UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Development of Framework for Drivers and Barriers in the Implementation of Supply Chain 4.0.

Master Degree Thesis in Logistics and Transport Management

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May 2020

ABSTRACT

Industrie 4.0 (I4.0), now commonly referred to as Industry 4.0 was a paradigm that originated from a 2011 high-tech strategy project by the German government which was to promote the digital revolution or *digitalization* of manufacturing.

Industry 4.0 had been analyzed by many authors in the context of industrial revolutions driven by a cluster of concepts and technologies. Though the potential of Industry 4.0 can be harnessed in its entirety by interconnecting companies, most previous research had been within the boundaries of an industry and/or enterprise. While studies about Industry 4.0 in relation to Supply Chain Management has predominantly covered trends in the manufacturing industry such as smart factories, smart manufacturing and IoT, other sectors and/or industries have embraced the concepts, principles and technologies of Industry 4.0 as an enabler of *digitalization*. *Supply Chain 4.0* is the re-organization of supply chain processes such as design and planning, production, distribution, consumption and reverse logistics using Industry 4.0 technologies.

This thesis performs a Systematic Literature Review (SLR) of relevant literature to understand previous research conducted about industry 4.0 in supply chains; explored the different concepts, principles and dimensions involved, interpreted them and proposed a conceptual framework. The systematic review covered Supply Chain 4.0 relevant literature from 2015 to 2020 in Scopus database. The bibliometric research method used in the analysis of the Scopus data was Co-word analysis of keywords related to the SC 4.0 using *VOSviewer*. The context of the thesis is a holistic analysis that cuts across the end-to-end business functions in a supply chain. The key finding is that there are Political, Economic, Social, Technological, Environmental and Legal dimensions to the drivers and barriers in SC 4.0.

The result of the SLR is a conceptual framework that addressed the drivers and barriers in the implementation of Supply Chain 4.0. The framework which is designed with PESTEL, a strategic management analysis tool, can be applied in strategic decision-making irrespective of the industry. The list of bibliographic references from the SLR and the conceptual framework can also be utilized in future research.

Keywords: Industry 4.0, Supply Chain 4.0, Digitalization, Systematic Literature Review, PESTEL, Drivers, Adoption, Barriers and Implementation.

ACKNOWLEDGEMENT

My deepest gratitude goes to God Almighty for granting me strength, wisdom and perseverance to complete this thesis.

I would like to express my sincere appreciation to my supervisor, **Shahryar Sorooshian** whose persistent support, guidance and expert knowledge was key to the success of this thesis. Thank you very much for your patience and understanding, I truly appreciate it.

I would also like to express my profound gratitude to my wonderful family for their unwavering support, patience and understanding throughout the whole study period and when this thesis was written. To my lovely husband**, Olusegun,** thank you for making sure I had nothing to worry about but to focus on completing my work. To my wonderful children, **Daniella**, **Amanda** and my little baby **Lenora,** you all are my source of inspiration without which the completion of this thesis would not have been possible. I love you all.

Stella Ngwaba Adare

Gothenburg, May 2020

GLOSSARY

Acronym	Description
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
AI	Artificial Intelligence
AIDC	Automatic Identification and Data Collection (AIDC)
API	Application Programming Interface
AMP	Advanced Manufacturing Partnership
AR	Augmented Reality
BDA	Big Data Analytics
CAD	Computer-Aided Design
CE	Circular Economy
COVID-19	Corona Virus Disease - 2019
CPS	Cyber-Physical Systems
CSR	Corporate Social Responsibility
CSV	Comma-Separated Values
DC	Distribution Centre
DDBM	Data Driven Business Model
DEMATEL	Decision Making Trial and Evaluation Laboratory
DSC	Digital Supply Chain
DSN	Digital Supply Network
EFFRA	European Factories of the Future Research Association
ERP	Enterprise Resource Planning
FMCG	Fast-Moving Consumer Goods
FoF	Factories of the Future
FX	Foreign Exchange
GDPR	General Data Protection Regulation
GVC	Global Value Chain
HSE	Health Safety and Environment
PBA	Patterns of Business Activity
HA	High Availability
HSE	Health Safety and Environment
I4.0	Industry 4.0
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Reference Architecture
IT	Information Technology
ICT	Information and Communication Technology
IoS	Internet of Services
IoT	Internet of Things
IoE	Internet of Everything
IP	Intellectual Property

Acronym	Description
MDS	Multi-Dimensional Scaling (MDS)
MSME	Micro, Small and Medium Enterprise
NLP	Natural Language Processing
OECD	Organization for Economic Cooperation and Development
OT	Operations Technology
PEST	Political, Economic, Socio-cultural, Technological
PESTEL	Political, Economic, Socio-cultural, Technological, Environmental and Legal
PMESII-PT	Political, Military, Economic, Social, Information Infrastructure Physical environment and Time
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RAMI 4.0	Reference Architectural Model Industrie 4.0
RFID	Radio Frequency Identification
R&D	Research and Development
SC	Supply Chain
SCC	Supply Chain Council
SCOR	Supply Chain Operations Reference
SCM	Supply Chain Management
SSCM	Sustainable Supply Chain Management
S&T	Science and Technology
STEEPLE	Social, Technological, Economic, Environmental, Political, Legal and Ethical.
STEER	Socio-cultural, Technological, Economic, Ecological, and Regulatory.
STEM	Science Technology Engineering and Mathematics
SWOT	Strength Weakness Opportunities and Threats
TOE	Technological-Organizational-Environmental
T&C	Terms and Conditions
VR	Virtual Reality
VUCA	Volatility, Uncertainty, Complexity and Ambiguity

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1. Introduction

This chapter provides a high-level background information about the thesis and a detailed description of the problem. Also, the purpose and objectives of the research was covered in this chapter.

1.1 Background

In 2020 that the world is facing uncertainty due to the COVID-19 pandemic, there had been a lot of disruptions to supply chains. Post COVID-19, industry 4.0 technologies in automatization and digitalization of business processes in supply chains will be of strategic importance. The industrial and business landscape will be re-shaped after the pandemic as global enterprises re-define ways of doing business. Industry 4.0 is one of the enablers for the change. As the world goes through a VUCA (Volatility, Uncertainty, Complexity and Ambiguity) scenario (Millar et al., 2018; Bennett & Lemoine, 2014), there is a need to understand the drivers and barriers that shape the managerial decision-making process for the adoption and implementation of Industry 4.0 concepts, principles and technologies in supply chains across several industries/sectors, geographical boundaries, political systems, economic systems and socio-cultural norms.

Industry 4.0 is enabling the re-organization of Supply chain processes using State-of-the-art technologies. Supply chains typically operate along the traditional Supply Chain Operations Reference (SCOR) model - Plan, Source, Make, Deliver, Return, and Enable processes. Ferrantino & Koten (2019) describes Digital Supply Chain (also sometimes referred to as *Supply Chain 4.0*) as the re-organization of Supply chain processes such as design and planning, production, distribution, consumption and reverse logistics using Industry 4.0 technologies. Alicke et al (2016) defined Supply Chain 4.0 as ñ*the application of the Internet of Things, the use of advanced robotics, and the application of advanced analytics of big data in Supply Chain Management (SCM): place sensors in everything, create networks everywhere, automate anything, and analyze everything to significantly improve performance and customer satisfaction*ò.

While studies about Industry 4.0 in relation to Supply Chain Management has predominantly covered trends in the manufacturing industry such as smart factories, smart manufacturing and

IoT, other sectors and/or industries have embraced the concepts, principles and technologies of Industry 4.0 as an enabler of *digitalization*.

A lot of literature both in the academia and by professional institutions have disserted the benefits and potential of Industry 4.0 and its adoption in Supply chains to include enhanced efficiency and flexibility, increased collaboration, prompt responsiveness, end-to-end communication and data-driven decision-making channels. Studies have covered industry 4.0 trends, opportunities and challenges with a lot of focus on smart factories, smart manufacturing and IoT. (Kang et al, 2016; Brettel et al, 2014; CGI, 2017b; Rüßmann et al, 2015; Schlaepfer et al.,2014; Geissbauer et al., 2014; Burke et al., 2017; Hermann et al., 2015). Analysis of the trends and opportunities in supply chain management that lead to digital transformation shows that there are *endogenous* and *exogenous* trends. (Kersten et al.,2017; Mazzarino, 2012).

1.2 Problem Description and Problem Analysis

As the spate of disruption is intensifying in the Fourth Industrial revolution, application of I4.0 concepts, principles and technologies in supply chains is still a buzzword rather than standard practice. (Brinch & Stentoft, 2017). The adoption and implementation of digital supply chains still lags behind in several industries and is at varying degrees. (OECD, 2017). In a globalized world, digitalization of supply chains transcends across geographical boundaries, political systems, economic systems and socio-cultural norms and this makes many of the drivers and challenges of harnessing the potential benefits of industry 4.0 in Supply Chains (SCs) not to be fully known yet. (Nicolescu et al., 2019). There are competing initiatives to Industry 4.0 as a paradigm that creates a lot of confusion across enterprises. Strategically, adoption of a new paradigm comes with an initial high financial investment requirement which could skyrocket if implemented improperly. (ślusarczyk, 2018; Schröder, 2016). Firms are potentially losing money and incurring more costs through the wrong selection of the industry 4.0 enablers that could sustainably enhance digitalization in their supply chains, thereby leading to implementation failures. (Schröder, 2016)

The concepts, principles and technologies of Industry 4.0 are enablers of *digitalization* and have been embraced in sectors and/or industries other than manufacturing such as service industry, process industry, food industry, construction, etc. (Kamble et al., 2018; Müller et al.; Soosay & Kannusamy, 2018; Dutzler et al., 2016). Though the potential of Industry 4.0 can be harnessed in its entirety by interconnecting companies, most research had been focused on the boundaries within an industry or a company. The implementation of Industry 4.0 concepts requires a holistic approach. There are few studies that had taken this holistic approach in understanding digital supply chains. There is a need to understand the strategic dimensions considered in the adoption of I4.0 paradigm as well as the drivers and barriers that shape the managerial decision-making process in the adoption and implementation of SC 4.0.

1.3 Research Purpose and Objectives

This Thesis develops a conceptual framework of strategic dimensions to consider while adopting I4.0 in supply chains as well as potential drivers and barriers in the implementation of industry 4.0 in supply chains by systematically reviewing relevant literature that covers the subject area.

The research purpose and objectives in this thesis are captured succinctly in the research questions that are to be answered by the research which are:

- RQ1: What are the drivers and barriers in the implementation of industry 4.0 in Supply Chain Management?
- RQ2: Which strategic dimensions should be considered in the adoption of industry 4.0 in Supply Chain Management?

1.4 Scope and Delimitations

The implementation of Industry 4.0 concepts requires a holistic approach. There are several considerations in managerial decision-making process before arriving at the best strategic, tactical and operational approaches needed in implementation of Supply Chain 4.0. There are few studies that had taken this holistic approach in understanding digital supply chains. This thesis conducts a holistic analysis that cuts across the end-to-end business functions in a supply chain irrespective of the industry. The conceptual framework developed has a multidisciplinary focus and could be utilized across several industries. However, the research data was delimited in Scopus to cover only specific subject areas such as Multidisciplinary; Social Sciences; Business, Management and Accounting; Decision Sciences; Agricultural and Biological sciences; Economics, Econometrics and Finance and Environmental Science. This helps to screen out too technologically focused research data as the concept ñIndustry 4.0ò and ñdigitalizationò has become buzzwords utilized across many industries and this creates tons of research data which can be difficult to analyze when a SLR is performed. This also ensures a focus on strategic management areas. Environmental science was included to get insights related to sustainability. Agricultural and Biological sciences was included because Fast-Moving Consumer Goods (FMCG) which has their primary raw materials from the aforementioned sciences is one of the industries at the forefront of adoption of state-of-the-art I4.0 technologies in their supply chains. (Soosay & Kannusamy, 2018). Also, only English publications were considered in the SLR.

2. Literature Framework

This chapter provides a literature review of the concepts, principles and technologies in the research. This was developed by a literature review of articles, international journals and studies published by consulting companies such as PwC Strategy&, Deloitte, CGI, McKinsey, etc. This literature framework provides insights into the concepts, principles and characteristics of Industry 4.0 and its deployment in Supply Chain Management.

2.1 Supply Chain Management

Supply Chain Management (SCM) is the active strategic management of interrelated business functions or activities required to maximize customer value and create competitive advantage for enterprises. These business functions or activities, commonly referred to as *value chain*, involves physical and information flows and storage from suppliers through the *logistics networks* to the customers. (Porter, 1998; Rushton et al, 2017). SCM consists of three major closely related elements ï Business processes, Management components and structure of the supply chain. (Cooper et al, 1997).

Depending on the industry concerned, the Supply Chain activities include demand planning; product development; procurement; manufacturing/production; sales and marketing; inbound and outbound logistics; maintenance and services; (CGI,2017a; CGI,2017b; Merli, 2020; Ferrantino & Koten, 2019).Logistics network is an important part of SCM and it is made of five main components ï Storage facilities, Inventory management, Transportation, Unitization & Packaging, and Communications (Fernie & Sparks, 2014 p4)

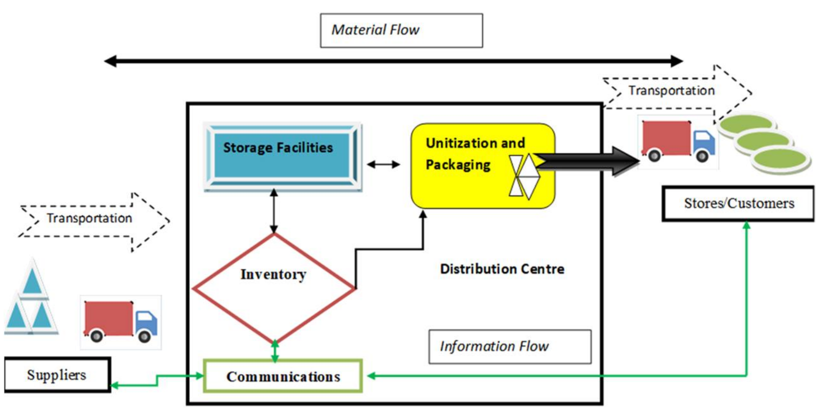

Figure 1: Logistics *Components and Interlinkages (Source: Author)*

Supply chains typically operate along the traditional Supply Chain Operations Reference (SCOR) model - Plan, Source, Make, Deliver, Return, and Enable processes. In 1996, the SCOR model was developed by the Supply Chain Council (SCC) (*In 2014, SCC was merged with APICS*). (APICS SCC, 2014)

SCOR model is a powerful and robust diagnostics toolset for describing, analyzing and improving the Supply Chain and has since been adopted by several large enterprises in different industries. It is a supply chain process reference model with 5 primary management processes (Plan, Source, Make, Deliver and Return), over 200 process elements, over 500 metrics and best practices and is continuously reviewed and updated. (SCOR, 2010; APICS, 2017; Zhou et al, 2011)

Figure 2:*SCOR Management Processes (Source: SCOR,2010)*

Supply Chain Management (SCM) has progressively evolved from traditional mass manufacturing in the 1960s where most of the processes were fragmented, through a consolidation era in the 1980s with two key processes ï *materials management* and *physical distribution*. The 1990s were characterized by increasing level of integration while the 2000s saw the adoption of ICT for better value capture. From 2010 and beyond, SCM has witnessed a growing level of automation and digitalization. (Rodrigue, 2020)

Silos in supply chains are dissolving as organizations adopt digital enterprise processes thereby making traditional supply chains to evolve towards a connected, smart, and highly efficient supply chain ecosystem (Schrauf & Berttram, 2016).

