THE ROLE OF INDUSTRY 4.0 IN ENHANCING SUPPLY CHAIN MANAGEMENT: AN EMPIRICAL ANALYSIS OF MALAYSIAN MANUFACTURING FIRMS USING PLS-SEM

YEANG KAI XIANG

UNIVERSITI TUNKU ABDUL RAHMAN

THE ROLE OF INDUSTRY 4.0 IN ENHANCING SUPPLY CHAIN MANAGEMENT: AN EMPIRICAL ANALYSIS OF MALAYSIAN MANUFACTURING FIRMS USING PLS-SEM

YEANG KAI XIANG

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Mechanical Engineering with Honours

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

May 2024

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature	:	
Name	:	Yeang Kai Xiang
ID No.	:	2100041
Date	:	15 May 2024

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"THE ROLE OF INDUSTRY 4.0 IN ENHANCING SUPPLY CHAIN MANAGEMENT: AN EMPIRICAL ANALYSIS OF MALAYSIAN MANUFACTURING FIRMS USING PLS-SEM"** was prepared by **YEANG KAI XIANG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Mechanical Engineering with Honours at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________

Supervisor : Cheong Wen Chiet

Date : 17 May 2024

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Mr. Cheong Wen Chiet for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parents and friends who helped and encouraged me throughout this project. Besides that, I would like to thank all the respondents who had participated and responded to my email and the Google Forms questionnaire survey as well as the academic and industrial experts who were involved in the questionnaire prestest section for providing their valuable suggestions to improve the questionnaire.

ABSTRACT

The rapid emerging of digital revolution and intelligent technologies have reshaping the operations in every sectors include the supply chain of manufacturing sector globally. This empirical study explores into how supply chain management (SCM) and performance (SCP) are affected by Industry 4.0 (IR4.0) as well as how SCM mediates this relation in manufacturing companies in Malaysia. The study uses Partial Least Square Structural Equation Modelling (PLS-SEM) to assess the correlations between IR4.0, SCM and SCP by utilising empirical data gathered from 108 industrial respondents digitally with Google Forms. The outcomes show that IR4.0 technologies have a favourable impact on SCM and SCP, with SCM behaving as a mediator in this interaction. The study also looks into the managerial and theoretical implications of combining the IR4.0 and SCM. This highlights the need of ongoing planning and effective execution of IR4.0 and SCM simulteneously to further boosting the SCP. In shorts, this study advances the understanding and exploration on how the implementation of IR4.0 and SCM could enhance the SCP of manufacturing firms in Malaysia, providing insightful information to the academics and managers worldwide.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

f^2	effect size
α	significance level
1-β	power level
α	Cronbach's Alpha
ρ_c	composite reliability
R^2	predictive accuracy
Q^2	predictive relevance

AVE	Average Variance Extracted
BDA	Big data analytic
BWM	Best worst method
CAD	Computer aided design
CMV	Common method variance
CPS	Cyber-physical system
CSCMP	Council of Supply Chain Management Professionals
HOC	Higher order construct
HTMT	Heterotrait-Monotrait
INT	Interoperability
IoT	Internet of Things
IPMA	Importance-performance method analysis
IR4.0	Industry 4.0
LM	Linear regression model
LOC	Lower order construct
MAE	Mean Absolute Error
OL	Outer Loadings
PLS-SEM	Partial least square structural equation modelling
RFID	Radio frequency identification
RMSE	Root Mean Squared Error
SC	Supply chain
SC4.0	Supply chain 4.0
SCM	Supply chain management
SCM4.0	Supply chain management 4.0

SCP	Supply chain performance
SEM	Structural equation modelling
SF	Smart factory
SSCM	Smart supply chain management
VIF	Variance Inflation Factor
VR	Virtual reality
WSN	Wireless sensor network

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In year 2011, Industry 4.0 (IR4.0) was initially introduced at Germany which bring digital and smart transformation to the world especially in the industrial fields (Vaidya, Ambad and Bhosle, 2018). The terminology IR4.0 refers to as the fourth industrial revolution, certainly there will be first, second and third industrial revolution before this which contributed by the mechanization, electrical power and information technology (Kagermann, Wahlster and Helbig, 2013). As a recall, Industry 1.0 starts with the mechanization, steam power and weaving loom in the year 1784. Next, the Industry 2.0 concept shown up in 1870 which is related to the mass production and electrical energy. After 99 years in 1969, Industry 2.0 is being transformed to Industry 3.0 with the introduce and implement of automation, computer and electronics technologies which improve the manufacturing process speed significantly (Klingenberg, Borges and do Vale Antunes Jr., 2022). Figure 1.1 illustrates the phases of industrial revolution from Industry 1.0 to 4.0 (Ferrantino and Koten, 2017).

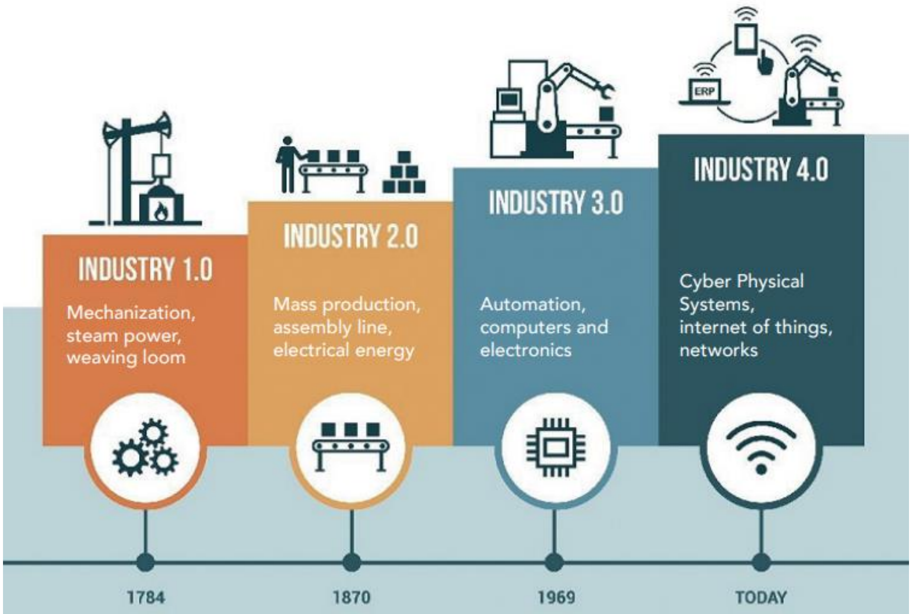

Figure 1.1: Industrial Revolution (Ferrantino and Koten, 2017).

Industrial 4.0 comprises the use of various advanced technologies and concepts which has listed and critically reviewed by Ghobakhloo (2018). These smart technologies may include the cyber-physical system (CPS), Internet of Things (IoT), big data analytic (BDA), cloud computing, blockchain, 3D printing etc. On the other hands, the principles involve smart factory (SF), smart product, interoperability (INT), virtualization, real-time capability etc. Among all these IR4.0 technologies, CPS and IoT are the two main key technologies concluded by Lu (2017b) and Ghobakhloo (2018). Other than these, the BDA, SF and INT are the another three significant technologies and foundation to successfully drive the implementation of IR4.0 (Govindan, et al. 2018; Imran, Hameed and Haque, 2018).

Besides that, supply chain management (SCM) and performance (SCP) is another area that will be studied in the research. Supply chain consists of the connection and cooperation between all supply chain parties, like the suppliers, manufacturers, distributors, retailers and lastly the customers (Raja Santhi and Muthuswamy, 2022). The handling of the supply chain processes and activities to enable all the supply chain members work together is defined as the SCM (Basuki, 2021; Duong, et al., 2019). Whereas SCP is a measure of how well the performance and the effects bring to the supply chain to satisfy the daily demands in the market (Som, Cobblah and Anyigba, 2019; Lee, et al., 2022).

As the introduce of IR4.0 concept, this has been implemented into the supply chain and management as well, so called the smart supply chain management (SSCM) or supply chain 4.0 (SC4.0) according to Hofmann, et al. (2019) and Yuan and Xue (2023). This implementation further improves the SCP based on Govindan, et al. (2022).

1.2 Importance of the Study

The integration and effect of the IR4.0 key technologies and foundation on the SCM and SCP will be reviewed and studied empirically in the context of manufacturing firms in Malaysia. Sample data will be collected from various fields of manufacturing industry to showcase how the industrial people is thinking and concerning on the impact of IR4.0 technologies and concepts on the performance and management of supply chain in Malaysia. The sample data will then be analysed using PLS-SEM method. In addition, due to the huge negative impact causes by the Covid-19 pandemic and the Russia and Ukraine War to the world, a lot of manufacturing plants and retail shops are shutting down in this period. The logistic and harvest supply is also negatively affected, results in the shortage of supply and price increases, ultimately affecting the whole supply chain. Therefore, the adoption of IR4.0 technologies and concepts is vital and necessary to minimize and overcome these scenarios now and in the future world although if the pandemic has over, still the people might already have different point of view after this pandemic (Erboz, G. and Yumurtacı Hüseyinoğlu, I.Ö, 2023; Liu and Chiu, 2021). Some researchers (Reza, et al., 2022; Raja Santhi and Muthuswamy, 2022) have carry the research study as well on how the problems in supply chain will be affected and solved by the IR4.0 during this pandemic.

1.3 Problem Statement

Despite the IR4.0 technologies and concept is very advanced and useful in enhancing the supply chain, Tay, Alipal and Lee (2021) have found out that the manufacturer in Malaysia still in a “trying” stage to implement IR4.0 in various aspects include SCM. This is due to the IR4.0 complexity, traditional mindset, investment cost, lack of expertise and knowledge. Besides that, there is also lack of empirical study on how IR4.0 affecting SCM and SCP and how SCM mediates this relation. This empirical study may further help to promote and boost the confidence level of manufacturing firms in Malaysia to implement IR4.0 in supply chain without solely rely on the theoretical research studies. Table 1.1 summarizes the research gaps among some previous empirical study that is relevant to the topic of this research study.

Table 1.1: Summary of Previous Related Empirical Study.

Source	Methodology	Variables	Country
Imran, et al., 2018	Empirical, PLS-SEM	- Industry 4.0 - Production/Services - Production/Services industry performance	Pakistan
Erboz, et al., 2022	Empirical, PLS-SEM	- Industry 4.0 - SC integration - SCP	Turkey

Lee, et al., 2022	Empirical, PLS-SEM	- Digitalization - Technology implementation - SCM - SCP - Organizational performance	Malaysia
Sundram, et al., 2018	Empirical, Mediated Multiple Regression Analysis	- SC information management - SC information system infrastructure - SC integration - Manufacturing performance	Malaysia
Duong, et al., 2019	Empirical, SEM	- SCM - Organizational performance	Veitnam
Gupta, et al., 2021	Empirical, Best Worst Method (BWM)	- Industry 4.0 - SCP	-
Jayashree, et al., 2021	Empirical, SEM	- Technologies innovation characteristics - Industry 4.0 implementation - Three bottom line sustainability	Malaysia
Liu and Chiu, 2021	Empirical, PLS-SEM	- SC digitalization - Internal integration - Financial performance	China

1.4 Aim and Objectives

This final year project study aims to investigate and evaluate the influences and role of IR4.0 in enhancing the SCM and SCP of manufacturing firms in Malaysia through partial least square structural equation modelling (PLS-SEM). Objectives of this study are listed as below:

(i) To examine the influence of IR4.0 key technologies and concepts on SCM and SCP.

(ii) To develop the research model for this study.

(iii) To evaluate the correlation between IR4.0 and supply chain in manufacturing firms.

(iv) To determine the mediation effect of SCM on IR4.0 and SCP.

1.5 Scope and Limitation of the Study

This research study targets to review and understand on how the IR4.0 technologies and principles influence the SCM and SCP. Next, the measurement items are determined to form the questionnaire and distribute to the industrial people who are working in a manufacturing plant in Malaysia. The collected sample data are then analysed using PLS-SEM method to obtain the findings.

However, there are limitations in this research study. Firstly, this study is only focused on the manufacturing firms in supply chain but not other supply chain members such as the raw material suppliers, distributors, retailers and end users. Secondly, the target manufacturing firms of this study is only located in Malaysia but not other countries or regions. Besides, the respondents from the manufacturing firms may not only having the expertise in the IR4.0 or supply chain fields but yet at least having some working experiences in the related fields and able to understand and answer to the questionnaire.

1.6 Contribution of the Study

The management of supply chain is crucial to ensure the products and services are delivered smoothly from the initial suppliers until the final end users. Therefore, the enhancement of SCP is necessary to ensure a more effective supply chain flows as well as the necessity to implement both IR4.0 and SCM simultaneously or either one through the IPMA study in section 4.6.

In this study, the relationship between IR4.0, SCM and SCP are examined empirically to showcase the integration of IR4.0 and SCM in the manufacturer's supply chain able to improve the SCP as well as lessen the literature gap (Chauhan and Singh, 2020; Govindan, et al., 2022). Researchers and industrial people can determine the impact magnitude and significance of implementing both IR4.0 and SCM with the support of empirical data. After the integration of IR4.0 and SCM, the manufacturers may get some improvement in the SCP. Besides, the researchers may investigate and study more the colleration among the variables from the proposed research model.

