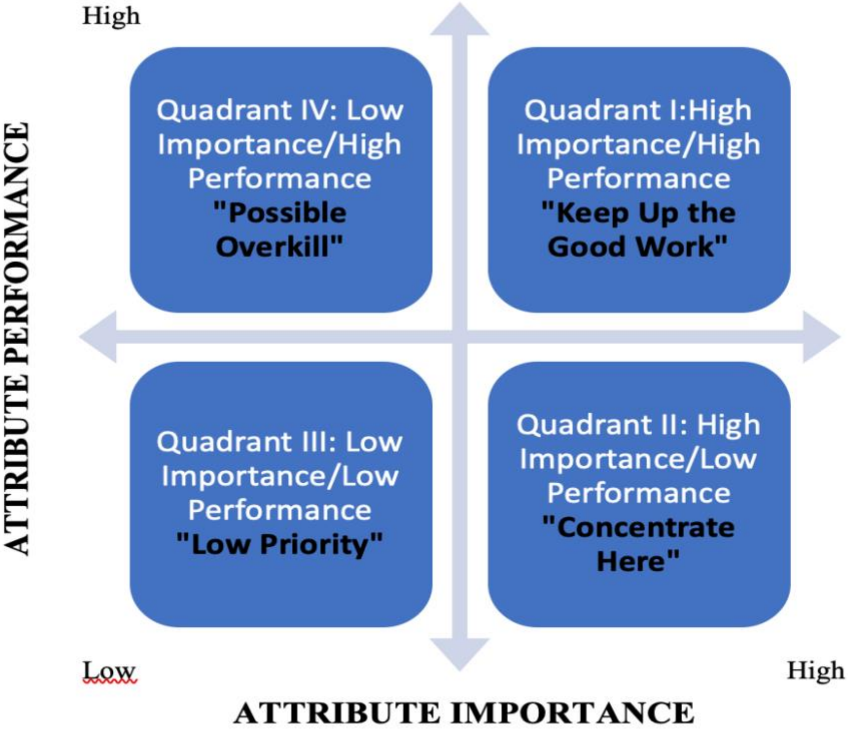


Figure 22. The Framework of IPMA
Source: Adopted from Martilla and James (1977)

Table 29. Importance-Performance Analysis for SCP (Dimensions)

Dimension	Performance	Importance
I.4.0	57,439	0,389
SCI	66,068	0,519

Source: Author's own analysis

Based on the framework of the IPMA, first, the importance and performance scores of Industry 4.0 and SCI were measured for a target construct, SCP. The findings of the IPMA were shown in Table 29 and Figure 23. Compared with Industry 4.0, SCI achieved both higher importance score (0.519) and a higher performance score (66.068) for SCP. The scores of Industry 4.0 show 0.389 and 57.439 for importance and performance for SCP respectively. The results of the importance and performance of these constructs are consistent with the findings of the path analysis above. Therefore, organisations first should prioritise SCI for achieving higher SCP since this construct has a more important score than Industry 4.0. However, to deepen the understandings of the level of importance and performance analysis, IPMA has been conducted at the indicator level analysis with each construct's items.

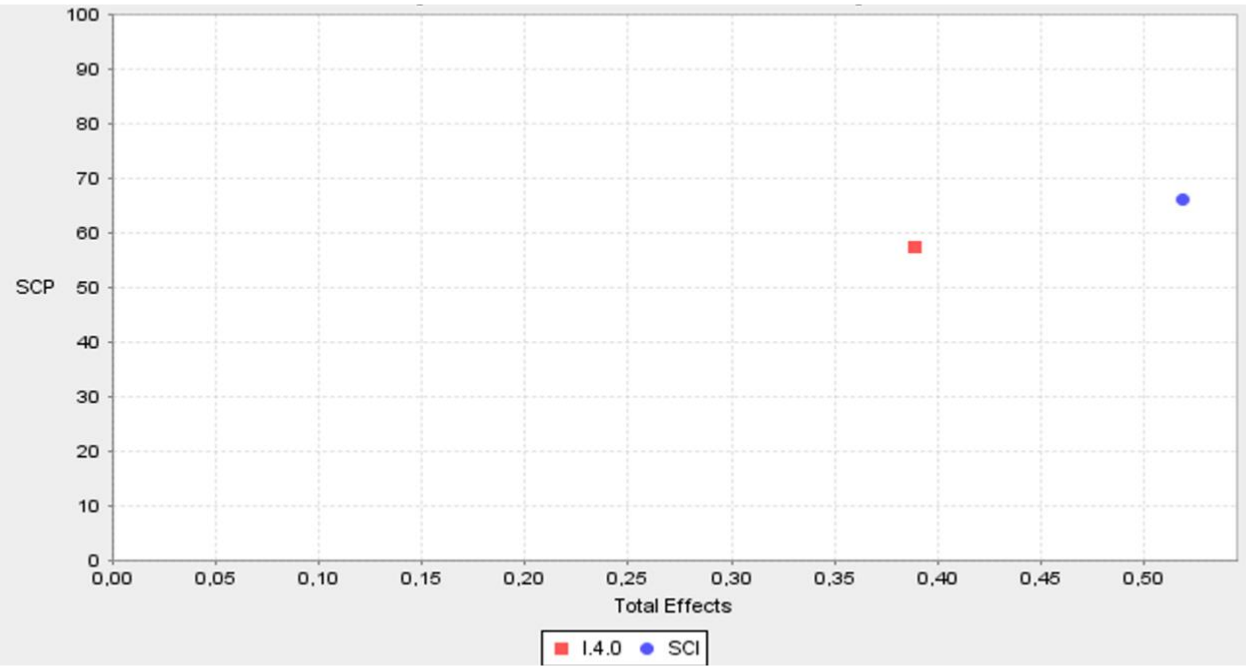
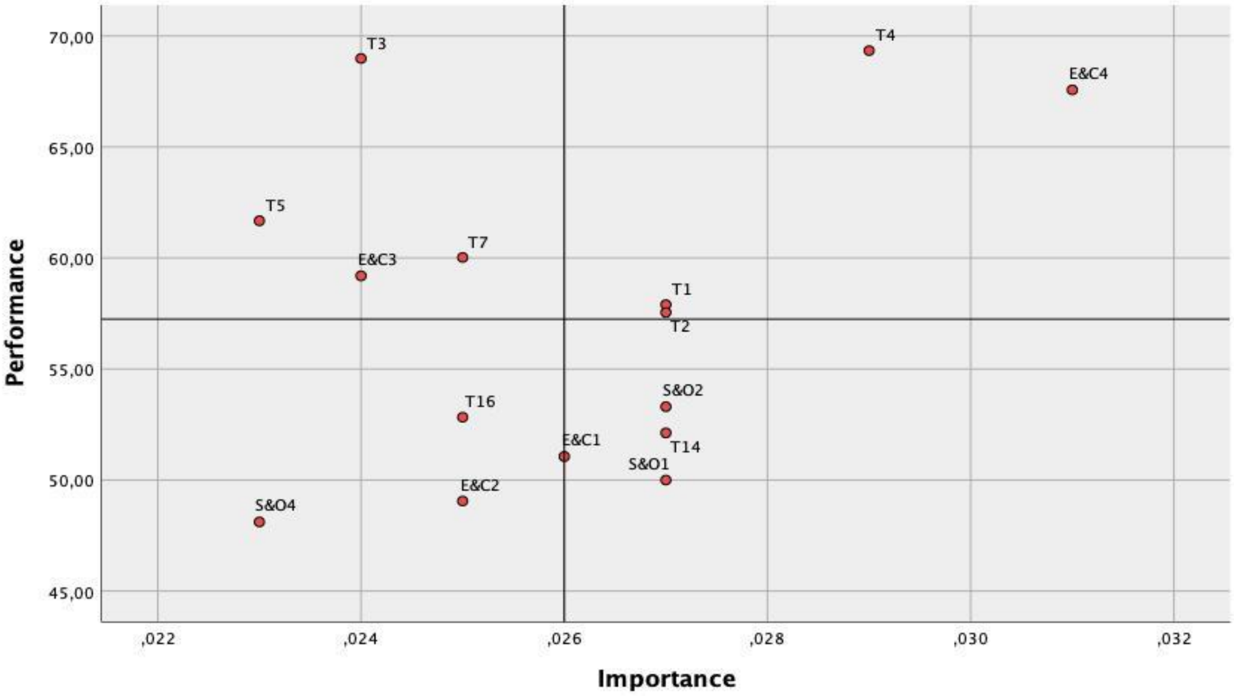


Figure 23. IPMA for Industry 4.0 and SCI
Source: Author

Furthermore, it is important to investigate which items of Industry 4.0 should be prioritised for SCP; therefore, the IPMA matrix at the item level was measured (Figure 24 and Table 30). As indicated in the matrix, the items of S&O1, S&02, E&C1 and T14 represent the "availability of roadmap", "investing Industry 4.0 infrastructure", "employee familiarity" and "embrace to digitalisation" consecutively, having low performance, but high importance for SCP. These indicators are placed in Quadrant II; for this reason, organisations firstly concentrate on these indicators, which could offer more potential for improvement of SCP. Immediate investments to these indicators could increase the performance in supply chains.



Note: The reference lines on X and Y axes correspond to mean values of indicators' importance and performance respectively

Figure 24. IPMA for Industry 4.0 indicators
Source: Author's own analysis

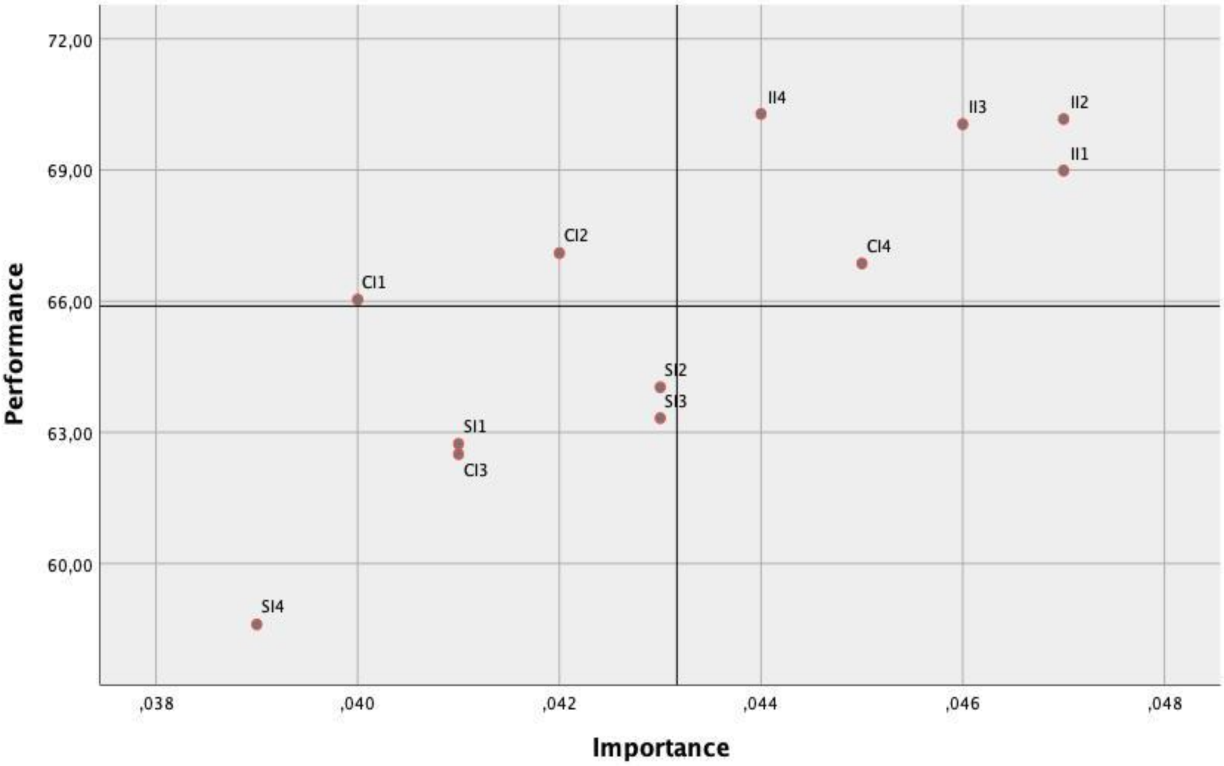
The items of T1, T2, T4 and E&C4 represent the "advanced connectivity of technology", "level of supplier technology", "analysing data for decision making" and "continuous culture of organisation" respectively, showing high performance and importance. Therefore, organisations should keep up their current performance on these indicators since they have high importance scores. The items of E&C3, T3, T5 and T7 refer to "openness to innovation", "data access for operations", "usage of sensor technology" and "trace to manufacturing systems" consecutively, displaying high performance; however, low importance. Therefore, the resources of these items must be reallocated to the other areas. Also, S&O4, E&C2 and T16 representing "external collaborations", "employee training" and "high automation" must be deprioritised because they have both low performance and importance.

Table 30. Importance-Performance Map for SCP (I.4.0 Indicators)

Indicator	Performance	Importance
S&O1	50,000	0,027
S&O2	53,302	0,027
S&O4	48,113	0,023
E&C1	51,061	0,026
E&C2	49,057	0,025
E&C3	59,198	0,024
E&C4	67,571	0,031
T1	57,901	0,027
T2	57,547	0,027
T3	68,986	0,024
T4	69,340	0,029
T5	61,675	0,023
T7	60,024	0,025
T14	52,123	0,027
T16	52,830	0,025

Source: Author's own analysis

Another step was to examine which items of SCI should be prioritised for SCP; thus, the IPMA matrix was evaluated for each item of SCI (Table 31 and Figure 25).



Note: The reference lines on X and Y axes correspond to mean values of indicators' importance and performance respectively

Figure 25. IPMA for SCI indicators

Source: Author's own analysis

As displayed in Figure 25 and the indicators' scores on Table 31, the items of II1, II2, II3, II4 and CI4 represent to "information sharing with the purchasing department", "decision -making with the purchasing department", "information sharing with the sales department", "decision -making with the sales department" and "decision making" with main customers respectively, showing high performance and importance. For this reason, organisations should continue their performance on these indicators because they could lead to the development of SCP. The items of CI1 and CI2 correspond to "information sharing" and "collaboration" with main customers consecutively, having high performance, but low importance. Therefore, companies could reduce their resources on these indicators. Finally, the items of SI1, SI2, SI3, SI4 and CI3 present "information sharing", "collaboration", "decision making", "system development" with main suppliers and system development with main customers respectively, displaying low performance and low importance. These indicators could have a low priority by organisations.

Table 31. Importance-Performance Map for SCP (SCI Indicators)

Indicator	Performance	Importance
SInt1	62,736	0,041
SInt2	64,033	0,043
SInt3	63,325	0,043
SInt4	58,608	0,039
IInt1	68,986	0,047
IInt2	70,165	0,047
IInt3	70,047	0,046
IInt4	70,283	0,044
CInt1	66,038	0,040
CInt2	67,099	0,042
CInt3	62,500	0,041
CInt4	66,863	0,045

Source: Author's own analysis

4.5. New Scientific Results

The unprecedented improvement of digital technologies will lead to significant changes in supply chains; however, there are ongoing discussions regarding how these changes will affect supply chains. As a reflection of these discussions, more empirical contributions are necessary for the linkages between Industry 4.0 and supply chains. The main contribution of this dissertation is to fill the research gap in this field by giving empirical evidence. In this context, the author underlines the novel results of this dissertation as follows below:

1) The dissertation offers a novelty of the proposed model: The complex and structured model was created to analyse the effect of Industry 4.0 practices on supply chains. Prior to devising the conceptual model, the literature was systematically reviewed and the findings of the literature were synthesised for three constructs: Industry 4.0, SCI and SCP. Furthermore, semi-structured interviews were conducted to examine the current level of Industry 4.0 on supply chain operations. This helps the author create a consistent model of under-investigated research. The final proposed model consists of 24 items for Industry 4.0, 12 items for SCI and 17 items for SCP. These items were also tested in reliability and validity for each construct. Thus, the complex relationships were observed between three constructs; this also gives more precise findings on three constructs. Notably, the model of Industry 4.0 was mainly measured by technological items by the scholars; however, in this dissertation, the items of Industry 4.0 was perceived in both managerial and technological point of view. Finally, the analyses confirmed that Industry 4.0 has an important role in enhancing integration and performance in supply chains, whilst, the integration in supply chains increases SCP. Also, integration in supply chains partially mediates the linkage between Industry 4.0 and performance in supply chains.

2) The dissertation contributes to up-to-date analysis on SCI and SCP literature: Although the relationship between integration and performance in supply chains has been researched in many prior studies, this dissertation provides the novelty towards up-to-date analysis in relevance to this relationship. Since the scholars had conflicting arguments related to the influence of SCI on SCP, this dissertation has empirically proved the importance of SCI on performance. Moreover, with the help of in-depth review analysis, these two concepts were conceptualised attentively.

3) The dissertation provides the analysis of an emerging country context: Prior studies generally concentrate on the role of Industry 4.0 in the developed economies; however, it is not widely known how the technologies of Industry 4.0 are utilised by the emerging economies. This dissertation offers a model in an emerging country context, Turkey; it is among the first studies that identify an empirical relationship between Industry 4.0 and the performance in supply chains in an emerging context. Thus, the proposed model could be used for further academic investigations. Furthermore, it helps organisations understand the impacts of Industry 4.0 on their supply chains and provide better insights on their digital transformations.

4) The effects of company size and sector have been shown on Industry 4.0, SCI and SCP: This dissertation also displays that Industry 4.0, SCI and SCP are affected by company size; however, the sectors of organisations do not have any effects on these three constructs. Therefore, these findings raise further investigations in academic research. The adoption level of large companies could be different from small and medium sized companies; for this reason, different assessment models could be suggested considering the company size.

5) The dissertation contributes to prioritisation of the items for SCP: It is also significant to guide organisations about which items of Industry 4.0 and SCI should be used to have higher performance in supply chains because the allocation of the resources could be considered as strategic decision-making for companies. Thus, this dissertation provides the importance and performance regarding the indicators of Industry 4.0 and SCI, and which of them should be prioritised by organisations. After the data analysis, the findings indicated that how strategy, organisational culture, employee familiarity and embrace to digitalisation are important for organisations while they perform at a low level to implement these items to have a higher SCP. Also, the internal integration items are viewed as more important than customer and supplier integration; thus, organisations should allocate their resources more into the indicators of internal integration to accomplish SCP.

6) The dissertation used the two well-known theories for the relationships between Industry 4.0, SCI and SCP: This dissertation also contributes to Industry 4.0, SCI and SCP literature theoretically; additionally, these relationships are grounded the two well-known theories in the strategic management, the Resource-Based View (RBV) and Relational View (RV). This is particularly imperative because the theories explain the application of the dissertation to the practice and give clear insights into the field. The role of Industry 4.0 was identified as a resource and SCI as a capability that both increase the dyadic relationships between partners in order to capture an increase on SCP.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The overarching aim of this dissertation is to fill the gap in the assessment of Industry 4.0 within the supply chain. For this reason, the dissertation which has presented the mind-set of the respondents engaged in manufacturing industries in Turkey is in the context to the effects of Industry 4.0 on SCM practices particularly SCI and SCP. Four research questions have been formulated to shed light on the relationship between these concepts.

RQ.1. How does Industry 4.0 affect SCI?

RQ.2. How does SCI affect SCP?

RQ.3. How does Industry 4.0 affect SCP?

RQ4. How should organisations prioritise the indicators of Industry 4.0 and SCI strategically to achieve higher performance in the context of the supply chain?

The questionnaire method was employed in this dissertation as a quantitative-based approach, and the results are later empirically tested by using structural equation modelling (PLS-SEM) to identify the complex relationship between Industry 4.0, SCI and SCP.

Response to the Research Question 1: The relationship between Industry 4.0 and SCI

Through empirical analysis in PLS-SEM, the practices of Industry 4.0 are strongly related to the degree of SCI; and the relationship is taken as positive between these concepts. Therefore, H1 is supported in this dissertation, which is that “assessment of Industry 4.0 positively affects SCI”.

Broadly speaking, this finding of the dissertation is consistent with prior papers related to “ICT enabled digital integration”. For instance, Novais et al. (2019, p. 311) found that improvements in cloud computing enhance SCI through achieving “information, financial and physical flows”. Also, the dissertation emphasised that it improves supply chain activity integration such as “manufacturing, design, logistics, commercial and financial integration”. Additionally, the empirical study of De Vass et al. (2018, p. 17) indicated that IoT enabled integration and ICT capabilities of companies are viewed as sources to increase information sharing, coordination capabilities, which lead to higher process integration in supply chains. Mora-Monge et al. (2019, p. 532) found that Web-enabled technologies in supply chains streamline SCI because it increases supply chain visibility.

Response to the Research Question 2: The relationship between SCI and SCP

Based on the results of structural model analysis, SCI has a positive and significant effect on SCP; hence, a higher degree of SCI activities means to a higher degree of SCP, and H2 is supported.

This finding is also confirmed by a large set of research papers (Kaliani Sundram et al., 2016, p. 1459; Lii and Kuo, 2016, p. 153; Ataseven and Nair, 2017, p. 261; Kumar et al. 2017, p. 819; Chen et al., 2018, p. 210). However, some other studies found that SCI does not always improve SCP (Qi et al., 2017, p. 169; Shou et al., 2017, p. 357; Huo et al., 2016, p. 139). Though these findings contradict with the result of this dissertation. For example, Qi et al. (2017) argue that external integration does not significantly affect the performance attributes, probably, this relationship could be mediated by other constructs. Similarly, Shou et al. (2017) indicated that customer integration could not enhance some of the performance dimensions such as “cost and quality”. In addition, Huo et al. (2016) demonstrated that supplier integration does not have a significant effect on the performance; however, the study explained this result as that synergy between supplier and customer integration could lead to competitive performance.