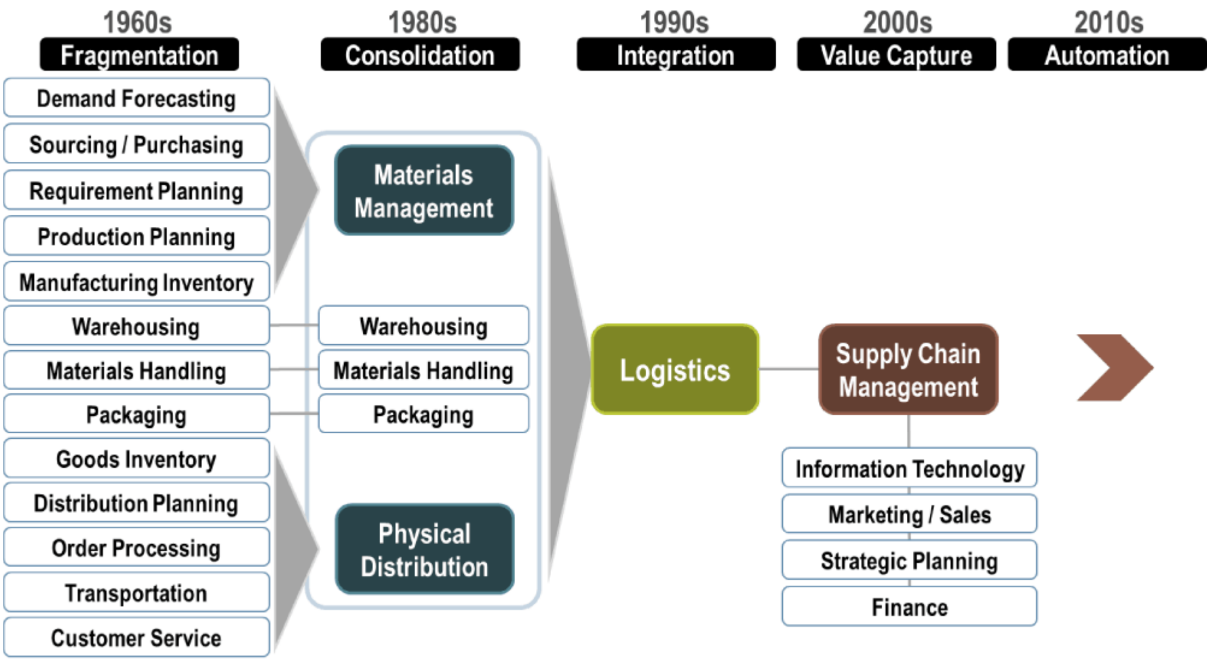

Figure 3: *Evolution of Supply Chain Management (Source: Rodrigue,2020)*

2.2 Industry 4.0

Industrie 4.0 (I4.0) was a paradigm that originated from a 2011 high-tech strategy project by the German government which was to promote the digital revolution of manufacturing. Ever since then, Industry 4.0 has been at the core of several strategic initiatives for the future as envisioned by business leaders, economists and policy makers. (Blanchet 2014;2016)

ñ*Industry 4.0 describes 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.*ò (Smit et al, 2016)

The Kagermann et al (2013) *Industrie 4.0* Working Group report envisioned a future for German manufacturing powerhouse in which global networks of businesses incorporate their entire value chain - machinery, warehousing systems and production facilities in the shape of Cyber-Physical Systems (CPS) that foster dynamic business and engineering processes, optimized decision-making, novel business models, continuous resource productivity and efficiency, and a better work-life balance. The CPS strategy features proposed for smart factories include Horizontal integration through value networks; End-to-End digital integration of engineering across the entire value chain; and Vertical integration and networked manufacturing systems. (Kagermann et al., 2013).

Industry 4.0 technologies such as mobility, cloud computing, IoT, Artificial Intelligence (AI) and big data analytics are enabling a future of ñsmart everythingò and ñInternet of Everythingò. According to Alliance for Logistics Innovation through Collaboration in Europe (ALICE), the European Technology Platform for Logistics, 90% of the global economic growth will come from outside the European Union (EU) in the next 10-15 years. Therefore, joining the Global Value Chains (GVCs) in delivering products, services and technologies is inevitable to stay competitive. Logistics business function in supply chains helps to increase the competitiveness of other industries or sectors of the economy. (ALICE, 2014). According to Eurostat, ñ*In recent decades there have been wide-ranging transformations impacting on manufacturing in the EU, such as deindustrialisation, outsourcing, globalisation, changes to business paradigms (such as just-in-time manufacturing), the growing importance of digital technologies, or concerns linked to sustainable production and the environment. Furthermore, the performance of the manufacturing in the EU has become increasingly linked to the competitiveness of (business) services, insofar as many manufactured goods contain a growing share of services inputs: for example, logistical support; research and development; design; computer services; advertising and marketing*ò (Eurostat, 2019, p. 106). In the EU for example, the manufacturing industry is a major employer of labour, one of the largest contributors to non-financial business economy value add and a major source of EU-28 exports. While it can be deceiving to see manufacturing only through the prism of the multinational manufacturing enterprises, it is good to note that Micro, Small and Medium Enterprises (MSME) are the backbone of manufacturing in the EU in terms of value addition and employment figures. (Eurostat, 2019, p. 101-115; EFFRA, 2013).

There are strategic initiatives and paradigms equivalent to industry 4.0 such as the Industrial Internet by Industrial Internet Consortium (IIC); Smart Factory in the Netherlands; Usine du Futur in France; Fabbrica del Futuro in Italy; High Value Manufacturing Catapult in the United Kingdom; Advanced Manufacturing Partnership (AMP) in the US; and Factories of the Future (FoF), a Public Private Partnership (PPP) in the EU; (MAPI foundation, 2015; Liao et al., 2017). There are several collaborations at domestic, regional (e.g. European Union) and global levels.

There is a collaboration between the German Federal Ministry of Education and Research/Acatech initiative - Plattform Industrie 4.0 which is behind the Industrie 4.0 initiative and the Industrial Internet of Things (IIoT) referred to simply as *Industrial Internet* by Industrial Internet Consortium to ensure interoperability and architecture alignment. The reference architecture for the Industrial Internet is the Industrial Internet Reference Architecture (IIRA) while Industrie 4.0 utilizes the Reference Architectural Model Industrie 4.0 (RAMI 4.0) architecture. (IIC & Plattform Industrie 4.0, 2017; Schweichhart, 2016)

According to IIC & Platform, 2017, ñ*Industrie 4.0 is about making things smartly, while the industrial internet is about making things work smartly. In other words, Industrie 4.0 is about making products by managing the entire value chains along with product lifecycles, while the industrial internet is about building, deploying and operating large connected systems*.ò

MAPI foundation also presented a comparison between the Industrial Internet and Industry 4.0. IIoT has an extended sectoral focus, holistic and global market focus and only three industrial revolutions compared to Industry 4.0. (MAPI Foundation, 2015; Bledowski, 2015).

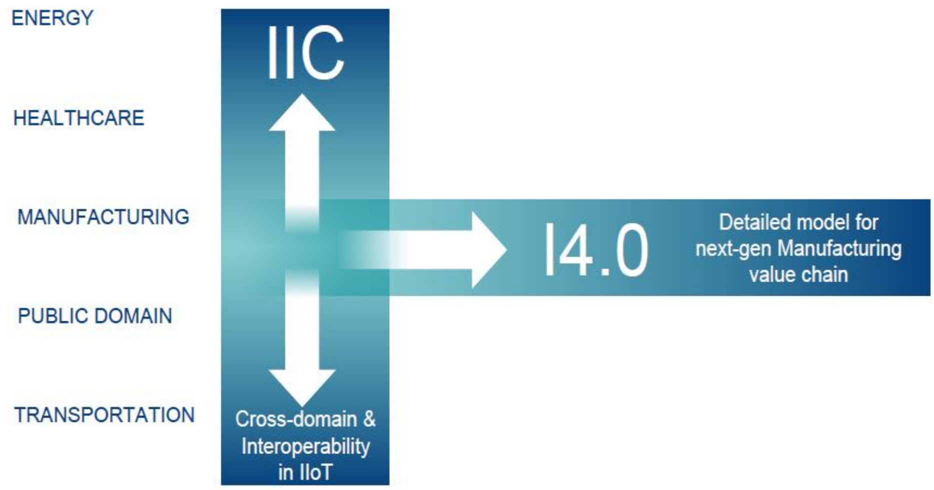

Figure 4: *IIoT vs I4.0 (Source: IIC & Plattform Industrie 4.0, 2017).*

The ñSmart factoriesò involves embedded manufacturing systems which are vertically networked with business processes within enterprises and horizontally networked to value networks that are spatially dispersed and could be managed in real time through the logistics network. They are digital and I4.0-enabled manufacturing factory that has connected, optimized, proactive, agile and transparent operational characteristics. (Burke et al., 2017).

According to Smit et al (2016) in a policy document for the European Parliament, this integration blurs the distinction between industry and services as digital technologies connect industrial products and services into hybrid products that cannot be separated exclusively from each other.

Since the beginning of industrialization, technological leaps have created paradigm shifts in the form of industrial revolutions. (Lasi et al., 2014). The first industrial revolution (Industry 4.0) between 1780 and 1870 had steam powered engines, weaving looms and mechanization. The second industrial revolution between 1900 and 1960 was characterized by introduction of assembly lines, mass production, internal combustion engines and electrical energy. From 1960-2000, the third industrial revolution was based on automation, Information Technology (IT), computing and electronics. Industry 4.0 which kickstarted in the early 2000s is the fourth industrial paradigm shift in which high-tech industries creates a network of people, objects, information and resources - *Internet of Everything (IoE)* using Information and Communication Technology (ICT). (Prisecaru, 2016; Kagermann et al 2013).

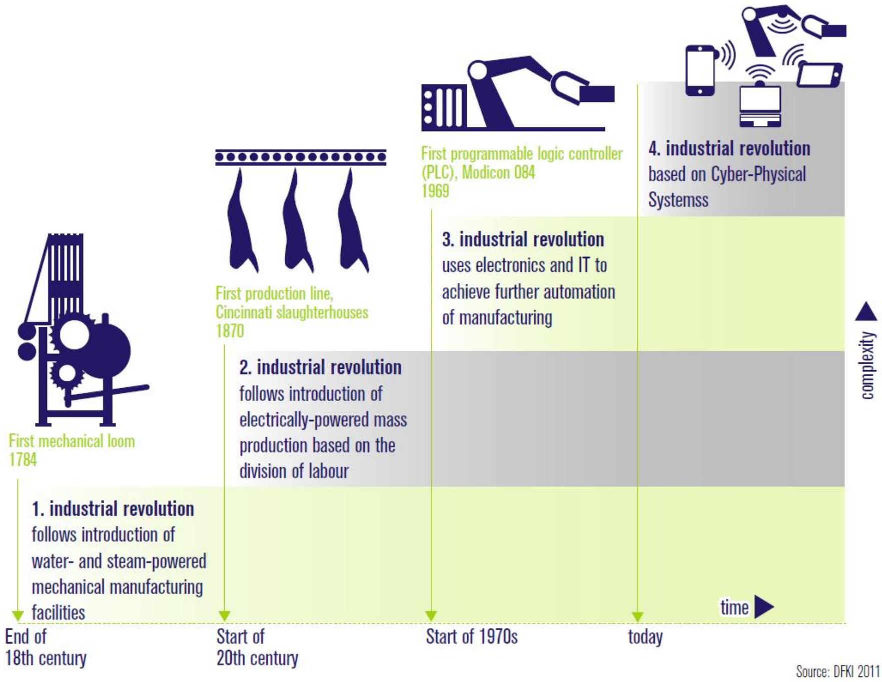

Figure 5: *Industrial Revolutions. (Source: Adapted from Kagermann et al.,2013, p8 [DFKI, 2011])*

2.2.1. Industry 4.0 Concepts

Industry 4.0 creates a network of people, objects, information and resources to create the *Internet of Things and Services* sometimes referred to as *Internet of Everything (IoE)* using Information and Communication Technology (ICT). A structured literature review and concept analysis by Pfohl et al., 2017 showed 49 technologies and concepts. From the result, 7 key characterizing features of Industry 4.0 were defined ï Digitalization, Autonomization, Transparency, mobility, modularization, network-collaboration and socializing of products and processes. The analysis also discovered that digitalization is the most important characteristic feature that enables all other aforementioned features/concepts. (Pfohl et al., 2017).