1.7 Outline of the Report

This report comprises a total of five chapters. In the first chapter, a brief introduction to the background of title related content is discussed as well as the significance of study, problem statement, aims and objectives. In the following second chapter, the topics of study are reviewed throughoutly from various journal articles, which include the IR4.0, SCM, SCP and the impact of IR4.0 on supply chain. Furthermore, all the procedures and work plans that required in this study are addressed in the third chapter. In the coming fourth chapter, the PLS-SEM analysis results and implications are displayed and assessed in detailed. Ultimately, conclusion is made and possible future works are suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review chapter comprises detailed study of journals and articles that are relevant to this project. The review areas include the IR4.0, SCM and SCP while the hypotheses and research framework are being proposed and formed.

2.2 Industry 4.0 (IR4.0)

Fourth Industrial Revolution or widely recognised as IR4.0, was first originated at the Hannover Exhibition by the government of Germany in 2011 and formally declared in 2013. The introduce of IR4.0 had transformed the industrial sector with highly integrated and automated systems. IR4.0 illustrates the shift of the industrial system from embedded networks to cyber-physical networks. This revolution is connecting and combining the physical worlds and the virtual worlds together (Li, Eric and Ling, 2018).

Erboz, Yumurtacı Hüseyinoğlu and Szegedi (2022) had summarized that CPS, IoT, SF as well as any other knowledges that are related to computer operation, autonomous control system, robotics and sensors are all included in the broad understanding of IR4.0 ideas. IR4.0 includes combining of various digital technologies for building the interconnected system. Besides, in order to be prepared for the implementation of IR4.0, Sony and Naik (2019) came out with the six main criteria which are the top management participation, staff adaptability, organizational strategy readiness, degree of digitalization, extent of supply chain digitalization as well as smart product and services.

Furthermore, Govindan, et al. (2018) also stated IR4.0 concept is closely related to CPS, IoT and SF. This IR4.0 concept seeks to automate the manufacturing process, enhance transparency and allow customized production. This IR4.0 concept also able to combine automation with computers, with robots linked to computer systems and guided by machine learning. In order to link all these technologies, IR4.0 requires to have some significant characteristics such as interoperability (INT), information transparency, real-time analysis, technical assistance as well as decentralised decision making (Tay, Alipal and Lee, 2021). In addition, IR4.0 promotes vertical, horizontal and end-to-end integration within organization and with other organizations such as the supplier. This allows the relation and communication enhancement between the consumer, manufacturer and supplier (Li, Eric and Ling, 2018).

According to Imran, Hameed and Haque (2018), the fundamental drivers of IR4.0 could be classified into two main categories. First, IR4.0 is driven by the advanced technologies development, so called the IR4.0 key technology and foundation. These IR4.0 technologies and foundations primarily include the CPS, IoT, BDA, SF and INT as shown in Figure 2.1 which these five will be used as the parameters in this research study (Manavalan and Jayakrishna, 2019; Lu, 2017a). Second, IR4.0 is motivated by the urge from multiple industrial companies to reduce the labour costs and human errors by implementing the integrated and automated system with the help of the development of IR4.0.

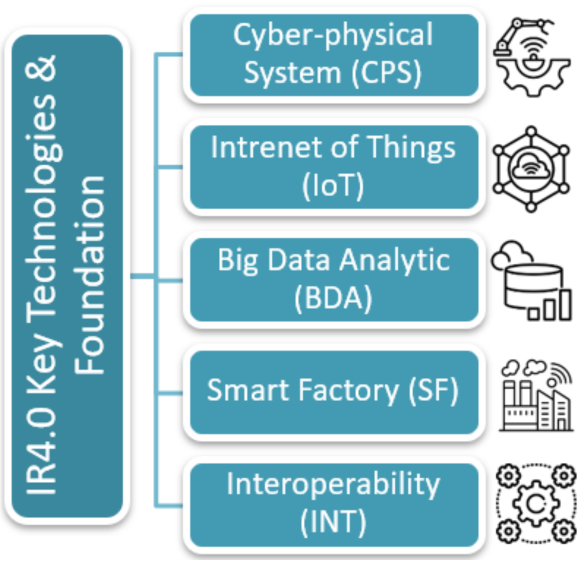

Figure 2.1: Industry 4.0 Key Technologies and Foundations.

In short, both Lu (2017b) and Ghobakhloo (2018) have summarized and concluded that CPS and IoT are the two main key technologies and how well these two interoperate with other significant technologies and concepts of Industry 4.0.

2.2.1 Cyber-Physical System (CPS)

Based on the research by few scholars (Roblek, Meško and Krapež, 2016; Wang, et al., 2017; Pivoto, et al., 2021), CPS is one of the IR4.0 key foundations. CPS has completed three stages of evolution, which are the radio frequency identification (RFID) technologies, sensors and actuators as well as storage capable and data analysed sensors and actuators (Wang, et al., 2017). CPS is an advanced embedded system that allows the linkage and integration between digital worlds and physical worlds. With this linkage, CPS allows real-time information exchange and interaction across multiple machines and devices. In the Industry 4.0 environment, organizations place a high priority on security, stability, adaptability, safety and usability to ensure the secure transfer of confidential and private information by the CPS infrastructure (Pivoto, et al., 2021; Li, Eric and Ling, 2018).

As compared to the traditional embedded system, CPS includes networked interactions which require uses of sensors to help in detecting the wrong or failure operations in the machines and provide necessary actions or signals to correct the operations immediately (Zhong, et al., 2017; Vaidya, Ambad and Bhosle, 2018). Besides, Govindan, et al. (2018) had summarized the benefits of CPS where CPS able to perform design improvement and validation by utilising CAD software as well as Virtual Reality (VR) equipment. CPS also helps in waste and cost reduction, autonomous error detection, fake product detection, load time reduction as well as improvement of delivery and shipping time and timeliness.

2.2.2 Internet of Things (IoT)

IoT is normally known as the powerful and networked communication across the physical and digital worlds globally. Nowadays, IoT has rapidly developed as a result of explosively growth of internet, sensors and wireless technology. IoT typically links devices, sensors and actuators through internet network to allow object-to-object interaction for data collection and information exchange anytime anywhere immediately. Currently, in order to create intelligent systems, products and services, IoT is implemented in many industry fields and daily life to allow remote monitoring and controlling, for instance smart home, smart manufacturing, healthcare, automotive and smart devices (Manavalan and Jayakrishna, 2019; Zhong, et al., 2017; Vaidya, Ambad and Bhosle, 2018).

IoT technology has undergone an amazing evolution, with origins in the 1980s when radio frequency identification (RFID) technology was first utilised for management of warehouse, followed by the emergence wireless sensor network (WSN) in the 1990s (Manavalan and Jayakrishna, 2019; Li, Eric and Ling, 2018). By offering immediate data collection and information exchange across linked devices, IoT has slowly changed the industry. The dynamic operation of IoT minimizes the need of human involvement by reacting and responding to different scenarios. RFID, cloud-based computing as well as hardware and software applications are the important IoT technologies that allow immediate and effective information transmission everywhere (Mubarak, et al., 2021; Jing, et al., 2014). IoT improves the effectiveness of the supply chain and decision making process because IoT provides real time information gathering, forecasting and remote operations (Raja Santhi and Muthuswamy, 2022).

2.2.3 Big Data Analytic (BDA)

Big data is the huge volume of data collected and produced by numerous devices. Big data analytic (BDA) refers to a process of able to store, handle, access, visualise and analyse complex and massive amounts of data which are unable to be processed by a single machine or computer (Zhong, et al., 2016). When big data is discussed, the thing that will probably come into mind would be the three V’s (3V’s) or five V’s (5V’s) which represent the dimensions for the big data. According to few scholars (Molka-Danielsen, et al., 2018; Zhong, et al., 2016; Gupta, et al, 2022), the dimension of big data can be grouped into total seven V’s (7V’s), which include volume, velocity, variety, verification, value, veracity and variability as shown in Figure 2.2.

Figure 2.2: Seven V's (7V's) of Big Data.

This BDA as one of the main technologies of IR4.0, becomes crucial when data enters the system's database continuously. Big data is the accumulating and detailed analysis of data and information from multiple sources which forms the basis for decision making and operational optimization (Mubarak, et al., 2021; Wang, et al., 2017). These data and information may include the customer contacts, sales, business processes and much more (Govindan, et al., 2018). In order to discover hidden patterns, connection and beneficial data, BDA includes the investigation of gigantic database (Raja Santhi and Muthuswamy, 2022). Nowadays, every organizations have to utilise this BDA technology to make best and accurate decisions, simplify various operations, improve efficiency of assets as well as forecast market future trends to maintain competitive advantages with other organizations (Ghobakhloo, 2018).

2.2.4 Smart Factory (SF)

Smart factory as one of the primary components of IR4.0, sometimes may refer to as intelligent factory, smart manufacturing or real-time factory (Strozzi, et al., 2017). Smart factory is an intelligent, dynamic and versatile manufacturing system equipped with advanced technologies and systems that interact and interoperate with each other. For instance, the advanced technologies and systems include CPS, IoT, BDA, additive manufacturing, simulation, sensors and actuators as well as autonomous robotic systems, allowing the machines and systems able to make decision and optimize manufacturing system performance independently without human involvement. All the smart devices and machines will be built into smart factories' higher level decision making systems, leading to a continuous and smooth interconnected manufacturing system where the machinery equipment, products and people can work together simultaneously (Ghobakhloo, 2018; Lu, 2017a; Strozzi, et al., 2017; Wang, et al., 2016).

Furthermore, smart factory intends to perform self-optimization to reduce manufacturing waste, errors and process downtime and enhance the efficiency of manufacturing process (Ghobakhloo, 2018). This smart factory concept has changed the manufacturing sector by providing an economical and flexible way of manufacture the products (Kagermann, Wahlster and Helbig, 2013). In addition, as compared to the concept of mass production, smart factory allows mass customization which is more cost effective to manufacture customized product (Strozzi, et al., 2017). Smart factory concept is essential to achieve industrial process that is highly interconnected, effective and smart throughout the supply chain involving suppliers, manufacturing plants, distribution centers until the consumers (Chen, et al., 2018). In short, the creation of smart factory enables interaction between machines, products and data, even the people through CPS and IoT, resulting in flexible and efficient manufacturing process (Li, Eric and Ling, 2018; Hermann, Pentek and Otto, 2016).

2.2.5 Interoperability (INT)

Interoperability as one of the significant foundations of IR4.0, refers to a principle that allows the communication of each system and machine with another and uses each other's capabilities. In IR4.0, interoperability is known as the potential of multiple smart systems, technologies, even people to exchange, communicate as well as grasp the significance of each information and data across many layers of the organizations as well as applications. Interoperability can be categorized into four categories, which are the technical, operational, systematically and semantic. This concept is crucial in concentrating on the meaning of each information and how every single different system can understand and manage the data for greater flexibility (Lu, 2017a; Ghobakhloo, 2018).

2.3 Supply Chain Management (SCM)

SCM is being introduced at the beginning of the 1980s, which is based on the logistic concept (Habib, 2011). According to the description provided by Council of Supply Chain Management Professionals (CSCMP, 2013), SCM refers to the scheduling and managing of operations that related to procurement, conversion, production, logistics, distribution and marketing. SCM helps to coordinate, cooperate and collaborate across all the supply chain members such as the suppliers, middlemen, external vendors, distributors, retailers, customers as well as the competitors, so called the co-opetition concept (Vedpal, Jain and Bhatnagar, 2012).

Likewise, based on the definitions by other researchers (Basuki, 2021; Duong, et al., 2019; Habib, 2011; Govindan, et al., 2018), SCM is a methodology or strategy to plan and coordinate daily business operations in the organization and together with other supply chain organizations such as suppliers and retailers. The business operations may include the locating and purchasing of materials from supplier, manufacturing the products and lastly, deliver, distribute and promote the products to the retailers and end users where Figure 2.3 shows the whole supply chain flows starting from the vendors to the final users (Raja Santhi and Muthuswamy, 2022).

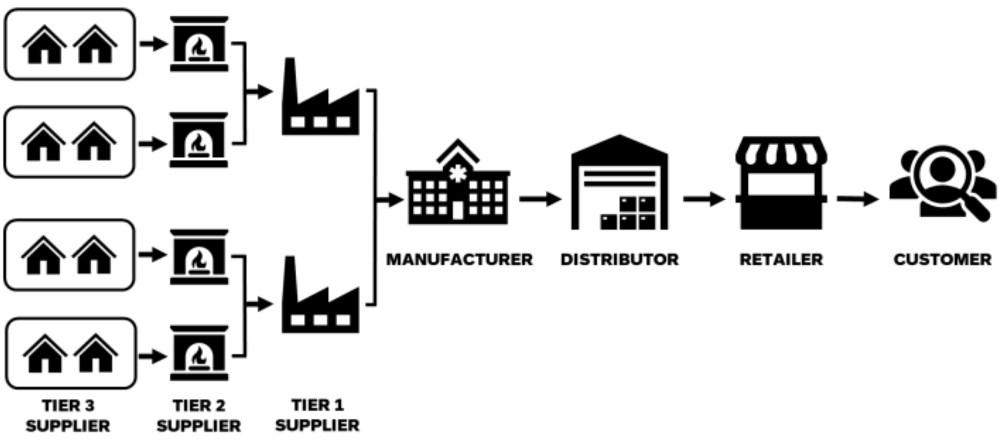

Figure 2.3: Supply Chain Flow (Raja Santhi and Muthuswamy, 2022).