Response to the Research Question 3: The relationship between Industry 4.0 and SCP

The results reveal that Industry 4.0 is positively related to SCP; which means a higher degree of the practices of Industry 4.0 increases the degree of SCP. Therefore, H3 is supported. However, a weak relationship has been observed between these two in terms of the results.

Despite the limited empirical analysis of Industry 4.0 on SCP; expectedly, Industry 4.0 has a positive relationship with SCP. This finding is also confirmed by some studies (Dalenogare et al., 2018, p. 383; Tortorella et al., 2019, p. 290; Fatorachian and Kazemi, 2020, forthcoming). Dalenogare et al. (2018) examined the level of Industry 4.0 technologies on SCP, providing their analysis in the emerging country context, Brazil. Therefore, it gives consistent results with the findings of this dissertation. However, their Industry 4.0 framework concentrates on a much more technology-oriented model, while the model used in this dissertation views the Industry 4.0 concept as both managerial and technological perspectives. Moreover, Fatorachian and Kazemi, 2020, forthcoming) investigated the effects of Industry 4.0 technologies on performance activities in supply chains. Their exploratory research showed that Industry 4.0 had the potential to develop the supply chain operations “product development and production, fulfilment, procurement and logistics, inventory management and retailing”. On the other hand, their Industry 4.0 model also covers technological items such as CPSs, big data, cloud technologies and IoT. Although this dissertation involves these technologies as the items of Industry 4.0; however, the final proposed model explains Industry 4.0 as a multidimensional construct.

The indirect effect of SCI was also observed between Industry 4.0 and SCP; which means SCI plays a mediating role in the positive relationship between Industry 4.0 and SCP. Based on the results of the analysis of this thesis, SCI is partially mediating the link between Industry 4.0 and SCP. Therefore, H4 is partially supported.

The mediating role of SCI between Industry 4.0 and SCP has been underestimated in the literature; therefore, this dissertation could be counted as among the very first studies, which reflects the relationships between these three concepts empirically. Hence, it could be obtained more precise results from the literature regarding the mediating role of SCI between digital technologies, IT or particular Industry 4.0 technologies and SCP (Rai et al., 2006, p. 236; Li et al., 2009, p. 131; Bruque-Cámara et al., 2016, p.149; Delic et al., 2019, forthcoming). For instance, Bruque- Cámara et al. (2016, p.149) stressed that the utilisation of cloud technologies improve SCI, which also assists the higher operational performance. Similarly, Delic et al. (2019, forthcoming) examined the usage of additive manufacturing technologies on SC practices. The findings of the study displayed that the implementation of additive manufacturing enhances supplier and internal integration, and the only weak relationship has been obtained on customer integration. Furthermore, all SCI dimensions have the strongest impact on SCP dimensions.

Response to the Research Question 4: prioritisation of the indicators of Industry 4.0 and SCI for higher performance in supply chains

The findings which correspond to the relationships between three constructs were also extended by the IPMA matrix. This analysis also showed which items of Industry 4.0 and SCI should be prioritised to achieve higher SCP. Based on the results, strategy items such as roadmap and investments to Industry 4.0 infrastructure as well as employee familiarity were viewed as important items, but organisations perform at a low level on these items. Thus, companies should focus on these indicators first, by reducing their investments from less important items. The resources could be reallocated more to the strategical, employee, culture factors, and some technological items such as advanced connectivity of the systems, supplier technology, data analysis and embrace to digitalisation by organisations, showing high importance on Industry 4.0 implementation. Conversely, external collaborations, openness to innovation, data access, sensor technology, production automation, and trace to manufacturing systems were taken as low important items compared with the other indicators. As Ghobakhloo (2018, p. 911) suggested that, companies first formulate the accurate strategies to implement Industry 4.0. Additionally, Mittal et al. (2018, p. 212) defined the maturity model for companies, showing that the levels of the digital transformation process. The elements lying on “level 0 and 1” were the fundamental ones such as “connectivity, computerisation of business processes, organisational culture and assessment tools” rather than adapting highly advanced technologies at first. Hence, these two studies support the finding of this dissertation in relevance to prioritisation items of Industry 4.0 for SCP. As for the items of SCI, all internal integration items and decision making with main customers showed high importance to increase SCP. The rest of the items of customer and supplier integration showed lower importance. Therefore, organisations first accomplish internal integration items and allocate their investments to this area to succeed in their SCP. Also, this result is relative with the finding of Huo et al. (2016, p. 139), indicating that internal integration plays an important role on SCI, and enables organisations to boost both customer and supplier integration.

Beyond these research questions mentioned above, three control variables were also included in the structural model to see their impacts on the main variables; employee numbers, annual revenue and sector of the companies. Regarding the findings, Industry 4.0 and SCP can be affected by the employee numbers, while SCI and Industry 4.0 can be influenced by the annual revenue of the companies. Therefore, the effects of firm size could be observed in all main constructs. However, despite adding these constructs into the model, the relationships between Industry 4.0 and SCI, and SCI and SCP still have been found as positive and highly significant. Conversely, the relationship between Industry 4.0 and SCP has been obtained as insignificant when these control variables are annexed into the model. To be concluded that, the linkage between Industry 4.0 and SCP is significant when it is independently taken from these two control variables. Unexpectedly, the final control variable, the sector of the companies, do not show any effect on all of the main constructs. In the light of the relationship between Industry 4.0 and firm size, this finding is related to what some scholars (Lin et al., 2019, p. 9; Bosman et al., 2019, forthcoming) suggested. Interestingly, Bosman et al. (2019) found that smaller manufacturing firms are likely to invest more technological items and support better their workforce. On the other hand, Lin et al. (2018, p. 600) contradict the direct relationship between company size and technology adoption. One of the prospective reasons for this finding might be the different requirements of industrial and product characteristics; therefore, the study calls for more empirical research behind of this. Additionally, the literature provides more concrete findings regarding the relationship between company size and SCI or SCP. According to Wang et al. (2018, p. 11), firm size has a great effect on SCP, while Song et al. (2017, p. 9) indicated firm size affects both integration and business performance for the organisations. However, some scholars (Lee et al., 2016, p. 675; Jajja et al., 2018, p. 126) argue that firm size does not have any effect on the performance in supply chains, which are not consistent with the results of this dissertation. Interestingly, the sector of organisations does not affect Industry 4.0 implementation, this finding is also inconsistent with the result of Müller et al. (2018b, p. 12). Their study found that the industries vary on the level of implementation of Industry 4.0 in terms of strategical, operational, social, competitiveness and employee factors. On the other hand, some studies (Birkie et al., 2017, 517; Zaridis et al., 2020, forthcoming) do not find any significant relationships between the sector of organisations and SCI, and SCP.

5.2. Theoretical Implications

From an academic perspective, this dissertation comprehensively explains the concepts of Industry 4.0, SCI and SCP. The elements were determined for each concept to measure their conceptual frameworks; and further, these frameworks were validated through large scale questionnaire and empirically tested. By discussing the current literature, this dissertation offers an analysis of Industry 4.0 practices on the SCM concept, which will be practical for operations management and supply chain researchers who are likely to develop further research on that field.

The dissertation firstly seeks the relevant framework related to Industry 4.0; otherwise, it may be hard to explore the issues in a developing country since they are considered as a low degree of assessment on advanced technologies. The many studies in the literature explain the assessment/readiness and maturity models from a technological point of view; however, regarding the findings of this dissertation through comprehensive literature analysis, Industry 4.0 is explained both as in technological and management perspectives because the concept also has a strategic role in the success of companies and in sustaining these technologies. Therefore, the concept of Industry 4.0 is explained as a multidimensional construct, including both technological and management approaches. In this sense, the framework could be viewed as value-seeking focused approach for further studies.

Secondly, the dissertation also extended the current literature on SCI and SCP by employing their definitions and key elements, which might be relevant for different SCs. For decades, the importance of SCI on SCP has been taken in previous studies; however, this concern is still a dilemma in the SCM literature. To elucidate this question, the present dissertation also attempts to contribute to the current literature by providing novel and empirically tested results which can be useful for further studies.

Thirdly, the proposed model that examines the relationship between Industry 4.0, SCI and SCP, covers the research gap in Industry 4.0 activities on SCM context. There is only limited knowledge on how Industry 4.0 yields SCP and what the essential frameworks are to do this. This dissertation also examines the direct and indirect effects of the constructs in order to observe this relationship clearly.

Finally, the current dissertation applied in two strategic management theories, the “Resource-Based View” and “Relational View”, to present the role of Industry 4.0 for SCP, thereby, extending the insights of this dissertation through theoretical support. Following the suggestions of the RBV, Industry 4.0 was identified as an important asset and capability of organisations to improve their competitive advantage and performance superiority. As for the Relational View approach, the networks and collaboration of organisations on their performance superiority were examined. These two theories enable the current dissertation to analyse the linkages between Industry 4.0, SCI and SCP accurately.

5.3. Managerial Implications

From a managerial point of view, the results of this dissertation can be practical for operations, production and supply chain managers and practitioners. From an operational perspective, the results demonstrate that the implementations of Industry 4.0 enhance not only the activities of SC integration but also overall performance across SC in an emerging country context, according to the perceptions of the manufacturing industry. The enterprises which are willing to start to assess their production and operational activities toward the Industry 4.0 path should also consider their strategic objectives, employee factor, technology-driven culture and requirements of implementing a particular technology for their organisations. For this reason, the findings of this research provide a guideline about what items need to be followed and prioritised by managers and practitioners regarding improvements of Industry 4.0 practices. Although the concepts of advanced technologies such as “big data”, “cloud”, “3DP” or “augmented reality” could be regarded as more dominant in developed countries than developing ones; these technological streams must be pursued by emerging markets to attain their competitiveness standards in the manufacturing context.

The assessment of Industry 4.0 would be viewed as a typological analysis (Sony and Naik, 2019, p. 15); consequently, its critical success factors should be understood at a supply chain level. When organisations understand their supply chain dynamics in a better way, they will set some strategies to improve their network integration and performance. As an aid to practice, the enterprises could exploit the elements to assess Industry 4.0 as well as the frameworks for integration and performance of their SCs as suggested in this dissertation. All three elements of Industry 4.0 are significant and interrelated with each other; thus, organisations can shape their activities by either implementing new technological trends or converting their current production into a smart process. Since the dissertation strongly highlights the linkages between Industry 4.0 and the supply chain concept; it can be used as an outline for structuring the horizontal strategy across SCs.

This dissertation also investigated the important items of Industry 4.0 and SCI to enhance SCP. Through the findings of this dissertation, managers could examine the current level of their companies in particular items of Industry 4.0 and SCI and prioritise them to achieve higher performance. The strategical items of Industry 4.0 such as the availability of roadmap and Industry 4.0 infrastructure, and employee familiarity are important to achieve SCP. Additionally, the items of internal integration are pioneered to achieve better on SCP. Hence, managers could seek how their organisations perform on these items and allocate their resources into more important items for SCP.

Given the above considerations, this dissertation motivates industrial professionals to perceive the potentials of Industry 4.0 with a more explicit and comprehensive approach. Due to the lack of utilisation of Industry 4.0 practices in organisations, it will not be simple to recognise the needs and benefits of Industry 4.0 for SCs. In addition, this would make it difficult to allocate the resources of companies, employee tasks for certain areas to be improved and accurate tools for better integration in a network perspective. For this reason, this dissertation may help supply chain and operational practitioners identify their current capabilities of Industry 4.0 and SC activities and monitor them in an inter-organisational business need.

5.4. Limitations

Although this dissertation is based on empirical evidence on the practices of Industry 4.0 and SCM, it is noted that the main limitation of this dissertation is that all the practices and applications of Industry 4.0 are explored in a broad overview in an emerging country context, where the implementation of these technologies is not feasible yet, and probably will not be obtained in a short term. There is proof of that in the proposed model of this dissertation, where many of the items related to advanced technologies such as cloud, 3DP, autonomous machines, customisation, customer access into the manufacturing systems, etc. have been removed. In addition, the level of implementation of these particular technologies might be based on the specific requirements of companies such as improving their KPIs in a particular area in SCs; therefore, the degree of their utilisation may differ from firm to firm. Thus, these concerns might be the obstructions to generalise the results of this dissertation in terms of Industry 4.0 assessment for all developing countries.

Noteworthily, the level of adoption may not solely hinge on internal decisions of organisations, but also depend on some external aspects, particularly, government incentives and access to public funds (Dalenogare et al., 2018, Frank et al., 2016). The government agencies may come up with several solutions to embolden the adoption of technological trends in manufacturing industries by addressing the requirements of countries (Bahrin et al., 2016, p. 142). According to Kumar et al. (2019), there are some weaknesses of Turkey on its Industry 4.0 journey such as limited R&D share of its national income, inadequate support of university-industry cooperation, lack of legal standards for Industry 4.0, less qualified staffs in SMEs or challenges on accessing EU financial support. In this dissertation, Industry 4.0 plans of the government and their incentives into the local industry have been neglected. One of the reasons for that, as in the case of Turkey, there are still some shortcomings in the patterns of pilot projects on smart factories and holistic approaches such as vocational training of the workforce toward Industry 4.0, although last year the country launched its Industry 4.0 roadmap. Also, what kind of standards must be achieved by the government to shape the SC ecosystem in the country such as readiness or training of the suppliers needed to be explained in detail. Presumably, more particular emphasis on government plans about Industry 4.0 should be overhauled when analysing assessment models rather than focusing on a broader analysis.

Lastly, the percent of firm sizes and sectors of the companies are not equally divided in this dissertation; therefore, these may create a challenge to observe the effects of these variables on Industry 4.0, SCI and SCP. The representatives are predominantly employed in large companies and automotive and electronic sectors which may be the pioneers of adapting Industry 4.0 practices and more effective SC solutions. Thus, more specific Industry 4.0 and SC models that represent the requirements of SMEs might be conducted in further studies.

5.5. Future Research Directions and Recommendations

Despite some arguments of this dissertation regarding the assessment of Industry 4.0 in SC practices; due to the theoretical nature of the field, there are still several open questions to be responded to, which delimitate the generalisability of the results of this dissertation. Thus, the current dissertation recommends that future studies also consider implementation and standardised facets of these technologies as well as creating a digital environment in workplaces where employees, network partners, or machines can integrate with each other. However, it is not enough to only focus on the technological side of Industry 4.0, but also the impacts must be evaluated at a management level. There are many concerns that Industry 4.0 outweighs the related costs, specifically, investing heavily in new technologies, qualified manpower costs, or technical expenditures such as data security, integrity might be taken as outlays for organisations. For this reason, scholars must be encouraged to put forth more research on performance assessments including both short and long-term strategies of organisations when they utilise these technologies. In reality, it is not always enough to provide a comprehensive assessment model for enterprises, transformation toward Industry 4.0 may also begin with particular areas such as procurement, ordering or inventory activities. In this sense, future studies should concentrate on case studies, pilot projects, or interviews to identify the particular needs of organisations at a company level basis.

The resistance of employees against these technologies should not be underestimated since they are an important factor in enterprises. The new methods of training and adaptation and familiarity of employees with new technologies must be examined in more detailed forms. The improvement of specific job profiles and individual qualification layouts should be exploited as a part of increasing the operational performance of organisations. Therefore, the current dissertation also calls for further empirical studies that may be done on the competencies of organisations.

Future studies could also concentrate on how different sectors and sizes of companies affect Industry 4.0 implementation and supply chain practices because their effects are still uncertain in the literature. The level of Industry 4.0 implementation could be distinguished by the company size, sector and countries. This sort of analysis is also important to examine the prioritisation of the items for Industry 4.0 and SCI, which will lead to higher SCP. Organisations could perform differently in terms of the level of Industry 4.0 and supply chain practices; and the prioritisation of the items might be changed based on the specific needs of organisations. Therefore, more empirical studies should be conducted regarding which items are important for organisations and how they perform on these particular items depending on their company size and sector.

Finally, this dissertation explained the organisational and human aspects as well as the technological point of view of the assessment of Industry 4.0. Future studies might extend this work by adding more aspects such as government role, leadership, agile architecture and several competencies of organisations by examining their benefits and challenges in the SCM concept.

6. SUMMARY

The aim of this dissertation was to analyse the effect of Industry 4.0 on Supply Chain Integration (SCI) and Supply Chain Performance (SCP) in the manufacturing industry in Turkey. After reviewing the literature comprehensively, four hypotheses were formulated in this dissertation: (1) Industry 4.0 positively affects SCI, (2) SCI positively affects SCP, (3) Industry 4.0 positively affects SCP and (4) SCI mediates the relationship between Industry 4.0 and SCP. Since Industry 4.0 is not a well-established term in supply chain practices, the huge gap has been identified through the literature.

Before evaluating these hypotheses, the pilot study has been applied with 14 manufacturers to develop the items of the questionnaire. To examine the hypotheses put forth above, the author adopted the survey instrument from different studies for Industry 4.0, SCI and SCP through the insights of the literature review and the interviews. To gather the primary data, the questionnaire was distributed to 1000 largest manufacturing companies in Turkey according to the Istanbul Chamber of Industry (ISO). A total of 212 usable responses were taken out of 1000 companies. Therefore, the response rate is 21.2% among the targeted sample.

As for the analysis of the data collected, firstly, "Confirmatory Factor Analysis (CFA)" has been conducted for the items of Industry 4.0, SCI and SCP. The findings indicated that a total of 9 items were eliminated from the Industry 4.0 scale while only one item was removed from the SCP scale because they did not perform in satisfying thresholds. Later, the rest of the items were analysed in structural equation modelling by using the PLS-SEM method which examines the relationships between Industry 4.0, SCI and SCP.

The findings of the analysis indicated that the practices of Industry 4.0 have a strong and positive impact on SCI, SCI positively and significantly affect SCP, Industry 4.0 has a positive impact on SCP; however, this relationship is weak and SCI partially mediates the relationship between Industry 4.0 and SCP. Therefore, hypotheses 1, 2 and 3 were supported while hypothesis 4 was partially supported. Although three control variables - employee numbers, annual revenue and sector of the companies- were added into the model, the results still remained the same for the relationships between Industry 4.0 and SCI, and SCI and SCP; however, these variables changed the findings of the relationship between Industry 4.0 and SCP since the relationship was insignificant with the control variables. Therefore, the impact of Industry 4.0 on SCP is significant when it is independently taken from these control variables.

This dissertation provides an analysis of Industry 4.0 practices on the SCM concept, that might be practical for operations management and supply chain researchers who are likely to develop further research on that field as well as for operations, production and supply chain managers and practitioners. However, there are still several open questions to be responded to; therefore, this dissertation also recommends that future studies might concentrate on implementation and standardisation of the practices of Industry 4.0 on SCM by integrating the network partners, machines and employees with the digital technologies.

REFERENCES

1. ADEL EL-BAZ, M. (2011). Fuzzy performance measurement of a supply chain in manufacturing companies. *Expert Systems with Applications,* 38(6), 6681–6688.
2. AININ, S., PARVEEN, F., MOGHAVVEMI, S., JAAFAR, N. I., & MOHD SHUIB, N. L. (2015). Factors Influencing the use of social media by SMEs and its performance outcomes. *Industrial Management & Data Systems*, 115(3), 570-588.
3. AKDIL, K. Y., USTUNDAG, A., & CEVIKCAN, E. (2018). Maturity and readiness model for industry 4.0 strategy. In *Industry 4.0: Managing The Digital Transformation* (pp. 61-94). Springer, Cham.
4. AKHTAR, P. ET AL. (2017). The Internet of Things, dynamic data and Information processing capabilities, and operational agility. *Technological Forecasting and Social Change*. 136, 307-316.
5. AKYUZ, G. A., & ERMAN ERKAN, T. (2009). Supply chain performance measurement: a literature review. *International Journal of Production Research,* 48(17), 5137–5155.
6. ALFALLA-LUQUE, R., MARIN-GARCIA, J. A., & MEDINA-LOPEZ, C. (2015). An analysis of the direct and mediated effects of employee commitment and supply chain integration on organisational performance. *International Journal of Production Economics*, 162, 242–267.
7. ALICKE, K., REXHAUSEN, D., AND SEYFERT, A. (2017). Supply Chain 4.0 in Consumer Goods. New York, NY: Mckinsey & Company. p.1-11.
8. ANAND, N., & GROVER, N. (2015). Measuring retail supply chain performance. *Benchmarking: An International Journal,* 22(1), 135–166.
9. ANGERHOFER, B. J., & ANGELIDES, M. C. (2006). A model and a performance measurement system for collaborative supply chains. *Decision Support Systems,* 42(1), 283–301.
10. WORLD ECONOMİC FORUM. (2016, January). The future of jobs: Employment, skills and workforce strategy for the fourth industrial revolution. In *Global challenge insight report. Geneva: World Economic Forum*. Available at: https://www.voced.edu.au/content/ngv:71706
11. ARDITO, L., PETRUZZELLI, A., PANNIELLO, U. AND GARAVELLI, A. (2019). Towards Industry 4.0: Mapping digital technologies for supply chain management-marketing integration, *Business Process Management Journal*, 25(2), pp. 323-346.
12. ARNOLD, C., KIEL, D., & VOIGT, K. I. (2016). How the industrial internet of things changes business models in different manufacturing industries. *International Journal of Innovation Management*, 20(08), 1640015.
13. ARYEE, G., NAIM, M. M., & LALWANI, C. (2008). Supply chain integration using a maturity scale. *Journal of Manufacturing Technology Management,* 19(5), 559–575.
14. ASDECKER, B., & FELCH, V. (2018). Development of an Industry 4.0 maturity model for the delivery process in supply chains. *Journal of Modelling in Management*, 13(4), 840-883.
15. ATASEVEN, C., & NAIR, A. (2017). Assessment of supply chain integration and performance relationships: A meta-analytic investigation of the literature. *International Journal of Production Economics,* 185, 252–265.