There are several terms used in literature to refer to paradigms related to industry 4.0 and its application in several fields. The table below provides a list of some key terms as seen in several literatures reviewed:

Concept	Description	Some Reference Literature(s)
Internet of Things (IoT)	This is a generic term used to describe the internetwork of computing devices, mechanical and digital machines, objects, animals, people, etc (Internet of Everything - IoE) by providing them with Unique Identifiers (UIDs) and providing them with the capability to transfer data over a network without requiring human-to-human and/or human-to-machine interaction.	Kagermann et al., 2013; Nicolescu et al., 2019; Howard, 2015; Smit et al., 2016; Pfohl et al., 2017; Plattform Industrie 4.0 (2020a); Plattform Industrie 4.0 (2020b); CGI, 2017a.
Internet of Services (IoS)	This refers to the ICT-driven internetwork of vertically and horizontally integrated services offered and utilized across value chains either within enterprises or across several enterprises.	Kagermann et al., 2013; Nicolescu et al., 2019; Plattform Industrie 4.0 & Alliance Industrie du Futur (2018); Terzidis, 2012a,2012b; Smit et al., 2016; Rennung et al., 2016;

Concept	Description	Some Reference Literature(s)
		Reis & Gonçalves, 2018.
Industrial Internet of Things (IIoT)	This is the internetwork of industrial computing devices (Smart objects, Cyber-physical assets, sensors, etc) connected via the internet which enables real-time, intelligent and autonomous access, communications and control within the industrial environment for overall optimization of production value. The scope of IIoT (also referred to as *Industrial Internet*) is extended across manufacturing, public sector, healthcare, etc compared to Industry 4.0 which is manufacturing focused. IIC is responsible for the coordination of initiatives about Industrial Internet.	Boyes et al., 2018; IIC & Plattform Industrie 4.0, 2017; MAPI Foundation (2015); Bledowski (2015); Geissbauer et al., 2014.
Cyber-Physical Systems	Interconnected Systems (sensors, processors and communication technologies) with embedded software used in manufacturing value chains - machinery, warehousing systems and production facilities, that can independently control and trigger actions thereby fostering dynamic business and engineering processes, optimized decision-making, novel business models, continuous resource productivity and efficiency, and a better work-life balance.	Kagermann et al., 2013; Smit et al., 2016; MAPI Foundation (2015); Bledowski (2015); Liao et al., 2017.
Smart Factory	This is a digital and I4.0-enabled manufacturing factory that has connected, optimized, proactive, agile and transparent operational characteristics. ñ*The smart factory is a flexible system that can self-optimize performance across a broader*	Burke et al., 2017; Hermann et al., 2015; Kang et al, 2016; Brettel et al, 2014; CGI, 2017b; Rüßmann et al, 2015;

Concept	Description	Some Reference Literature(s)
	network, self-adapt to and learn from new conditions in real or near-real time, and autonomously run entire production processes. (Burke et al., 2017)ò	Schlaepfer et al.,2014; Geissbauer et al., 2014; Kagermann et al., 2013.
Digitalization	Digitalization is a generic concept used to refer to the transformation of everyday life using ICT concepts, technologies and processes.	*Seiberth & Gründinger, 2018; Hartmann et al.; 2014; Brownlow et al., 2015; OECD, 2017; Probst et al., 2017,2018.*
Supply Chain 4.0	Supply Chain 4.0 is the transformation of global value chains (technology, processes and organization) using Industry 4.0 concepts, principles and technologies.	Mussomeli et al., 2016; Frederico et al.,2019; Daus et al., 2018; Schrauf & Berttram, 2016; Ferrantino & Koten, 2019.

Table 1: *Industry 4.0 Concepts (Source: Created by Author)*

2.2.2. Industry 4.0 Technologies

Industry 4.0 technologies such as mobile services, cloud technologies, IoT, Cybersecurity solutions, Robotics, Artificial Intelligence (AI), 3D printing, Social media and big data analytics are enabling a future of ñsmart everythingò and ñInternet of Everythingò. (*Probst et al., 2017, 2018;* OECD, 2017).

The cluster of Industry 4.0 technologies enabling digital supply chain is summarized in the table below (Pfohl et al, 2017; CGI, 2017a; Al-Fuqaha et al.; 2015; OECD, 2017; Probst et al., 2017, 2018)

Industry 4.0 Technologies	Description
Internet of Things (IoT)	This generic terms refers to the internetwork of computing devices, digital and mechanical machines, objects, animals, people, etc (*Internet of Everything* - IoE) by providing them with Unique Identifiers (UIDs) and providing them with the capability to transfer data over a network without requiring human-to-human and/or human-to-machine interaction.

Industry 4.0 Technologies	Description
Big Data and Data Analytics	This is a system of Hardware and software that is used to store, analyze and systematically extract information and intelligence from harvested datasets for value-based decision making. It utilizes computer algorithms for analytics using AI techniques.
Cloud Computing	These are on-demand High Availability (HA) hardware and software digital computing platforms which can be automatically managed without direct interventions by end-users.
Advanced (Autonomous) Robotics	Programmable Cyber Physical Systems that can independently perform routines and tasks done previously by humans. They are connected, agile, proactive and can be optimized.
3D Printing	Use of Computer-Aided Design (CAD) models to build 3-Dimensional objects by successively adding layers of materials - additive manufacturing. For example, during the COVID-19 pandemic, 3D printing has been very useful for rapid manufacturing of face masks and guards for use in the health care system.
Augmented Reality/Virtual Reality (AR/VR)	AR and VR are immersive and interactive experiences of real-world environments using computer-generated experiences. These are increasingly used even in consumer products such that customers can have a feel of the product before purchase. With AR, the objects that reside in the real world are enhanced via computer-generated perceptual information, sometimes across several sensory modalities, including visual, haptic, auditory, somatosensory and olfactory thereby altering the ongoing perceptions of the real-world environment. On the other hand, VR completely replaces the user's real-world environment with a simulated or virtual one.
Blockchain	This is a technology used to build a list of digital records (blocks) which are linked by cryptography. In Supply Chains, this has been applied in electronic shipping documentations e.g. electronic bill of lading.
AI & Machine Learning	Artificial Intelligence (AI) refers to intelligence displayed by machines by mimicking cognitive functions often associated with human intelligence. These cognitive functions include reasoning, planning, knowledge representation, learning, perception, Natural Language Processing (NLP) and the ability to move and manipulate objects. This is sometimes referred to as *Cognitive Computing*. Machine Learning is a subset of AI that trains machines to perform the cognitive functions.
Quantum Computing	Quantum computers have the ability to turn classical memory states into quantum memory states, and vice-versa unlike classical computers that are designed to only perform computations with memory that never deviates from clearly defined values. This enables non-classical computational models and unleashes huge computational power and capacity for devices.

Industry 4.0 Technologies	Description
Smart Sensors and Smart Mobile Devices	Smart sensors are devices that can utilize inputs from physical environment, perform computational activities on the inputs to perform predefined functions and provides an intelligent output. They are an integral part of IoT. Sensor fusion is an area where data from a cluster of smart sensors are combined such that the resulting information has less uncertainty compared to information from the individual sensors. These also includes miniaturized electronic components that can be used for collecting, managing and analyzing data using Automatic Identification and Data Collection (AIDC) and Radio Frequency Identification (RFID) technologies.
5G	This is an advanced wireless cellular technology that supports higher data speeds up to 1Gbps with less latency compared to 4G. 5G works in the non-ionizing radiation spectrum. While 5G can support up to a million devices per square kilometre, 4G supports only up to 100,000 devices per square kilometre.
Automation	This is the use of technology to process or perform tasks automatically with minimum or no human intervention.
Human Machine Interface (HMI)	These are hardware and software components of devices that handle interactions between the humans and the machine (devices). Examples of physical aspects of HMI include push button, touch display, keypad, etc.
Cybersecurity	Best practices used to minimize threats and risks which interconnected devices and humans are exposed to in the cyberspace.
Social Media	These are interactive and collaborative ICT platforms that facilitate the creation and sharing of information, ideas, etc in virtual communities.

Table 2: *Industry 4.0 Technologies (Source: Created by Author)*

2.3 Digitalization

Industry 4.0 as a paradigm enables digitalization of the horizontal and vertical value chains, births new data-driven business models and fosters innovation in products and services. Like the human body, *connectivity* acts as the circulatory system enabling the flow of information through the business functions or value chains. *Ubiquitous computing* (cloud-enabled and mobile platforms), *automation* (software-defined processes) and *security* are at the core (brain) of digital transformation and creation of digital value networks. (CGI, 2017a; CGI2017b; Schrauf & Berttram, 2016). With Industry 4.0, Enterprise Resource Planning (ERP) systems which had been utilized by enterprises for planning, control and execution for a while now, will shift from centralized data collection points to support of decentralized data storage with user interfaces that are simple; can be personalized; are role-based; and supports mobile devices.(Hochmuth et al., 2017). With the rise of platform economies ï ñ*API economy*ò, born-digital companies like Amazon, Google and Microsoft just to mention a few have innovatively changed the business landscape such that Data-Driven Business Models (DDBMs) using cloud computing and big data infrastructure are now the norm. Data can add value to a key resource or form the key resource itself leading to 3 value dimensions ï Product innovation, Process innovation and Business model innovation. *The future belongs to enterprises that can control their digital value chain (Hardware, Data, Insights and Services) and digital value networks such that they can deliver superior brand experience to their customers. DDBMs are projected to be the substantial revenue-generator for enterprises in the future. The data monetization models utilized by enterprises include data harvesting (bartering model), data matching, and As-a-service (Business intelligence). Apart from the monetization benefits of such innovations, it goes a long way in brand improvement for many enterprises. (*Seiberth & Gründinger, 2018; Hartmann et al.; 2014; Brownlow et al., 2015; Plattform Industrie 4.0, 2019a, 2019b).

2.4 Supply Chain 4.0 – Digital Supply Chains

Supply Chain 4.0 is at the core of digital enterprises (Digital workforce; Digital engineering & manufacturing, Digital products, services and business models; Digital customer and channel management) and it has a huge impact on global value chains which involves technology, processes and organization. (Schrauf & Berttram, 2016; Ferrantino & Koten, 2019).

Supply Chain 4.0 is the re-organization of Supply chain using Industry 4.0 concepts, principles and technologies. Industry 4.0 fosters the convergence of the physical and digital worlds thereby shifting linear sequential supply chain operations to interconnected, transparent system of supply operations sometimes referred to as *Digital Supply Networks* (DSNs) or Digital supply chains in some literature (Burke et al., 2017; Mussomeli et al., 2016)

The digital network of supply chain involves 8 key elements that can foster the achievement of the key features in the Cyber-Physical System (CPS) strategy earlier proposed by Kagermann et al (2013), depicted in Figure 1 ï Prescriptive Supply Chain Analytics; Logistics Visibility; Integrated Planning and Execution; Procurement 4.0; Smart Warehousing; Efficient Spare Parts Management; Autonomous and B2C Logistics; and Digital Supply Chain Enablers.

These key elements enabled by digital technologies create a chain of capabilities that fosters proactive responses to disruptions in the supply chain by modelling the network to capture necessary intelligence about Patterns of Business Activities (PBA) and creating anticipatory scenarios for supply chain adjustments in real time as conditions change (Schrauf & Berttram, 2016; Fernie & Sparks, 2014,p 4).

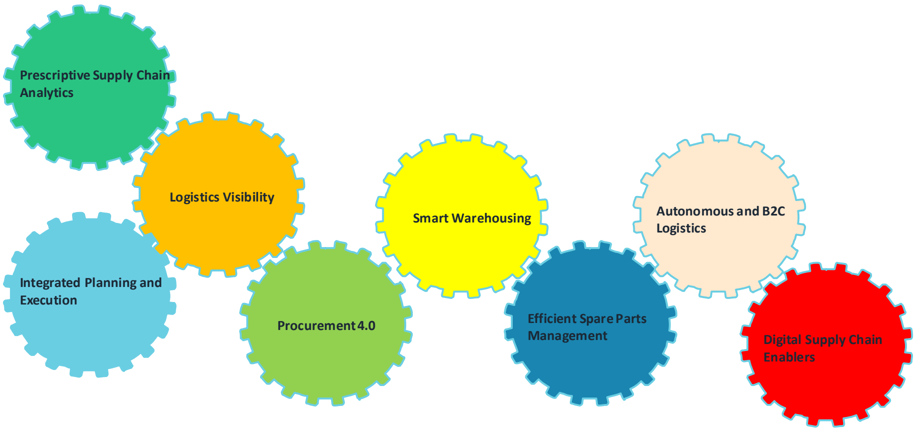

Figure 6: *Supply Chain 4.0 Core Elements (Adapted from Schrauf & Berttram, PwC 2016)*

For example, Prologis research found that e-commerce retailers require three times more logistics space than brick and mortar retailers as 77,000 sqm of new logistics demand is generated by EUR 1 Billion of additional online sales. (Savills Investment Management, 2016). This means there is a need for proactive optimization of technology-driven retail services. The integration of Operations Technology (OT) and Information Technology (IT) is required for digitally integrated and intelligent value chains (CGI, 2017a). Companies are increasingly considering sustainable development in the digitalization of their supply chains. This is increasingly seen in many of their Corporate Social Responsibility (CSR) policies. Analysis of the trends and opportunities in supply chain management that lead to digital transformation shows that there are endogenous trends (digitalization of business processes, business analytics, transparency in the supply chain, automation, networking/collaboration, and decentralization) and exogenous trends (cost pressure, demand fluctuations, need for compliance with government regulations, individualization/personalization, staff shortages, risk of disruptions/interruptions, complexity, sustainability, and changed consumer behaviour).(Kersten et al.,2017; Mazzarino, 2012; Piecyk and Björklund, 2015; Kamble et al., 2018; Kiel et al., 2017)

There are also concerns around security and privacy. On May 25, 2018, the European Unionʼs General Data Protection Regulation (GDPR)became applicable in EU-28 and it was to address some of the privacy and security concerns.

3. Methodology

This chapter outlines the research strategy in this Thesis. This is done by outlining the research design and research methods deployed. Also, the theoretical framework and tools used for the analysis of research data is presented here.