The main purposes of this SCM strategy are to ensure the smooth forward and backward flow of goods, materials, money, services and data throughout the supply chain (Basuki, 2021; Habib, 2011). As shown in Figure 2.4, this traditional supply chain model illustrates the coordination of every supply chain member linearly (Ferrantino and Koten, 2017).

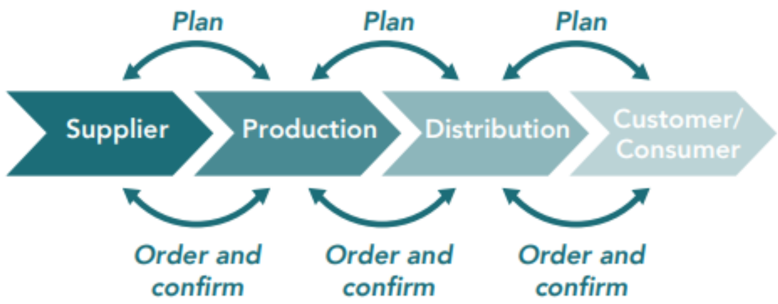

Figure 2.4: Traditional Supply Chain Model (Ferrantino and Koten, 2017).

Additionally, SCM allows the improvement of organization's value and profit, also satisfy the customers' requirements and demands. SCM intends to lower the operating expenses, ordering and delivery times. Besides, SCM also helps to enhance marketing effectiveness, delivery capacity and efficiency of raw material usage (Duong, et al., 2019). SCM places a significant focus on the seamless integration and effective collaboration between all supply chain activities in order to be a competing organization (Habib, 2011). In whole, SCM is a comprehensive strategy to manage and coordinate every flow and activity in the supply chain to ensure ideal cooperation between all supply chain parties.

2.4 Supply Chain Performance (SCP)

SCP is indicated as the measurement and evaluation of how well an organization performs in managing and carrying out the activities and operation in the supply chain to achieve customer demands and satisfaction and able to compete in the markets. SCP includes the results and impacts gained through the effective handling of the supply chain flows of the products or even services from the suppliers until the final customers (Som, Cobblah and Anyigba, 2019; Lee, et al., 2022).

There are various important dimensions that are frequently used to evaluate the performance of the supply chain activities which mainly consist of the scheduling, sourcing, manufacturing, delivering and retrieving (Gupta, et al., 2021). For instance, SCP can be evaluated by cost efficiency, quality, flexibility, responsiveness, visibility and delivery rate (Fatorachian and Kazemi, 2020; Som, Cobblah and Anyigba, 2019; Lee, et al., 2022). Additionally, the SCP can also be measured by the customer satisfaction, time and timeliness of delivery, order fulfilment rate and production lead time (Erboz, Yumurtacı Hüseyinoğlu and Szegedi, 2022). Shepherd and Günter, 2006 and Lehyani, et al. have also listed a full and detailed list of the SCP's indicators based on the key supply chain activities accordingly.

2.5 IR4.0 on Supply Chain

Recently, the rapid development of highly modern technologies and revolution of IR4.0, supply chain has been transformed and improved around the world. The adoption of IR4.0 concept and technologies into supply chain and SCM has generated new concepts or terms such as SC4.0, SCM4.0 or SSCM (Ferrantino and Koten, 2017; Liu and Chiu, 2021; Hofmann, et al., 2019; Yuan and Xue, 2023). As a result, the SCP will be improved and the advantages gained have been critically reviewed and discussed by Govindan, et al. (2022) which include a total of 32 benefits.

The adoption of IR4.0 technologies, for instance, CPS, IoT and BDA allow the whole supply chain to be more integrated. The flows of information and data are in any direction between all supply chain members through as control tower as illustrated in Figure 2.5, rather than linearly from the suppliers to the end users in the conventional supply chain as shown in Figure 2.4 previously (Ferrantino and Koten, 2017; Bentaher and Rajaa, 2022). In addition, the exchange of real time data in any direction able to improve the collaboration and engagement between all supply chain participants. The seamless flow of information and goods can lower the processing fees and further encourage stronger bonds between all supply chain members (Hofmann, et al., 2019).

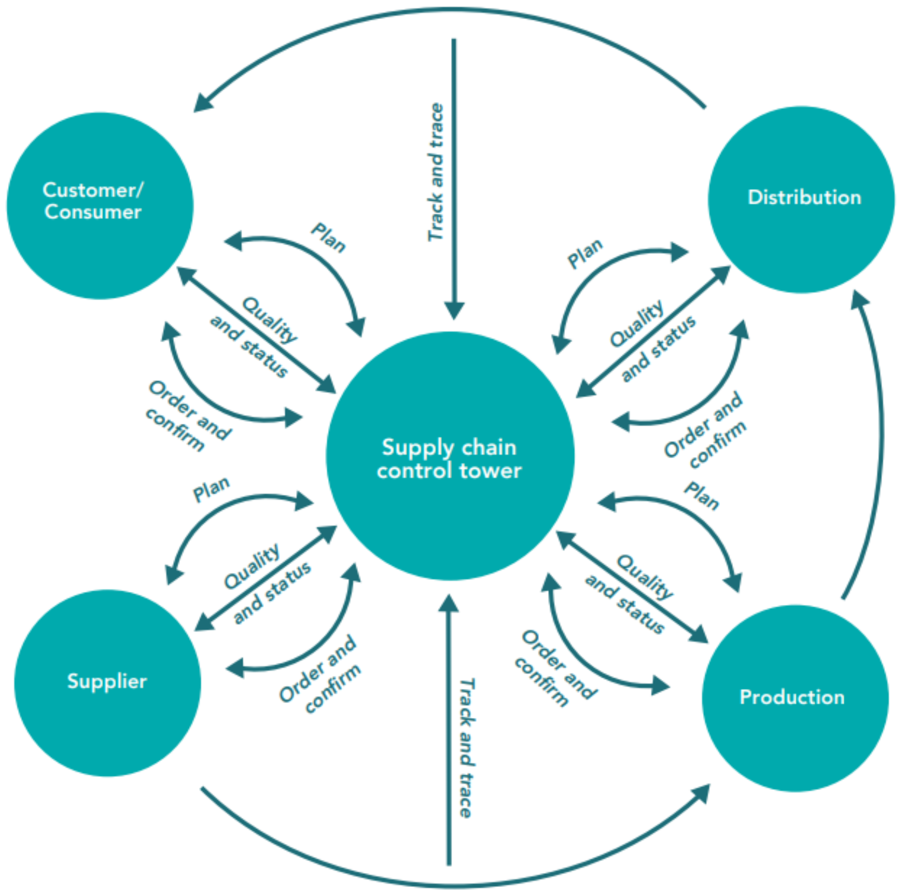

Figure 2.5: Supply Chain 4.0 Integration (Ferrantino and Koten, 2017).

Besides that, the transparency and visibility of the supply chain flows and activities can be enhanced as well. Any supply chain parties are able to track the location and quantity of each product and discover various components and activities to obtain the right information immediately throughout the supply chain (Rad, et al. 2022). This can ensure that the information transmitted and received by everyone is real and true to avoid bullwhip effect (Fatorachian and Kazemi, 2020; Raja Santhi and Muthuswamy, 2022). This advantage can further strengthen the rate of detection, responsiveness and managing ability to any delays happened and obstacles faced (Hofmann, et al., 2019).

Moreover, the utilise of IR4.0 key technology, big data analytic (BDA) able to provide relevant and valuable information and data to the supply chain. IoT devices, RFID tags and other different media will continuously capture and produce huge amounts of real-time data at a high speed which can be integrated with BDA devices to help and improve the production process planning, demands and market conditions forecasting as well as operations and delivery route optimization in supply chain (Rad, et al. 2022; Raja Santhi and Muthuswamy, 2022). As a result, this can help to minimize the cost incurred and improve efficiency as the planning, forecasting and optimizing of supply chain activities have done at the initial stage (Erboz and Yumurtacı Hüseyinoğlu, 2023; Zhang, Yang and Yang, 2023). BDA can also aid in making the decision such as selecting the right and best supplier based on the evaluation of various supplier performance (Bentaher and Rajaa, 2022).

In addition, based on the smart factory concept as discussed earlier, the manufacturer can implement customer-centric strategy. This strategy allows the customers to customize own products design and specifications in small amounts or even only one by utilizing the additive manufacturing (Hofmann, et al., 2019). Likewise, SC4.0 can also improve the customer value, expectations and satisfaction with the help of statistical analysis of data and continuous observing in real time (Rad, et al. 2022).

2.6 Hypotheses and Research Framework

In relation to the above review and study, the hypotheses and research framework of this study are developed. There are total of four hypotheses are created which are the direct interactions of IR4.0 key technologies and foundations and SCM on the SCP as well as the IR4.0 key technologies and foundations on the SCM. Additionally, the mediating role of SCM among the IR4.0 key technologies and foundations and SCP is also being investigated. IR4.0 is assigned as a higher order construct (HOC) which is determined with five lower order constructs (LOC) that include the BDA, CPS, INT, IOT and SF. Figure 2.6 illustrates the research framework while the hypotheses are:

H1: IR4.0 key technologies and foundations favourably affect the SCM.

H2: IR4.0 key technologies and foundations favourably affect the SCP.

H3: SCM favourably affect the SCP.

H4: SCM mediates the correlation among IR4.0 key technologies and foundations and SCP.

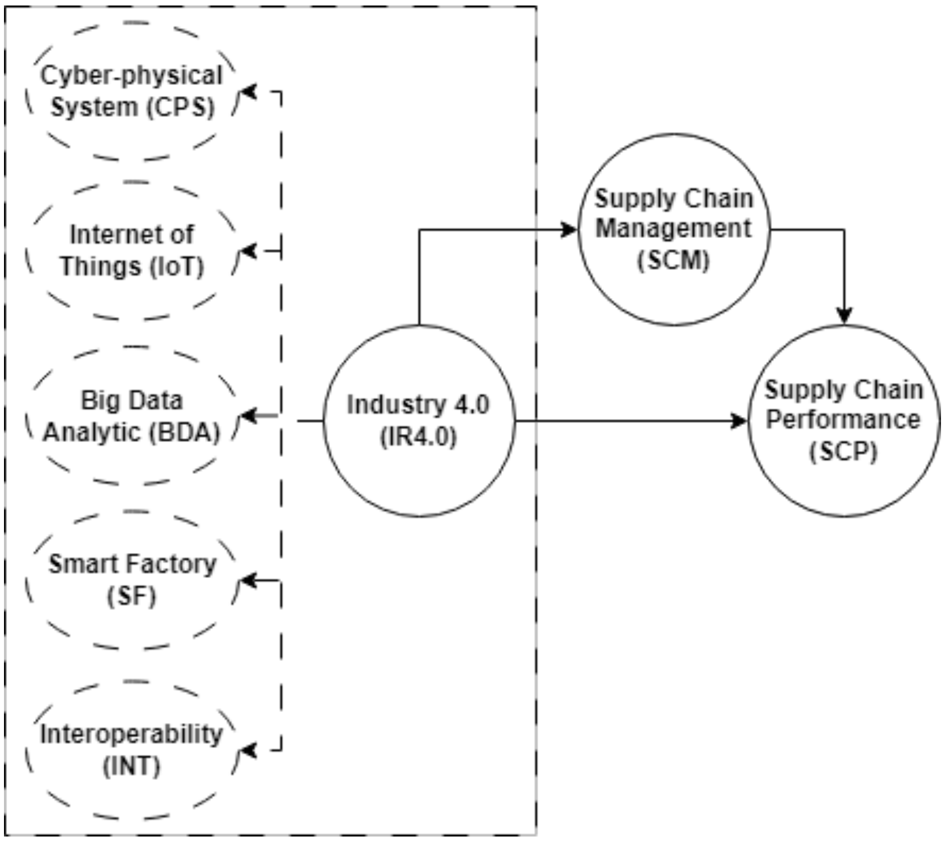

Figure 2.6: Research Framework.

2.7 Summary

In this chapter two, the various parameters such as IR4.0, SCM and SCP are critically reviewed and studied. The contribution of the IR4.0 on the SCM and SCP is evaluated as well. Lastly, the hypotheses and research framework are developed for this research study.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

Procedures along with the work plan needed to carry out the research study will be discussed in this chapter. Figure 3.1 displays the flow of work plan to complete the entire research study.