16. AVITTATHUR, B., & SWAMIDASS, P. (2007). Matching plant flexibility and supplier flexibility: lessons from small suppliers of US manufacturing plants in India. *Journal of Operations Management*, 25(3), 717-735.

17. BABICEANU, R. F., AND R. SEKER. (2015). Manufacturing Cyber-Physical Systems Enabled by Complex Event Processing and Big Data Environments: A Framework for Development. *Service Orientation in Holonic and Multi-Agent Manufacturing* 594 (1), 165–173.

18. BAGCHI, P. K., CHUN HA, B., SKJOETT-LARSEN, T., & BOEGE SOERENSEN, L. (2005). Supply chain integration: a European survey. *The International Journal of Logistics Management,* 16(2), 275–294.

19. BAHRIN, M. A. K., OTHMAN, M. F., AZLI, N. N., & TALIB, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi*, 78(6-13), 137-143.

20. BALFAQIH, H., NOPIAH, Z. M., SAIBANI, N., & AL-NORY, M. T. (2016). Review of supply chain performance measurement systems: 1998–2015. *Computers in Industry,* 82, 135–150.

21. BARNEY, J. B., & ARIKAN, A. M. (2001). The resource-based view: Origins and implications. *The Blackwell handbook of strategic management*, 124-188.

22. BARRETO, L., AMARAL, A., & PEREIRA, T. (2017). Industry 4.0 implications in logistics: an overview. *Procedia Manufacturing*, 13, 1245-1252.

23. BEAMON, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management*, 19(3), 275–292.

24. BEHESHTI, H., OGHAZI, P., MOSTAGHEL, R., & HULTMAN, M. (2014). Supply chain integration and firm performance: an empirical study of Swedish manufacturing firms. *Competitiveness Review,* 24(1), 20–31.

25. BERNARDES, E. S., & HANNA, M. D. (2009). A theoretical review of flexibility, agility and responsiveness in the operations management literature: Toward a conceptual definition of customer responsiveness. *International Journal of Operations & Production Management*, 29(1), 30-53.

26. BHAGWAT, R., & SHARMA, M. K. (2007). Performance measurement of supply chain management: A balanced scorecard approach. *Computers & Industrial Engineering*, 53(1), 43-62.

27. BIBBY, L., & DEHE, B. (2018). Defining and assessing industry 4.0 maturity levels–case of the defence sector. *Production Planning & Control*, 29(12), 1030-1043.

28. BIENHAUS, F., & HADDUD, A. (2018). Procurement 4.0: factors influencing the digitisation of procurement and supply chains. *Business Process Management Journal*, 24(4), 965-984.

29. BIRASNAV, M., & BIENSTOCK, J. (2019). Supply chain integration, advanced manufacturing technology, and strategic leadership: An empirical study. *Computers & Industrial Engineering*, 130, 142-157.

30. BIRKIE, S.E., TRUCCO, P. AND FERNANDEZ CAMPOS, P. (2017), Effectiveness of resilience capabilities in mitigating disruptions: leveraging on supply chain structural complexity, *Supply Chain Management,* 22(6), pp. 506-521.

31. BITITCI, U., GARENGO, P., DÖRFLER, V., & NUDURUPATI, S. (2012). Performance measurement: challenges for tomorrow. *International journal of management reviews*, 14(3), 305-327.

32. BLINDER, A. S. (2006). Offshoring: the next industrial revolution?. *Foreign affairs*, 113-128.

33. BOON-ITT, S., & YEW WONG, C. (2011). The moderating effects of technological and demand uncertainties on the relationship between supply chain integration and customer delivery performance. *International Journal of Physical Distribution & Logistics Management*, 41(3), 253–276.

34. BORTOLINI, M., FERRARI, E., GAMBERI, M., PILATI, F., & FACCIO, M. (2017). Assembly system design in the Industry 4.0 era: a general framework. *IFAC-PapersOnLine*, 50(1), 5700-5705.

35. BOSMAN, L., HARTMAN, N. AND SUTHERLAND, J. (2019). How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies, *Journal of Manufacturing Technology Management*, (forthcoming) https://doi.org/10.1108/JMTM-09-2018-0283

36. BOYD, B. K., BERGH, D. D., & KETCHEN JR, D. J. (2010). Reconsidering the reputation—performance relationship: A resource-based view. *Journal of management*, 36(3), 588-609.

37. BRETTEL, M., FRIEDERICHSEN, N., KELLER, M., & ROSENBERG, M. (2014). How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective. *International journal of mechanical, industrial science and engineering*, 8(1), 37-44.

38. BRISCOE, G., & DAINTY, A. (2005). Construction supply chain integration: an elusive goal? *Supply Chain Management: An International Journal*, 10(4), 319–326.

39. BRUQUE-CÁMARA, S., MOYANO-FUENTES, J., & MAQUEIRA-MARÍN, J. M. (2016). Supply chain integration through community cloud: Effects on operational performance. *Journal of Purchasing and Supply Management*, 22(2), 141–153.

40. BUER, S. V., STRANDHAGEN, J. O., & CHAN, F. T. (2018). The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International Journal of Production Research*, 56(8), 2924-2940.

41. BULLINGER, H. J., KÜHNER, M., & VAN HOOF, A. (2002). Analysing supply chain performance using a balanced measurement method. *International Journal of Production Research*, 40(15), 3533-3543.

42. BURGESS, K., SINGH, P. J., & KOROGLU, R. (2006). Supply chain management: a structured literature review and implications for future research. *International Journal of Operations & Production Management*. 26(7) pp. 703-729.

43. BÜYÜKÖZKAN, G., & GÖÇER, F. (2018). Digital Supply Chain: Literature review and a proposed framework for future research. *Computers in Industry*, 97, 157-177.

44. CAGLIANO, R., CANIATO, F., & SPINA, G. (2006). The linkage between supply chain integration and manufacturing improvement programmes. *International Journal of Operations & Production Management*, 26(3), 282–299.

45. CAI, J., LIU, X., XIAO, Z., & LIU, J. (2009). Improving supply chain performance management: A systematic approach to analyzing iterative KPI accomplishment. *Decision Support Systems*, 46(2), 512–521.

46. CAMPBELL & SANKARAN (2005) An inductive framework for enhancing supply chain integration, *International Journal of Production Research*, 43(16), 3321-3351.

47. CASTELO-BRANCO, I., CRUZ-JESUS, F., & OLIVEIRA, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, 107, 22-32.

48. CHAE, B. K. (2009). Developing key performance indicators for supply chain: an industry perspective. *Supply Chain Management: An International Journal*. 14(6), 422-428

49. CHAIWAN, W., BOONMEE, C., KASEMSET, C. (2015). Waste Reduction in Meat Processing Industry: the Application of MFCA (ISO 14051). Springer, Cham, pp. 183-193.

50. CHAN, F. T. S. (2003). Performance Measurement in a Supply Chain. *The International Journal of Advanced Manufacturing Technology,* 21(7), 534–548.

51. CHAN, F. T. S., QI, H. J., CHAN, H. K., LAU, H. C. W., & IP, R. W. L. (2003). A conceptual model of performance measurement for supply chains. *Management Decision*, 41(7), 635–642.

52. CHANG, S.-J., VAN WITTELOOSTUIJN, A., & EDEN, L. (2010). From the Editors: Common method variance in international business research. *Journal of International Business Studies,* 41(2), 178–184.

53. CHANG, W., ELLINGER, A. E., KIM, K. (KATE), & FRANKE, G. R. (2016). Supply chain integration and firm financial performance: A meta-analysis of positional advantage mediation and moderating factors. *European Management Journal*, 34(3), 282–295.

54. CHAUDHURI, A., BOER, H., & TARAN, Y. (2018). Supply chain integration, risk management and manufacturing flexibility. *International Journal of Operations & Production Management,* 38(3), 690–712.

55. CHEN, D. Q., PRESTON, D. S., & XIA, W. (2013). Enhancing hospital supply chain performance: A relational view and empirical test. *Journal of Operations Management,* 31(6), 391–408

56. CHEN, M., LIU, H., WEI, S., & GU, J. (2018). Top managers' managerial ties, supply chain integration, and firm performance in China: A social capital perspective. *Industrial Marketing Management*, 74, 205-214.

57. CHEN, M., LIU, H., WEI, S., & GU, J. (2018). Top managers' managerial ties, supply chain integration, and firm performance in China: A social capital perspective. *Industrial Marketing Management*, 74, 205-214.

58. CHEN, S., & TSENG, M. M. (2007). Aligning demand and supply flexibility in custom product co-design. *International Journal of Flexible Manufacturing Systems*, 19(4), 596-611.

59. CHENG, J. M. J., SIMMONS, J. E. L., & RITCHIE, AMES M. (1997). Manufacturing system flexibility: the "capability and capacity" approach. *Integrated Manufacturing Systems,* 8(3), 147–158.

60. CHIN, A., JUHN, C., & THOMPSON, P. (2006). Technical Change and the Demand for Skills during the Second Industrial Revolution: Evidence from the Merchant Marine, 1891–1912. *Review of Economics and Statistics*, 88(3), 572–578.

61. CHITHAMBARANATHAN, P., SUBRAMANIAN, N., & PALANIAPPAN, P. K. (2015). An innovative framework for performance analysis of members of supply chains. *Benchmarking: An International Journal,* 22(2), 309–334.

62. CHLEBUS, E., & KROT, K. (2016). CAD 3D models decomposition in manufacturing processes. *Archives of Civil and Mechanical Engineering*, 16(1), 20-29.

63. CHRISTOPHER, M. (2000). The agile supply chain: competing in volatile markets, *Industrial Marketing Management*, 29(1), pp. 37-44.

64. CHU, P., CHANG, K., & HUANG, H. (2012). How to increase supplier flexibility through social mechanisms and influence strategies? *Journal of Business & Industrial Marketing,* 27(2), 115–131.

65. CHUNG, C. C., CHAO, L. C., CHEN, C. H., & LOU, S. J. (2016). A balanced scorecard of sustainable management in the Taiwanese bicycle industry: Development of performance indicators and importance analysis. *Sustainability*, 8(6), 518.

66. CIRTITA, H., & GLASER-SEGURA, D. A. (2012). Measuring downstream supply chain performance. *Journal of Manufacturing Technology Management,* 23(3), 299–314.

67. CLEMENT, S., SCHAUMAN, O., GRAHAM, T., MAGGIONI, F., EVANS-LACKO, S., BEZBORODOVS, N., ... & THORNICROFT, G. (2015). What is the impact of mental health-related stigma on help-seeking? A systematic review of quantitative and qualitative studies. *Psychological medicine*, 45(1), 11-27.

68. COLLI, M., MADSEN, O., BERGER, U., MØLLER, C., WÆHRENS, B. V., & BOCKHOLT, M. (2018). Contextualizing the outcome of a maturity assessment for Industry 4.0. *Ifac-papersonline*, 51(11), 1347-1352.

69. COLOMBO, A. W., KARNOUSKOS, S., KAYNAK, O., SHI, Y., & YIN, S. (2017). Industrial cyberphysical systems: A backbone of the fourth industrial revolution. *IEEE Industrial Electronics Magazine*, 11(1), 6-16.

70. COLTMAN, T., DEVINNEY, T. M., MIDGLEY, D. F., & VENAIK, S. (2008). Formative versus reflective measurement models: Two applications of formative measurement. *Journal of Business Research*, 61(12), 1250-1262.

71. CONWAY, J. M., JAKO, R. A., & GOODMAN, D. F. (1995). A meta-analysis of interrater and internal consistency reliability of selection interviews. *Journal of applied psychology*, 80(5), 565.

72. COUSINS, P.D. AND MENGUC, B. (2006). The implications of socialization and integration in supply chain management, *Journal of Operations Management*, 24(5), pp. 604-20.

73. CRESPO MARQUEZ, A., BIANCHI, C., & GUPTA, J. N. D. (2004). Operational and financial effectiveness of e-collaboration tools in supply chain integration. *European Journal of Operational Research,* 159(2), 348–363.

74. CUNNINGHAM, W. A., PREACHER, K. J., & BANAJI, M. R. (2001). Implicit attitude measures: Consistency, stability, and convergent validity. *Psychological science*, 12(2), 163-170.

75. DA SILVA, V. L., KOVALESKI, J. L., & PAGANI, R. N. (2019). Technology transfer in the supply chain oriented to industry 4.0: a literature review. *Technology Analysis & Strategic Management*, 31(5), 546-562.

76. DAINTY, A. R. J., MILLETT, S. J., & BRISCOE, G. H. (2001). New perspectives on construction supply chain integration. *Supply Chain Management: An International Journal,* 6(4), 163–173.

77. DALENOGARE, L. S., BENITEZ, G. B., AYALA, N. F., & FRANK, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, 204, 383-394.

78. DANESE, P., & BORTOLOTTI, T. (2014). Supply chain integration patterns and operational performance: a plant-level survey-based analysis. *International Journal of Production Research*, 52(23), 7062–7083.

79. DANESE, P., ROMANO, P., & FORMENTINI, M. (2013). The impact of supply chain integration on responsiveness: The moderating effect of using an international supplier network. *Transportation Research Part E: Logistics and Transportation Review,* 49(1), 125–140.

80. DAS, A., NARASIMHAN, R., TALLURI, S. (2006). Supplier integration – finding an optimal configuration. *Journal of Operations Management*, 24 (5), 563–582.

81. DE VASS, T., SHEE, H., & MIAH, S. J. (2018). The effect of "Internet of Things" on supply chain integration and performance: An organisational capability perspective. *Australasian Journal of Information Systems*, 22, https://doi.org/10.3127/ajis.v22i0.1734

82. DELIC M., EYERS D. R., MIKULIC J. (2019). Additive manufacturing: empirical evidence for supply chain integration and performance from the automotive industry, *Supply Chain Management: An International Journal,* 24(5), 604-621

83. DENG, J., & PIERSKALLA, C. D. (2018). Linking Importance–Performance Analysis, Satisfaction, and Loyalty: A Study of Savannah, GA. *Sustainability*, *10*(3), 704.

84. DESHPANDE, A. (2012). Supply chain management dimensions, supply chain performance and organizational performance: An integrated framework. *International Journal of Business and Management*, *7*(8), 2-19.

85. DISSANAYAKE, C. K., & CROSS, J. A. (2018). Systematic mechanism for identifying the relative impact of supply chain performance areas on the overall supply chain performance using SCOR model and SEM. *International Journal of Production Economics*, 201, 102-115.

86. DOMBROWSKI, U., RICHTER, T., & KRENKEL, P. (2017). Interdependencies of Industrie 4.0 & Lean production systems: A use cases analysis. *Procedia Manufacturing*, 11, 1061-1068.

87. DOSSOU, P. E. (2018). Impact of Sustainability on the supply chain 4.0 performance. *Procedia Manufacturing*, 17, 452-459.

88. DOSSOU, P. E., & NACHIDI, M. (2017). Modeling supply chain performance. *Procedia Manufacturing*, 11, 838-845.

89. DRATH, R., & HORCH, A. (2014). Industrie 4.0: Hit or hype?. *IEEE industrial electronics magazine*, *8*(2), 56-58.

90. DROGE, C., VICKERY, S. K., & JACOBS, M. A. (2012). Does supply chain integration mediate the relationships between product/process strategy and service performance? An empirical study. *International Journal of Production Economics*, 137(2), 250-262.

91. DUNAY, A., LEHOTA, J., MÁCSAI, É., & ILLÉS, C. B. (2018). Short Supply Chain: Goals, Objectives and Attitudes of Producers. *Acta Polytechnica Hungarica*, 15(6), 199-217.

92. DUNUWILA, P., RODRIGO, V. H. L., & GOTO, N. (2018). Financial and environmental sustainability in manufacturing of crepe rubber in terms of material flow analysis, material flow cost accounting and life cycle assessment. *Journal of Cleaner Production,* 182, 587–599.

93. DWEEKAT, A. J., HWANG, G., & PARK, J. (2017). A supply chain performance measurement approach using the internet of things. *Industrial Management & Data Systems*, 117(2), 267–286.

94. DYER, J.H., SINGH, H. (1998). The relational view: Cooperative strategy and sources of competitive advantage. *Academy of Management Review*, 23, 660-679.

95. EGUÍA, I., VILLA, G., & LOZANO, S. (2017). Efficiency assessment of reconfigurable manufacturing systems. *Procedia Manufacturing*, 11, 1027-1034.

96. ELLINGER, A. E., CHEN, H., TIAN, Y., & ARMSTRONG, C. (2015). Learning orientation, integration, and supply chain risk management in Chinese manufacturing firms. *International Journal of Logistics Research and Applications*, 18(6), 476-493.

97. ELSER, A., KÖNIGS, M., VERL, A., & SERVOS, M. (2018). On achieving accuracy and efficiency in Additive Manufacturing: Requirements on a hybrid CAM system. *Procedia CIRP*, 72, 1512-1517.

98. ENKEL, E., KAUSCH, C., & GASSMANN, O. (2005). Managing the risk of customer integration. *European Management Journal*, 23(2), 203-213.

99. ERCIKAN, K., & ROTH, W. M. (2006). What good is polarizing research into qualitative and quantitative?. *Educational researcher*, 35(5), 14-23.

100. EROL, S., SCHUMACHER, A., & SIHN, W. (2016, January). Strategic guidance towards Industry 4.0–a three-stage process model. In *International conference on competitive manufacturing* (Vol. 9, No. 1, pp. 495-501).

101. ESMAEILIKIA, M., FAHIMNIA, B., SARKIS, J., GOVINDAN, K., KUMAR, A., & MO, J. (2014). Tactical supply chain planning models with inherent flexibility: definition and review. *Annals of Operations Research,* 244(2), 407–427.

102. ESTAMPE, D., LAMOURI, S., PARIS, J.-L., & BRAHIM-DJELLOUL, S. (2013). A framework for analysing supply chain performance evaluation models. *International Journal of Production Economics*, 142(2), 247–258.

103. EUROPEAN PARLIAMENT (2016). POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY- Industry 4.0. *European Union,* pp.1-90, available at: http://www.europarl.europa.eu/studies

104. FABBE-COSTES, N., & JAHRE, M. (2008). Supply chain integration and performance: a review of the evidence. *The International Journal of Logistics Management,* 19(2), 130–154.

105. FANTAZY, K. A., TIPU, S. A. A., & KUMAR, V. (2016). Conceptualizing the relative openness of supply chain and its impact on organizational performance. *Benchmarking: An International Journal,* 23(5), 1264–1285.

106. FATORACHIAN, H., & KAZEMI, H. (2020). Impact of Industry 4.0 on supply chain performance. *Production Planning & Control,* (forthcoming). doi:10.1080/09537287.2020.1712487

107. FATTAHI, F., NOOKABADI, A. S., & KADIVAR, M. (2013). A model for measuring the performance of the meat supply chain. *British Food Journal*, 115(8), 1090-1111.

108. FAWCETT, S. E., MCCARTER, M. W., FAWCETT, A. M., WEBB, G. S., & MAGNAN, G. M. (2015). Why supply chain collaboration fails: the socio-structural view of resistance to relational strategies. *Supply Chain Management: An International Journal*. 20(6), pp. 648-663

109. FAWCETT, S. E., OSTERHAUS, P., MAGNAN, G. M., BRAU, J. C., & MCCARTER, M. W. (2007). Information sharing and supply chain performance: the role of connectivity and willingness. *Supply Chain Management: An International Journal*, 12(5), 358-368.

110. FEHER, I. (2012). Direct food marketing at farm level and its impacts on rural development. *INTECH Open Access Publisher.* pp. 337-353

111. FEHER, J., & REICH, M. (2016). Leadership behavior in companies with and without a workplace health management. *Polish Journal of Management Studies*, 13(1), 50-58

112. FEKETE FARKAS, M., & TOROK, G. L. (2011). Knowledge workers: competencies: virtuality and management. *Polish journal of management studies,* 4, 67-77.