3.1 Research Design

This research was designed using the practical guides about the research paradigms presented by Hussey & Collis (2014). In addition, Saunders *et al*, 2009 research onion was also consulted to design the research. The research philosophy or paradigm utilized in this thesis is closely related to Interpretivism and the choice of research methods is greatly influenced by the main characteristics of research under the Interpretivist paradigm. Pfohl et al., 2017 clustered the research fields that are related to ñIndustry 4.0ò using the management-level, technology-level and process-level analytical dimensions. Four clusters as shown in the table below was discovered:

Type of Research	Cluster	Description
Exploratory Qualitative	Cluster A	Scientific research that focus on how to implement Industry 4.0 technologies and concepts on the process-level (Analysis on technology- and process-level) using qualitative methods.
	Cluster C	Scientific research that analyzes the whole value-chain, business models or evaluate the impact of Industry 4.0 from a holistic management perspective (Analysis on management-level) using qualitative methods.
Confirmatory Quantitative	Cluster B	Scientific research of Industry 4.0 using quantitative methods in the analysis and implementation models for specific technologies.
	Cluster D	Scientific research that analyzes the whole value-chain, business models or evaluate the impact of Industry 4.0 from a holistic management perspective (Analysis on management-level) using quantitative methods.

Table 3: *Industry 4.0 Research Clusters (Source: Adapted from Pfohl et al., 2017)*

This thesis is an exploratory research that maps within Cluster C. However, in order to clearly choose the best methods that can solve the research questions, pragmatism as a paradigm for mixed method research (qualitative and quantitative methods) as outline by Morgan (2013) and Mayring (2014) was explored. According to Morgan, 2013, qualitative research methods has features that are inductive, subjective and contextual. In contrast, quantitative methods focus on deductions, objectivity and generality as characteristic features.

This Thesis is inductive as its purpose is to perform an exploratory research with a view to generating theory from observations. The subjectivity of this research is evident in the fact that this research employs a Systematic Literature Review (SLR) to understand previous research conducted about Supply Chain 4.0, interprete them and propose a theoretical framework that can be utilized for future research. The context is a holistic analysis that cuts across the end-to-end business functions in a supply chain. Systematic literature review can be done using both quantitative and qualitative methods.

3.2 Research Method

Systematic Literature Review (SLR) is used in academic research to gather existing knowledge and state of a field. It provides a methodology for conducting reviews in a replicable, transparent and scientific manner compared to narrative reviews. The reviews can either be *author-centric* or *theme-centric* (Linnenluecke et al., 2019). Compared to traditional narrative review, systematic review is an evidence-based approach that minimizes bias via exhaustive literature searches of published and unpublished studies and provides an audit trail of the reviewerőś decisions, procedures and conclusions. Meta-analysis is the associated procedure used with the process of systematic review and had been used in medical and health care research for decades. (Gibbons et al., 1994; Tranfield et al., 2003)

Utilizing systematic review in social sciences and management research provides the opportunity to produce knowledge that are theoretically sound, methodologically rigorous, context-sensitive and relevant to the practitioner community. (Tranfield et al., 2003). Several business Research and Development (R&D) studies published by consulting companies such as PwC Strategy&, Deloitte, Mckinsey, CGI, etc. had been at the forefront of many insights into the concepts and characteristics of Supply Chain 4.0. The transdisciplinarity, heterogeneity, and organizational diversity of research in industry 4.0 in the context of supply chain management makes *mode 2* knowledge production approach as outlined by Gibbons et al. (1994) more suitable for this thesis because it helps to innovate by mutually integrating research in academia and by practitioners in business R&D. Thus, SLR provides a tool for a holistic research into the drivers and barriers that shape the managerial decision-making process for adoption and implementation of Industry 4.0 concepts, principles and technologies in supply chains across several industries/sectors, geographical boundaries, political systems, economic systems and socio-cultural norms. The research data is gathered from business research by practitioners and Scopus database which is one of the largest abstracts and citation database of peer-reviewed literature that has multidisciplinary focus - Physical sciences, health sciences, life sciences, social sciences and humanities.

Li & Cavusgil (1995) outlined three basic approaches that could be used when conducting an investigation about the state of knowledge in a field or subject ï Delphi method, Meta-analysis and Content analysis. While Delphi method utilizes a survey of the experts in a particular field, meta-analysis involves the use of statistical methods to analyze empirical studies in a field or subject area.

“Content analysis is a research technique for systematic, qualitative and quantitative description of the manifest content of literature in an area” (Li & Cavusgil, 1995*)*. Content analysis systematically analyzes data from multiple sources and depending on the research question, qualitative and/or quantitative methods can be used (Seidiaghilabadi et al., 2019).

Content analysis is the method of choice in this Thesis as it provides the appropriate tool to extract, analyze and interprete data about previous research conducted about ñSupply Chain 4.0ò; identify the research gaps and develop a framework that addresses the drivers and barriers in the adoption and implementation of industry 4.0 in Supply Chain Management.

3.2.1. Research Process

Before the SLR is performed, a literature framework was first developed to understand the current state of research and build knowledge by performing an internet search for the following terms - "Supply Chain 4.0"; "Industry 4.0"; ñDigitalizationò and "Drivers and Barriers of Supply Chain 4.0". The results provided a preliminary overview and insights into the concepts and characteristics of Industry 4.0 and its deployment in Supply Chain Management from the academia and practitioners. The relevancy of the search results to the research questions were validated based on the title, abstract and content of the body of literature in the search results. Since research into industry 4.0 is just gaining traction, the search results were not only limited to peer-reviewed publications as working papers, position papers and conference papers were utilized in developing the theoretical framework. One important conference pack that provided a lot of interdisciplinary and cross-sectoral insights on digitalization was the Hamburg International Conference of Logistics (HICL). The results of the internet search are captured in the *Literature review* chapter of this thesis (Chapter 2). This was then used to develop an initial set of drivers and barriers.

For the SLR, a similar approach used in the research method by Azim & Sorooshian (2019) was utilized in the thesis by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline. (Moher et al./PRISMA Group, 2009). Literature related to Industry 4.0 in supply chains from 2015-2020 were chosen. The concept of industry 4.0 started around 2011 and the first recommendation from the working group came out in 2013, though IoT which is a concept often used in relation to Industry 4.0 had started earlier. However, publications about ñSupply Chain 4.0ò did not start until around 2014. The search results in Scopus actually produced publications from 2015-2020 for keyword combinations that include ñIndustry 4.0ò and ñSupply Chain*ò.

Co-word analysis similarity approach and visualization of the findings from the analysis of the comprehensive dataset from Scopus was done using *VOSviewer*. Co-word analysis (sometimes called *Co-occurrence*) was chosen because it fosters the projection of the data into useful visualization while still maintaining the essential information in the data. Other similarity approaches only use bibliographic meta-data. The keywords used in the research are summarized in the figure below.

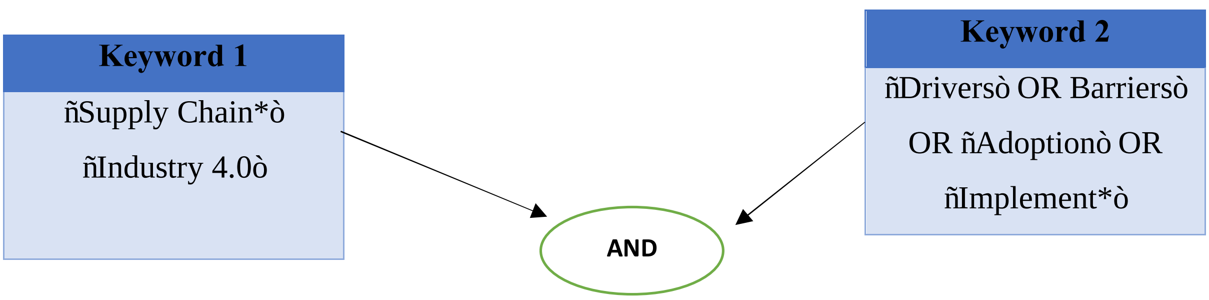

Figure 7: *Keywords used in Scopus Search*

The content analysis steps utilized in this Thesis is shown below. Steps 1-4 of the research process is related to the development of a literature framework via internet search of relevant publications and compilation of a brain map of initial set of drivers and barriers in the implementation of Supply Chain 4.0. Steps 5-7 covers the Systematic Literature Review in Scopus based on PRISMA guideline.

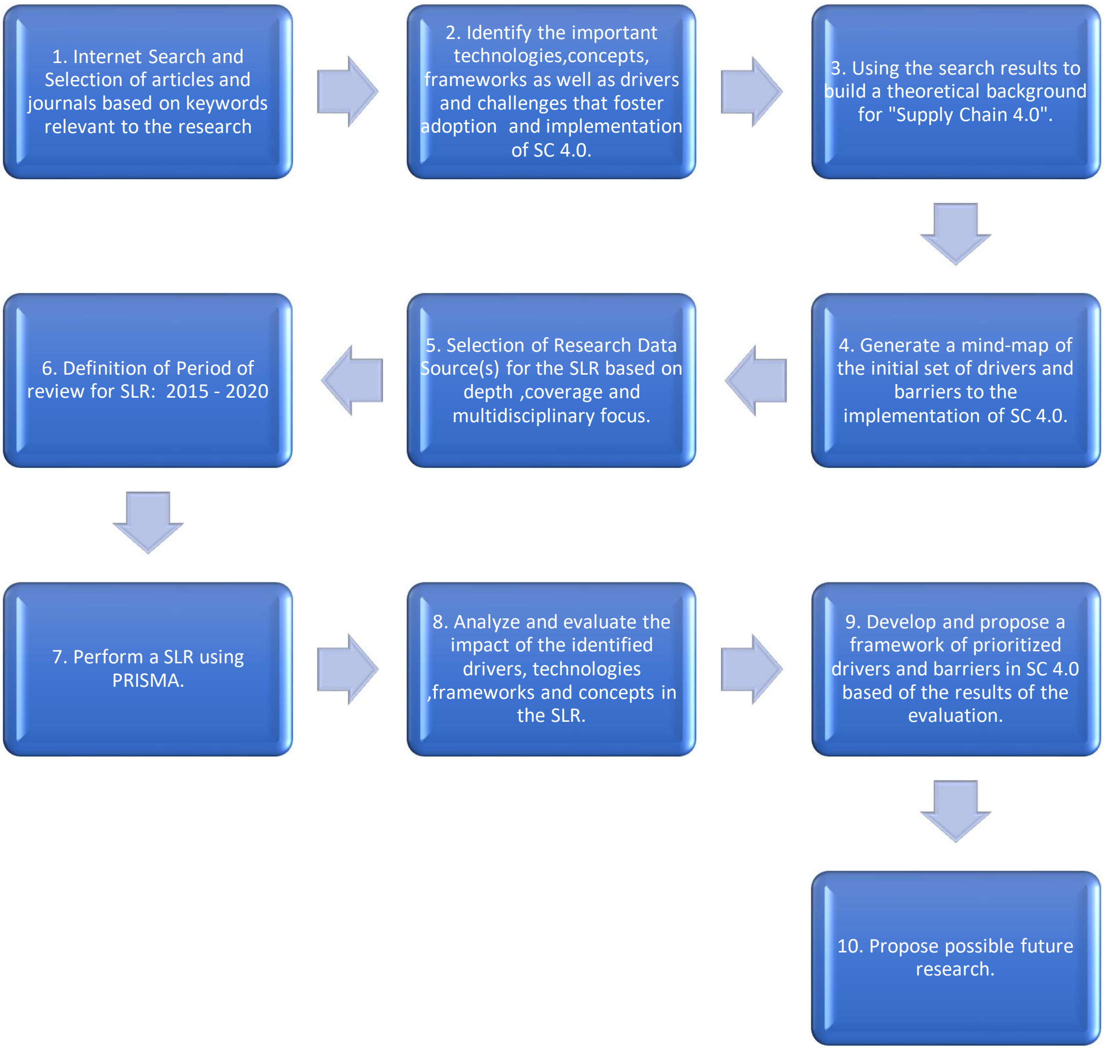

Figure 8: *Content Analysis Steps (Source: Created by Author)*

3.2.2. Research Data

For the thesis, the database for data collection was chosen based on its relevance to Supply Chain 4.0, ease of use, and the coverage of multi-dimensional and multi-disciplinary aspects of the concepts to be researched. Scopus is one of the largest abstracts and citation database of peer-reviewed literature that has multidisciplinary focus - Physical sciences, health sciences, life sciences, social sciences and humanities. Since the research questions has several dimensions to be analyzed, Scopus was chosen for the thesis because it has global interdisciplinary field coverage of required data for conceptual development. Also compared to other databases, it has more options and formats for exporting reports. Scopus also has article level metrics that will make content analysis easier. *(*Burnham*,* 2006*)*. Publications from 2015-2020 was considered in this research.

The key words for the Systematic Literature review was chosen based on the research questions and the included methods and technologies in the thesis. The relevancy of the search results to the research questions were validated based on their title, abstract and content.

3.3 Theoretical Framework and Decision Tools

This section provides a theoretical framework of some of the methods, approaches and tools that is used for the analysis of the research data. According to Clark (1996), decision tools are ñ*techniques, tools, methods, models, frameworks, approaches, and methodologies which are available to support decision-making within strategic management*ò. In Strategic management, decision-making is usually done with a range of decision tools such as SWOT analysis, PEST analysis, Balanced Scorecard, Benchmarking, etc. (Koseoglu et al., 2019)

For the research questions in this thesis, the decision tools and frameworks utilized in the conceptual framework development are highlighted in this section.

3.3.1. PEST Framework

PEST (**P**olitical, **E**conomic, **S**ocio-cultural, and **T**echnological) analysis is a tool or framework of macro-economic factors used by enterprises for strategic analysis of external factors. (CIPD,2020). There are several variants of the framework such as PESTEL (incorporates **E**nvironmental and **L**egal factors); STEER (incorporates **S**ocio-cultural, **T**echnological,

Economic, **E**cological, and **R**egulatory factors) (Carr & Nanni Jr, 2009); STEEPLE (incorporates **S**ocial, **T**echnological, **E**conomic, **E**nvironmental, **P**olitical, **L**egal and **E**thical factors) and PMESII-PT (incorporates **P**olitical, **M**ilitary, **E**conomic, **S**ocial, **I**nformation **I**nfrastructure **P**hysical environment and **T**ime factors) (Walden, 2011).

PESTEL analysis will be used in reviewing the drivers and barriers in the implementation of Industry 4.0 in Supply chains.