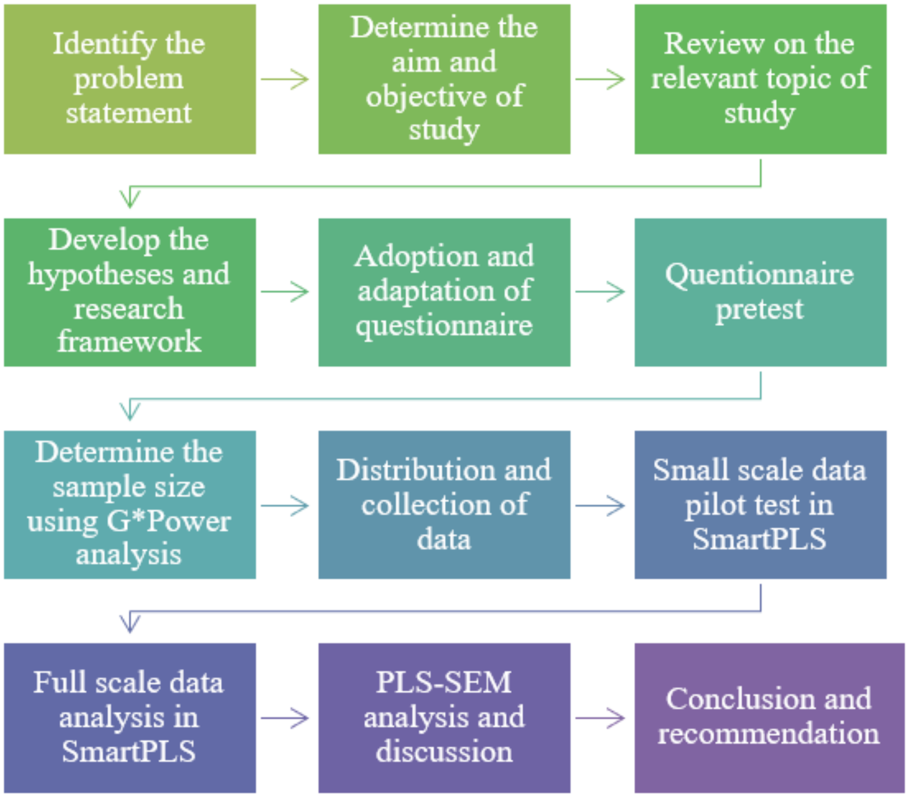

Figure 3.1: Work Plan Flows.

3.2 Adoption and Adaptation of Questionnaire

After the review of journal articles, the measurement items for all the variables in the research framework are determined and selected from those literature that had carried out the empirical analysis and listed all the involved measurement items that are relevant to the area of study.

During the preparation of questionnaire, four sections is being divided which are from Section A to Section D as shown in Appendix A. Section A is intended to gather demographic information of respondents to generally know about whether those data collected from each respondent individually is usable for further analysis. Section B to Section D consist of the three main variables which the measurement items are adopted and adapted from the literatures. For instance, Industry 4.0 key technologies and foundations with twenty-three measurement items in Section B (Imran, Hameed and Haque, 2018), supply chain management with five measurement items in Section C (Lee, et al., 2022) and supply chain performance with seventeen measurement items in Section D (Erboz, Yumurtacı Hüseyinoğlu and Szegedi, 2022; Lee, et al., 2022).

In this questionnaire preparation, five scores Likert scale is making use of to quantify the level of agreement by the respondents to each question in Section B, C and D, starting from strongly disagree to strongly agree (one to five).

3.3 Questionnaire Pretest

Pretest is a process to test and validate on the understandable by the respondents to the questionnaire designed. The pretest form (Appendix A) comprises all the questionnaire to be answer by the respondents is prepared to be sent to academic and industrial experts to scrutinize the validity of each questionnaire. Total two academic staffs and four industrial experienced people had participated in this questionnaire pretest.

Table 3.1 summarize all the comments and suggestions given by each pretest participant and whether those suggestions are taken into consideration to make necessary amendments. In section A, “your company” is rephrased to “your current working company”. The department and gender are added into the demographic questions, but the job scope and salary range are not added in. Job scope might be a lengthy answer leading to the respondents choose not to participate in this survey, while the salary range may be a secret which the respondents are not willing to disclose. Besides, the scale of work experiences and company established years are changed accordingly based on the comment. In section B, the five dimensions of IR4.0 are not separated into different sections as these dimensions are considered as second-order higher construct in PLS-SEM. Additionally, the five dimensions are explained briefly to aid the respondents to understand more on those technical vocabulary. Lastly, the statements in section C and D are reframed as well to link the IR4.0 together with the SCM and SCP.

Table 3.1: Pretest Comments.

No.	Participant	Comments	Changes (Yes/No)
1	Academic	- In section A, rephrase “your company”.	Yes
2	Academic	- In section A, add in gender.	Yes
		- In section A, if use five years scale, all use five years scale for questions one and four.	Yes
		- In section B, all the five dimensions are suggested to be separated if they are different variables.	No
3	Industrial	- In section B, explain those five variables before the questions.	Yes
		- In section C and D, reframe the statements to relate the supply chain to Industry 4.0 in section B.	Yes
4	Industrial	- In section A, add in job scope.	No
5	Industrial	- In section A, add in department.	Yes
		- In section B, the five variables might be unfamiliar to some respondents.	Yes
6	Industrial	- In section A, add in salary range.	No
		- In section A, add in department, gender.	Yes
		- In section B, add more description and terminology.	Yes

3.4 Sample Size Determination

The sample size is needed to determine to ensure the number of data collected from the respondents meet the minimum required sampling scale. G*Power software will be utilised to generate the sample size needed (Faul, et al., 2009). F tests, a priori analysis and linear multiple regression will be applied to obtain the required amount of responses. For the input parameters section, the default medium effect size (f^2) of 0.15, power level (1-β) as well as significance level (α) of 0.05 are set respectively. Since the SCP variable has the most direct input connections, which is two, thus the predictors number is set to be two. The output parameter will be shown once the "calculate" button is clicked. The final minimum respondents needed is obtained to be 68 as shown in Figure 3.2.

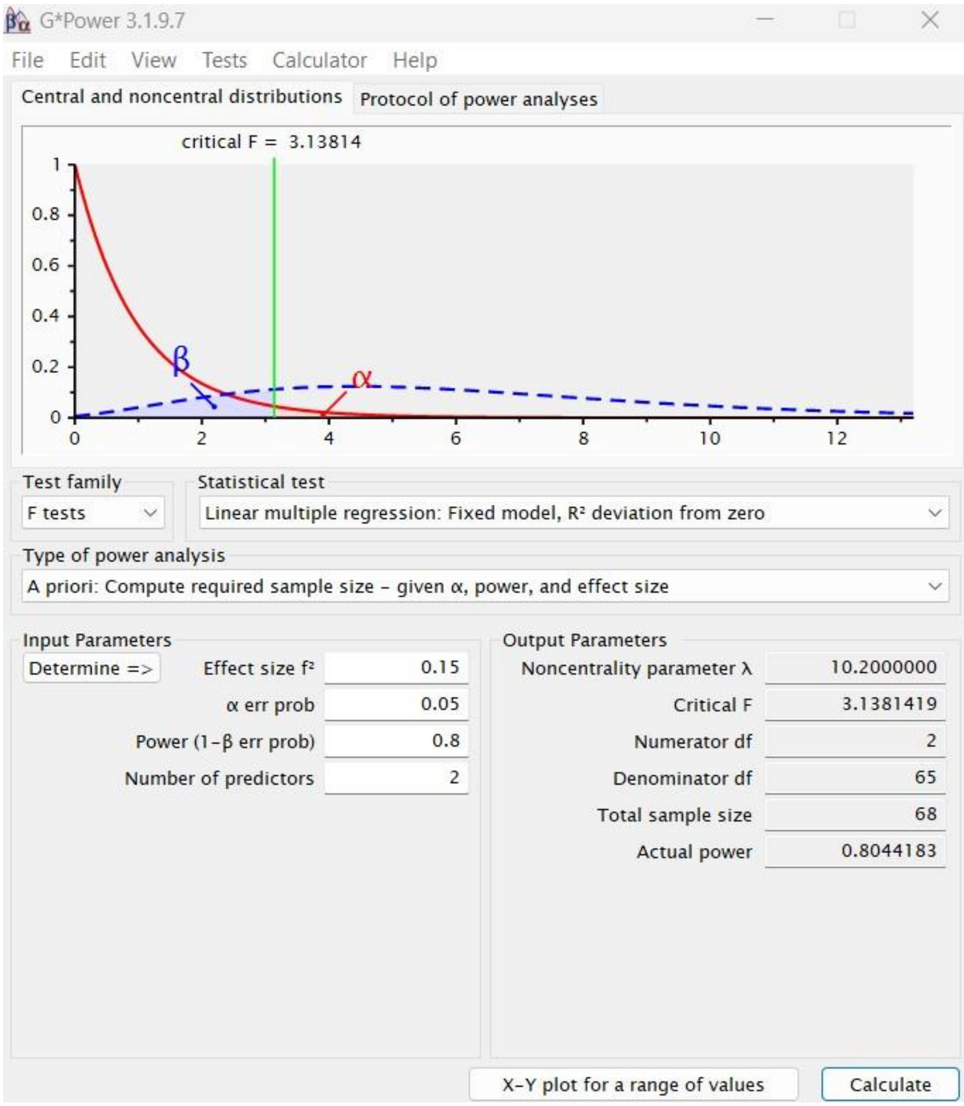

Figure 3.2: G*Power Analysis.

3.5 Questionnaire Distribution and Data Collection

The questionnaire that undergone the pretest is distributed digitally through email by utilising the Google Forms. The target participants will be the industrial people who works in the manufacturing firms located in Malaysia regardless of the company sector and size. A total of 108 responses are collected throughout the four months data collection. Data cleaning is performed but none of the data is removed as all the responses are valid and no blank data as all the questions are set to “must be answered” in the Google Forms to ease the data cleaning process.

3.6 Pilot Test

Pilot test is a small-scale initial assessment to evaluate the data collected is suitable and valid with the proposed model before a full-scale data analysis is carried out. A total of 30 sets of responses are used to undergo the pilot test. The PLS algorithm is calculated to obtain the Cronbach’s Alpha (α), composite reliability (ρ_c) and Average Variance Extracted (AVE) values for each variable. Table 3.2 shows the pilot test results, where all the results meet and above the minimum threshold values respectively. For instance, 0.7 for the α value, 0.708 for the ρ_c value as well as 0.5 for the AVE value (Hair et al., 2022).

Table 3.2: Pilot Test Results.

Variables	α	ρ_c	AVE
BDA	0.933	0.949	0.789
CPS	0.875	0.914	0.726
INT	0.934	0.958	0.883
IOT	0.948	0.958	0.793
SCM	0.902	0.928	0.722
SCP	0.956	0.960	0.591
SF	0.945	0.958	0.819

3.7 Partial Least Square Structural Equation Modeling (PLS-SEM)

PLS-SEM is a flexible statistical method that is specifically useful for small sample sizes and complicated theoretical frameworks. It is used to examine the correlations among the latent and observed variables. In this study, PLS-SEM approach is used to examine the correlations between IR4.0, SCM and SCP with the following steps which will be discussed detailed in the next chapter (Hair et al., 2022):

1. Common method variance (CMV) bias
2. Measurement model assessment
3. Higher order construct (HOC) assessment
4. Structural model and mediation assessment: Hypotheses Testing
5. Importance-performance method analysis (IPMA)

3.8 Summary

The research study's method and execution plan chapter describes the steps and schedule for carrying out the analysis. First, a pretest is conducted to confirm the applicability of the questionnaire, which has been adopted and modified based on reviewed literature. G*Power software is utilised to determine sample size and the minimum number of required respondents is 68. After that, the survey is sent digitally using Google Forms, where 108 valid responses are obtained. A pilot test with 30 responses is undergoing to verify that the data collected is valid and appropriate for analysis. PLS-SEM analysis is then carried out to evaluate the correlation between IR4.0, SCM and SCP.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The 108 responses data collected from the industries are analysed with the PLS-SEM technique by using the SmartPLS 4.0 software. The results are obtained and evaluated which include the common method variance (CMV) bias, measurement model assessment, higher order construct (HOC) assessment as well as the structural model and mediation assessment. After this, the theoretical and managerial implications are discussed on the implementation and role of IR4.0 in enhancing the SCM and SCP in the industrial sectors.

4.2 Common Method Variance (CMV) Bias

In order to verify that the importance of the relationship between those constructs is not overstated, common method variance (CMV) bias is required to be checked as each of the data set is gathered from a single person. The CMV bias was assessed through full collinearity test where Variance Inflation Factor (VIF) values of the inner model are assessed. Since all the VIF results in the current study are less than 3.3 as shown in Table 4.1, it can be said that the model is free of CMV bias (Kock, 2015).

Table 4.1: Full Collinearity Test.