113. FERREIRA, L.M.D.F., SILVA, C. AND AZEVEDO, S.G. (2016). An environmental balanced scorecard for supply chain performance measurement (Env_BSC_4_SCPM), *Benchmarking: An International Journal*, 23(6), pp. 1398-1422.
114. FETTERMANN, D. C., CAVALCANTE, C. G. S., ALMEIDA, T. D. D., & TORTORELLA, G. L. (2018). How does Industry 4.0 contribute to operations management?. *Journal of Industrial and Production Engineering*, 35(4), 255-268.
115. FINCK, C., LI, R., KRAMER, R., & ZEILER, W. (2018). Quantifying demand flexibility of power-to-heat and thermal energy storage in the control of building heating systems. *Applied Energy,* 209, 409-425.
116. FINDIK, D., & TANSEL, A. (2016). Resources on the stage: A firm level analysis of the ICT adoption in Turkey. In *Comparative Economics and Regional Development in Turkey* (pp. 106-126). IGI Global.
117. FLYNN, B. B., HUO, B., & ZHAO, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of Operations Management,* 28(1), 58–71.
118. FORD, S. J., MORTARA, L., & MINSHALL, T. H. (2015). The emergence of additive manufacturing: introduction to the special issue. Available at: https://www.repository.cam.ac.uk/bitstream/handle/1810/253041/Ford%20et%20al%202015%20Technological%20Forecasting%20and%20Social%20Change.pdf?sequence=1
119. FRANK, A. G., DALENOGARE, L. S., & AYALA, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, 210, 15-26.
120. FRANK, A.G., CORTIMIGLIA, M.N., RIBEIRO, J.L.D., OLIVEIRA, L.S. DE (2016). The effect of innovation activities on innovation outputs in the Brazilian industry: Market-orientation vs. technology-acquisition strategies. *Res. Policy* 45, 577–592.
121. FREDERICO, G.F., GARZA-REYES, J.A., ANOSIKE, A.I., KUMAR, V. (2019). Supply Chain 4.0: concepts, maturity and research agenda. *Supply Chain Management: An International Journal,* 25(2), 262-282.
122. FROHLICH, M. T., & WESTBROOK, R. (2001). Arcs of integration: an international study of supply chain strategies. *Journal of Operations Management,* 19(2), 185–200.
123. GALANTUCCI, L. M., PERCOCO, G., ANGELELLI, G., LOPEZ, C., INTRONA, F., LIUZZI, C., & DE DONNO, A. (2006). Reverse engineering techniques applied to a human skull, for CAD 3D reconstruction and physical replication by rapid prototyping. *Journal of medical engineering & technology*, 30(2), 102-111.
124. GALBRAITH, J.R. (1974). Organization design: an information processing view. *Interfaces,* 4 (3), 28–36.
125. GANBOLD, O., MATSUI, Y., & ROTARU, K. (2020). Effect of information technology-enabled supply chain integration on firm's operational performance. *Journal of Enterprise Information Management,* (forthcoming). doi:10.1108/jeim-10-2019-0332
126. GARAVELLI, A. C. (2003). Flexibility configurations for the supply chain management. *International Journal of Production Economics*, *85*(2), 141-153.
127. GARDAS, B., RAUT, R., JAGTAP, A.H. AND NARKHEDE, B. (2019). Exploring the key performance indicators of green supply chain management in agro-industry, *Journal of Modelling in Management*, 14(1), pp. 260-283.

128. GAWANKAR, S., KAMBLE, S., & RAUT, R. (2016). Development, measurement and validation of supply chain performance measurement (SCPM) scale in Indian retail sector. *Benchmarking: An International Journal*, 23(1), 25–60.

129. GEISSBAUER R, VEDSO J, SCHRAUF S. INDUSTRY 4.0: BUILDING THE DIGITAL ENTERPRISE: (2016) global industry 4.0 survey Retrieved April 2018 from Munich: PricewaterhouseCoopers; 2016https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf.

130. GELO, O., BRAAKMANN, D., & BENETKA, G. (2008). Quantitative and Qualitative Research: Beyond the Debate. *Integrative Psychological and Behavioral Science,* 42(3), 266–290.

131. GERWIN, D. (1993). Manufacturing flexibility: a strategic perspective. *Management science*, *39*(4), 395-410.

132. GHOBAKHLOO, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, 29(6), 910-936.

133. GIMENEZ, C., VAN DER VAART, T., & PIETER VAN DONK, D. (2012). Supply chain integration and performance: the moderating effect of supply complexity. *International Journal of Operations & Production Management,* 32(5), 583–610.

134. GIVEHCHI, O., TRSEK, H., & JASPERNEITE, J. (2013). Cloud computing for industrial automation systems—A comprehensive overview. In *Emerging Technologies & Factory Automation (ETFA), 2013 IEEE 18th Conference on* (pp. 1-4). IEEE.

135. GLAS, A. H., & KLEEMANN, F. C. (2016). The impact of industry 4.0 on procurement and supply management: A conceptual and qualitative analysis. *International Journal of Business and Management Invention*, *5*(6), 55-66.

136. GLENN RICHEY, R., CHEN, H., UPRETI, R., FAWCETT, S. E., & ADAMS, F. G. (2009). The moderating role of barriers on the relationship between drivers to supply chain integration and firm performance. *International Journal of Physical Distribution & Logistics Management,* 39(10), 826–840.

137. GÖKALP, E., ŞENER, U., & EREN, P. E. (2017, October). Development of an assessment model for industry 4.0: industry 4.0-MM. In *International Conference on Software Process Improvement and Capability Determination* (pp. 128-142). Springer, Cham.

138. GOLDEN, W., & POWELL, P. (2000). Towards a definition of flexibility: in search of the Holy Grail? *Omega,* 28(4), 373–384.

139. GUNASEKARAN, A., & KOBU, B. (2007). Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. *International Journal of Production Research,* 45(12), 2819–2840.

140. GUNASEKARAN, A., & NGAI, E. W. (2004). Information systems in supply chain integration and management. *European Journal of Operational Research,* 159(2), 269–295.

141. GUNASEKARAN, A., PATEL, C., & MCGAUGHEY, R. E. (2004). A framework for supply chain performance measurement. *International Journal of Production Economics,* 87(3), 333–347.

142. GUNASEKARAN, A., PATEL, C., & TIRTIROGLU, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management,* 21(1/2), 71–87.

143. GYENGE, B., SZILÁGYI, H., & KOZMA, T. (2015). Lean management in case of a logistics service provider company. *Journal of Central European Green Innovation, 3*(1063-2016-86239), 119-134. Doi: 10.22004/ag.econ.199428

144. HAIR JR, J. F., SARSTEDT, M., HOPKINS, L., & KUPPELWIESER, V. G. (2014). Partial least squares structural equation modeling (PLS-SEM). *European business review*. 26(2), 106-121

145. HAIR JR, J. F., SARSTEDT, M., RINGLE, C. M., & GUDERGAN, S. P. (2017). Advanced issues in partial least squares structural equation modeling. SAGE publications.

146. HAIR, J. F., RINGLE, C. M., & SARSTEDT, M. (2011). PLS-SEM: Indeed a silver bullet. *Journal of Marketing theory and Practice*, 19(2), 139-152.

147. HAIR, J. F., RISHER, J. J., SARSTEDT, M., & RINGLE, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*. 31 (1), 2-24

148. HAIR, J. F., SARSTEDT, M., RINGLE, C. M., & MENA, J. A. (2012). An assessment of the use of partial least squares structural equation modeling in marketing research. *Journal of the academy of marketing science,* 40(3), 414-433.

149. HAIR, J., HOLLINGSWORTH, C. L., RANDOLPH, A. B., & CHONG, A. Y. L. (2017). An updated and expanded assessment of PLS-SEM in S&02ormation systems research. *Industrial Management & Data Systems*, 117(3), 442–458.

150. HAN, D., KWON, I.-W. G., BAE, M., & SUNG, H. (2002). Supply chain integration in developing countries for foreign retailers in Korea: Wal-Mart experience. *Computers & Industrial Engineering,* 43(1-2), 111–121.

151. HAN, J. H. (2017). Reconceptualisation of information technology flexibility for supply chain management: a multidimensional approach (Doctoral dissertation, Cardiff University).

152. HARRIS, L. R., & BROWN, G. T. (2010). Mixing interview and questionnaire methods: Practical problems in aligning data. *Practical Assessment, Research, and Evaluation*, 15(1), 1.

153. HASEEB, M., HUSSAIN, H. I., ŚLUSARCZYK, B., & JERMSITTIPARSERT, K. (2019). Industry 4.0: A solution towards technology challenges of sustainable business performance. *Social Sciences*, 8(5), 154.

154. HAUSMAN, W. H. (2004). Supply chain performance metrics. In *The practice of supply chain management: Where theory and application converge* (pp. 61-73). Springer, Boston, MA.

155. HAYTON, J. C., ALLEN, D. G., & SCARPELLO, V. (2004). Factor retention decisions in exploratory factor analysis: A tutorial on parallel analysis. *Organizational research methods*, *7*(2), 191-205.

156. HE, Q., GHOBADIAN, A., & GALLEAR, D. (2013). Knowledge acquisition in supply chain partnerships: The role of power. *International Journal of Production Economics*, 141(2), 605-618.

157. HE, Y., & LAI, K. K. (2012). Supply chain integration and service-oriented transformation: Evidence from Chinese equipment manufacturers. *International Journal of Production Economics*, 135(2), 791-799.

158. HEDELIND, M. & JACKSON, M. (2011). How to improve the use of industrial robots in lean manufacturing systems. *Journal of Manufacturing Technology Management,* 22(7), pp.891–905.

159. HELO, P., SUORSA, M., HAO, Y., & ANUSSORNNITISARN, P. (2014). Toward a cloud-based manufacturing execution system for distributed manufacturing. *Computers in Industry*, 65(4), 646–656.

160. HENSELER, J., RINGLE, C. M., & SARSTEDT, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the academy of marketing science*, 43(1), 115-135.

161. HERMANN, M., PENTEK, T., & OTTO, B. (2016, January). Design principles for industrie 4.0 scenarios. In *2016 49th Hawaii international conference on system sciences (HICSS)* (pp. 3928-3937). IEEE.

162. HERVANI, A. A., HELMS, M. M., & SARKIS, J. (2005). Performance measurement for green supply chain management. *Benchmarking: An international journal*, 12(4), 330-353.

163. HOFMANN, E., & RÜSCH, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry,* 89, 23–34.

164. HOFMANN, E., STERNBERG, H., CHEN, H., PFLAUM, A. AND PROCKL, G. (2019). Supply chain management and Industry 4.0: conducting research in the digital age, *International Journal of Physical Distribution & Logistics Management*, 49(10), pp. 945-955

165. HOLMBERG, S. (2000). A system perspective on supply chain measurement, *International Journal of Physical Distribution & Logistics*, 30(10), pp. 847-868.

166. HUANG, M. C., YEN, G. F., & LIU, T. C. (2014). Reexamining supply chain integration and the supplier's performance relationships under uncertainty. *Supply Chain Management: An International Journal*. 19(1), 64-78

167. HUANG, S. H., & KESKAR, H. (2007). Comprehensive and configurable metrics for supplier selection. *International journal of production economics*, *105*(2), 510-523.

168. HUDSON, M., LEAN, J., & SMART, P. A. (2001). Improving control through effective performance measurement in SMEs. *Production Planning and Control*, 12(8), 804–813.

169. HUNG GOH, S., & ELDRIDGE, S. (2019). Sales and Operations Planning: The effect of coordination mechanisms on supply chain performance. *International Journal of Production Economics*, 214, 80-94.

170. HUO B. (2012). The impact of supply chain integration on company performance: an organizational capability perspective, *Supply Chain Management: An International Journal*, 17(6), pp. 596 - 610

171. HUO, B., YE, Y., ZHAO, X., & SHOU, Y. (2016). The impact of human capital on supply chain integration and competitive performance. *International Journal of Production Economics*, 178, 132-143.

172. IBARRA, D., GANZARAIN, J., & IGARTUA, J. I. (2018). Business model innovation through Industry 4.0: A review. *Procedia Manufacturing*, 22, 4-10.

173. IVANOV, D., DOLGUI, A., & SOKOLOV, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *International Journal of Production Research*, 57(3), 829-846.

174. IVANOV, D., SETHI, S., DOLGUI, A., & SOKOLOV, B. (2018). A survey on control theory applications to operational systems, supply chain management, and Industry 4.0. *Annual Reviews in Control*, 46, 134-147.

175. IZOGO, E. E., & OGBA, I. E. (2015). Service quality, customer satisfaction and loyalty in automobile repair services sector. *International Journal of Quality & Reliability Management*, 32(3), 250-269.

176. JABBOUR, C. J. C., JUGEND, D., JABBOUR, A. B. L. DE S., GUNASEKARAN, A., & LATAN, H. (2015). Green product development and performance of Brazilian firms: measuring the role of human and technical aspects. *Journal of Cleaner Production,* 87, 442–451.

177. JAFARI, H., NYBERG, A., & HILLETOFTH, P. (2016). Postponement and logistics flexibility in retailing: a multiple case study from Sweden. *Industrial Management & Data Systems,* 116(3), 445–465.

178. JAJJA, M. S. S., CHATHA, K. A., & FAROOQ, S. (2018). Impact of supply chain risk on agility performance: Mediating role of supply chain integration. *International Journal of Production Economics*, 205, 118-138.

179. JI, W. & WANG, L. (2017). Big data analytics-based fault prediction for shop floor scheduling. *Journal of Manufacturing Systems,* 43, pp.187–194.

180. JUNG, K., KULVATUNYOU, B., CHOI, S., & BRUNDAGE, M. P. (2016). An Overview of a Smart Manufacturing System Readiness Assessment. In *IFIP International Conference on Advances in Production Management Systems*, (pp. 705–712), Springer, Cham.

181. KAGERMANN, H., HELBİG, J., HELLİNGER, A., & WAHLSTER, W. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; *final report of the Industrie 4.0 Working Group*. Forschungsunion.

182. KALIANI SUNDRAM, V.P., CHANDRAN, V. AND AWAIS BHATTI, M. (2016). Supply chain practices and performance: the indirect effects of supply chain integration, *Benchmarking: An International Journal*, 23(6), pp. 1445-1471.

183. KAMALAHMADI, M., & MELLAT-PARAST, M. (2016). Developing a resilient supply chain through supplier flexibility and reliability assessment. *International Journal of Production Research*, 54(1), 302-321.

184. KAMBLE, S. S., & GUNASEKARAN, A. (2020). Big data-driven supply chain performance measurement system: a review and framework for implementation. *International Journal of Production Research*, 58(1), 65-86.

185. KAPLAN, R. S., & NORTON, D. P. (1996). Using the balanced scorecard as a strategic management system. *Harvard Business Review*, 74(1), 75-85.

186. KAPLAN, R. S., & NORTON, D. P. (2001). Transforming the balanced scorecard from performance measurement to strategic management: Part II. *Accounting horizons*, 15(2), 147-160.

187. KAPLAN, R.S. AND NORTON, D.P. (1992), “The balanced scorecard – measures that drive performance”, *Harvard Business Review*, Vol. 70, pp. 71-79.

188. KASIRI, L. A., GUAN CHENG, K. T., SAMBASIVAN, M., & SIDIN, S. M. (2017). Integration of standardization and customization: Impact on service quality, customer satisfaction, and loyalty. *Journal of Retailing and Consumer Services*, 35, 91–97.

189. KAUREMAA, J., & TANSKANEN, K. (2016). Designing interorganizational information systems for supply chain integration: a framework. *The International Journal of Logistics Management,* 27(1), 71–94.

190. KHAN, S. A., CHAABANE, A., & DWEIRI, F. (2019). A knowledge-based system for overall supply chain performance evaluation: a multi-criteria decision-making approach. *Supply Chain Management: An International Journal.* 24(3), 377-396.
191. KHARE, A., SAXSENA, A., & TEEWARI, P. (2012). Supply chain performance measures for gaining competitive advantage: A review. *Journal of Management and Strategy*, *3*(2), 25-32.
192. KIM, D., & CAVUSGIL, E. (2009). The impact of supply chain integration on brand equity. *Journal of Business & Industrial Marketing*. 24(7), 496-505
193. KIM, D., KUMAR, V., & KUMAR, U. (2010). Performance assessment framework for supply chain partnership. *Supply Chain Management: An International Journal,* 15(3), 187–195.
194. KIM, M., & CHAI, S. (2016). Assessing the impact of business uncertainty on supply chain integration. *The International Journal of Logistics Management*. 27(2), 463-485
195. KILIÇASLAN, Y., & TÖNGÜR, Ü. (2018). ICT and employment generation: evidence from Turkish manufacturing. *Applied Economics Letters*, 26(13), 1053-1057.
196. KOCK, N. (2017). Common method bias in PLS-SEM: A full collinearity assessment method for PLS-SEM. In *Partial least squares path modeling* (pp. 245-257). Springer, Cham.
197. KOTRLIK, J. W. K. J. W., & HIGGINS, C. C. H. C. C. (2001). Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research. *Information technology, learning, and performance journal*, 19(1), 43.
198. KOTTALA, S.Y. AND HERBERT, K. (2019). An empirical investigation of supply chain operations reference model practices and supply chain performance: Evidence from manufacturing sector", *International Journal of Productivity and Performance Management*, (forthcoming), https://doi.org/10.1108/IJPPM-09-2018-0337
199. KUMAR, K., ZINDANI, D., & DAVIM, J. P. (Eds.). (2019). Digital Manufacturing and Assembly Systems in Industry 4.0. CRC Press.
200. KUMAR, P., & SINGH, A. P. (2019). Flexibility in service operations: review, synthesis and research agenda. *Benchmarking: An International Journal*. 27(7), 2108-2129.
201. KUMAR, V., CHIBUZO, E. N., GARZA-REYES, J. A., KUMARI, A., ROCHA-LONA, L., & LOPEZ-TORRES, G. C. (2017). The impact of supply chain integration on performance: Evidence from the UK food sector. *Procedia Manufacturing*, 11, 814-821.
202. LAI, F., ZHANG, M., LEE, D. M., & ZHAO, X. (2012). The impact of supply chain integration on mass customization capability: an extended resource-based view. *IEEE Transactions on Engineering Management*, 59(3), 443-456.
203. LASI, H., FETTKE, P., KEMPER, H. G., FELD, T., & HOFFMANN, M. (2014). Industry 4.0. *Business & Information systems engineering*, 6(4), 239-242.
204. LEE, H.-Y., SEO, Y.-J., & DINWOODIE, J. (2016). Supply chain integration and logistics performance: the role of supply chain dynamism. *The International Journal of Logistics Management,* 27(3), 668–685.
205. LEE, H., KIM, M. S., & KIM, K. K. (2014). Interorganizational information systems visibility and supply chain performance. *International Journal of Information Management*, 34(2), 285-295.
206. LEE, J., BAGHERI, B., & KAO, H. A. (2015). A cyber-physical systems architecture for industry 4.0 based manufacturing systems. *Manufacturing Letters*, 3, 18-23.

207. LEE, J., KAO, H. A., & YANG, S. (2014). Service innovation and smart analytics for industry 4.0 and big data environment. *Procedia Cirp*, 16, 3-8.

208. LEE, N., & CADOGAN, J. W. (2013). Problems with formative and higher-order reflective variables. *Journal of Business Research*, 66(2), 242-247.

209. LEE, S. J. (1992). Quantitative versus qualitative research methods—Two approaches to organisation studies. *Asia Pacific Journal of Management*, 9(1), 87-94.

210. LI, G., YANG, H., SUN, L., & SOHAL, A. S. (2009). The impact of IT implementation on supply chain integration and performance. *International Journal of Production Economics*, 120(1), 125–138.

211. LIAO, Y., DESCHAMPS, F., LOURES, E. D. F. R., & RAMOS, L. F. P. (2017). Past, present and future of Industry 4.0- a systematic literature review and research agenda proposal. *International journal of production research*, 55(12), 3609-3629.

212. LICHTBLAU, K., STICH, V., BERTENRATH, R., BLUM, M., BLEIDER, M., MILLACK, A., SCHMITT, K., SCHMITZ, E. AND SCHRÖTER, M. (2015), IMPULS-Industrie 4.0-readiness, *IMPULS-Stiftung*, Cologne.

213. LII, P., & KUO, F.-I. (2016). Innovation-oriented supply chain integration for combined competitiveness and firm performance. *International Journal of Production Economics,* 174, 142–155.

214. LIMA-JUNIOR, F. R., & RIBEIRO CARPINETTI, L. C. (2019). Predicting supply chain performance based on SCOR® metrics and multilayer perceptron neural networks. *International Journal of Production Economics,* 212, 19-38.

215. LIN, B., WU, W. & SONG, M. (2019). Industry 4.0: driving factors and impacts on firm's performance: an empirical study on China's manufacturing industry. *Annals of Operations Research*, (forthcoming), https://doi.org/10.1007/s10479-019-03433-6

216. LIN, D., LEE, C. K. M., LAU, H., & YANG, Y. (2018). Strategic response to Industry 4.0: an empirical investigation on the Chinese automotive industry. *Industrial Management & Data Systems*, 118(3), 589-605

217. LIN, Y., & WU, L. Y. (2014). Exploring the role of dynamic capabilities in firm performance under the resource-based view framework. *Journal of business research*, 67(3), 407-413.

218. LIU, H., WEI, S., KE, W., WEI, K. K., & HUA, Z. (2016). The configuration between supply chain integration and information technology competency: A resource orchestration perspective. *Journal of Operations Management,* 44, 13–29.

219. LOCKAMY, A., & MCCORMACK, K. (2004). Linking SCOR planning practices to supply chain performance: An exploratory study. *International journal of operations & production management*, 24(12), 1192-1218.

220. LONG, Y., PAN, J., ZHANG, Q., & HAO, Y. (2017). 3D printing technology and its impact on Chinese manufacturing. *International Journal of Production Research,* 55(5), 1488–1497.