- *Political factors* ï This includes factors such as political policy, trade policy, fiscal and taxation policies which could impact the enterprises deploying industry 4.0 in their supply chains.
- *Economic factors* - This includes factors that impact the economy and performance, thereby impacting economic performance of enterprises deploying industry 4.0 in their supply chains. Such factors include interest rates, employment/unemployment, Foreign Exchange (FX) rates, input costs, etc.
- *Socio-cultural factors* – This includes identified emerging trends in the social environment such as behavioural patterns and cultural practices across demographies and communities and its impact on enterprises deploying industry 4.0 in their supply chains.
- *Technological factors* – This includes developments in technical aspects such as innovation, research and development, technical solutions, etc and their impact on enterprises deploying industry 4.0 in their supply chains.
- *Environmental factors* - This includes ecological and environmental aspects such as Carbon footprint, recycling procedures, and other sustainability policies and their impact on enterprises deploying industry 4.0 in their supply chains.
- *Legal factors* – This includes aspects of legislation, consumer law and other binding local, regional and international legal aspects and their impact on enterprises deploying industry 4.0 in their supply chains.

3.3.2. Bibliometric Research Methods

Bibliometric research is used for qualitatively and quantitatively analyzing dataset of scientific literature from research databases in several fields of study. Hierarchy of evidence had been used in medical research for decades. (Daly et al., 2007). Tranfield et al., 2003 highlighted some of the differences between medical research and management research. While medical research is convergent; subject to rigorous scientific evaluation; uses predominantly quantitative methods; data qualitatively synthesized; and reporting is standardized, management research on the other hand is divergent; split between positivist and phenomenological perspectives; uses quantitative and qualitative methods; data is usually qualitatively synthesized with narratives; and reporting structure is non-standardized. (Tranfield et al, 2003, p. 213). Some of the systematic review methods utilized in medical research has also found its way into research in other fields like social sciences. Some of the prominent research databases include Scopus, Web of Science, PubMed, EBSCOHOST, Google Scholar, etc.

There are a couple of bibliometric methods or techniques that are useful for mapping reviews of scientific literature and performance analysis. They are sometimes referred to as similarity approaches. Bibliometric methods foster aggregation of bibliographic data produced by scientists working in the field who usually express their opinions via collaboration, citation and authoring of academic and practitionersô knowledge products. (Boyack & Klavans, 2010; Ģupiļ & Ļater, 2015; Ding et al., 2001). Similarity approaches include citation-based approaches, text-based approaches and Hybrid approach. (Boyack & Klavans, 2010)

There are several tools that can be used for creating, exploring and visualizing research data using the different bibliometric techniques. VOSviewer, a software tool for creating, visualizing and exploring maps based on network data was utilized for bibliometric research in this thesis. In the identification and selection of *terms* in text data, VOSviewer uses Natural Language Processing (NLP) algorithms in Apache OpenNLP library for sentence detection and part-of-speech tagging. The custom weight and score attributes which are made available for map created with bibliographic data or text data depends on the choice of link, type of data item and the data source. Where keywords in bibliographic data is utilized in the creation of a bibliographic map, the Occurrences attribute indicates the number of documents in which a keyword occurs. (Van Eck & Waltman, 2020).

Ģupiļ & Ļater, 2015 summarized the pros and cons of the different bibliometric methods or similarity approaches as presented in the table below:

Method	Description	Unit of Analysis	Pros	Cons
Direct Citation (Sometimes called intercitation)	This estimate influence of documents, authors or journals through citation rates.	Document Author Journals	Can be used to quickly find the most important works in a field of study.	Citation count as a measure of influence is biased towards older publications. Newer publications can be missed.
Co-citation analysis	This connects documents, authors or journals based on joint appearances in reference lists. This usually involves a co-citation clustering before the co-citation analysis. (Boyack & Klavans, 2010)	Document Author Journals	This is the most widely used bibliometric method and has been adjudged to be very reliable since citation is a measure of influence.	Since co-citation is done on already cited articles and thus might not be optimal for scientific mapping. It is time-consuming to gather citations. Therefore, new publications cannot be directly connected and has to be done via knowledge base clusters. Several citations are needed to map publications and it will be impossible to map publications that are not cited.

Method	Description	Unit of Analysis	Pros	Cons
Bibliographic Coupling	This connects the unit of analysis based on the number of shared references.	Document Author Journals	This makes scientific data immediately available as it does not require citations to accumulate. Therefore, it is useful for new publications which are yet to be cited, emerging fields and smaller subfields.	It has a limitation in terms of the timeframe it can be used for (up to a 5-year interval). Inherently, it does not identify the most important works by citation counts as co-citation. Thus, it is difficult to know whether mapped publications are important or not.
Co-author analysis	This connects authors when they co-author a publication.	Author	This produces the social structure of a field of study and can provide evidence of collaboration.	Collaboration is not always acknowledged with co-authorship.
Co-word analysis	This connects keywords when they appear in the same title, abstract or keyword list.	Word	This uses the actual content of publications for analysis (useful for *content analysis*)	Words can appear in different forms and can have different interpretations.

Table 4: *Bibliometric Research Methods (Source: Adapted from Župič & Čater, 2015)*

For this thesis, Co-word analysis was selected as it assists in analyzing the actual content of the data. It also fosters the projection of the data into useful visualization while still maintaining the essential information in the data. Other similarity approaches only use bibliographic meta-data compared to Co-word analysis which uses the actual content of publications for the analysis.

3.4 Research Quality

The evaluation of the quality of the qualitative data in this thesis is done based on 4 criteria ï *Credibility*, *Transferability*, *Dependability* and *Confirmability*. The quality of the quantitative data and results are assessed based on its *reliability* and *validity.*

3.4.1. Credibility

For this research, the author explored the concepts, principles and technologies of I4.0 that enables digitalization in supply chains across several industries. The literature framework in the thesis was developed by the authorôs exploration of relevant publications in academia and by practitioners in business R&D with a view to produce knowledge that is transdisciplinary, heterogeneous and organizationally diverse.

3.4.2. Transferability

The conceptual framework developed in this thesis can be utilized across several industries as the data utilized were not industry-specific. Also, a holistic research into the drivers and barriers that shape the managerial decision-making process for adoption and implementation of Industry 4.0 in supply chains across several industries/sectors, geographical boundaries, political systems, economic systems and socio-cultural norms were considered.

3.4.3. Dependability

The SLR in the thesis was done using PRISMA guideline which makes the process systematic, comprehensive, rigorous, replicable and unbiased. The research process, data and methods utilized in the SLR are well documented.

3.4.4. Confirmability

The findings of the SLR are well documented with references from the data analyzed systematically.

3.4.5. Reliability

Reliability is the accuracy and precision of measurement in a research such that when the research is repeated, it produces the same results. (Hussey & Collis, 2014). This research is reliable as the search strings and eligibility criteria used in gathering data in Scopus database will produce similar results if applied by another researcher.

3.4.6. Validity

Validity of a research shows the extent to which a research result captures the phenomenon under investigation. This research explored concepts, principles and technologies utilized in the adoption and implementation of Industry 4.0 in Supply chains first via a literature review done with an internet search. An initial set of drivers was developed from the study. The final conceptual framework which resulted from this thesis is a pairwise-comparison of the initial list of drivers and barriers developed conceptually via observations in literature and brain mapping with what was observed via co-word analysis in a Systematic Literature Review following PRISMA guideline. The use of multiple publications from academia and practitioners to understand the concepts in the literature review was important for the validation of the concepts and gave the opportunity of cross-referencing with some keywords that was generated systematically in Scopus database.

4. Data Collection, Analysis and Presentation of Results

This chapter provides in detail the data collection guideline for the Systematic Literature Review in Scopus and the analysis of the research data using bibliometric methods and NLP algorithms in VOSviewer tool. The results of the analysis and the framework developed is also presented in this chapter.

4.1 Data Collection and Filtering based on PRISMA Guideline

A similar approach used in the research method by Azim & Sorooshian (2019) was utilized in the thesis by following the PRISMA guideline. (Moher et al./PRISMA Group, 2009).

PRISMA Section	PRISMA Item	Description as related to the SLR
Methods	Information source.	Scopus Database
	Eligibility Criteria.	Literature related to industry 4.0 in supply chains from 2015-2020 were chosen because the concept of Supply Chain 4.0 started around 2014. The keyword search results in Scopus actually only produced publications from 2015-2020. Keywords in the Research Questions (RQs) were used in the search string on Scopus database. The keywords utilized in the Scopus search was a pairwise query and/or combination of the following: • ñSupply Chainò • ñIndustry 4.0ò • ñAdoptionò • ñBarriersò • ñDriversò Only English publications were considered. The subject areas were limited to Multidisciplinary; Social Sciences; Business, Management and Accounting; Decision Sciences; Agricultural and Biological sciences; Economics, Econometrics and

PRISMA Section	PRISMA Item	Description as related to the SLR
		Finance; and Environmental Science. These subject areas were chosen to ensure technology-centric publications are screened out and to focus on strategic management areas. Environmental science was included to get insights related to sustainability. Agricultural and Biological sciences was included because Fast-Moving Consumer Goods (FMCG) which has their primary raw materials from the aforementioned sciences is one of the industries at the forefront of adoption of state-of-the-art I4.0 technologies in their supply chains.
Methods	Search	The inclusion criteria used in the search on Scopus database was: • Searched for different combinations of the keywords in the research questions ï ○ S1 = "Supply Chain*" AND "Industry 4.0"; ○ S2 = "Supply Chain*" AND "Industry 4.0" AND ñImplement*ò; ○ S3 = "Supply Chain*" AND "Industry 4.0" AND ñAdoptionò; ○ S4 = "Supply Chain*" AND "Industry 4.0" AND ñBarriersò; ○ S5 = "Supply Chain*" AND "Industry 4.0" AND ñDriversò; • The Title, Abstract, and Keywords of the publications were considered. • Limit to search records with 2015-2020 as year of publication. • Only English publications were considered. • Subject area on Scopus was limited to the following: ○ Multidisciplinary ○ Social Sciences

PRISMA Section	PRISMA Item	Description as related to the SLR
		○ Business, Management and Accounting ○ Decision sciences ○ Economics, Econometrics and Finance ○ Environmental Science ○ Agricultural and Biological Sciences • All document types and publication stages were considered. • An example of Search string used in Scopus was ï ○ TITLE-ABS-KEY (*"Supply Chain*"* AND *"Industry 4.0"*) AND (LIMIT-TO (SUBJAREA , *"BUSI"*) OR LIMIT-TO (SUBJAREA , *"DECI"*) OR LIMIT-TO (SUBJAREA , *"SOCI"*) OR LIMIT-TO (SUBJAREA , *"ENVI"*) OR LIMIT-TO (SUBJAREA , *"ECON"*) OR LIMIT-TO (SUBJAREA , *"AGRI"*) OR LIMIT-TO (SUBJAREA , *"MULT"*)) AND (LIMIT-TO (LANGUAGE , *"English"*))
Methods	Study Selection, Data collection process and Data Items	The records from Scopus were exported from Scopus as Comma-Separated Value (CSV) files. The results from Searches S1 to S5 (delimited with the eligibility criteria) yielded a total of 387 records in CSV format. These records were combined and duplicates eliminated using Microsoft Excel resulting in 256 records. The resulting data from Excel in CSV is used in the analysis. In VOSviewer, maps were created based on bibliographic data in the CSV file. The type of analysis used in VOSviewer was Co-occurrence and full counting method. VOSviewer quantitatively uses Natural Language Processing (NLP) algorithms. When only ñindex keywordsò were used in the Unit of analysis, 1157 keywords were obtained while when ñAll

PRISMA Section	PRISMA Item	Description as related to the SLR
		keywordsò were used, 1580 keywords were produced. For the analysis the latter was considered. VOSviewer shows that only 1564 records were connected items. The selected keywords were exported to a text file and analyzed using Microsoft Excel program. Also, the Scopus extract in CSV format was analyzed using Microsoft Excel.

Table 5: *PRISMA Checklist for Research Data Analysis (Source: Created by Author)*

The PRISMA flow diagram for the SLR for the period 2015- 2020 is shown below:

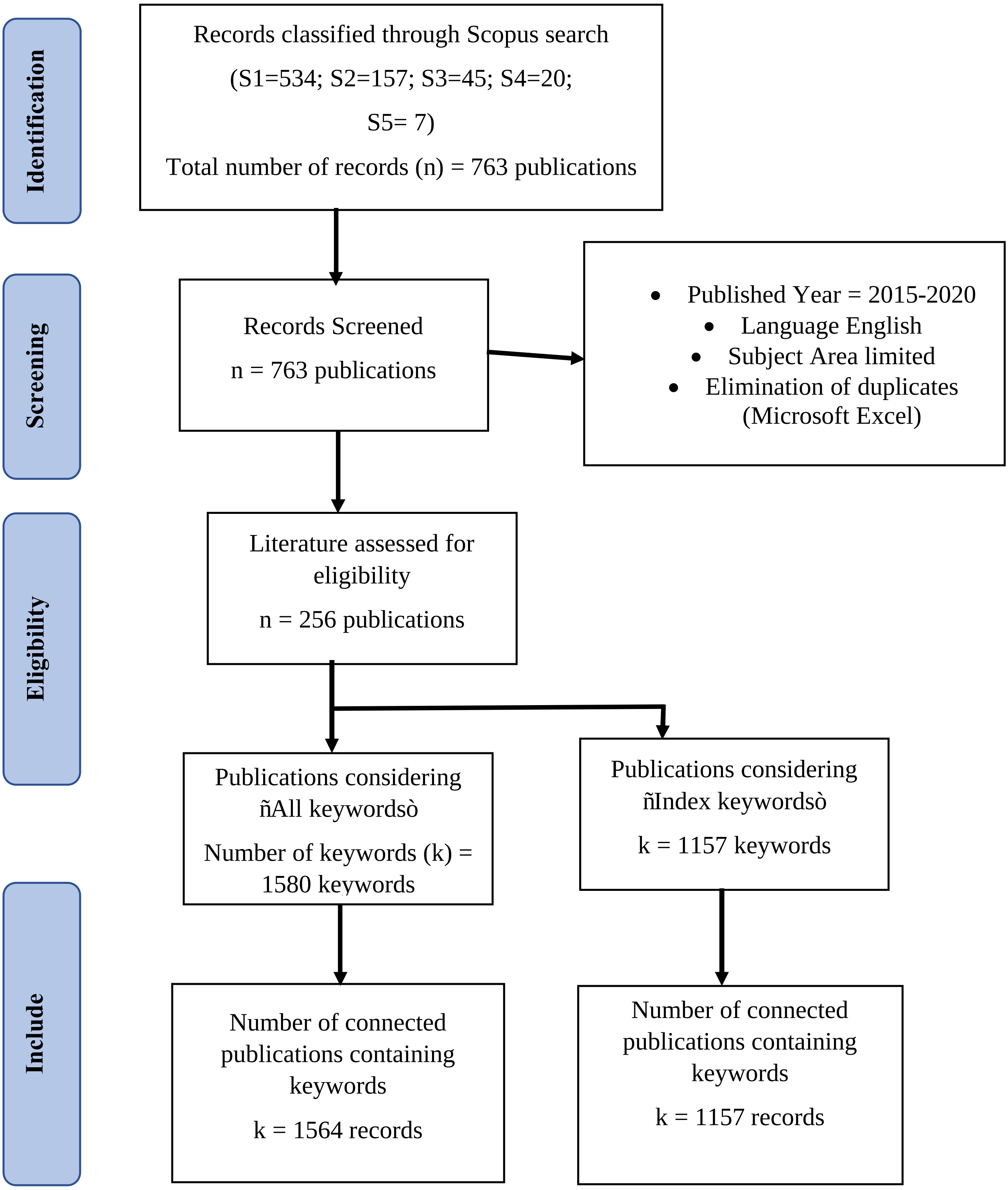

Figure 9: *PRISMA Flow Diagram*

4.2 Scopus Descriptive Statistics

Scopus has some analytical tools that can be used to analyze the results of the search. With PRISMA guideline and using the eligibility criteria, screening and excluding duplicates, 256 documents were discovered in Scopus. From the publication period considered (2015-2020) it could be seen that the highest number of publications on the research area was in 2019 and it was 106 publications (check *Appendix B* for more details). It can be seen that research in industry 4.0 vis-à-vis supply chains are gaining traction as the first 5 months of the year 2020 produced 41 documents already.

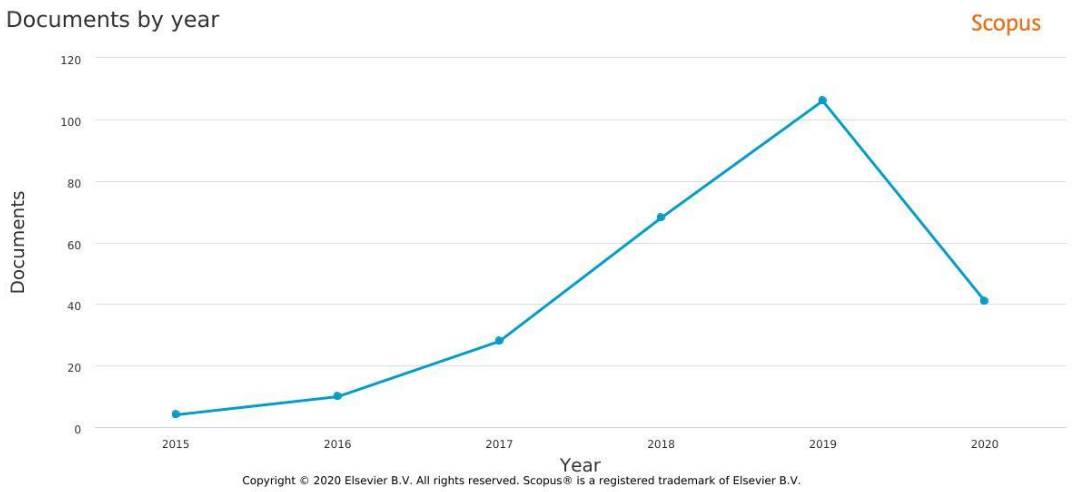

Figure 10: *Publications per Year (Source: Scopus)*

Germany has the highest number of publications (33 publications) followed by United States (31 publications).

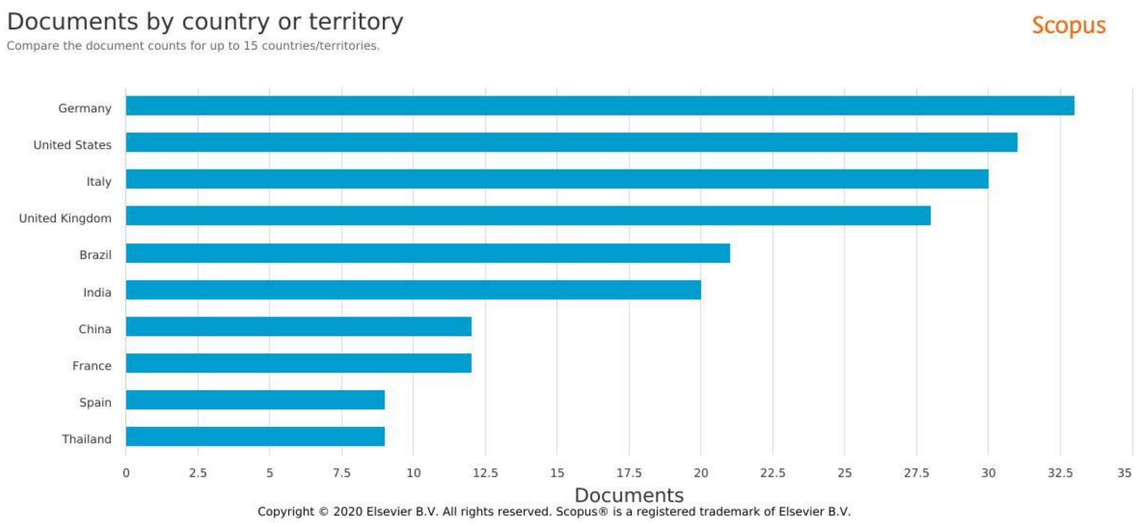

Figure 11: *Publications by Country/Territory (Source: Scopus)*

Articles were the highest document type in the Scopus data with 125 items (48.6%) closely followed by Conference papers with 83 items (32.3%).

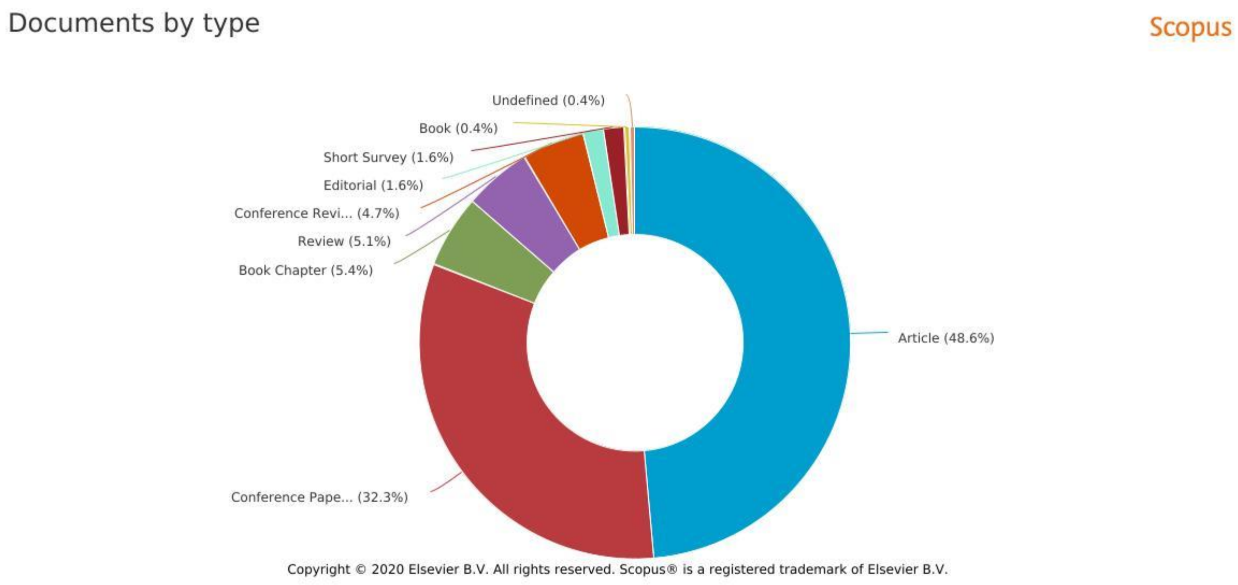

Figure 12: *Stats by document type (Source: Scopus)*

Ivanov, D. was the highest contributor by authorship with 8 publications while Dolgui, A.; Jermsittiparsert, K.; and Telukdarie, A. had 5 publications each.

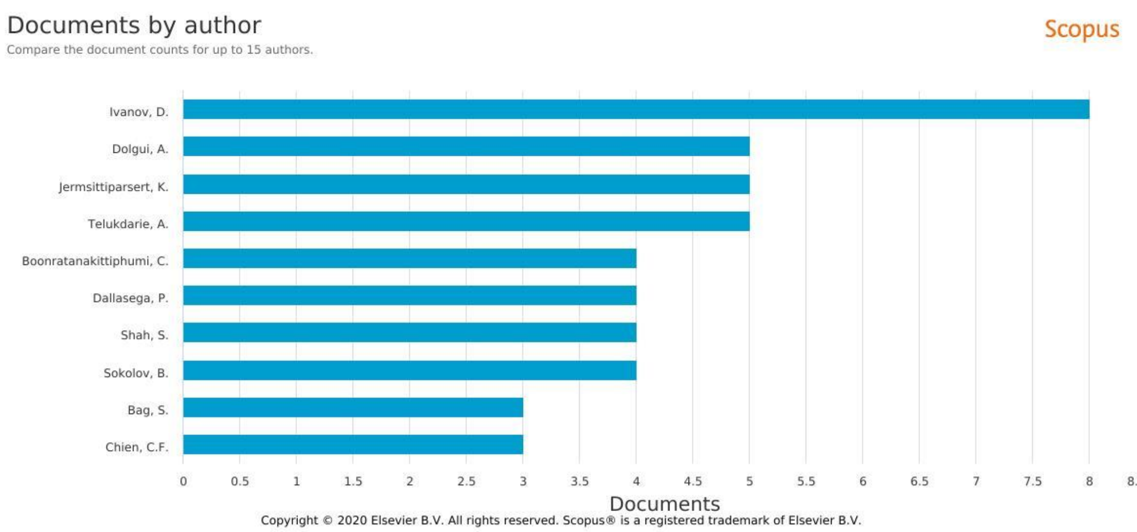

Figure 13: *Stats by Authorship (Source: Scopus)*

Finally, the highest sources of documents in the search result and their CiteScores up till 2018 are shown below.

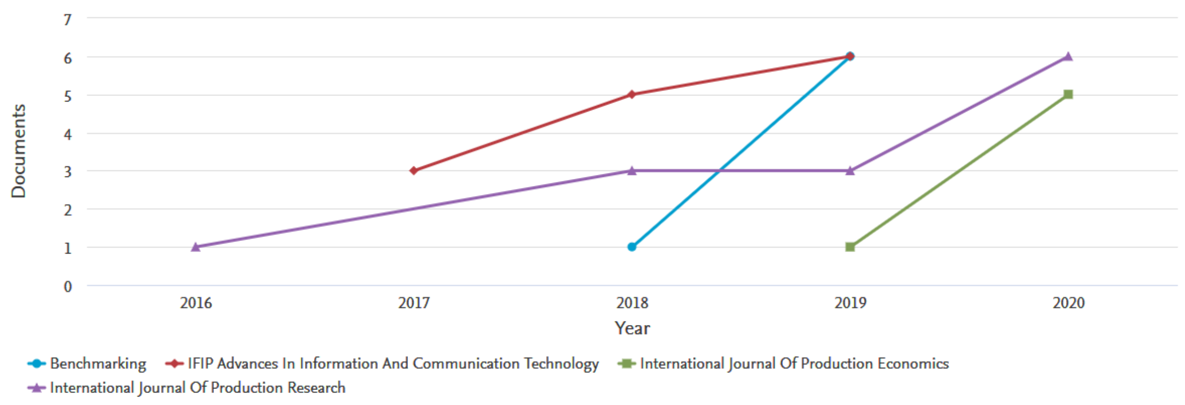

Figure 14: *Top Document Sources (Source: Scopus)*

CiteScore publication by year

Source	2011	2012	2013	2014	2015	2016	2017	2018
International Journal of Supply Chain Management					0.31	0.46	0.58	0.63
IFIP Advances in Information and Communication Technology	0.16	0.15	0.22	0.22	0.21	0.33	0.37	0.51
International Journal of Production Research	1.69	1.93	2.09	2.15	2.29	2.67	2.9	4.34
Benchmarking	1.36	1.33	1.25	1.63	1.48	1.37	1.97	2.8
International Journal of Production Economics	3.19	3.02	3.64	4.06	4.34	4.28	5.42	7.13

Figure 15: *CiteScore of Top Document Sources (Source: Scopus)*

4.3 Visualization, Analysis and Presentation of Results

For analysis, visualization and presentation of some of the patterns seen in the Scopus data, VOSviewer version 1.6.15 was used. The guidelines in the manual authored by Van Eck & Waltman (2020) for the tool was utilized in the creation, query and processing of the bibliographic data extracted from Scopus in CSV format. Co-word analysis of bibliographic data was done with the VOSviewer tool.

4.3.1. Bibliographic Map and Visualizations

Using Multi-Dimensional Scaling (MDS) techniques, VOSviewer creates a map of texts based on the gap or distance between them in terms of their meaning or similarity. The smaller the gap between two texts, the higher the strength between them. These texts or labels are the most important keywords or ñitemsò from the Scopus data processed by VOSviewer and the connections or ñlinksò between them can be presented in 3 visualizations in VOSviewer ï Network Visualization, Overlay Visualization and Density Visualization.

For 1580 keywords analyzed, only 1564 links were connected. Network visualization of the labels from Scopus data yielded 6 clusters, 20022 links and 22338 total link strength.