Path	VIF
IR4.0 → SCM	1.000
IR4.0 → SCP	2.338
SCM → SCP	2.338

4.3 Measurement Model Assessment

In the PLS-SEM approach, to determine the validity and reliability of the structures and the linked measurement items, the measurement model is evaluated with three significant steps. These three steps involve internal consistency, discriminant validity and convergent validity (Hair et al., 2022). Besides, two (BDA4 and SCP15) out of forty-five measurement items are removed during the preliminary run of the results as these two measurement items caused failure in the discriminant validity by checking on the cross loadings of each measurement items. The final measurement model is shown in Figure 4.1.

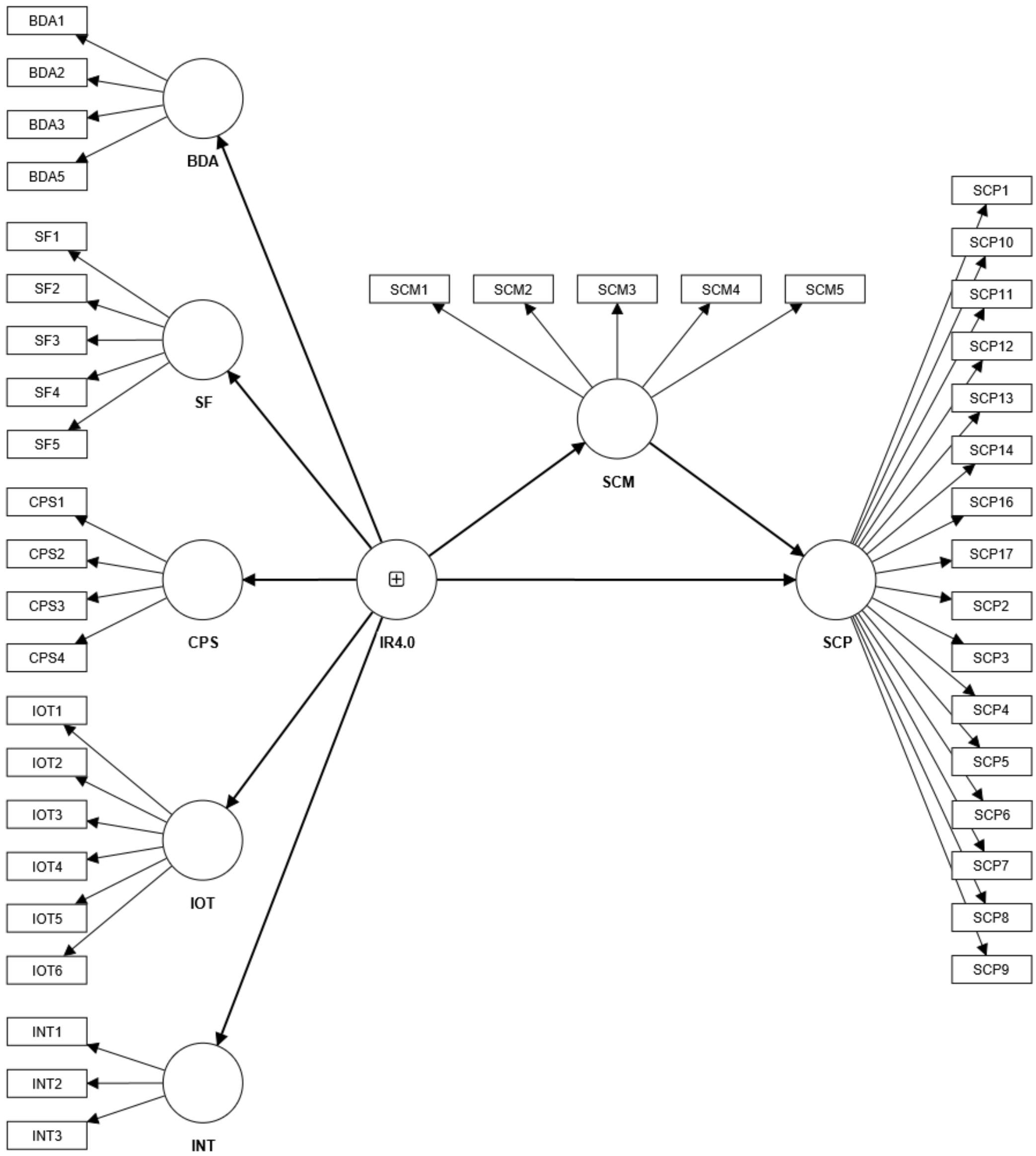

Figure 4.1: Measurement Model.

First and foremost, to ensure the model's internal consistency, the Cronbach's Alpha (α) and composite reliability (ρ_c) are determined. As shown in Table 4.2, the α and ρ_c values are accepted where both should be more than 0.7 (α) and 0.708 (ρ_c) respectively (Hair et al., 2022).

Next, the convergent validity is assessed by referring to the outer loadings (OL) as well as Average Variance Extracted (AVE) values obtained. All the variables' AVE values as shown in Table 4.2 are above the threshold value of 0.5. On the other hand, for the outer loadings of each measurement item, the results obtained ranges from 0.655 to 0.928 where some are below the threshold value of minimum 0.708. However, according to Hair et al. (2022) and Byrne (2016), these outer loadings obtained which are above 0.5 are still acceptable, given the condition where the ρ_c and AVE are above their threshold values as discussed earlier.

Table 4.2: Measurement Model.

Variables	**Items**	**OL**	**α**	**ρ_c**	**AVE**
BDA	BDA1	0.831	0.853	0.901	0.695
	BDA2	0.863			
	BDA3	0.822			
	BDA5	0.818			
SF	SF1	0.812	0.908	0.931	0.731
	SF2	0.874			
	SF3	0.896			
	SF4	0.869			
	SF5	0.822			
CPS	CPS1	0.813	0.838	0.892	0.674
	CPS2	0.839			
	CPS3	0.871			
	CPS4	0.757			
IOT	IOT1	0.833	0.906	0.928	0.682
	IOT2	0.842			
	IOT3	0.863			
	IOT4	0.798			
	IOT5	0.779			
	IOT6	0.837			

INT	INT1	0.891	0.896	0.935	0.828
	INT2	0.910			
	INT3	0.928			
SCM	SCM1	0.786	0.872	0.907	0.661
	SCM2	0.820			
	SCM3	0.841			
	SCM4	0.797			
	SCM5	0.821			
SCP	SCP1	0.694	0.948	0.954	0.566
	SCP2	0.751			
	SCP3	0.726			
	SCP4	0.768			
	SCP5	0.801			
	SCP6	0.745			
	SCP7	0.734			
	SCP8	0.798			
	SCP9	0.757			
	SCP10	0.818			
	SCP11	0.820			
	SCP12	0.655			
	SCP13	0.678			
	SCP14	0.686			
	SCP16	0.784			
	SCP17	0.793			

Furthermore, the Heterotrait-Monotrait (HTMT) Ratio of Correlations approach is used to check on the model's discriminant validity. As shown in Table 4.3, the measurement model shows discriminant validity since all the values are lesser than the threshold values of 0.85 (Kline, 2023) and 0.90 (Gold, Malhotra and Segars, 2001).

Table 4.3: HTMT Criterion.

	BDA	CPS	INT	IOT	SCM	SCP	SF
BDA							
CPS	0.878						
INT	0.752	0.861					
IOT	0.821	0.861	0.849				
SCM	0.734	0.762	0.858	0.736			
SCP	0.793	0.853	0.882	0.821	0.871		
SF	0.897	0.831	0.786	0.669	0.686	0.714	

4.4 Higher Order Construct (HOC) Assessment

In this research study, the IR4.0 is assigned as a higher order construct (HOC) which is determined with five lower order constructs (LOC) that include the BDA, CPS, INT, IOT and SF. The two-stage approach is used to carry out this HOC assessment (Becker, Klein and Wetzels, 2012). In the initial stage, the LOC is evaluated same as the previous measurement model assessment. In the next stage, latent variable scores that gathered from five LOC are used to replace the measurement items of every LOC under IR4.0, whereas the SCM and SCP are remained similarly (Sarstedt et al., 2019). Figure 4.2 shows the HOC model.

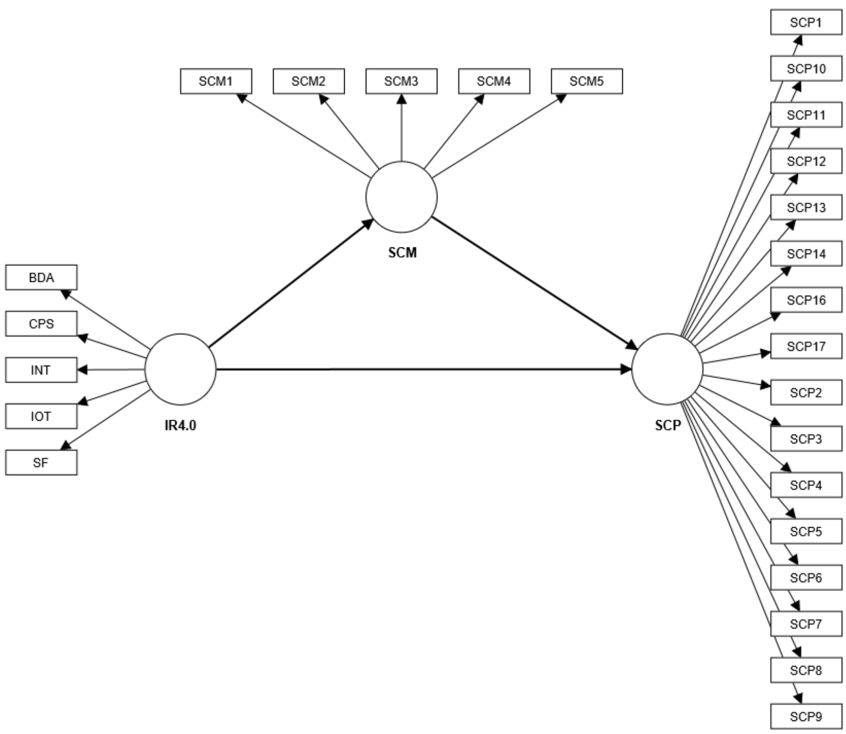

Figure 4.2: HOC Model.

Likewise, the internal consistency as well as the convergent validity are also assessed as previously done in the assessment of the measurement model. All the results obtained fulfil their threshold values respectively as shown in Table 4.4 as discussed in the earlier stage.

Table 4.4: Higher Order Construct (HOC) Assessment.

Variables	**Items**	**OL**	**α**	**ρ_c**	**AVE**
IR4.0	BDA	0.882	0.930	0.933	0.780
	CPS	0.901			
	INT	0.889			
	IOT	0.877			
	SF	0.867			
SCM	SCM1	0.786	0.872	0.873	0.661
	SCM2	0.820			
	SCM3	0.842			
	SCM4	0.798			
	SCM5	0.820			
SCP	SCP1	0.694	0.948	0.950	0.566
	SCP2	0.750			
	SCP3	0.725			
	SCP4	0.768			
	SCP5	0.801			
	SCP6	0.744			
	SCP7	0.734			
	SCP8	0.798			
	SCP9	0.757			
	SCP10	0.818			
	SCP11	0.820			
	SCP12	0.655			
	SCP13	0.679			
	SCP14	0.686			
	SCP16	0.785			
	SCP17	0.794			

Besides that, the discriminant validity for the HOC model is also tested as well using the HTMT criterion. As displayed in Table 4.5, the results obtained fulfil the threshold values of 0.85 or 0.90 as well.

Table 4.5: HTMT Criterion For HOC.

	IR4.0	SCM	SCP
IR4.0			
SCM	0.834		
SCP	0.896	0.871	

4.5 Structural Model and Mediation Assessment

The purpose of carrying out this structural model assessment is to identify whether the acquired data provides empirical support and validation for the suggested framework. Hair et al. (2022) has suggested five vital procedures in this structural model assessment:

1. Collinearity test (VIF)
2. Path-coefficient
3. Level of R^2 assessment
4. Effect size f^2 assessment
5. Predictive relevance Q^2 & PLSpredict assessment

Firstly, collinearity test is carried out to ensure each and every construct can be differentiated. This collinearity test has been performed and discussed in Section 4.2 CMV bias. The VIF results obtained meet the threshold values of below 3.3 (Kock, 2015).

Secondly, the hypotheses are then developed. A total of 5000 subsamples are used to bootstrap the path-coefficient of the proposed model and the findings are illustrated in Table 4.6. For the hypotheses H1 and H2, the IR4.0 shows a positive and direct influence on both SCM and SCP. These influences on SCM and SCP is supported with positive standard beta value of 0.756 and 0.570, standard deviation of 0.044 and 0.093, t-value of 17.036 and 6.117 (>1.645), p-value of both 0.000 (<0.05) as well as 95% confidence interval with lower to upper limit of 0.667-0.842 and 0.396-0.762 that does not overlap a zero (Hair et al., 2022). In addition, hypotheses H3 is also supported and fulfilled all the criteria as discussed similarly to H1 and H2, showing that SCM is affecting the SCP positively and directly as well.