221. LONGHURST, R. (2003). Semi-structured interviews and focus groups. *Key methods in geography*, 3(2), 143-156.

222. LORENZ M., RÜßMANN, M., STRACK, R., LUETH, K. L., & BOLLE, M. (2015). Man and Machine in Industry 4.0- How will technology transform the industrial workforce through 2025?, *The Boston Consulting Group,* Available at: https://www.voced.edu.au/content/ngv:73341

223. LORENZO-SEVA, U., & FERRANDO, P. J. (2006). FACTOR: A computer program to fit the exploratory factor analysis model. *Behavior research methods*, 38(1), 88-91.
224. LU, D., ASIAN, S., ERTEK, G., & SEVINC, M. (2019). Mind the perception gap: An integrative performance management framework for service supply chains. *International Journal of Physical Distribution & Logistics Management*, 49(1), 33-51.
225. LU, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of industrial information integration*, 6, 1-10.
226. MAESTRINI, V., LUZZINI, D., MACCARRONE, P., & CANIATO, F. (2017). Supply chain performance measurement systems: A systematic review and research agenda. *International Journal of Production Economics*, 183, 299-315.
227. MAGHSOUDI, A. AND PAZIRANDEH, A. (2016). Visibility, resource sharing and performance in supply chain relationships: insights from humanitarian practitioners, *Supply Chain Management*, 21(1), pp. 125-139.
228. MAGHSOUDI, A., & PAZIRANDEH, A. (2016). Visibility, resource sharing and performance in supply chain relationships: insights from humanitarian practitioners. *Supply Chain Management: An International Journal*, 21(1), 125-139.
229. MAKRIS, D., HANSEN, Z. N. L., & KHAN, O. (2019). Adapting to supply chain 4.0: an explorative study of multinational companies. In *Supply Chain Forum: An International Journal*, 20(2), pp. 116-131.
230. MALONE, T.W., CROWSTON, K. (1994). The interdisciplinary study of coordination. *ACM Comput. Surv.*, 26 (1), 87–119.
231. MANDERS, J. H. M., CANIËLS, M. C. J., & GHIJSEN, P. W. T. (2017). Supply chain flexibility. *The International Journal of Logistics Management*, 28(4), 964–1026.
232. MANUEL MAQUEIRA, J., MOYANO-FUENTES, J., & BRUQUE, S. (2019). Drivers and consequences of an innovative technology assimilation in the supply chain: cloud computing and supply chain integration. *International Journal of Production Research*, 57(7), 2083-2103.
233. MARCOULIDES & SAUNDERS. (2006). Editor's Comments: PLS: A Silver Bullet? *MIS Quarterly*, 30(2), 3-9
234. MARIANI, M., & BORGHI, M. (2019). Industry 4.0: A bibliometric review of its managerial intellectual structure and potential evolution in the service industries. *Technological Forecasting and Social Change*, 149, 119752.
235. MARTILLA, J. A., & JAMES, J. C. (1977). Importance– performance analyses. *Journal of Marketing*, 41(1), 77– 79.
236. MATSUYAMA, K. (1992). Agricultural productivity, comparative advantage, and economic growth. *Journal of economic theory*, 58(2), 317-334.
237. MATZLER, K., STIEGER, D., & FÜLLER, J. (2011). Consumer confusion in internet-based mass customization: Testing a network of antecedents and consequences. *Journal of Consumer Policy*, 34(2), 231-247.
238. MCCOLL-KENNEDY, J.R. ET AL. (2017). The changing role of the health care customer: review, synthesis and research, *Journal of Service Management*, 28(1), pp. 2-33.
239. MEHRALIAN, G., NAZARI, J. A., NOORIPARTO, G., & RASEKH, H. R. (2017). TQM and organizational performance using the balanced scorecard approach. *International Journal of Productivity and Performance Management*, 66(1), 111–125.

240. MIN, S., ZACHARIA, Z. G., & SMITH, C. D. (2019). Defining Supply Chain Management: In the Past, Present, and Future. *Journal of Business Logistics*. 40(1), 44-55.
241. MISHRA, D., SHARMA, R. R. K., KUMAR, S., & DUBEY, R. (2016). Bridging and buffering: Strategies for mitigating supply risk and improving supply chain performance. *International Journal of Production Economics,* 180, 183–197.
242. MITTAL, S., KHAN, M. A., ROMERO, D., & WUEST, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of manufacturing systems*, 49, 194-214.
243. MOAVENZADEH, J. (2015, October). The 4th Industrial Revolution: Reshaping the Future of Production. In *World Economic Forum*. Available at: https://na.eventscloud.com/file_uploads/fe238270f05e2dbf187e2a60cbcdd68e_2_Keynote_John_Moavenzadeh_World_Economic_Forum.pdf
244. MOEUF, A., PELLERIN, R., LAMOURI, S., TAMAYO-GIRALDO, S., & BARBARAY, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, 56(3), 1118-1136
245. MONOSTORI, L. (2014). Cyber-physical production systems: roots, expectations and R&D challenges. *Procedia Cirp*, 17, 9-13.
246. MORA-MONGE, C., QUESADA, G., GONZALEZ, M.E. AND DAVIS, J.M.(2019). Trust, power and supply chain integration in Web-enabled supply chains, *Supply Chain Management*, 24(4), pp. 524-539.
247. MORGAN, C. (2004). Structure, speed and salience: performance measurement in the supply chain. *Business process management journal*. 10(5), 522-536
248. MORVAI, R. (2014). The Examination of Supply Chain Integration of Small and Medium-Sized Enterprises Operating in the Food Industry. (Doctoral dissertation, Szent Istvan University).
249. MÜLLER, J. M., BULIGA, O., & VOIGT, K. I. (2018a). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, 132, 2-17.
250. MÜLLER, J. M., KIEL, D., & VOIGT, K. I. (2018b). What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, 10(1), 247.
251. NAGY, J., OLÁH, J., ERDEI, E., MÁTÉ, D., & POPP, J. (2018). The role and impact of Industry 4.0 and the internet of things on the business strategy of the value chain—the case of Hungary. *Sustainability*, 10(10), 3491.
252. NARASIMHAN, R., KIM, S.W. (2002). Effect of supply chain integration on the relationship between diversification and performance: evidence from Japanese and Korean firms. *Journal of Operations Management*, 20 (3), 303–323
253. NATH, P., NACHIAPPAN, S., & RAMANATHAN, R. (2010). The impact of marketing capability, operations capability and diversification strategy on performance: A resource-based view. *Industrial Marketing Management*, 39(2), 317-329.
254. NEELY, A., GREGORY, M., & PLATTS, K. (1995). Performance measurement system design: a literature review and research agenda. *International journal of operations & production management*, 15(4), 80-116.
255. NEWMAN, I., BENZ, C. R., & RIDENOUR, C. S. (1998). Qualitative-quantitative research methodology: Exploring the interactive continuum. SIU Press.

256. NOSALSKA, K., PIĄTEK, Z.M., MAZUREK, G. AND RZĄDCA, R. (2019). Industry 4.0: coherent definition framework with technological and organizational interdependencies, *Journal of Manufacturing Technology Management*, (forthcoming). https://doi.org/10.1108/JMTM-08-2018-0238
257. NOVAIS, L., MAQUEIRA, J. M., & ORTIZ-BAS, Á. (2019). A systematic literature review of cloud computing use in supply chain integration. *Computers & Industrial Engineering*, 129, 296-314.
258. NUVOLARI, A. (2019). Understanding successive industrial revolutions: A “development block” approach. *Environmental Innovation and Societal Transitions*, 32, 33-44.
259. NWANKPA, J. K., & ROUMANI, Y. (2016). IT capability and digital transformation: a firm performance perspective. In *ICIS Conference 2016* Available at: https://aisel.aisnet.org/icis2016/ISStrategy/Presentations/4/
260. OKE, A. (2005). A framework for analysing manufacturing flexibility. *International Journal of Operations & Production Management*, 25(10), 973–996.
261. PATNAYAKUNI, R., RAI, A., & SETH, N. (2006). Relational Antecedents of Information Flow Integration for Supply Chain Coordination. *Journal of Management Information Systems*, 23(1), 13–49.
262. PATRUCCO, A., CICCULLO, F. AND PERO, M. (2020). Industry 4.0 and supply chain process re-engineering: A coproduction study of materials management in construction, *Business Process Management Journal*, (forthcoming), https://doi.org/10.1108/BPMJ-04-2019-0147
263. PAULRAJ, A., LADO, A. A., & CHEN, I. J. (2008). Inter-organizational communication as a relational competency: Antecedents and performance outcomes in collaborative buyer–supplier relationships. *Journal of operations management*, 26(1), 45-64.
264. PERNEGER, T. V., COURVOISIER, D. S., HUDELSON, P. M., & GAYET-AGERON, A. (2015). Sample size for pre-tests of questionnaires. *Quality of Life Research*, 24(1), 147-151.
265. PETERSEN, K. J., HANDFIELD, R. B., & RAGATZ, G. L. (2005). Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of operations management*, 23(3-4), 371-388.
266. PETLJAK, K., ZULAUF, K., ŠTULEC, I., SEURING, S. AND WAGNER, R. (2018). Green supply chain management in food retailing: survey-based evidence in Croatia, *Supply Chain Management*, 23(1), pp. 1-15
267. PFOHL, H. C., YAHSI, B., & KURNAZ, T. (2015). The impact of Industry 4.0 on the Supply Chain. In *Innovations and Strategies for Logistics and Supply Chains: Technologies, Business Models and Risk Management. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 20* (pp. 31-58). Berlin: epubli GmbH.
268. PILLER, F. T., MOESLEIN, K., & STOTKO, C. M. (2004). Does mass customization pay? An economic approach to evaluate customer integration. *Production planning & control*, 15(4), 435-444.
269. PIOTROWICZ, W., & CUTHBERTSON, R. (2015). Performance measurement and metrics in supply chains: an exploratory study. *International Journal of Productivity and Performance Management*, 64(8), 1068–1091.

270. PODSAKOFF, P. M., MACKENZIE, S. B., LEE, J. Y., & PODSAKOFF, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of applied psychology*, 88(5), 879.

271. POPKOVA, E. G., RAGULINA, Y. V., & BOGOVIZ, A. V. (2019). Fundamental Differences of Transition to Industry 4.0 from Previous Industrial Revolutions. In I*ndustry 4.0: Industrial Revolution of the 21st Century* (pp. 21-29). Springer, Cham.

272. PRAJOGO, D., & OLHAGER, J. (2012). Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration. *International Journal of Production Economics*, 135(1), 514-522.

273. PRAJOGO, D., OKE, A., & OLHAGER, J. (2016). Supply chain processes. *International Journal of Operations & Production Management,* 36(2), 220–238.

274. PURBEY, S., MUKHERJEE, K., & BHAR, C. (2007). Performance measurement system for healthcare processes. *International Journal of Productivity and Performance Management*, 56(3), 241-251.

275. QI, Y., HUO, B., WANG, Z., & YEUNG, H. Y. J. (2017). The impact of operations and supply chain strategies on integration and performance. *International Journal of Production Economics*, 185, 162-174.

276. QUEIROZ, M.M., PEREIRA, S.C.F., TELLES, R. AND MACHADO, M.C. (2019). Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities, *Benchmarking: An International Journal*, (forthcoming), https://doi.org/10.1108/BIJ-12-2018-0435.

277. RAI, A., PATNAYAKUNI, R., & SETH, N. (2006). Firm performance impacts of digitally enabled supply chain integration capabilities. *MIS quarterly*, 30(2), 225-246.

278. RAJNAI, Z., & KOCSIS, I. (2018). Assessing industry 4.0 readiness of enterprises. *2018 IEEE 16th World Symposium on Applied Machine Intelligence and Informatics (SAMI)*, Kosice, pp. 000225-000230.

279. RAZMI, J., RAD, R. H., & SANGARI, M. S. (2010). Developing a two-echelon mathematical model for a vendor-managed inventory (VMI) system. *The International Journal of Advanced Manufacturing Technology*, *48*(5-8), 773-783.

280. REDDY. K, J. M., RAO. A, N., & L, K. (2019). A review on supply chain performance measurement systems. *Procedia Manufacturing*, 30, 40–47.

281. REINARTZ, W., HAENLEIN, M., & HENSELER, J. (2009). An empirical comparison of the efficacy of covariance-based and variance-based SEM. *International Journal of research in Marketing*, *26*(4), 332-344.

282. RICHARD, O. C. (2000). Racial diversity, business strategy, and firm performance: A resource-based view. *Academy of management journal*, 43(2), 164-177.

283. RIGDON, E. E., SARSTEDT, M., & RINGLE, C. M. (2017). On comparing results from CB-SEM and PLS-SEM: Five perspectives and five recommendations. *Marketing Zfp*, 39(3), 4-16.

284. RINGLE, C. M., SARSTEDT, M., & STRAUB, D. W. (2012). Editor's Comments: A Critical Look at the Use of PLS-SEM in" MIS Quarterly". *MIS quarterly*, 36(1), iii-xiv.

285. RIVARD, S., RAYMOND, L., & VERREAULT, D. (2006). Resource-based view and competitive strategy: An integrated model of the contribution of information technology to firm performance. *The Journal of Strategic Information Systems*, 15(1), 29-50.

286. ROBERTS, N., THATCHER, J. B., & GROVER, V. (2010). Advancing operations management theory using exploratory structural equation modelling techniques. *International Journal of Production Research*, 48(15), 4329-4353

287. ROBLEK, V., MEŠKO, M., & KRAPEŽ, A. (2016). A complex view of industry 4.0. *Sage Open*, 6(2), 2158244016653987.

288. RÜßMANN, M., LORENZ, M., GERBERT, P., WALDNER, M., JUSTUS, J., ENGEL, P. AND HARNISCH, M. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *Boston Consulting Group (BCG),* Available at: https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries

289. SACRISTÁN-DÍAZ, M., GARRIDO-VEGA, P., & MOYANO-FUENTES, J. (2018). Mediating and non-linear relationships among supply chain integration dimensions. *International Journal of Physical Distribution & Logistics Management*, 48(7), 698-723.

290. SÁENZ, M. J., KNOPPEN, D., & TACHIZAWA, E. M. (2018). Building manufacturing flexibility with strategic suppliers and contingent effect of product dynamism on customer satisfaction. *Journal of purchasing and supply management*, 24(3), 238-246.

291. SAGHIRI, S. S., & BARNES, S. J. (2016). Supplier flexibility and postponement implementation: An empirical analysis. *International Journal of Production Economics*, 173, 170-183.

292. SAJJAD, I. A., CHICCO, G., & NAPOLI, R. (2016). Definitions of demand flexibility for aggregate residential loads. *IEEE Transactions on Smart Grid*, 7(6), 2633-2643.

293. SANDERS, A., ELANGESWARAN, C., & WULFSBERG, J. (2016). Industry 4.0 implies lean manufacturing: research activities in industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management*, 9(3), 811-833.

294. SANDERS, N. R., AUTRY, C. W., & GLIGOR, D. M. (2011). The impact of buyer firm information connectivity enablers on supplier firm performance: a relational view. *The international journal of logistics management*, 22(2), 179-201.

295. SCHUH, G., ANDERL, R., GAUSEMEIER, J., TEN HOMPEL, M., & WAHLSTER, W. (2017). Industrie 4.0 Maturity Index. *Managing the Digital Transformation of Companies. Munich: Herbert Utz*. Available at: https://en.acatech.de/wpcontent/uploads/sites/6/2020/04/aca_STU_MatInd_2020_en_Web-1.pdf

296. SCHUH, G., POTENTE, T., WESCH-POTENTE, C., WEBER, A. R., & PROTE, J. P. (2014). Collaboration Mechanisms to increase Productivity in the Context of Industrie 4.0. *Procedia CIRP*, 19, 51-56.

297. SCHUMACHER, A., EROL, S., & SIHN, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia Cirp*, 52, 161-166.

298. SEELE, P. (2017). Predictive Sustainability Control: A review assessing the potential to transfer big data driven “predictive policing” to corporate sustainability management. *Journal of Cleaner Production*, 153, 673–686.

299. SEZEN, B. (2008). Relative effects of design, integration and information sharing on supply chain performance. *Supply Chain Management: An International Journal*, 13(3), 233-240.

300. SHAHBAZI, S., SALLOUM, M., KURDVE, M., & WIKTORSSON, M. (2017). Material efficiency measurement: empirical investigation of manufacturing industry. *Procedia Manufacturing*, 8, 112-120.

301. SHEPHERD, C., & GUNTER, H. (2010). Measuring Supply Chain Performance: Current Research and Future Directions. In *Behavioral Operations in Planning and Scheduling,* (pp. 105–121). Springer, Berlin, Heidelberg.

302. SHOU, Y., LI, Y., PARK, Y., & KANG, M. (2018). Supply chain integration and operational performance: the contingency effects of production systems. *Journal of Purchasing and Supply Management*, 24(4), 352-360.

303. SHUIABI, E., THOMSON, V., & BHUIYAN, N. (2005). Entropy as a measure of operational flexibility. *European journal of operational research*, 165(3), 696-707.

304. SILVESTRO, R., & LUSTRATO, P. (2014). Integrating financial and physical supply chains: the role of banks in enabling supply chain integration. *International Journal of Operations & Production Management,* 34(3), 298–324.

305. SIMON, A., & YAYA, L. H. P. (2012). Improving innovation and customer satisfaction through systems integration. *Industrial Management & Data Systems*. 112(7), 1026-1043.

306. SINGH, A. (2007). Globalization, Industrial Revolutions in India and China and Labour Markets in Advanced Countries: Implications for National and International Economic Policy. *ILO Working Paper 81.* Geneva: Policy Integration Department, ILO.

307. SINGH, P. J., & POWER, D. (2013). Innovative knowledge sharing, supply chain integration and firm performance of Australian manufacturing firms. *International Journal of Production Research,* 52(21), 6416–6433.

308. SJODIN, D. R., PARIDA, V., LEKSELL, M., & PETROVIC, A. (2018). Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. *Research-Technology Management*, 61(5), 22-31.

309. SLACK, N. (2005). The flexibility of manufacturing systems, *International Journal of Operations & Production Management*, 25(12), 1190-200.

310. SMART, A. (2008). eBusiness and supply chain integration. *Journal of Enterprise Information Management,* 21(3), 227–246.

311. SMITH, S., SMITH, G. C., JIAO, R., & CHU, C. H. (2013). Mass customization in the product life cycle. *Journal of Intelligent Manufacturing*, 24(5), 877-885.

312. SONG, Y., CAI, J., & FENG, T. (2017). The influence of green supply chain integration on firm performance: A contingency and configuration perspective. *Sustainability,* 9(5), 763.

313. SONY, M., & NAIK, S. (2019). Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking: An International Journal*, 27(7), 2213-2232.

314. SREEDEVI, R., & SARANGA, H. (2017). Uncertainty and supply chain risk: The moderating role of supply chain flexibility in risk mitigation. *International Journal of Production Economics,* 193, 332–342.

315. STEVENSON, M., & SPRING, M. (2007). Flexibility from a supply chain perspective: definition and review. *International Journal of Operations & Production Management,* 27(7), 685–713.

316. SUKAMOLSON, S. (2007). Fundamentals of quantitative research. *Language Institute Chulalongkorn University*, 1, 2-3.

317. SUNG, T. K. (2018). Industry 4.0: A Korea perspective. Technological Forecasting and Social Change, 132, 40–45.

318. SUPPLY CHAIN COUNCIL (1996), Supply Chain Operations Reference Model, *Supply-Chain Council*, Chicago, IL.

319. ŚWIERCZEK, A. (2014). The impact of supply chain integration on the “snowball effect” in the transmission of disruptions: An empirical evaluation of the model. *International Journal of Production Economics*, 157, 89–104.

320. SZEGEDI, Z., & ILLES, C. B. (2006, May). Logistics Management Awareness of Hungarian Small-and Mid-Size Companies. In Competitiveness in the EU–Challenge for the V4 Countries. *Proceedings of the International Scientific Conference of Competitiveness in the EU-Challenge for the V4 Countries*, (pp. 835-840). Nitra, Slovak University of Agriculture.

321. SZEGEDI, Z., GABRIEL, M., & PAPP, I. (2017). Green supply chain awareness in the Hungarian automotive industry. *Polish Journal of Management Studies*, 16(1), 259-268

322. TEO, T., KABAKÇI YURDAKUL, I., & URSAVAŞ, Ö. F. (2014). Exploring the digital natives among pre-service teachers in Turkey: a cross-cultural validation of the Digital Native Assessment Scale. *Interactive Learning Environments*, 24(6), 1231–1244.

323. THAMES, J. L., & SCHAEFER, D. (2016). Software-defined cloud manufacturing for industry 4.0. *Procedia CIRP*, 52, 12-17.

324. TIEDE, D., & BLASCHKE, T. (2005, May). A two-way workflow for integrating CAD, 3D visualization and spatial analysis in a GIS environment. In *The 6 the International Conference for Information Technologies in Landscape Architecture: Real-Time Visualization and Participation, Visualization in Landscape Architecture* (pp. 26-28), Dessau, Germany.

325. TJAHJONO, B., ESPLUGUES, C., ARES, E., & PELAEZ, G. (2017). What does industry 4.0 mean to supply chain?. *Procedia Manufacturing*, 13, 1175-1182.

326. TORTORELLA, G. L., VERGARA, A. M. C., GARZA-REYES, J. A., & SAWHNEY, R. (2020). Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers. *International Journal of Production Economics*, 219, 284-294.

327. TRUONG QUANG, H. AND HARA, Y. (2019). The push effect of risks on supply chain performance: service-oriented firms, *Business Process Management Journal*, 25(7), 1734-1758.

328. TSANOS, C. S., ZOGRAFOS, K. G., & HARRISON, A. (2014). Developing a conceptual model for examining the supply chain relationships between behavioral antecedents of collaboration, integration and performance. *The International Journal of Logistics Management*, 25(3), 418-462

329. TURKSTAT (2019). Use of Information and Communication Technology (ICT) by Enterprises, 2019, Available at http://www.turkstat.gov.tr/PreHaberBultenleri.do?id=30573

330. TURKULAINEN, V., ROH, J., WHIPPLE, J. M., & SWINK, M. (2017). Managing internal supply chain integration: integration mechanisms and requirements. *Journal of Business Logistics*, 38(4), 290-309.