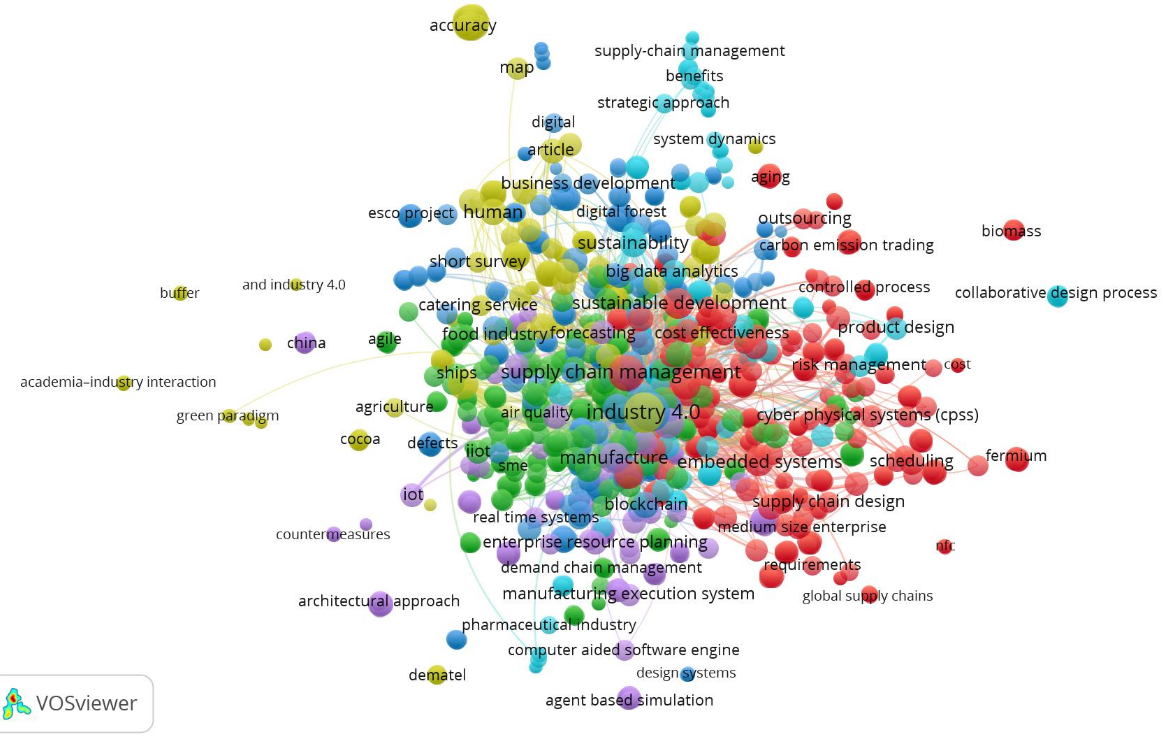

Figure 16: *VOSviewer Network Visualization of links*

In the visualization, size of the label and circle of an item is determined by their weight. The higher the weight of an item, the larger the label and the circle of the item. Also, the colour of an item is determined by the cluster to which it belongs. By default, 500 strongest links between items are shown by VOSviewer network visualization.

4.3.2. Keyword Analysis

The items or text-labels in VOSviewer visualization represent the keywords which have a number of occurrences in the publications extracted from Scopus. While some of the keywords might have common meanings, those that can have a high impact on the research vis-à-vis the research questions were considered. The default minimum number of occurrences suggested by VOSviewer is 5 and there are 76 key words that had this in the Scopus data. There are some keywords such as ñsystematic literature reviewò, ñsurveysò and ñliterature reviewsò that had high occurrences due to the fact that they are terms used frequently in fields of research. Their meaning might not provide any insight into the concept researched. Also, there were some keywords like ñThailandò that had high occurrences because there were many Industry 4.0 in Supply Chain case studies done for Thailand. All the keywords considered in the analysis are presented *Appendix A.*

A plot of the keywords with a minimum link strength of 100 is shown below

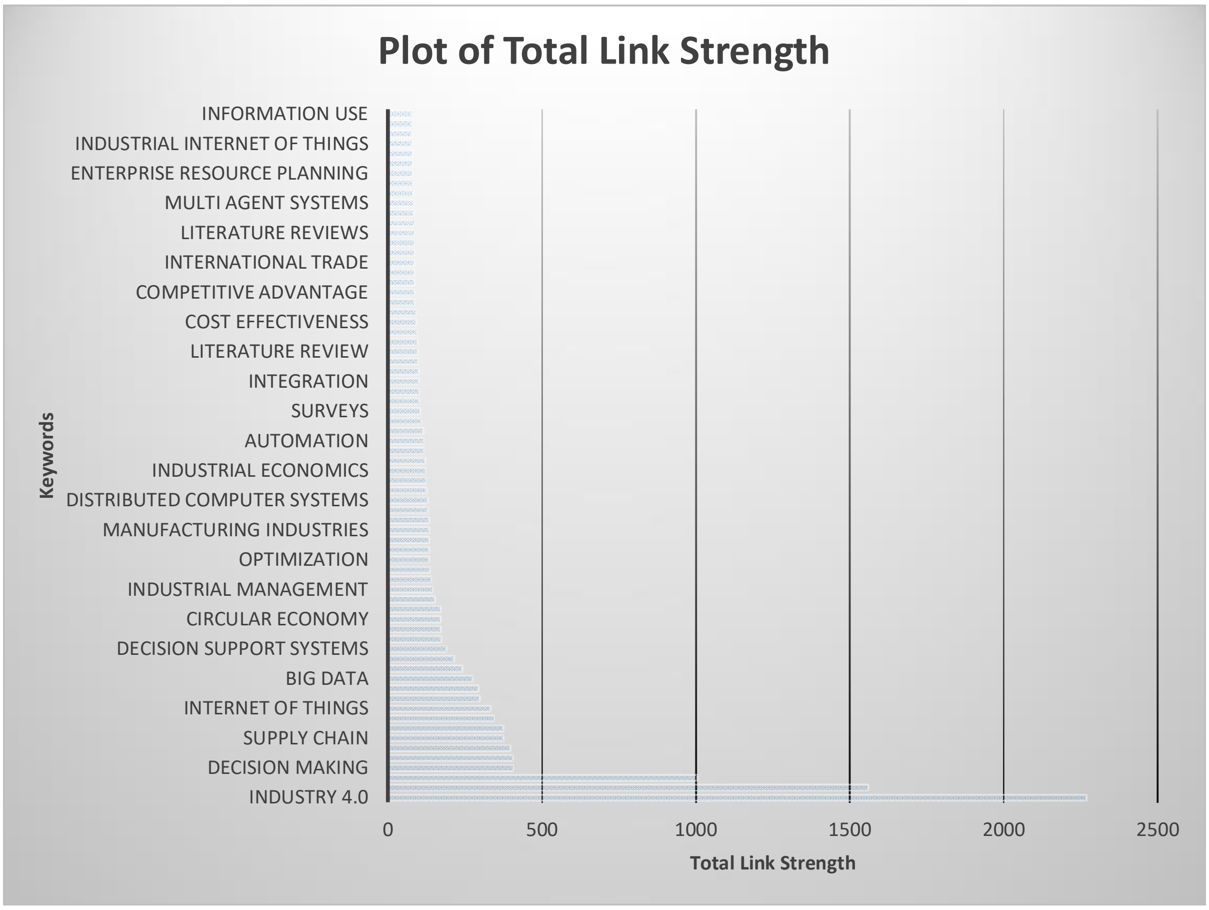

Figure 17: *Plot of Total Link Strength ≥ 75 for Keywords (Source: Scopus Dataset)*

4.3.3. Cluster Analysis

The 1580 keywords analyzed using VOSviewer produced 6 clusters, 20022 links and 22338 total link strength. The keywords in each cluster with the highest occurrences and link strengths are analyzed and presented in the table below.

Cluster	Keywords with Total Link Strengths ≥ 75
Cluster 1 (Red)	supply chain management, internet of things, sustainable development, big data, embedded systems, logistics, internet of things (iot), optimization, environmental impact, scheduling, surveys, cyber physical system, supply chain resilience, supply chain risk management, virtual corporation, information use, international trade, cost effectiveness, smart factory, environmental sustainability, multi agent systems.
Cluster 2 (Dark Green)	industrial revolutions, competition, digital transformation, life cycle, industrial management, manufacturing industries, production control, value chain, knowledge management, integration, competitive advantage.
Cluster 3 (Dark Blue)	supply chains, industrial research, information management, blockchain, decision support systems, systematic literature review, distributed computer systems, supply chain process, engineering education, collaborative manufacturing, digital supply chain.
Cluster 4 (Yellow)	industry 4.0, supply chain, circular economy, manufacturing, human, industrial economics, sustainable supply chains, human experiment, simulation, sustainable supply chain, economic aspect, forecasting.
Cluster 5 (Purple)	manufacture, decision making, automation, data analytics, industrial internet of things, enterprise resource planning, digital technologies.
Cluster 6 (Light Blue)	sustainability, big data analytics, commerce, accident prevention.

Table 6: *Cluster Analysis of Keywords with link strength ≥ 75*

4.3.4. Key Findings

This section provides the key insights from the review of the publications resulting from the Systematic review of literature in Scopus using the PRISMA guideline outlined in section 4.1. Content analysis of the title, keywords, abstract and some content of the 256 publications in the Scopus search results were reviewed. Analysis of the publications in the search results can be found in *Appendix B*. The focus was on publications that captured the drivers and barriers in the adoption and implementation of SC 4.0 while the others were screened out. The pair-wise comparison of the initial set of drivers developed from theoretical knowledge built in chapter 2 and those in the results of the SLR are screened and used as input to the final conceptual framework. The top 10 citations in the Scopus dataset is presented in *Appendix C*.

No.	Driver(s)	Insights	Literature Support
1.	Political System	Differences in political system of governance practised in different nations influences the direction of strategic initiatives in such countries. I4.0 will trigger the next wave of industrial competition and collaboration across nations.	Lin et al. (2017)
2.	Financial Resources, Capital and Funding	Digital Transformation requires huge capital and funding.	Omar et al. (2019); Yadav et al. (2020);
3.	Organizational Culture	Corporate vision, mission, goals and objectives. Corporate values, norms, beliefs and attitudes shape organizational behavioural pattern. Hierarchical vs Adhoc vs Inclusive. Agile, Innovative and entrepreneurial organization.	Mohelska & Sokolova (2018); Omar et al. (2019);
4.	Executive Management Involvement and Governance style.	Effective employee engagement and empowerment. Supportive management. Bureaucratic.	Mohelska & Sokolova (2018); Omar et al. (2019); Yadav et al. (2020);

No.	Driver(s)	Insights	Literature Support
		Power-oriented. Effective communication strategies.	Duarte & Cruz-Machado, (2017);
5.	Business Model/Process/Product Innovation	I4.0 Business Models (BMs) are data-driven and include the following super patterns - *Integration* (Process innovation), *Servitization* (Product and Service innovation) and *Expertization* (Hybrid of product- and Process-innovation). Industrial innovation has 3 aspects ï Policy perspective; Science and Technology strategy; and Business management perspective. Important aspect of the digital strategy and digital economy.	Weking et al. (2020); Lin et al. (2017); Chen (2019); Seiberth & Gründinger, 2018
6.	Government Environmental Policy and Regulation	Incentives for green initiatives. Government Environmental-policy instruments.	Yadav et al. (2020); Lin et al. (2017); Luthra et al. (2020)
7.	Sustainability Policies / Corporate Social Responsibility (CSR) Policies and Initiatives	Triple Bottom line initiatives in response to stakeholder engagements. Lean and green supply chain initiatives. Greater transparency of businesses due to adoption of ICT. Adoption of I4.0 and Circular Economy solution measures. Energy efficiency, Carbon foot prints, resource productivity and eco-friendliness. Organizational Health and Safety Management (OHSM) Initiatives	Duarte & Cruz-Machado, (2017); Bag et al. (2018); Simões et al. 2019; Yadav et al. (2020); Ma et al. (2020); Rajput & Singh (2019); Telukdarie, & Bag (2018); Bag et al. (2018); Erol, 2019.

No.	Driver(s)	Insights	Literature Support
8.	Service ecosystems and Platform economies.	Supply chain coordination and incentive schemes ï buy back, quantity discounts, revenue sharing; portfolio contracts, and other hybrid incentive schemes (Ma et al., 2020).	Ma et al. (2020); Chen (2019); Weking et al. (2020);
9.	Global Supply Chains	Internationalization of Trade. Global value networks.	Chen (2019)
10.	Benefit for Society	The benefit of a technology to the society is an important aspect that mitigates against resistance to change.	Nicolescu et al., 2019
11.	Growing Competition	Innovation and disruptions by born-digital startups.	Seiberth & Gründinger, 2018
12.	Business Alliances and Partnerships	Trust and Transparency. Collaborative strategies.	Lin et al. (2017); Chen (2019)
13.	Cost	Cost savings from the deployment of I4.0 technologies in Supply chains.	Yadav et al. (2020); Stevens & Johnson (2016)
14.	Profit	Value Co-creation. Revenue generation. I4.0 is an enabler of product/service differentiation and cost advantage.	Yadav et al. (2020); Ma et al. (2020); Stevens & Johnson (2016)
15.	National/Corporate/Digital/Innovation Strategy	National Innovation strategy. Digital Strategy. Digital vision. Technology Strategy. Manufacturing Strategy.	Lin et al. (2017); Sjøbakk, 2018; Preindl et al. (2020)
16.	Technological Maturity	Any technology is as good as its maturity level before its benefit can be fully harnessed.	Wagire et al., 2020; Facchini et al., 2020; Schumacher et al., 2016
17.	Intellectual Property (IP)	Patents and Trademark ownership create competitive advantage.	Ardito et al. (2019)
18.	Core Digital Technologies	Digital Infrastructure - Mobility, Connectivity and Cloud computational resources.	Pfohl et al, 2017; CGI, 2017a; Al-