On the other hand, based on the hypotheses H4 results, SCM mediated the relationship between IR4.0 and SCP with an indirect beta value of 0.277 positively. Whereas the remaining requirements are supported with values shown in Table 4.6. The 95% confidence interval with lower to upper limit of 0.129-0.416 also does not overlap zero. This shows that there is a mediation by the SCM which is statistically important (Preacher and Hayes, 2008), with small mediation effect of $0.277^2 = 0.077$ as proposed by Cohen (1988): 0.25 (large), 0.09 (medium) and 0.01 (small).

After performing the path-coefficient, the level of R^2 is examined to measure the predictive accuracy of the model. The level of predictive accuracy can be divided into significant (0.75), moderate (0.50) and weak (0.25) according to Hair et al. (2022). As shown in Table 4.6, SCM has a moderate level of predictive accuracy, where 57.2% of the variance in SCM can be explained by the IR4.0. Besides, 77.5% of the changes in SCP explained by the SCM shows a significant predictive accuracy.

Following that, the effect size, f^2 is evaluated based on the sizes of small (0.02), medium (0.15) and large (0.35) accordingly which is proposed by Cohen (1988). As displayed in Table 4.6, IR4.0 has a significant large effect size of 1.338 and 0.619 on SCM and SCP accordingly. Apart from that, SCM shows a medium effect size on SCP with f^2 value of 0.256.

Table 4.6: Structural Model and Hypotheses Testing.

Path	**Std. Beta**	**Indirect Effect**	**Std. Dev.**	**t-value**	**p-value**	**Confidence Interval**	**R^2**	**f^2**	**Q^2**	**Decision**
H1: IR4.0 - SCM	0.756	-	0.044	17.036	0.000	(0.667 - 0.842)	0.572	1.338	0.366	Supported
H2: IR4.0 - SCP	0.570	-	0.093	6.117	0.000	(0.396 - 0.762)	-	0.619	-	Supported
H3: SCM - SCP	0.366	-	0.095	3.846	0.000	(0.166 - 0.544)	0.775	0.256	0.429	Supported
H4: IR4.0 - SCM - SCP	-	0.277	0.071	3.879	0.000	(0.129 - 0.416)	-	-	-	Supported

Lastly, blindfolding approach is applied to examine the predictive relevance Q^2 value. The Q^2 value of 0.366 and 0.429 which are larger than 0.000 for both SCM and SCP respectively illustrate that SCM and SCP can predict the future. Moreover, PLSpredict as a powerful method is used as well to assess the predictive relevance of dependent variables, SCM and SCP (Hair, Sarstedt and Ringle, 2019; Sharma et al., 2021). Table 4.7 displays the PLSpredict's results obtained, which can be seen that the Q^2predict shown in green further support the predictive relevance of SCM and SCP. Besides, according to Shmueli et al. (2019), majority of the PLS-SEM's Root Mean Squared Error (RSME) as well as Mean Absolute Error (MAE) values are lesser than the linear regression model (LM). Therefore, this illustrates that both dependent variables have medium predictive power.

Table 4.7: PLSpredict.

	PLS-SEM		**LM**		**PLS-SEM-LM**		**Q^2predict**
	RMSE	**MAE**	**RMSE**	**MAE**	**RMSE**	**MAE**	
SCM1	0.546	0.421	0.577	0.436	-0.031	-0.015	0.360
SCM2	0.588	0.426	0.613	0.440	-0.025	-0.014	0.327
SCM3	0.565	0.428	0.565	0.435	0.000	-0.007	0.348
SCM4	0.527	0.407	0.538	0.408	-0.011	-0.001	0.343
SCM5	0.530	0.413	0.526	0.394	0.004	0.019	0.440
SCP1	0.646	0.505	0.663	0.526	-0.017	-0.021	0.259
SCP2	0.598	0.451	0.613	0.455	-0.015	-0.004	0.370
SCP3	0.680	0.546	0.697	0.548	-0.017	-0.002	0.319
SCP4	0.588	0.440	0.599	0.452	-0.011	-0.012	0.430
SCP5	0.505	0.393	0.507	0.392	-0.002	0.001	0.506
SCP6	0.673	0.527	0.695	0.556	-0.022	-0.029	0.304
SCP7	0.528	0.426	0.549	0.428	-0.021	-0.002	0.374
SCP8	0.486	0.377	0.474	0.359	0.012	0.018	0.439
SCP9	0.566	0.435	0.587	0.445	-0.021	-0.010	0.409
SCP10	0.506	0.383	0.514	0.404	-0.008	-0.021	0.433
SCP11	0.581	0.479	0.605	0.496	-0.024	-0.017	0.468
SCP12	0.604	0.482	0.659	0.510	-0.055	-0.028	0.288
SCP13	0.542	0.440	0.543	0.437	-0.001	0.003	0.325
SCP14	0.567	0.442	0.619	0.463	-0.052	-0.021	0.356
SCP16	0.486	0.347	0.468	0.317	0.018	0.030	0.515
SCP17	0.535	0.402	0.562	0.417	-0.027	-0.015	0.456

4.6 Importance-Performance Map Analysis (IPMA)

The purpose of IPMA is to determine the effectiveness and importance of each IR4.0 and SCM measurement items (Hair et al., 2022). The results obtained is divided into four quadrants as shown in Figure 4.3. All the five IR4.0 main technologies and foundations can be found located in the second quadrant, showing that IR4.0 is very vital in providing a high SCP. On the other hand, all the measurement items of SCM which located in the first quadrant illustrate the SCM is less important but still able to provide a significant improve in SCP.

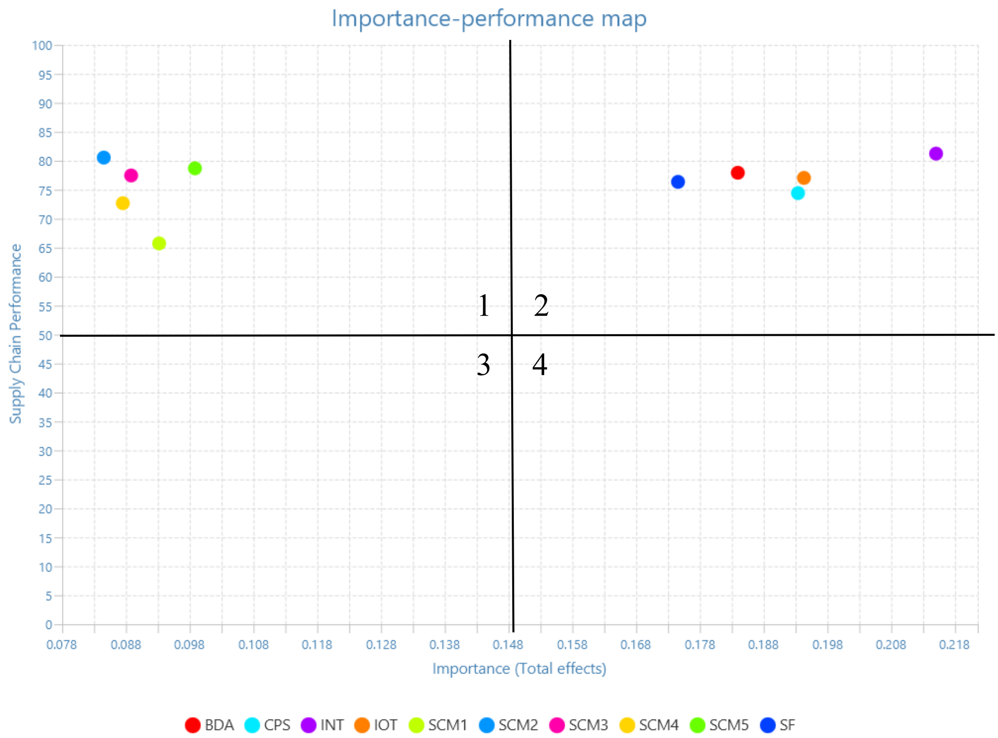

Figure 4.3: Importance-Performance Map

4.7 Theoretical Implication

By using PLS-SEM in predicting the correlations between IR4.0, SCM and SCP, this paper empirically explores the relationship between these constructs and closes the gap in the literature. Since all four hypotheses have been validated and verified, practitioners as well as scholars can obtain several important theoretical and managerial implications from this study.

In theoretical implication aspect, this study has delved into the implementation of IR4.0 and SCM in affecting the SCP as well as how the

SCM further mediates the relationship between IR4.0 and SCP. This correlation is examined empirically using PLS-SEM among manufacturing firms in Malaysia. This study able to show how the current mindset or thinking of industry people about IR4.0 on supply chain in Malaysia, giving the scholars and researchers in worldwide a valuable information into the latest Malaysian manufacturing environment. This able help to support those conceptual study by researchers on how the implementation of IR4.0 bring benefits to supply chain and modernize management of supply chain among big industries as well as SMEs in Malaysia(Chauhan and Singh, 2020; Sivan et al., 2022; Shahzad et al., 2023). Additionally, the results of positive influences of all four hypotheses showing that the essential of implement the IR4.0 to enhance the SCM and SCP. The small mediation effect of SCM on IR4.0 and SCP also proven the IR4.0 and SCM can be executed simultaneously to further improve the SCP.

4.8 Managerial Implication

In managerial implication aspect, this study's findings demonstrate the important consequences for the industrial people who are making decisions about the integration of IR4.0 and SCM. This able help to resolve the uncertainty of the decision maker to implement and interoperate both IR4.0 and SCM on the whole supply chain (Tay, Alipal and Lee, 2021). This uncertainty may include the high initial investment cost and implementation timeframe. Therefore, a continuous long-term strategy is necessary to execute both stages by stages as proven by the responses collected, 73.1% of the respondents' working companies out of 108 responses have been established more than 20 years as shown in Figure 4.4.

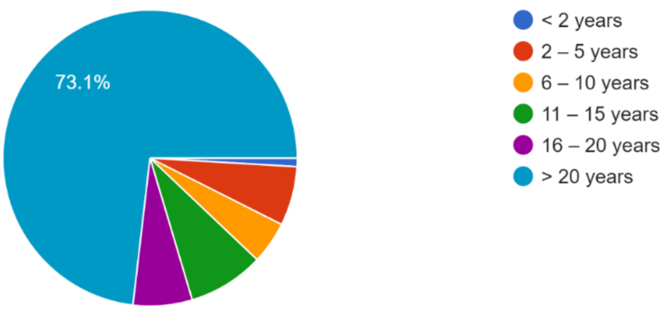

Figure 4.4: Respondents' Working Company Establishment Time

Besides that, this empirical study also displays that the industry people have a positive mindset of implementing the IR4.0 and SCM to enhance the SCP, even some have started this execution as was said by a Penang manufacturer in Malaysia (Jalil, 2024). In these competitive markets, the decision makers need to strategize the implementation of IR4.0 and SCM in their industrial organizations. This research indicates that manufacturing firms across various sectors and sizes have successfully used both strategies in enhancing the SCP significantly.

4.9 Summary

In short, throughout a series of PLS-SEM analysis steps using SmartPLS 4.0 software, the developed hypotheses and research framework are supported with the results obtained. The data gathered first passed the CMV bias assessment, measurement model assessment, HOC assessment and lastly the structural model hypotheses testing. Besides, IPMA is also done to further shows the impact of IR4.0 and SCM on the SCP as well as their importance. Lastly, the results delivered some significant theoretical and managerial implications to provide useful findings to the researchers and decision makers.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present empirical research study reveals significant findings regarding the interactions among IR4.0, SCM and SCP within the manufacturing environment in Malaysia. The empirical data was successfully collected from 108 respondents digitally to carry out all necessary assessments in the PLS-SEM analysis. Four hypotheses are empirically supported by the data, which also validate the direct positive effect and need of integrating IR4.0 and SCM simultaneously to further enhance SCP. In addition, this study delivers some theoretical and managerial implications, providing awareness and findings to the decision makers to be prepared and started to implement both IR4.0 and SCM in the manufacturing firms' supply chain.

5.2 Recommendations For Future Work

There are still a lot of improvements and recommendations can be done in the future work after this research study. Firstly, the current study is only focused on manufacturing firms located in Malaysia, a developing country. Therefore, future research can be done by collecting the response data from other different developing countries or even developed countries to provide a more precise results to further support this current study.

Besides that, due to the rapid emerging of technologies nowadays in this digitalisation world like Artificial Intelligence (AI), continuous study should be done by including different existing and future technologies from IR4.0 and above. From the supply chain perspective, the whole supply chain involves several parties, for instance, raw material suppliers, manufacturers, distributors, retailers, customers, etc. Further study can be done by including other supply chain parties rather than just the manufacturers.

REFERENCES

Basuki, M., 2021. SUPPLY CHAIN MANAGEMENT: A REVIEW. *Journal of Industrial Engineering and Halal Industries (JIEHIS)*, [e-journal] 2(1), pp.9-12. https://doi.org/10.14421/jiehis.2651.