331. UM, J. (2017). The impact of supply chain agility on business performance in a high-level customization environment. *Operations management research*, 10(1-2), 10-19.

332. UM, J., LYONS, A., LAM, H. K., CHENG, T. C. E., & DOMINGUEZ-PERY, C. (2017). Product variety management and supply chain performance: A capability perspective on their relationships and competitiveness implications. *International Journal of Production Economics*, 187,1-39.

333. UM, J., LYONS, A., LAM, H. K., CHENG, T. C. E., & DOMINGUEZ-PERY, C. (2017). Product variety management and supply chain performance: A capability perspective on their relationships and competitiveness implications. *International Journal of Production Economics*, 187, 15-26.

334. VAIDYA, S., AMBAD, P., & BHOSLE, S. (2018). Industry 4.0–a glimpse. *Procedia Manufacturing*, 20, 233-238.

335. VANPOUCKE, E., VEREECKE, A., & MUYLLE, S. (2017). Leveraging the impact of supply chain integration through information technology. *International Journal of Operations & Production Management*, 37(4), 510–530.

336. VICKERY, S.K., JAYARAM, J., DROGE, C. AND CALANTONE, R. (2003). The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationships, *Journal of Operations Management*, 21(5), 523-539.

337. WANG, J., ZHANG, Y., & GOH, M. (2018). Moderating the role of firm size in sustainable performance improvement through sustainable supply chain management. *Sustainability*, 10(5), 1654.

338. WANG, S., WAN, J., LI, D., & ZHANG, C. (2016). Implementing smart factory of industrie 4.0: an outlook. *International Journal of Distributed Sensor Networks*, 12(1), 3159805.

339. WIELAND, A., & WALLENBURG, C. M. (2013). The influence of relational competencies on supply chain resilience: a relational view. *International Journal of Physical Distribution & Logistics Management*. 43(4), p. 300-320.

340. WIENGARTEN, F., HUMPHREYS, P., CAO, G., & MCHUGH, M. (2012). Exploring the Important Role of Organizational Factors in IT Business Value: Taking a Contingency Perspective on the Resource-Based View. *International Journal of Management Reviews*, 15(1), 30–46.

341. WIENGARTEN, F., LI, H., SINGH, P.J. AND FYNES, B. (2019). Re-evaluating supply chain integration and firm performance: linking operations strategy to supply chain strategy. *Supply Chain Management*, 24(4), 540-559.

342. WILLIAMS, B., ONSMAN, A., & BROWN, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Australasian Journal of Paramedicine*, 8(3). 1-13

343. WILLIS, G., GENCHEV, S. E., & CHEN, H. (2016). Supply chain learning, integration, and flexibility performance: an empirical study in India. *The International Journal of Logistics Management*, 27(3), 755-769

344. WOLF, T., ZINK, M., & NAGURNEY, A. (2013, July). The cyber-physical marketplace: A framework for large-scale horizontal integration in distributed cyber-physical systems. In *2013 IEEE 33rd International Conference on Distributed Computing Systems Workshops* (pp. 296-302). IEEE.

345. WONG, C. W. Y., SANCHA, C., & THOMSEN, C. G. (2017). A national culture perspective in the efficacy of supply chain integration practices. *International Journal of Production Economics*, 193, 554–565.

346. WONG, C. Y., BOON-ITT, S., & WONG, C. W. (2011). The contingency effects of environmental uncertainty on the relationship between supply chain integration and operational performance. *Journal of Operations management*, 29(6), 604-615.

347. WONG, K. K. K. (2013). Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS. *Marketing Bulletin*, 24(1), 1-32.

348. WONG, K. V., & HERNANDEZ, A. (2012). A review of additive manufacturing. *ISRN Mechanical Engineering*, pp.1-10. doi:10.5402/2012/208760

349. WU, D., ROSEN, D. W., WANG, L., & SCHAEFER, D. (2015). Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. *Computer-Aided Design*, 59, 1-14.

350. WU, F., YENIYURT, S., KIM, D., & CAVUSGIL, S. T. (2006). The impact of information technology on supply chain capabilities and firm performance: A resource-based view. *Industrial Marketing Management,* 35(4), 493–504.

351. WU, I.-L., & CHIU, M.-L. (2015). Organizational applications of IT innovation and firm's competitive performance: A resource-based view and the innovation diffusion approach. *Journal of Engineering and Technology Management*, 35, 25–44.

352. WU, I.-L., & CHIU, M.-L. (2018). Examining supply chain collaboration with determinants and performance impact: Social capital, justice, and technology use perspectives. *International Journal of Information Management,* 39, 5–19.

353. XU, L. D., XU, E. L., & LI, L. (2018). Industry 4.0: state of the art and future trends. *International Journal of Production Research,* 56(8), 2941–2962.

354. YIN, Y., STECKE, K. E., SWINK, M., & KAKU, I. (2017). Lessons from seru production on manufacturing competitively in a high cost environment. *Journal of Operations Management*, 49, 67-76.

355. YU, K., CADEAUX, J., & SONG, H. (2012). Alternative forms of fit in distribution flexibility strategies. *International Journal of Operations & Production Management,* 32(10), 1199–1227.

356. YU, W. (2015). The effect of IT-enabled supply chain integration on performance. *Production Planning & Control*, 26(12), 945–957.

357. YU, W., JACOBS, M. A., CHAVEZ, R., & FENG, M. (2016). The impacts of IT capability and marketing capability on supply chain integration: a resource-based perspective. *International Journal of Production Research,* 55(14), 4196–4211.

358. YU, W., JACOBS, M. A., SALISBURY, W. D., & ENNS, H. (2013). The effects of supply chain integration on customer satisfaction and financial performance: An organizational learning perspective. *International Journal of Production Economics,* 146(1), 346–358.

359. YUMURTACI HÜSEYINOĞLU, I. Ö., KOTZAB, H., & TELLER, C. (2020). Supply chain relationship quality and its impact on firm performance. *Production Planning & Control*, 31(6), 470-482.

360. ZACHARIA, Z. G., NIX, N. W., & LUSCH, R. F. (2011). Capabilities that enhance outcomes of an episodic supply chain collaboration. *Journal of Operations Management,* 29(6), 591–603.

361. ZAILANI, S., & RAJAGOPAL, P. (2005). Supply chain integration and performance: US versus East Asian companies. *Supply Chain Management: An International Journal,* 10(5), 379–393.

362. ZARIDIS, A., VLACHOS, I., & BOURLAKIS, M. (2020). SMEs strategy and scale constraints impact on agri-food supply chain collaboration and firm performance. *Production Planning & Control,* (forthcoming). doi:10.1080/09537287.2020.1796136

363. ZHANG, C., GUNASEKARAN, A., & WANG, W. Y. C. (2015). A comprehensive model for supply chain integration. *Benchmarking: An International Journal,* 22(6), 1141–1157.

364. ZHANG, X., VAN DONK, D.P. AND VAN DER VAART, T. (2016). The different impact of inter-organizational and intra-organizational ICT on supply chain performance, *International Journal of Operations & Production Management*, 36(7), 803-824.

365. ZHAO, G., FENG, T., & WANG, D. (2015). Is more supply chain integration always beneficial to financial performance?. *Industrial Marketing Management*, 45, 162-172.

366. ZHONG, R. Y., XU, X., KLOTZ, E., & NEWMAN, S. T. (2017). Intelligent manufacturing in the context of industry 4.0: a review. *Engineering*, 3(5), 616-630.

367. ZHOU, K., TAIGANG LIU, & LIFENG ZHOU. (2015). Industry 4.0: Towards future industrial opportunities and challenges. In *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD),* (pp. 2147-2152), IEEE.

368. ZHOU, W., CHONG, A. Y. L., ZHEN, C., & BAO, H. (2018). E-Supply Chain Integration Adoption: Examination of Buyer–Supplier Relationships. *Journal of Computer Information Systems*, 58(1), 58–65.

369. ZHU, Q., KRIKKE, H., & CANIËLS, M. C. J. (2018). Supply chain integration: value creation through managing inter-organizational learning. *International Journal of Operations & Production Management,* 38(1), 211–229.

370. ZHUANG, Y., & LEDERER, A. L. (2006). A resource-based view of electronic commerce. *Information & management*, 43(2), 251-261.

371. ZOLAIT, A. H., IBRAHIM, A. R., CHANDRAN, V. G. R., & SUNDRAM, V. P. K. (2010). Supply chain integration: an empirical study on manufacturing industry in Malaysia. *Journal of Systems and Information Technology*, 12(3), 210-221.

APPENDICES

Appendix 1. Pilot Test (Interview) Guideline

Section I.

1. Can you explain your position and functions in the company including your experience in that position?
2. What are the particular tasks and areas of your responsibility in that position?

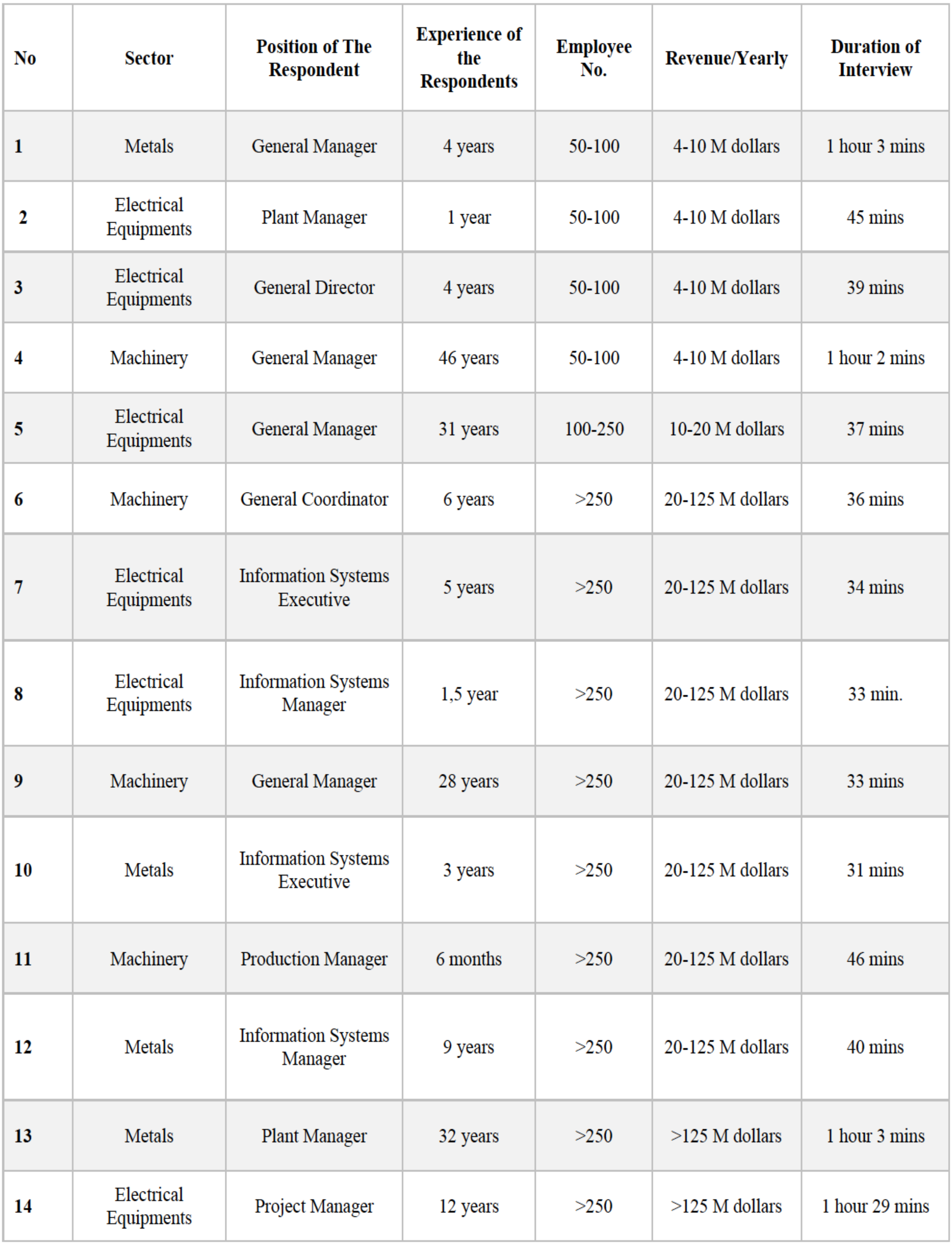
Section II.

1. What does the term of ‘Industry 4.0’ mean to you? Can you also explain that which technologies does the term bring to your mind?
2. Is Industry 4.0 already implemented in your company? If not, can you explain the time frame (short, mid-term or long term) for the adoption of Industry 4.0 in your organisation?
3. What kind of benefits do you see for your organisation when Industry 4.0 is introduced?
4. What kind of challenges do you see for your organisation when Industry 4.0 is introduced?
5. Can you explain that what necessary steps should be achieved for fully adoption of Industry 4.0 for your organisation (ex. related to Industry 4.0 strategy, employee, culture and technology)? How does your organisation perform on these steps?

Section III.

1. Do you think that Industry 4.0 is relevant for integration of supply chain activities? More specifically, how does it effect on integration of suppliers and customers and internal activities?
2. Can you explain the KPIs for your company? Do you think that Industry 4.0 is relevant for improving these performance metrics? (such as effects on resources/cost items, output and customer satisfaction items and flexibility items)

Appendix 2. Characteristics of the Respondents and the Companies (Pilot Test/Interview, N=14)



No	Sector	Position of The Respondent	Experience of the Respondents	Employee No.	Revenue/Yearly	Duration of Interview
1	Metals	General Manager	4 years	50-100	4-10 M dollars	1 hour 3 mins
2	Electrical Equipments	Plant Manager	1 year	50-100	4-10 M dollars	45 mins
3	Electrical Equipments	General Director	4 years	50-100	4-10 M dollars	39 mins
4	Machinery	General Manager	46 years	50-100	4-10 M dollars	1 hour 2 mins
5	Electrical Equipments	General Manager	31 years	100-250	10-20 M dollars	37 mins
6	Machinery	General Coordinator	6 years	>250	20-125 M dollars	36 mins
7	Electrical Equipments	Information Systems Executive	5 years	>250	20-125 M dollars	34 mins
8	Electrical Equipments	Information Systems Manager	1,5 year	>250	20-125 M dollars	33 min.
9	Machinery	General Manager	28 years	>250	20-125 M dollars	33 mins
10	Metals	Information Systems Executive	3 years	>250	20-125 M dollars	31 mins
11	Machinery	Production Manager	6 months	>250	20-125 M dollars	46 mins
12	Metals	Information Systems Manager	9 years	>250	20-125 M dollars	40 mins
13	Metals	Plant Manager	32 years	>250	>125 M dollars	1 hour 3 mins
14	Electrical Equipments	Project Manager	12 years	>250	>125 M dollars	1 hour 29 mins

Source: Author’s own analysis

Appendix 3. Questionnaire in English

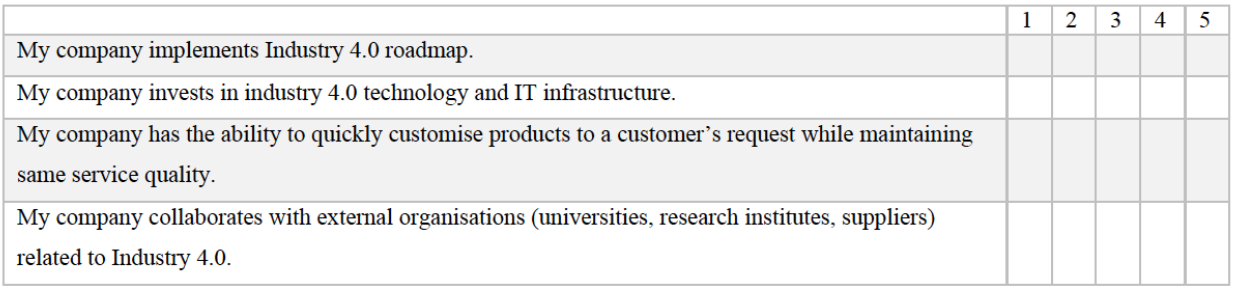
ASSESSMENT OF INDUSTRY 4.0 AND SUPPLY CHAIN PERFORMANCE

Dear Sir or Madam,

This questionnaire has been prepared for a doctoral thesis and will only be used for academic purposes. The aim of this questionnaire is to investigate the companies' Industry 4.0 assessment and supply chain performance. Thus, the data collected will be empirically tested and expressed with aggregated results so the name of the company and the respondent will be kept confidential. The results of this questionnaire could be shared with your company as a request of the respondent. Please let us know if you want the results of the questionnaire.

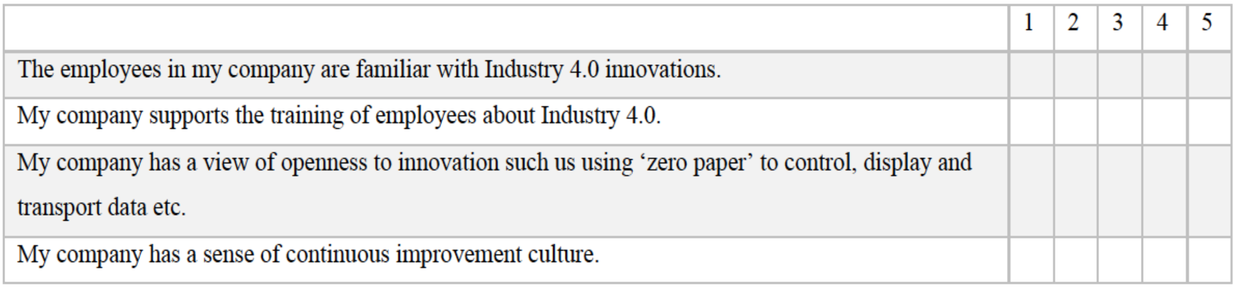
Section I. Industry 4.0 Assessment

1.1. Please indicate the extent of Industry 4.0 strategy implemented in your company (1- not at all, 2 - slightly, 3 - moderately, 4 - very, 5 - extremely)



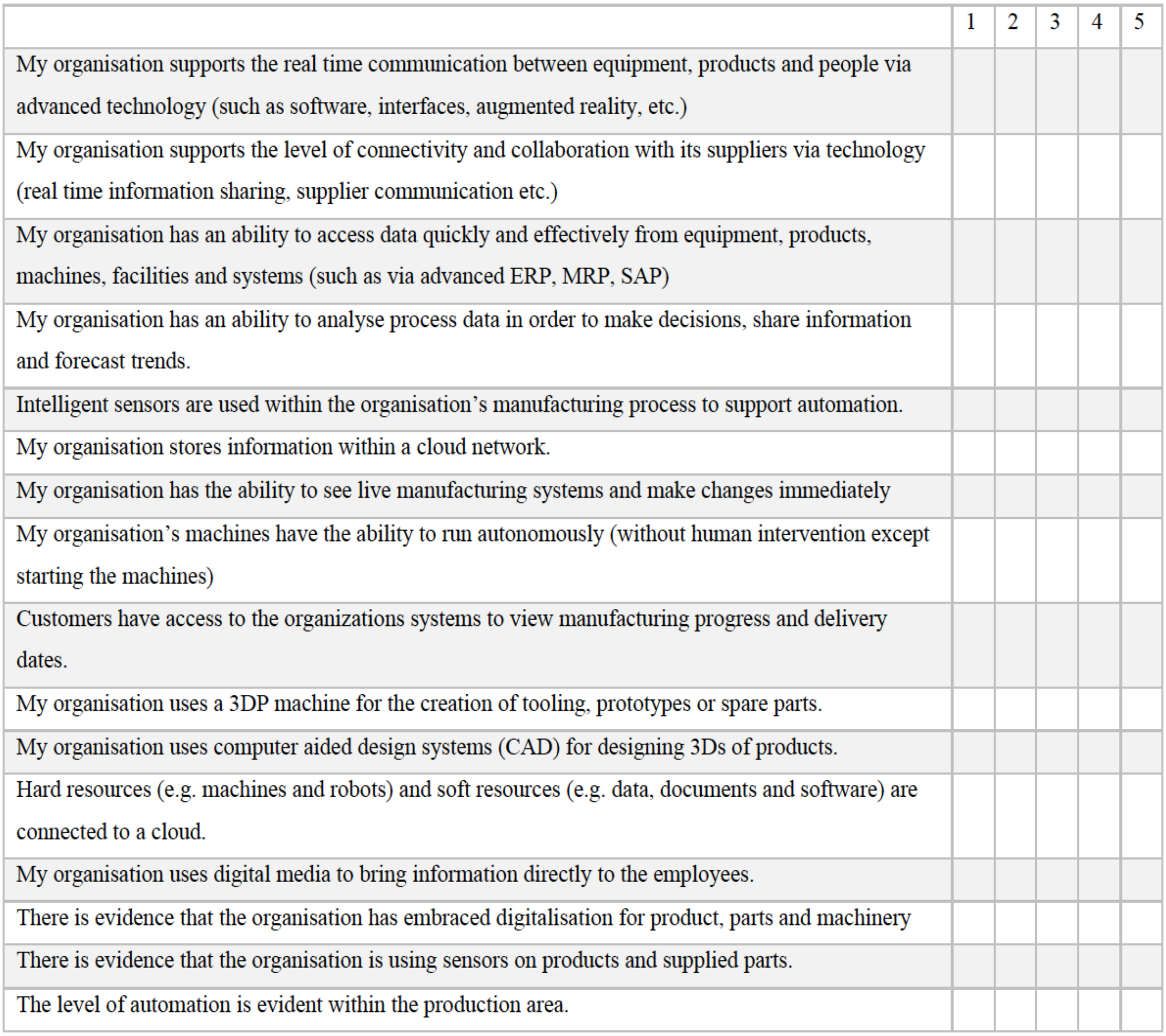
	1	2	3	4	5
My company implements Industry 4.0 roadmap.					
My company invests in industry 4.0 technology and IT infrastructure.					
My company has the ability to quickly customise products to a customer's request while maintaining same service quality.					
My company collaborates with external organisations (universities, research institutes, suppliers) related to Industry 4.0.					