Becker, J.M., Klein, K. and Wetzels, M., 2012. Hierarchical Latent Variable Models in PLS-SEM: Guidelines for Using Reflective-Formative Type Models. *Long Range Planning*, [e-journal] 45(5-6), pp.359-394. https://doi.org/10.1016/j.lrp.2012.10.001

Bentaher, C. and Rajaa, M., 2022. Supply Chain Management 4.0: A Literature Review and Research Framework. *European Journal of Business and Management Research*, [e-journal] 7(1), pp.117–127. https://doi.org/10.24018/ejbmr.2022.7.1.1246.

Byrne, B.M., 2016. *Structural Equation Modeling with Amos: Basic Concepts, Applications, and Programming*. 3rd ed. New York: Routledge.

Chauhan, C. and Singh, A., 2020. A review of Industry 4.0 in supply chain management studies. *Journal of Manufacturing Technology Management*, [e-journal] 31(5), pp.863-886. https://doi.org/10.1108/JMTM-04-2018-0105

Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M. and Yin, B., 2018. Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges. *IEEE Access*, [e-journal] 6, pp.6505-6519. https://doi.org/10.1109/ACCESS.2017.2783682.

Cohen, J., 1988. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. New York: Lawrence Erlbaum Associates.

Council of Supply Chain Management Professionals, 2013. CSCMP Supply Chain Management Definitions and Glossary. [online] Available at: < https://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx> [Accessed 11 September 2023].

Duong, B.A.T., Truong, H.Q., Sameiro, M., Sampaio, P., Fernandes, A.C., Vilhena, E., Bui, L.T.C. and Yadohisa, H., 2019. Supply chain management and organizational performance: the resonant influence. *International Journal of Quality & Reliability Management*, [e-journal] 36(7), pp.1053-1077. https://doi.org/10.1108/IJQRM-11-2017-0245.

Erboz, G. and Yumurtacı Hüseyinoğlu, I.Ö, 2023. The role of Industry 4.0 on supply chain cost and supply chain flexibility. *Business Process Management Journal*, [e-journal] 29(5), pp.1330-1351. https://doi.org/10.1108/BPMJ-11-2022-0605.

Erboz, G., Yumurtacı Hüseyinoğlu, I.Ö. and Szegedi, Z., 2022. The partial mediating role of supply chain integration between Industry 4.0 and supply chain performance. *Supply Chain Management*, [e-journal] 27(4), pp.538-559. https://doi.org/10.1108/SCM-09-2020-0485.

Fatorachian, H. and Kazemi, H., 2020. Impact of Industry 4.0 on supply chain performance. *Production Planning & Control*, [e-journal] 32(1), pp.63-81. https://doi.org/10.1080/09537287.2020.1712487.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, [e-journal] 41, pp.1149-1160. https://doi.org/10.3758/BRM.41.4.1149.

Ferrantino, M.J. and Koten, E.E, 2017. Understanding Supply Chain 4.0 and its potential impact on global value chains. *Global Value Chain Development Report 2019*, [e-journal] pp 103-119. https://doi.org/10.30875/10529e69-en.

Ghobakhloo, M., 2018. The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, [e-journal] 29(6), pp.910-936. https://doi.org/10.1108/JMTM-02-2018-0057.

Gold, A.H., Malhotra, A. and Segars A.H., 2001. Knowledge Management: An Organizational Capabilities Perspective. *Journal of Management Information Systems*, [e-journal] 18(1), pp.185-214. https://doi.org/10.1080/07421222.2001.11045669

Govindan, K., Kannan, D., Jørgensen, T.B. and Nielsen, T.S., 2022. Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence. *Transportation Research Part E: Logistics and Transportation Review*, [e-journal] 164. https://doi.org/10.1016/j.tre.2022.102725.

Gupta, H., Kumar, S., Kusi-Sarpong, S., Jabbour, C.J.C. and Agyemang, M., 2021. Enablers to supply chain performance on the basis of digitization technologies. *Industrial Management & Data Systems*, [e-journal] 121(9), pp.1915-1938. https://doi.org/10.1108/IMDS-07-2020-0421.

Gupta, S., Bag, S., Modgil, S. de Sousa Jabbour, A.B. and Kumar, A., 2022. Examining the influence of big data analytics and additive manufacturing on supply chain risk control and resilience: An empirical study. *Computers & Industrial Engineering*, [e-journal] 172, 108629. https://doi.org/10.1016/j.cie.2022.108629.

Habib, M., 2011. Supply Chain Management (SCM): Theory and Evolution. *Supply Chain Management – Applications and Simulations*, [e-journal] pp.3-14. https://doi.org/10.5772/24573.

Hair, J.F., Hult, G.T.M., Ringle, C.M. and Sarstedt, M., 2022. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*. 3rd ed. Los Angeles: SAGE.

Hair, J.F., Sarstedt, M. and Ringle, C.M., 2019. Rethinking some of the rethinking of partial least squares. *European Journal of Marketing*, [e-journal] 53(4), pp.566-584. http://dx.doi.org/10.1108/EJM-10-2018-0665

Hermann, M., Pentek, T. and Otto, B., 2016. Design Principles for Industrie 4.0 Scenarios. 2016 *49th Hawaii International Conference on System Sciences (HICSS)*, [e-journal] pp.3928-3937. https://doi.org/10.1109/HICSS.2016.488.

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*, [e-journal] 49(10), pp.945-955. https://doi.org/10.1108/IJPDLM-11-2019-399.

Imran, M., Hameed, W.u. and Haque, A.u., 2018. Influence of Industry 4.0 on the Production and Service Sectors in Pakistan: Evidence from Textile and Logistics Industries. *Soc. Sci*, [e-journal] 7(12), pp.246. https://doi.org/10.3390/socsci7120246.

Jalil, A., 2024. Adopt, grow with industry 4.0. *New Straits Times*, [online] 23 January. Available at: < https://www.nst.com.my/business/corporate/2024/01/1004563/adopt-grow-industry-40%C2%A0>

Jayashree, S., Hassan Reza, M.N., Malarvizhi, C.A.N., Maheswari, H., Hosseini, Z. and Kasim, A., 2021. The Impact of Technological Innovation on Industry 4.0 Implementation and Sustainability: An Empirical Study on Malaysian Small and Medium Sized Enterprises. *Sustainability*, [e-journal] 13, 10115. https://doi.org/10.3390/su131810115.

Jing, Q., Vasilakos, A.V., Wan, J., Lu, J. and Qiu, D., 2014. Security of the Internet of Things: perspectives and challenges. *Wireless Netw*, [e-journal] 20, pp.2481–2501. https://doi.org/10.1007/s11276-014-0761-7.

Kagermann, H., Wahlster, W. and Helbig, J., 2013. Recommendations for Implementing the Strategic Initiative Industrie 4.0: Final Report of the Industrie 4.0 Working Group. *Acatech-National Academy of Science and Engineering*, [online] Available at: <https://en.acatech.de/publication/recommendations-for-implementing-the-strategic-initiative-industrie-4-0-final-report-of-the-industrie-4-0-working-group/> [Accessed 7 September 2023].

Kline, R.B., 2023. *Principles and Practice of Structural Equation Modeling*. 5th ed. New York: The Guilford Press.

Klingenberg, C.O., Borges, M.A.V. and do Vale Antunes Jr., J.A., 2022. Industry 4.0: What makes it a revolution? A historical framework to understand the phenomenon. *Technology in Society*, [e-journal] 70, 102009. https://doi.org/10.1016/j.techsoc.2022.102009.

Kock, N., 2015. Common Method Bias in PLS-SEM: A Full Collinearity Assessment Approach. International Journal of e-Collaboration, [e-journal] 11(4), pp.1-10. https://doi.org/10.4018/ijec.2015100101

Lee, K L, Azmi, N.A.N., Hanaysha, J.R., Alzoubi, H.M. and Alshurideh, M.T., 2022. The effect of digital supply chain on organizational performance: An empirical study in Malaysia manufacturing industry. *Uncertain Supply Chain Management*, [e-journal] 10(2), pp.495-510. https://doi.org/10.5267/j.uscm.2021.12.002.

Lehyani, F., Zouari, A., Ghorbel, A. and Tollenaere, M., 2021. Defining and Measuring Supply Chain Performance: A Systematic Literature Review. *Engineering Management Journal*, [e-journal] 33(4), pp.283-313. https://doi.org/10.1080/10429247.2020.1834309.

Li, D.X., Eric, L.X. and Ling, L., 2018. Industry 4.0: state of the art and future trends. *International Journal of Production Research*, [e-journal] 56(8), pp.2941-2962. https://doi.org/10.1080/00207543.2018.1444806.

Liu, K.P. and Chiu, W., 2021. Supply Chain 4.0: the impact of supply chain digitalization and integration on firm performance. *Asian Journal of Business Ethics*, [e-journal] 10, pp.371-389. https://doi.org/10.1007/s13520-021-00137-8.

Lu, Y., 2017a. Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, [e-journal] 6, pp.1-10. https://doi.org/10.1016/j.jii.2017.04.005.

Lu, Y., 2017b. Cyber Physical System (CPS)-Based Industry 4.0: A Survey. *Journal of Industrial Integration and Management*, [e-journal] 2(3), 1750014. https://doi.org/10.1142/S2424862217500142.

Manavalan E. and Jayakrishna K., 2019. A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. *Computers & Industrial Engineering*, [e-journal] 127, pp.925-953. https://doi.org/10.1016/j.cie.2018.11.030.

Molka-Danielsen, J., Engelseth, P. and Wang, H., 2018. Large scale integration of wireless sensor network technologies for air quality monitoring at a logistics shipping base. *Journal of Industrial Information Integration*, [e-journal] 10, pp.20-28. https://doi.org/10.1016/j.jii.2018.02.001.

Mubarak, M.F., Tiwari, S., Petraite, M., Mubarik, M. and Raja Mohd Rasi, R.Z., 2021. How Industry 4.0 technologies and open innovation can improve green innovation performance? *Management of Environmental Quality*, [e-journal] 32(5), pp.1007-1022. https://doi.org/10.1108/MEQ-11-2020-0266.

Pivoto, D.G.S., Almeida, L.F.F.d, Rosa Righi, R.d., Rodrigues, J.J.P.C., Lugli, A.B. and Alberti, A.M., 2021. Cyber-physical systems architectures for industrial internet of things applications in Industry 4.0: A literature review. *Journal of Manufacturing Systems*, [e-journal] 58, pp.176-192. https://doi.org/10.1016/j.jmsy.2020.11.017.

Preacher, K.J. and Hayes, A.F., 2008. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, [e-journal] 40(3), pp.879-891. https://doi.org/10.3758/BRM.40.3.879

Rad, F.F., Oghazi, P., Palmié, M., Chirumalla, K., Pashkevich, N., Patel, P.C. and Sattari, S., 2022. Industry 4.0 and supply chain performance: A systematic literature review of the benefits, challenges, and critical success factors of 11 core technologies. *Industrial Marketing Management*, [e-journal] 105, pp.268-293. https://doi.org/10.1016/j.indmarman.2022.06.009.

Raja Santhi, A. and Muthuswamy, P., 2022. Pandemic, War, Natural Calamities, and Sustainability: Industry 4.0 Technologies to Overcome Traditional and Contemporary Supply Chain Challenges. *Logistics*, [e-journal] 6(4), pp.81. https://doi.org/10.3390/logistics6040081.

Reza, M.N.H., Jayashree, S., Malarvizhi, C.A.N., Rauf, M.A., Jayaraman, K. and Shareef, S.H., 2022. The implications of Industry 4.0 on supply chains amid the COVID-19 pandemic: a systematic review [version 2; peer review: 2 approved, 1 approved with reservations]. *F1000Research*, [e-journal] 10:1008, pp.1-38. https://doi.org/10.12688/f1000research.73138.2.

Roblek, V., Meško, M. and Krapež, A., 2016. A Complex View of Industry 4.0. *SAGE Open*, [e-journal] 6(2). https://doi.org/10.1177/2158244016653987.

Sarstedt, M., Hair, J. F., Cheah, J.H., Becker, J.M. and Ringle, C. M., 2019. How to Specify, Estimate, and Validate Higher-Order Constructs in PLS-SEM. *Australasian Marketing Journal*, [e-journal] 27(3), pp.197-211. https://doi.org/10.1016/j.ausmj.2019.05.003

Shahzad, A., Zakaria, M.S.A, Makki, M.A.M, Hussain, A. and Fischer, J., 2023. Adoption of fourth industrial revolution 4.0 among Malaysian small and medium enterprises (SMEs). *Humanities and Social Sciences Communications*, [e-journal] 10, pp.693. https://doi.org/10.1057/s41599-023-02076-0

Sharma, P.N., Shmueli, G., Sarstedt, M., Danks, N. and Ray, S., 2021. Prediction-Oriented Model Selection in Partial Least Squares Path Modeling.

Decision Sciences, [e-journal] 52(3), pp.567-607. https://doi.org/10.1111/deci.12329

Shepherd, C. and Günter, H., 2006. Measuring supply chain performance: current research and future directions. *International Journal of Productivity and Performance Management*, [e-journal] 55(3/4), pp.242-258. https://doi.org/10.1108/17410400610653219.