1.2. Please indicate the extent of Industry 4.0 practices in your company in terms of employees and company's culture (1 - not at all, 2 - slightly, 3 - moderately, 4 - very, 5 - extremely)



	1	2	3	4	5
The employees in my company are familiar with Industry 4.0 innovations.					
My company supports the training of employees about Industry 4.0.					
My company has a view of openness to innovation such us using 'zero paper' to control, display and transport data etc.					
My company has a sense of continuous improvement culture.					

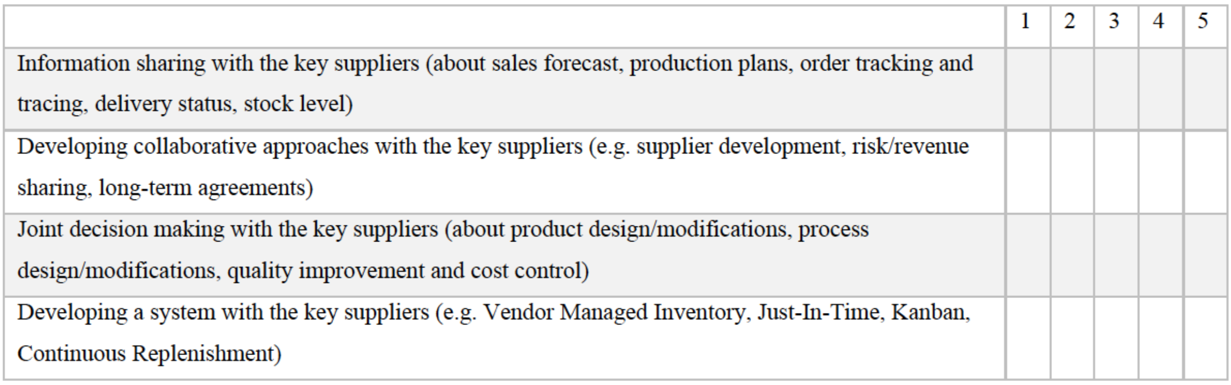
1.3. Please indicate the extent of the practices of your company in terms of Industry 4.0 technologies (1 - not at all, 2 - slightly, 3 - moderately, 4 - very, 5 - extremely)



	1	2	3	4	5
My organisation supports the real time communication between equipment, products and people via advanced technology (such as software, interfaces, augmented reality, etc.)					
My organisation supports the level of connectivity and collaboration with its suppliers via technology (real time information sharing, supplier communication etc.)					
My organisation has an ability to access data quickly and effectively from equipment, products, machines, facilities and systems (such as via advanced ERP, MRP, SAP)					
My organisation has an ability to analyse process data in order to make decisions, share information and forecast trends.					
Intelligent sensors are used within the organisation's manufacturing process to support automation.					
My organisation stores information within a cloud network.					
My organisation has the ability to see live manufacturing systems and make changes immediately					
My organisation's machines have the ability to run autonomously (without human intervention except starting the machines)					
Customers have access to the organizations systems to view manufacturing progress and delivery dates.					
My organisation uses a 3DP machine for the creation of tooling, prototypes or spare parts.					
My organisation uses computer aided design systems (CAD) for designing 3Ds of products.					
Hard resources (e.g. machines and robots) and soft resources (e.g. data, documents and software) are connected to a cloud.					
My organisation uses digital media to bring information directly to the employees.					
There is evidence that the organisation has embraced digitalisation for product, parts and machinery					
There is evidence that the organisation is using sensors on products and supplied parts.					
The level of automation is evident within the production area.					

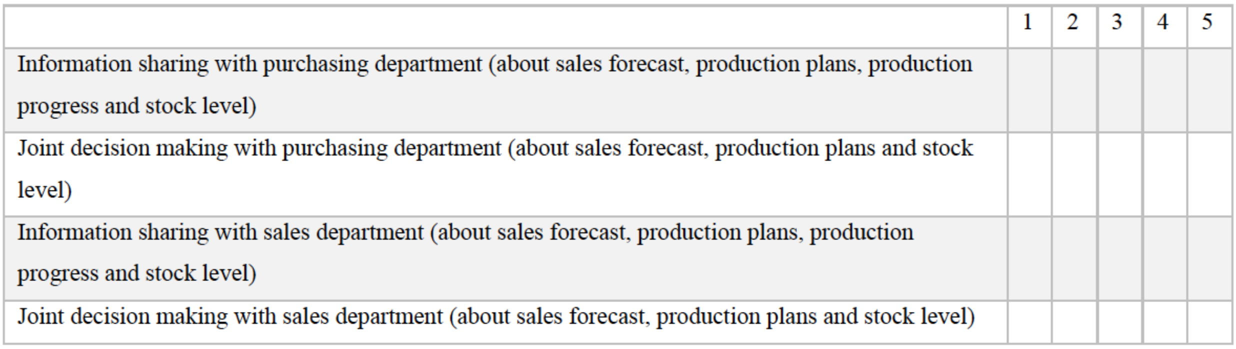
Section II: Supply Chain Integration

2.1. Please indicate the level of integration with the key suppliers of your company (1 - very low, 2 - low, 3 - moderate, 4 - high, 5 - very high



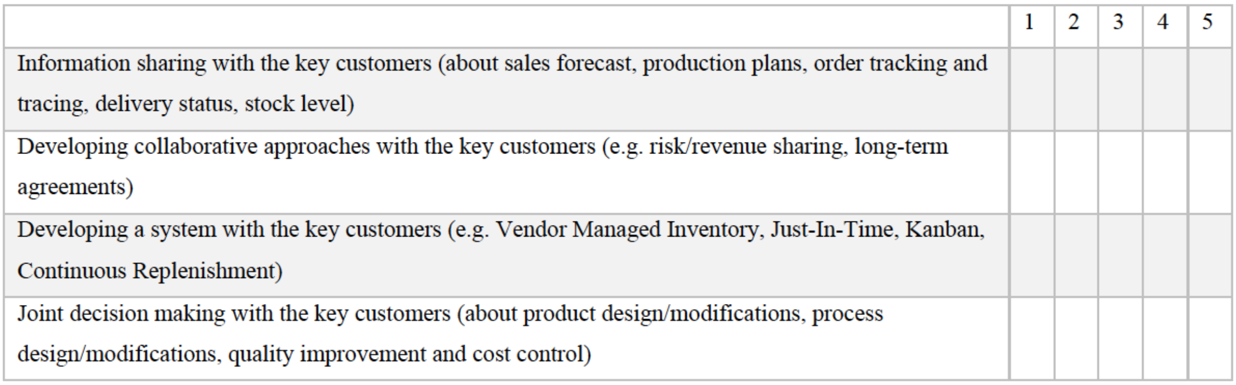
	1	2	3	4	5
Information sharing with the key suppliers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level)					
Developing collaborative approaches with the key suppliers (e.g. supplier development, risk/revenue sharing, long-term agreements)					
Joint decision making with the key suppliers (about product design/modifications, process design/modifications, quality improvement and cost control)					
Developing a system with the key suppliers (e.g. Vendor Managed Inventory, Just-In-Time, Kanban, Continuous Replenishment)					

2.2. Please indicate the level of internal integration in your company (1 - very low, 2 - low, 3 - moderate, 4 - high, 5 - very high)



	1	2	3	4	5
Information sharing with purchasing department (about sales forecast, production plans, production progress and stock level)					
Joint decision making with purchasing department (about sales forecast, production plans and stock level)					
Information sharing with sales department (about sales forecast, production plans, production progress and stock level)					
Joint decision making with sales department (about sales forecast, production plans and stock level)					

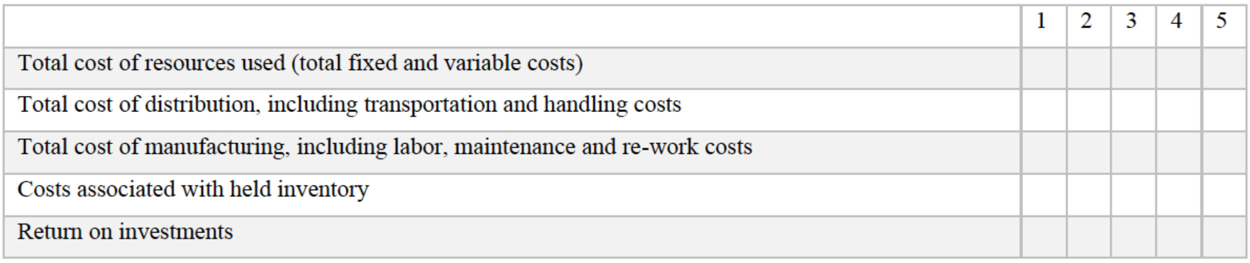
2.3. Please indicate the level of integration with the key customers of your company (1 - very low, 2 - low, 3 - moderate, 4 - high, 5 - very high)



	1	2	3	4	5
Information sharing with the key customers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level)					
Developing collaborative approaches with the key customers (e.g. risk/revenue sharing, long-term agreements)					
Developing a system with the key customers (e.g. Vendor Managed Inventory, Just-In-Time, Kanban, Continuous Replenishment)					
Joint decision making with the key customers (about product design/modifications, process design/modifications, quality improvement and cost control)					

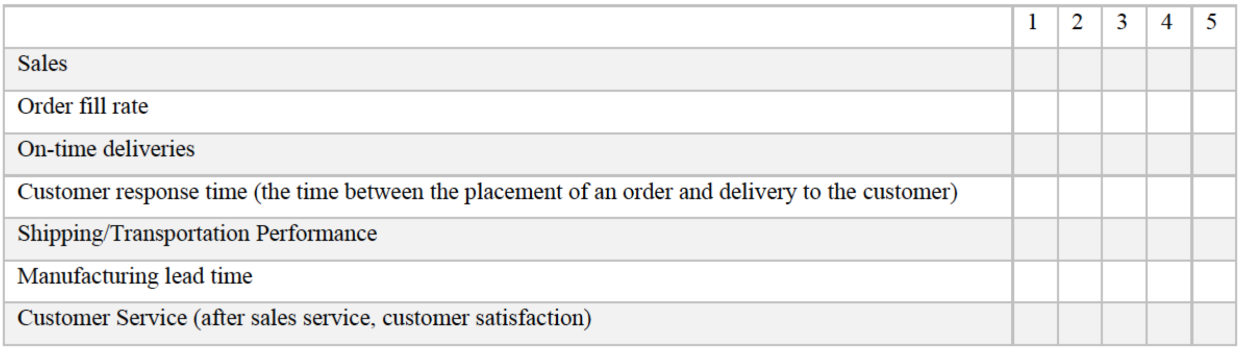
Section III. Supply Chain Performance

3.1. Please indicate the extent of your company's performance in terms of resource utilisation compared to the company's main competitors in its industry (1 - very low performance, 2 - low performance, 3 - moderate performance, 4 - high performance, 5 - excellent performance)



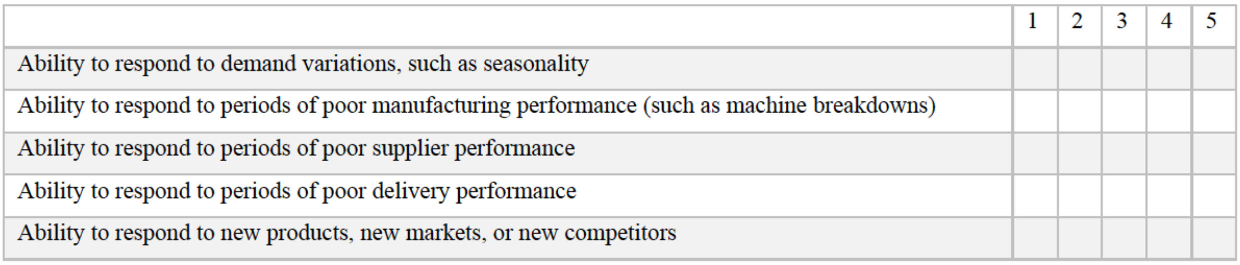
	1	2	3	4	5
Total cost of resources used (total fixed and variable costs)					
Total cost of distribution, including transportation and handling costs					
Total cost of manufacturing, including labor, maintenance and re-work costs					
Costs associated with held inventory					
Return on investments					

3.2. Please indicate the extent of your company's performance in terms of output compared to the company's main competitors in its industry (1- very low performance, 2 - low performance, 3 - moderate performance, 4 - high performance, 5 - excellent performance)



	1	2	3	4	5
Sales					
Order fill rate					
On-time deliveries					
Customer response time (the time between the placement of an order and delivery to the customer)					
Shipping/Transportation Performance					
Manufacturing lead time					
Customer Service (after sales service, customer satisfaction)					

3.3. Please indicate the extent of your company's performance in terms of output compared to the company's main competitors in its industry (1 - very low performance, 2 - low performance, 3 - moderate performance, 4 - high performance, 5 - excellent performance)



	1	2	3	4	5
Ability to respond to demand variations, such as seasonality					
Ability to respond to periods of poor manufacturing performance (such as machine breakdowns)					
Ability to respond to periods of poor supplier performance					
Ability to respond to periods of poor delivery performance					
Ability to respond to new products, new markets, or new competitors					

Section IV. General information About Respondents and The Company

4.1. Please indicate your position in the company.

☐ Top (Chief Executive, Chairperson)

☐ Senior Executive (General Managers, Managing Director)

☐ Upper Middle (Departmental Heads/Executives, Factory Managers)

☐ Middle (Office Managers, Professional Staff)

☐ First Level (Forepersons, Supervisors)

4.2. Which of the following best describes the sector of the organisation?

☐ Automotive ☐Chemicals ☐Electronics & Electrical Appliances þFood and Beverage ☐Machinery ☐Metals ☐Minerals ☐ Pharmaceuticals ☐Plastics ☐Textile ☐Other, Please specify here..

4.3. Roughly, how many people are employed in your company?

☐ 10-49 ☐ 50-249 ☐ 250-499 ☐More than 500

4.4. What is the average revenue of your company?

☐ less than 3 million TL or equal ☐ between 3 to 25 million TL ☐ between 25 to 125 million TL ☐ more than 125 million TL

Appendix 4. Spearman Rank Correlations (Items of Industry 4.0 Selected for PLS-SEM)

	S&01	S&02	S&04	E&C1	E&C2	E&C3	E&C4	T1	T2	T3	T4	T5	T7	T14	T16
S&01	1,000	,848**	,685**	,642**	,702**	,495**	,481**	,525**	,497**	,510**	,480**	,503**	,463**	,622**	,569**
S&02	,848**	1,000	,683**	,628**	,650**	,512**	,497**	,608**	,563**	,593**	,497**	,598**	,506**	,639**	,597**
S&04	,685**	,683**	1,000	,624**	,700**	,360**	,431**	,458**	,476**	,507**	,414**	,478**	,377**	,560**	,470**
E&C1	,642**	,628**	,624**	1,000	,771**	,425**	,457**	,508**	,495**	,498**	,507**	,414**	,462**	,595**	,509**
E&C2	,642**	,628**	,624**	1,000	,771**	,508**	,491**	,530**	,505**	,510**	,492**	,427**	,433**	,592**	,475**
E&C3	,495**	,512**	,360**	,425**	,508**	1,000	,532**	,620**	,456**	,468**	,545**	,438**	,451**	,447**	,414**
E&C4	,481**	,497**	,431**	,457**	,491**	,532**	1,000	,595**	,554**	,401**	,581**	,374**	,493**	,512**	,390**
T1	,525**	,608**	,458**	,508**	,530**	,620**	,595**	1,000	,640**	,577**	,523**	,405**	,528**	,549**	,493**
T2	,497**	,563**	,476**	,495**	,505**	,456**	,554**	,640**	1,000	,542**	,566**	,476**	,534**	,577**	,474**
T3	,510**	,593**	,507**	,498**	,510**	,468**	,401**	,577**	,542**	1,000	,678**	,553**	,627**	,613**	,563**
T4	,480**	,497**	,414**	,507**	,492**	,545**	,581**	,523**	,566**	,678**	1,000	,533**	,586**	,568**	,508**
T5	,503**	,598**	,478**	,414**	,427**	,438**	,374**	,405**	,476**	,553**	,533**	1,000	,574**	,589**	,669**
T7	,463**	,506**	,377**	,462**	,433**	,451**	,493**	,528**	,534**	,627**	,586**	,574**	1,000	,563**	,626**
T14	,622**	,639**	,560**	,595**	,592**	,447**	,512**	,549**	,577**	,613**	,568**	,589**	,563**	1,000	,606**
T16	,569**	,597**	,470**	,509**	,475**	,414**	,390**	,493**	,474**	,563**	,508**	,669**	,626**	,606**	1,000

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author’s own analysis

Appendix 5. Spearman Rank Correlations (Items of SCI Selected for PLS-SEM)

	SInt1	**SInt2**	**SInt3**	**SInt4**	**IInt1**	**IInt2**	**IInt3**	**IInt4**	**CInt1**	**CInt2**	**CInt3**	**CInt4**
SInt1	1,000	,669**	,615**	,621**	,527**	,527**	,485**	,423**	,521**	,506**	,647**	,519**
SInt2	,669**	1,000	,721**	,620**	,532**	,574**	,453**	,443**	,445**	,492**	,549**	,548**
SInt3	,615**	,721**	1,000	,681**	,525**	,544**	,492**	,462**	,464**	,486**	,544**	,533**
SInt4	,621**	,620**	,681**	1,000	,525**	,553**	,494**	,465**	,468**	,497**	,623**	,546**
IInt1	,527**	,532**	,525**	,525**	1,000	,797**	,707**	,636**	,426**	,425**	,474**	,462**
IInt2	,527**	,574**	,544**	,553**	,797**	1,000	,774**	,691**	,442**	,376**	,441**	,503**
IInt3	,485**	,453**	,492**	,494**	,707**	,774**	1,000	,850**	,502**	,444**	,463**	,496**
IInt4	,423**	,443**	,462**	,465**	,636**	,691**	,850**	1,000	,518**	,466**	,468**	,501**
CInt1	,521**	,445**	,464**	,468**	,426**	,442**	,502**	,518**	1,000	,748**	,661**	,643**
CInt2	,506**	,492**	,486**	,497**	,425**	,376**	,444**	,466**	,748**	1,000	,748**	,706**
CInt3	,647**	,549**	,544**	,623**	,474**	,441**	,463**	,468**	,661**	,748**	1,000	,758**
CInt4	,519**	,548**	,533**	,546**	,462**	,503**	,496**	,501**	,643**	,706**	,758**	1,000

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author’s own analysis

Appendix 6. Spearman Rank Correlations (Items of SCP Selected for PLS-SEM)

	RPER F1	**RPER F2**	**RPER F3**	**RPER F4**	**RPER F5**	**OPER F2**	**OPER F3**	**OPER F4**	**OPER F5**	**OPER F6**	**OPER F7**	**FPER F1**	**FPER F2**	**FPER F3**	**FPER F4**	**FPER F5**
RPER F1	1,000	,696**	,604**	,549**	,395**	,329**	,327**	,354**	,309**	,366**	,286**	,320**	,409**	,350**	,402**	,398**
RPER F2	,696**	1,000	,633**	,648**	,429**	,328**	,365**	,431**	,425**	,442**	,304**	,343**	,417**	,435**	,445**	,437**
RPER F3	,604**	,633**	1,000	,621**	,526**	,408**	,421**	,343**	,327**	,419**	,330**	,334**	,420**	,382**	,455**	,370**
RPER F4	,549**	,648**	,621**	1,000	,549**	,415**	,357**	,392**	,340**	,432**	,397**	,383**	,524**	,499**	,474**	,437**
RPER F5	,395**	,429**	,526**	,549**	1,000	,442**	,368**	,382**	,359**	,432**	,391**	,414**	,479**	,447**	,452**	,529**
OPER F2	,329**	,328**	,408**	,415**	,442**	1,000	,681**	,531**	,448**	,529**	,351**	,443**	,445**	,387**	,453**	,425**
OPER F3	,327**	,365**	,421**	,357**	,368**	,681**	1,000	,616**	,536**	,540**	,399**	,436**	,476**	,446**	,520**	,435**
OPER F4	,354**	,431**	,343**	,392**	,382**	,531**	,616**	1,000	,535**	,548**	,466**	,516**	,497**	,483**	,587**	,486**
OPER F5	,309**	,425**	,327**	,340**	,359**	,448**	,536**	,535**	1,000	,566**	,403**	,484**	,474**	,439**	,526**	,436**
OPER F6	,366**	,442**	,419**	,432**	,432**	,529**	,540**	,548**	,566**	1,000	,419**	,489**	,449**	,458**	,500**	,469**
OPER F7	,286**	,304**	,330**	,397**	,391**	,351**	,399**	,466**	,403**	,419**	1,000	,416**	,444**	,410**	,443**	,484**
FPER F1	,320**	,343**	,334**	,383**	,414**	,443**	,436**	,516**	,484**	,489**	,416**	1,000	,601**	,488**	,515**	,493**
FPER F2	,409**	,417**	,420**	,524**	,479**	,445**	,476**	,497**	,474**	,449**	,444**	,601**	1,000	,737**	,734**	,567**
FPER F3	,350**	,435**	,382**	,499**	,447**	,387**	,446**	,483**	,439**	,458**	,410**	,488**	,737**	1,000	,787**	,605**
FPER F4	,402**	,445**	,455**	,474**	,452**	,453**	,520**	,587**	,526**	,500**	,443**	,515**	,734**	,787**	1,000	,579**
FPER F5	,398**	,437**	,370**	,437**	,529**	,425**	,435**	,486**	,436**	,469**	,484**	,493**	,567**	,605**	,579**	1,000

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author's own analysis

Appendix 7. Common Method Bias Test (All Items)

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	20,464	38,610	38,610	19,864	37,480	37,480
2	5,132	9,683	48,294			
3	2,150	4,057	52,350			
4	1,719	3,244	55,594			
5	1,534	2,894	58,488			
6	1,447	2,731	61,219			
7	1,359	2,564	63,782			
8	1,206	2,275	66,057			
9	1,102	2,079	68,136			
10	1,055	1,990	70,126			
11	,953	1,798	71,924			
12	,899	1,697	73,620			
13	,826	1,558	75,179			
14	,815	1,537	76,716			
15	,704	1,329	78,045			
16	,676	1,275	79,320			
17	,629	1,186	80,506			
18	,613	1,157	81,663			
19	,588	1,110	82,773			
20	,541	1,021	83,794			
21	,523	,986	84,780			
22	,491	,927	85,707			
23	,459	,865	86,572			
24	,450	,850	87,422			
25	,433	,817	88,239			
26	,411	,775	89,014			
27	,395	,746	89,759			
28	,356	,672	90,432			
29	,346	,653	91,085			
30	,335	,631	91,716			
31	,318	,601	92,317			
32	,310	,584	92,901			
33	,300	,566	93,467			
34	,268	,506	93,973			
35	,254	,480	94,452			
36	,245	,462	94,914			
37	,239	,451	95,365			
38	,230	,434	95,800			
39	,218	,412	96,211			
40	,212	,399	96,611			
41	,189	,356	96,967			
42	,186	,352	97,318			
43	,182	,344	97,663			
44	,171	,322	97,985			
45	,167	,315	98,300			
46	,150	,283	98,583			
47	,142	,269	98,851			
48	,132	,250	99,101			
49	,118	,223	99,324			
50	,106	,200	99,524			
51	,095	,179	99,703			
52	,083	,156	99,859			
53	,075	,141	100,000			

Extraction Method: Principal Axis Factoring.

Source: Author’s own analysis

Appendix 8. Tests of Normality (All Items)

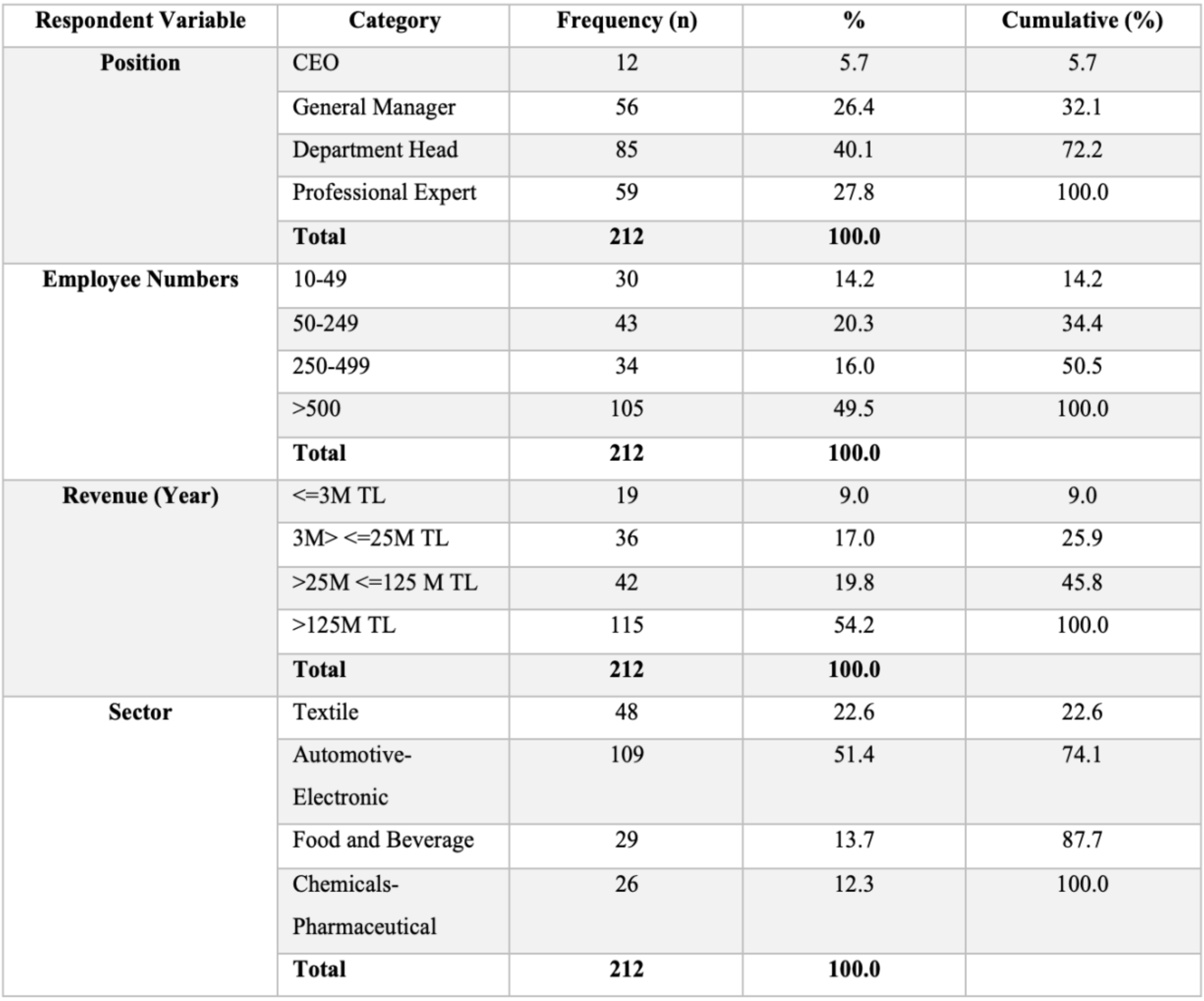
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
S&01	,192	212	,000	,906	212	,000
S&02	,224	212	,000	,897	212	,000
S&03	,286	212	,000	,826	212	,000
S&04	,160	212	,000	,904	212	,000
E&C1	,165	212	,000	,915	212	,000
E&C2	,163	212	,000	,909	212	,000
E&C3	,219	212	,000	,897	212	,000
E&C4	,241	212	,000	,881	212	,000
T1	,216	212	,000	,889	212	,000
T2	,219	212	,000	,903	212	,000
T3	,272	212	,000	,833	212	,000
T4	,226	212	,000	,869	212	,000
T5	,220	212	,000	,889	212	,000
T6	,177	212	,000	,895	212	,000
T7	,205	212	,000	,902	212	,000
T8	,164	212	,000	,896	212	,000
T9	,205	212	,000	,857	212	,000
T10	,232	212	,000	,808	212	,000
T11	,297	212	,000	,770	212	,000
T12	,215	212	,000	,858	212	,000
T13	,201	212	,000	,905	212	,000
T14	,166	212	,000	,916	212	,000
T15	,169	212	,000	,881	212	,000
T16	,169	212	,000	,916	212	,000
RPERF1	,245	212	,000	,881	212	,000
RPERF2	,247	212	,000	,872	212	,000
RPERF3	,219	212	,000	,887	212	,000
RPERF4	,206	212	,000	,894	212	,000
RPERF5	,246	212	,000	,862	212	,000
OPERF1	,295	212	,000	,846	212	,000
OPERF2	,254	212	,000	,814	212	,000
OPERF3	,256	212	,000	,798	212	,000
OPERF4	,283	212	,000	,840	212	,000
OPERF5	,274	212	,000	,826	212	,000
OPERF6	,264	212	,000	,832	212	,000
OPERF7	,269	212	,000	,800	212	,000
FPERF1	,269	212	,000	,814	212	,000
FPERF2	,249	212	,000	,862	212	,000
FPERF3	,259	212	,000	,879	212	,000

FPERF4	,259	212	,000	,867	212	,000
FPERF5	,245	212	,000	,865	212	,000
SInt1	,227	212	,000	,896	212	,000
SInt2	,271	212	,000	,876	212	,000
SInt3	,234	212	,000	,893	212	,000
SI4nt	,200	212	,000	,908	212	,000
IInt1	,242	212	,000	,876	212	,000
IInt2	,269	212	,000	,865	212	,000
IInt3	,243	212	,000	,868	212	,000
IInt4	,244	212	,000	,868	212	,000
CInt1	,220	212	,000	,888	212	,000
CInt2	,242	212	,000	,883	212	,000
CInt3	,192	212	,000	,896	212	,000
CInt4	,234	212	,000	,885	212	,000

Source: Author’s own analysis

Appendix 9. The demographic profiles of the respondents and companies



Respondent Variable	Category	Frequency (n)	%	Cumulative (%)
Position	CEO	12	5.7	5.7
	General Manager	56	26.4	32.1
	Department Head	85	40.1	72.2
	Professional Expert	59	27.8	100.0
	Total	**212**	**100.0**	
Employee Numbers	10-49	30	14.2	14.2
	50-249	43	20.3	34.4
	250-499	34	16.0	50.5
	>500	105	49.5	100.0
	Total	**212**	**100.0**	
Revenue (Year)	<=3M TL	19	9.0	9.0
	3M> <=25M TL	36	17.0	25.9
	>25M <=125 M TL	42	19.8	45.8
	>125M TL	115	54.2	100.0
	Total	**212**	**100.0**	
Sector	Textile	48	22.6	22.6
	Automotive-Electronic	109	51.4	74.1
	Food and Beverage	29	13.7	87.7
	Chemicals-Pharmaceutical	26	12.3	100.0
	Total	**212**	**100.0**	

Source: Author’s own analysis

Appendix 10. The Descriptive Statistics of Industry 4.0 Items

Elements	**Items**	**Frequency**					**Mean**	**SD**
		1	2	3	4	5		
S&O	S&O1	14.2	20.8	25.5	30.2	9.4	3	1.20
	S&O2	12.3	21.7	19.3	34.0	12.7	3.13	1.24
	S&O3	0.5	4.7	15.1	51.4	28.3	4.02	0.81
	S&O4	17.9	22.2	23.6	22.2	14.2	2.92	1.31
E&C	E&C1	12.3	20.8	29.2	25.9	11.8	3.04	1.19
	E&C2	17.0	17.9	29.7	22.6	12.7	2.96	1.26
	E&C3	8.5	12.7	27.8	35.4	15.6	3.37	1.14
	E&C4	2.4	9.0	26.4	40.6	21.7	3.70	0.98
T	T1	9.4	10.4	31.6	36.3	12.3	3.32	1.11
	T2	7.1	16.0	28.8	35.8	12.3	3.30	1.09
	T3	8.0	9.0	13.7	37.7	31.6	3.76	1.21
	T4	3.8	7.5	24.5	35.8	28.3	3.77	1.06
	T5	8.5	14.2	22.2	32.5	22.6	3.47	1.22
	T6	17.0	15.1	24.1	25.0	18.9	3.14	1.35
	T7	7.5	14.6	26.9	32.1	18.9	3.40	1.17
	T8	25.0	22.6	25.9	19.3	7.1	2.61	1.24
	T9	34.9	20.8	17.9	16.5	9.9	2.46	1.37
	T10	18.4	11.3	9.4	22.2	38.7	3.51	1.53
	T11	50.0	13.7	13.2	9.4	13.7	2.23	1.48
	T12	31.6	27.8	19.8	9.9	10.8	2.41	1.31
	T13	9.0	18.4	24.5	30.7	17.5	3.29	1.21
	T14	10.4	20.8	30.7	26.4	11.8	3.08	1.16
	T15	27.4	20.3	18.9	23.6	9.9	2.68	1.35
	T16	9.9	19.3	33.5	24.1	13.2	3.11	1.16

Source: Author’s own analysis

Appendix 11. The Descriptive Statistics of SCI Items

Elements	Items	Frequency					Mean	SD
		1	2	3	4	5		
SInt	SInt1	2.8	12.7	30.7	38.2	15.6	3.51	0.99
	SInt2	2.8	11.3	26.4	45.8	13.7	3.56	0.95
	SInt3	1.9	12.7	30.7	39.6	15.1	3.53	0.96
	SInt4	4.7	17.9	30.2	32.5	14.6	3.34	1.07
IInt	IInt1	0.5	8.5	27.4	42.0	21.7	3.76	0.90
	IInt2	0.9	7.5	23.1	46.7	21.7	3.81	0.89
	IInt3	1.4	5.2	27.8	42.9	22.6	3.80	0.89
	IInt4	1.4	5.2	27.4	42.9	23.1	3.81	0.89
CInt	CInt1	2.8	9.0	30.2	37.3	20.8	3.64	0.99
	CInt2	1.9	9.4	27.4	41.0	20.3	3.68	0.96
	CInt3	4.2	10.4	36.3	29.2	19.8	3.50	1.05
	CInt4	1.4	9.4	29.2	40.1	19.8	3.67	0.94

Source: Author’s own analysis

Appendix 12. The Descriptive Statistics of SCP Items

Elements	Items	Frequency					Mean	SD
		1	2	3	4	5		
RPERF	RPERF1	1.4	10.4	44.3	33.0	10.8	3.42	0.86
	RPERF2	0.9	8.5	43.9	36.3	10.4	3.47	0.82
	RPERF3	1.4	9.9	37.3	38.2	13.2	3.52	0.89
	RPERF4	2.4	13.2	38.7	35.4	10.4	3.38	0.92
	RPERF5	2.4	3.8	31.1	43.9	18.9	3.73	0.89
OPERF	OPERF1	1.4	5.2	25.0	52.4	16.0	3.76	0.83
	OPERF2	0.9	2.4	15.1	46.2	35.4	4.13	0.81
	OPERF3	0.9	1.4	13.2	48.1	36.3	4.17	0.78
	OPERF4	1.4	3.8	20.8	50.5	23.6	3.91	0.84
	OPERF5	1.4	2.4	18.4	49.5	28.3	4.01	0.83
	OPERF6	0.5	2.8	17.9	49.1	29.7	4.05	0.79
	OPERF7	0.5	1.4	12.7	52.8	32.5	4.16	0.72
FPERF	FPERF1	1.4	2.8	15.1	47.6	33.0	4.08	0.84
	FPERF2	0.5	6.1	23.6	43.9	25.9	3.89	0.88
	FPERF3	1.4	9.9	27.4	44.3	17.0	3.66	0.92
	FPERF4	0.5	6.1	28.8	46.2	18.4	3.76	0.84
	FPERF5	0.9	7.1	23.1	42.0	26.9	3.87	0.92

Source: Author’s own analysis

Appendix 13. Path Coefficients (PLS-SEM)

	CInt	**E&C**	**FPERF**	**I.4.0**	**IInt**	**OPERF**	**RPERF**	**SCI**	**SCP**	**SInt**	**S&O**	**T**
CInt												
E&C												
FPERF												
I.4.0		0,907						0,630	0,169		0,879	0,956
IInt												
OPERF												
RESPERF												
SCI	0,874				0,852				0,632	0,891		
SCP			0,904			0,905	0,842					
SInt												
S&O												
T												

Source: Author’s own analysis

Appendix 14. Specific Indirect Effects (PLS-SEM)

	Specific Indirect Effects
I.4.0 -> SCI -> CInt	0,551
I.4.0 -> SCP -> FPERF	0,153
SCI -> SCP -> FPERF	0,571
I.4.0 -> SCI -> SCP -> FPERF	0,360
I.4.0 -> SCI -> IInt	0,537
I.4.0 -> SCP -> OPERF	0,153
SCI -> SCP -> OPERF	0,572
I.4.0 -> SCI -> SCP -> OPERF	0,360
I.4.0 -> SCP -> RPERF	0,143
SCI -> SCP -> RPERF	0,532
I.4.0 -> SCI -> SCP -> RPERF	0,335
I.4.0 -> SCI -> SCP	0,398
I.4.0 -> SCI -> SInt	0,561

Source: Author’s own analysis

Appendix 15. Total Effects (PLS-SEM)

	CInt	E&C	FPERF	I.4.0	IInt	OPERF	RPERF	SCI	SCP	SInt	S&O	T
CInt												
E&C												
FPERF												
I.4.0	0,551	0,907	0,513		0,537	0,514	0,478	0,630	0,568	0,561	0,879	0,956
IInt												
OPERF												
RPERF												
SCI	0,874		0,571		0,852	0,572	0,532		0,632	0,891		
SCP			0,904			0,905	0,842					
SInt												
S&O												
T												

Source: Author’s own analysis

Appendix 16. R Square (PLS-SEM)

	R Square	R Square Adjusted
CInt	0,765	0,763
E&C	0,822	0,822
FPERF	0,817	0,816
IInt	0,727	0,725
OPERF	0,819	0,818
RPERF	0,709	0,707
SCI	0,398	0,395
SCP	0,566	0,56
SInt	0,793	0,792
S&O	0,773	0,772
T	0,914	0,914

Source: Author's own analysis

Appendix 17. f square (PLS-SEM)

	CInt	E&C	FPERF	I.4.0	IInt	OPERF	RPERF	SCI	SCP	SInt	S&O	T
CInt												
E&C												
FPERF												
I.4.0		**4,629**						**0,659**	0,040		**3,411**	**10,632**
IInt												
OPERF												
RPERF												
SCI	**3,247**				**2,658**				**0,551**	**3,839**		
SCP			**4,461**			**4,531**	**2,433**					
SInt												
S&O												
T												

Source: Author's own analysis

Appendix 18. Construct Reliability and Validity (PLS-SEM)

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
CInt	0,912	0,913	0,938	0,791
E&C	0,823	0,828	0,883	0,655
FPERF	0,892	0,894	0,921	0,701
I.4.0	0,947	0,948	0,953	0,576
IInt	0,919	0,919	0,943	0,805
OPERF	0,871	0,872	0,903	0,609
RPERF	0,870	0,872	0,906	0,660
SCI	0,938	0,938	0,946	0,595
SCP	0,936	0,937	0,943	0,511
SInt	0,889	0,890	0,924	0,751
S&O	0,900	0,906	0,938	0,834
T	0,913	0,914	0,930	0,623

Source: Author’s own analysis

Appendix 19. Construct Reliability and Validity (PLS-SEM)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
I.4.0 -> E&C	0,91	0,907	0,014	65,506	0,000
I.4.0 -> SCI	0,630	0,630	0,054	12,135	0,000
I.4.0 -> SCP	0,17	0,171	0,067	2,670	0,011
I.4.0 -> S&O	0,879	0,880	0,015	60,355	0,000
I.4.0 -> T	0,956	0,956	0,006	148,525	0,000
SCI -> CInt	0,874	0,875	0,019	46,607	0,000
SCI -> IInt	0,852	0,851	0,024	35,344	0,000
SCI -> SCP	0,635	0,630	0,064	9,964	0,000
SCI -> SInt	0,891	0,891	0,016	57,291	0,000
SCP -> FPERF	0,904	0,905	0,013	69,780	0,000
SCP -> OPERF	0,905	0,905	0,018	51,106	0,000
SCP -> RPERF	0,842	0,842	0,026	31,789	0,000

Source: Author’s own analysis

Appendix 20. Total Effects (Bootstrapping)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
I.4.0 -> CInt	0,551	0,552	0,052	10,569	**0,000**
I.4.0 -> E&C	0,907	0,907	0,014	65,506	**0,000**
I.4.0 -> FPERF	0,513	0,514	0,056	9,147	**0,000**
I.4.0 -> IInt	0,537	0,537	0,051	10,448	**0,000**
I.4.0 -> OPERF	0,514	0,515	0,058	8,807	**0,000**
I.4.0 -> RPERF	0,478	0,479	0,058	8,228	**0,000**
I.4.0 -> SCI	0,630	0,630	0,054	11,599	**0,000**
I.4.0 -> SCP	0,568	0,568	0,060	9,513	**0,000**
I.4.0 -> SInt	0,561	0,562	0,052	10,885	**0,000**
I.4.0 -> S&O	0,879	0,880	0,015	60,355	**0,000**
I.4.0 -> T	0,956	0,956	0,006	148,525	**0,000**
SCI -> CInt	0,874	0,875	0,019	46,607	**0,000**
SCI -> FPERF	0,571	0,571	0,061	9,322	**0,000**
SCI -> IInt	0,852	0,851	0,024	35,344	**0,000**
SCI -> OPERF	0,572	0,571	0,062	9,242	**0,000**
SCI -> RPERF	0,532	0,531	0,059	8,994	**0,000**
SCI -> SCP	0,632	0,630	0,064	9,811	**0,000**
SCI -> SInt	0,891	0,891	0,016	57,291	**0,000**
SCP -> FPERF	0,904	0,905	0,013	69,780	**0,000**
SCP -> OPERF	0,905	0,905	0,018	51,106	**0,000**
SCP -> RPERF	0,842	0,842	0,026	31,789	**0,000**

Source: Author’s own analysis