Shmueli, G., Sarstedt, M., Hair, J.F., Cheah, J.H., Ting, H., Vaithilingam, S. and Ringle, C.M., 2019. Predictive model assessment in PLS-SEM: Guidelines for using PLSpredict. *European Journal of Marketing*, [e-journal] 53(11), pp.2322-2347. https://doi.org/10.1108/EJM-02-2019-0189

Sivan, S., Ghadiri, S.M., Rajagopal, P., Bahrin, A.S. and Sundram, V.P.K., 2022. Adoption and Benefit of Industrial Revolution 4.0 in Logistics Industry: A Conceptual Paper. *Journal of Entrepreneurship, Business and Economics*, [e-journal] 10(2S1), pp.79-94. https://scientificia.com/index.php/JEBE/article/view/181

Som, J.O., Cobblah, C. and Anyigba, H., 2019. The effect of Supply Chain Integration on Supply Chain Performance. *Proceedings of the Ninth International Conference on Engaged Management Scholarship (2019)*, [e-journal] pp.1-18. http://dx.doi.org/10.2139/ssrn.3468798.

Sony, M. and Naik, S., 2019. Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking: an international journal*, [e-journal] 27(7), pp.2213-2232. https://doi.org/10.1108/BIJ-09-2018-0284.

Strozzi, F., Colicchia, C., Creazza, A. and Noè, C., 2017. Literature review on the 'Smart Factory' concept using bibliometric tools. *International Journal of Production Research*, [e-journal] 55(22), pp.6572-6591. https://doi.org/10.1080/00207543.2017.1326643.

Tay, S.I., Alipal, J. and Lee, T.C., 2021. Industry 4.0: Current practice and challenges in Malaysian manufacturing firms. *Technology in Society*, [e-journal] 67, 101749. https://doi.org/10.1016/j.techsoc.2021.101749.

Vaidya, S., Ambad, P. and Bhosle, S., 2018. Industry 4.0 – A Glimpse. *Procedia Manufacturing*, [e-journal] 20, pp.233-238. https://doi.org/10.1016/j.promfg.2018.02.034.

Vedpal, Jain, V. and Bhatnagar, N., 2012. Four C's in supply chain management: Research issues and challenges. *2012 Third International Conference on Emerging Applications of Information Technology*, [e-journal] pp.264-267. https://doi.org/10.1109/EAIT.2012.6407919.

Wang, S., Wan, J., Li, D. and Zhang, C., 2016. Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*, [e-journal] 12(1), pp.1-10. https://doi.org/10.1155/2016/3159805.

Wang, Y., Ma, H.S., Yang, J.H. and Wang K.S., 2017. Industry 4.0: a way from mass customization to mass personalization production. *Advances in Manufacturing*, [e-journal] 5, pp.311-320. https://doi.org/10.1007/s40436-017-0204-7.

Yuan, X.M. and Xue, A., 2023. Supply Chain 4.0: New Generation of Supply Chain Management. *Logistics*, [e-journal] 7(1), pp.1-4. https://doi.org/10.3390/logistics7010009.

Zhang, G., Yang, Y. and Yang, G., 2023. Smart supply chain management in Industry 4.0: the review, research agenda and strategies in North America. *Annals of Operations Research*, [e-journal] 322, pp.1075-1117. https://doi.org/10.1007/s10479-022-04689-1.

Zhong, R.Y., Newman, S.T., Huang, G.Q. and Lan, S., 2016. Big Data for supply chain management in the service and manufacturing sectors: Challenges, opportunities, and future perspectives. *Computers & Industrial Engineering*, [e-journal] 101, pp.572-591. https://doi.org/10.1016/j.cie.2016.07.013.

Zhong, R.Y., Xu, X., Klotz, E. and Newman S.T., 2017. Intelligent Manufacturing in the Context of Industry 4.0: A Review. *Engineering*, [e-journal] 3(5), pp.616-630. https://doi.org/10.1016/J.ENG.2017.05.015.

APPENDICES

Appendix A: Questionnaire Pretest Form

The Role of Industry 4.0 in Enhancing Supply Chain Management: An Empirical Analysis of Malaysian Manufacturing Firms using PLS-SEM

Date: 22nd August 2023

Dear Sir/Madam,

Firstly, thank you for agreeing to be one of the expert validators of the questionnaire for my Bachelor's Degree Final Year Project study. With your expertise, I am humbly asking your permission to evaluate the attached questionnaire. It would also be really helpful if you could write your comments, suggestions, and recommendations that can improve the questionnaire. I believe that your valuable observations and experiences will contribute to the knowledge in academia.

Thank you again for your effort and valuable contribution in this respect. If you have any questions about this study, feel free to contact me at yeangkaixiang0107@1utar.my or 016-5509465.

Yours sincerely,

Yeang

Yeang Kai Xiang (2100041)
Student
Bachelor of Mechanical Engineering with Honours
Department of Mechanical and Material Engineering
Lee Kong Chian Faculty of Engineering and Science
Sungai Long Campus, Universiti Tunku Abdul Rahman

Email: yeangkaixiang0107@1utar.my
Mobile: 016-5509465

Please evaluate if the questions are perfect, moderate, or poorly matched, and comment at the end of each section.

Section A Demographic Questions

The questions in this section are devised to collect information about the background of your company. Please choose the BEST answer which best describes you and your company.

1. Years of work experience:

   ☐ < 2 years ☐ 2 – 5 years ☐ 5 – 10 years ☐ 10 – 20 years

   ☐ > 20 years

2. Position Title:

   ____

3. Company Location (Eg. Penang, Kuala Lumpur, Selangor):

   ____

4. How many years has the company been established?

   ☐ < 2 years ☐ 2 – 5 years ☐ 5 – 10 years ☐ 10 – 20 years

   ☐ > 20 years

5. What is the approximate number of employees in your company?

   ☐ < 5 ☐ 5 – 75 ☐ 76 – 200 ☐ > 200

6. What is your company's industrial sector?

   ☐ Textile, Wearing Apparel, Leather & Footwear

   ☐ Electrical & Electronics

   ☐ Machinery & Equipment, Engineering Support Industry (ESI), Basic Metal Products & Fabricated Metal Products

   ☐ Wood-based & Furniture

   ☐ Paper Products, Printing & Publishing

   ☐ Aerospace, Automotive, Rail, Shipbuilding, Ship Repair & Transport Equipment

   ☐ Petroleum, Chemical, Rubber, Oleochemical & Plastic

   ☐ Pharmaceutical, Medical & Biotechnology

   ☐ Agriculture, Food, Beverages, Tobacco & Palm Oil

☐ Non-Metallic Mineral Products & Industrialised Building System (IBS)

☐ Others, please specify: ________________________

Comment and suggestion:

Section B Industry 4.0 Key Technologies and Foundation

Since the rapid evolution of advanced technologies, the primary drivers of Industry 4.0 technologies, such as big data analytics, smart factory, cyber-physical system, IoT, and interoperability are reshaping supply chain management. These technologies allow real-time monitoring and predictive analytics. The questions in this section are designed to collect information to the extent of your opinion on Industry 4.0 technologies. Please choose the BEST answer which best describes your opinions.

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

BDA1	Big data analytic improves planning and decision-making.	1	2	3	4	5
BDA2	Big data analytic helps to construct operational frameworks and forecasting models.	1	2	3	4	5
BDA3	Big data analytic analyses real-time data to optimize inventory levels.	1	2	3	4	5
BDA4	Big data analytic optimizes shipping routes and reduces shipping costs.	1	2	3	4	5
BDA5	Big data analytic helps company to locate the most trustworthy and affordable suppliers.	1	2	3	4	5
SF1	Smart factory provides ways to address the issues successfully.	1	2	3	4	5
SF2	Smart factory provides the capability to work in real time.	1	2	3	4	5
SF3	Smart factory allows for adjustment and data-based learning.	1	2	3	4	5
SF4	Smart factory has a close connection to proactive, responsive and predictive practices which improve accuracy.	1	2	3	4	5

SF5	Smart factory helps the company to stay away from productivity issues like operational downtime.	1	2	3	4	5
CPS1	Cyber-physical system provides important online resources that support the company.	1	2	3	4	5
CPS2	Cyber-physical system improves the local storage and processing power.	1	2	3	4	5
CPS3	Cyber-physical system offers previously unheard of potential for innovation.	1	2	3	4	5
CPS4	Cyber-physical system is able to deal with obstacles, threats, and challenges.	1	2	3	4	5
IOT1	Internet of Things offers consumers with shorter lead times and cheaper total costs.	1	2	3	4	5
IOT2	Internet of Things increases the production capability.	1	2	3	4	5
IOT3	Internet of Things links devices to the internet to support manufacturing processes.	1	2	3	4	5
IOT4	Internet of Things enhances communication among employees.	1	2	3	4	5
IOT5	Internet of Things strengthens the relationship between customers and company and raises customer satisfaction.	1	2	3	4	5
IOT6	Internet of Things connects with suppliers to increase supply chain visibility.	1	2	3	4	5
INT1	Interoperability is capable of accurately and meaningfully interpreting the information exchanged automatically.	1	2	3	4	5
INT2	Interoperability implies trades involving various products or comparable goods purchased from several suppliers.	1	2	3	4	5
INT3	Interoperability offers improved technology in enhancing cross-organizational collaboration.	1	2	3	4	5

Adapted from:
Imran M., Hameed, W.u., Haque, A.u., 2018. Influence of Industry 4.0 on the Production and Service Sectors in Pakistan: Evidence from Textile and Logistics Industries. Social Sciences., 7(12), pp.246. https://doi.org/10.3390/socsci7120246.

Comment and suggestion:

Section C Supply Chain Management

Supply chain management is the strategic coordination of tasks that guarantees the efficient transfer of goods, services, and information from the supply of raw materials to end users. It comprises the synchronization, optimization, and collaboration of a variety of operations, including procurement, manufacturing, distribution and shipping. The questions in this section are designed to collect information to the extent of your opinion on supply chain management. Please choose the BEST answer which best describes your opinions.

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

SCM1	Form a supply chain management team/department to improve the integration of supply chain activities from different departments.	1	2	3	4	5
SCM2	Ensure purchase materials from the supplier are delivered on time.	1	2	3	4	5
SCM3	Build contact with supply chain members more frequently.	1	2	3	4	5
SCM4	Decrease response time throughout the supply chain.	1	2	3	4	5
SCM5	Share formal and accurate information with suppliers and customers.	1	2	3	4	5

Adapted from:

Lee, K., Azmi, N., Hanaysha, J., Alzoubi, H & Alshurideh, M., 2022. The effect of digital supply chain on organizational performance: An empirical study in Malaysia manufacturing industry. Uncertain Supply Chain Management, 10(2), pp.495-510. https://doi.org/10.5267/j.uscm.2021.12.002.

Comment and suggestion:

Section D Supply Chain Performance

Supply chain performance is about the measure of the effectiveness and value of supply chains. It includes significant metrics including efficiency, cost-effectiveness, responsiveness and quality. The questions in this section are designed to collect information to the extent of your opinion on supply chain performance. Please choose the BEST answer which best describes your opinions.

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

SCP1	The total resources cost used is improved.	1	2	3	4	5
SCP2	The total distribution cost is improved.	1	2	3	4	5
SCP3	The total manufacturing cost is improved.	1	2	3	4	5
SCP4	The inventory cost is improved.	1	2	3	4	5
SCP5	The employee-specific value-added productivity within the company is improved.	1	2	3	4	5
SCP6	The total sales performance is improved.	1	2	3	4	5
SCP7	The order fill rate is improved.	1	2	3	4	5
SCP8	The shipping and delivery performance is improved.	1	2	3	4	5
SCP9	The customer response time is improved.	1	2	3	4	5
SCP10	The manufacturing lead time is improved.	1	2	3	4	5
SCP11	The product's quality is improved.	1	2	3	4	5
SCP12	The customer satisfaction is improved.	1	2	3	4	5
SCP13	Respond capability to demand changes is improved.	1	2	3	4	5
SCP14	Respond capability to unsatisfactory manufacturing performance is improved.	1	2	3	4	5
SCP15	Respond capability to unsatisfactory supplier performance is improved.	1	2	3	4	5
SCP16	Respond capability to unsatisfactory shipping and delivery performance is improved.	1	2	3	4	5
SCP17	Respond capability to new products, markets and competitors is improved.	1	2	3	4	5

Adapted from:

Erboz, G., Yumurtacı Hüseyinoğlu, I.Ö. and Szegedi, Z., 2022. The partial mediating role of supply chain integration between Industry 4.0 and supply chain performance. Supply Chain Management, [e-journal] 27(4), pp.538-559. https://doi.org/10.1108/SCM-09-2020-0485.

Lee, K., Azmi, N., Hanaysha, J., Alzoubi, H & Alshurideh, M., 2022. The effect of digital supply chain on organizational performance: An empirical study in Malaysia manufacturing industry. Uncertain Supply Chain Management, [e-journal] 10(2), pp.495-510. https://doi.org/10.5267/j.uscm.2021.12.002.

Comment and suggestion:

Signature: ______________________________

Name of Validator: ______________________

Contact/Email: ___________________________

Company Name: __________________________

Job Title: ________________________________

---END----- --