No.	Driver(s)	Insights	Literature Support
		The core technologies create a baseline for the full rollout of I4.0.	Fuqaha et al.; 2015; OECD, 2017; Probst et al., 2017, 2018.
19.	Technical Integration	Supplier Integration and collaborative initiatives. Proper matchmaking in team formation for collaborative manufacturing.	Yadav et al. (2020); Cisneros-Cabrera et al. (2018)
20.	Decentralization	I4.0 has decentralization as one of its core principles.	Kagermann et al., 2013; Rejikumar et al. (2019)
21.	Consumer Behaviour Customer expectations	I4.0 enables Business intelligence on Consumer purchasing patterns. A feedback system for improvement of products and services to meet customer expectations.	Tseng et al. (2019); Reyes et al. (2020)
22.	Human Resource/Employee skills	Digital and ICT Education and Training. Digital skills are important in the digital transformation of industries, enterprises, governments and society. Development of knowledge-driven digital capabilities. Personal competences, Social competences and technical competences.	Liboni et al. (2019); Ralston & Blackhurst, 2020; Flynn et al. (2017); Yadav et al. (2020); Di Maria et al. (2018); Umachandran et al. (2019); Brinch & Stentoft (2017)

Table 7: *Drivers in SC4.0 (Source: Author)*

No.	Barrier (s)	Insights	Literature Support
1.	Collaboration Challenge.	Trust and Transparency issues. Governance issues. Opportunism of Suppliers.	Kazantsev et al. (2018); Yadav et al. (2020); El Hamdi et al. (2019);

No.	Barrier (s)	Insights	Literature Support
		Differences in legal jurisdictions, tax jurisdictions and patent systems.	
2.	Data Governance, Data Ownership and Data Sharing issues.	Data is a strategic asset and several enterprises are increasingly exploring ways of extracting value from it to create a competitive advantage. Even with proper business relation agreements set up, market competition is intensifying. According to Omar et al. (2019), there is a need for ñstandardizationò of data collection, aggregation and storage. This enhances innovation in Supply Chain Management.	Omar et al. (2019); Mukhrizal et al. (2019); Preindl et al. (2020)
3.	Cybersecurity and Privacy Concerns	Fear of improper Cybersecurity risk mitigation frameworks. Unethical use of data.	Pandey et al. (2020); Ch, Mohan & Rao (2018); Omar et al. (2019);
4.	Protectionism	Protectionist trade policies.	Schröder, 2016
5.	Job Insecurity	Fear that technological advancement will lead to job losses and high unemployment rates.	Flynn et al. (2017);
6.	Standardization Frameworks	Different initiatives similar to I4.0 in several countries requires standardization frameworks for interoperability.	Rajput & Singh (2019);
7.	Intellectual Property/Licensing frameworks.	Some improper licensing agreements could create bottlenecks for SC4.0 adopters.	Ardito et al. (2019); Schröder, 2016.
8.	Business, Regulatory and Governance Frameworks	Constitutionally drafted National policies; Legal agreements; Executive orders; Policy and legal frameworks; Terms and Conditions; Consumer Protection laws.	Lin et al. (2017)
9.	Technological acceptance	Societal Technical knowledge.	Yadav et al. (2020); Nicolescu et al., 2019
10.	Cultural Norm	Behavioural pattern and cultural practices. Societal resistance to culture change. Employee resistance to culture change.	Yadav et al. (2020); Nicolescu et al., 2019

Table 8: *Barriers in SC4.0 (Source: Author)*

5. Conceptual Framework

This chapter presents the final framework of prioritized drivers and barriers which was developed by considering the Political, Economic, Socio-cultural, Technological, Environmental and Legal dimensions of the drivers and barriers in the adoption and implementation of Supply Chain 4.0.

5.1 Initial Set of Drivers and Barriers in Supply Chain 4.0

After the literature review in chapter 2 of the thesis, a brain map of the initial set of drivers and barriers in the adoption and implementation of industry 4.0 was carried out using PESTEL analysis for the dimensions in the framework. The initial set of drivers and barriers are presented in the figure below. It should be noted that some factors can both be a driver and/or a barrier. (Kersten et al.,2017; Mazzarino, 2012; Kamble et al., 2018; Kiel et al., 2017)

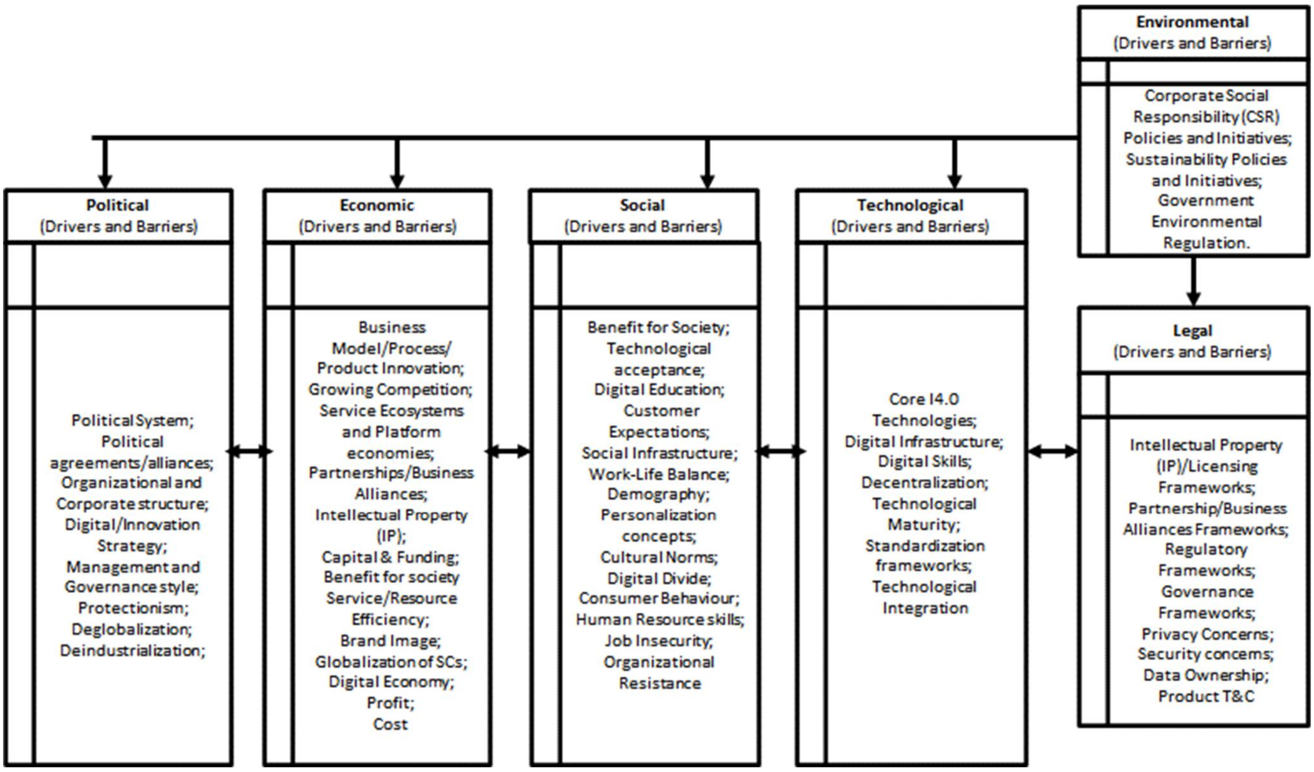

Figure 18: *PESTEL Analysis of Drivers and Barriers in SC 4.0 Implementation. (Source: Author)*

5.2 SC 4.0 Conceptual Framework

The conceptual framework is created by clustering the drivers and barriers in the results of the Systematic Literature Review using PESTEL. There was a pair-wise comparison of the initial set of drivers previously developed and the keywords found in the SLR. The resulting framework presented below is a prioritized set of drivers and barriers and strategic dimensions that can influence decision-making towards the adoption and implementation of Supply Chain 4.0 in countries, organizations, enterprises, etc.

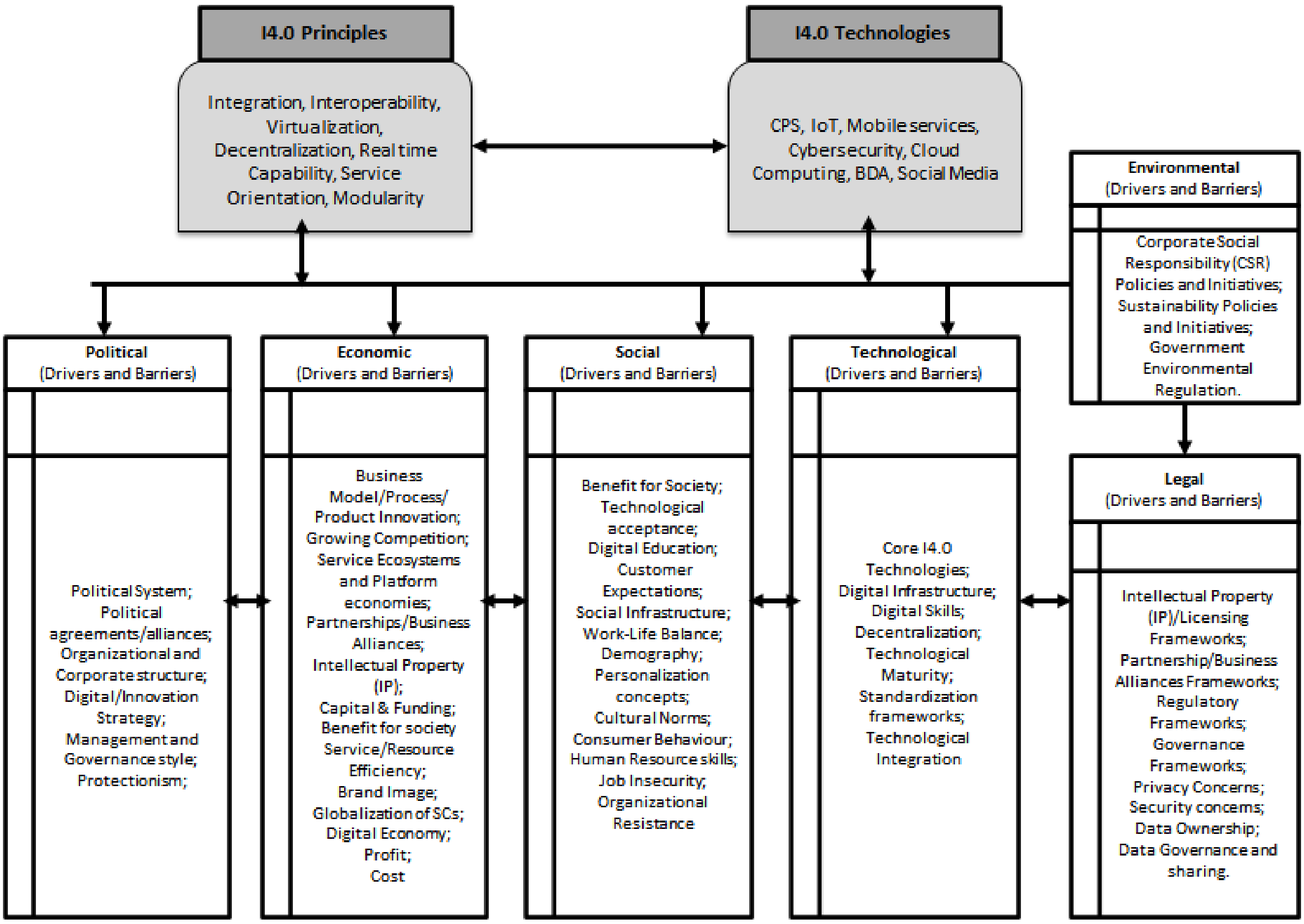

Figure 19: SC 4.0 *Conceptual Framework. (Source: Author)*

5.3 Review Discussions

From the SLR, there were publications in the Scopus dataset that covered the research questions in this thesis. However, there were some authors that used complementary terms to ñdriversò and ñbarriersò such as ñfactorsò/ ñenablersò and ñchallengesò to describe their findings. To the best of the authorôs knowledge, this is the first publication that analyzes the drivers and barriers in the adoption and implementation of I4.0 paradigm using PESTEL though Cezarino et al. (2019) used technological, economic, institutional-legal (referred to as Political by the author) and social dimensions in their analysis. Also, El Hamdi et al. (2019) explored Political, Economic, Social and Technological aspects of the I4.0 challenges without specific reference to the PEST framework. To analyze the drivers and barriers of I4.0 adoption and implementation in supply chains, some authors in literature utilized the Technological-Organizational-Environmental (TOE) framework. (Arcidiacono et al., 2019; Simões et al. 2019).

Political and Economic Dimensions

Lin et al. (2017) corroborated some insights already captured in the literature framework in Chapter 2 with reference to equivalent paradigms to Industry 4.0 in different countries e.g. US AMP and went further to perform a comparative policy analysis between China and Taiwan which hitherto has had cross-strait relations. While China has the ñChina Manufacturing 2025ò strategic initiative, Taiwan has the ñTaiwan Productivity 4.0ò strategic initiative. I4.0 is going to be a trigger for the next wave of industrial competition and collaboration/coalition trends across nations, regions and continents. Industrial innovation has 3 aspects ï policy perspective, Science and Technology (S&T) strategy and business management perspective which combines to provide industrial leadership and competitive advantage. (Lin et al. ,2017)

According to Rothwell & Zegveld (1981) policy framework (as cited by Lin et al. ,2017), there are 12 innovation policy tools categorized as Supply-side (public enterprise; education; information; S&T), Demand side (procurement, public service, commercial and overseas agents) and Environmental (Financial, Taxation, Legal & Regulatory and Political). The comparative study between China and Taiwan shows that they focus on different aspects of the innovation policy framework (China focuses more on ñpoliticalò and ñlegal/regulatoryò aspects of environmental policy and ñPublic serviceò of the demand-side policies; Taiwan focuses more on the ñeducation/trainingò of the supply-side policy).

The Political and Economic policies are even more tightly coupled in this era than it was when the innovation policy framework was first developed. Innovation policy of a country definitely reinforces other aspects such as its digital strategy, environmental policies and economic policies (including Trade policies). Protectionism is a major barrier to adoption of I4.0 principles in Supply chains. (Schröder, 2016)

With data as a new strategic asset, there has been a lot of focus on data-driven business models which involves co-creation and service ecosystems. Trends has shown that three areas of I4.0 business models have emerged ï *Integration* (Process innovation), *Servitization* (Product and Service innovation) and *Expertization* (Hybrid of product- and Process-innovation). Expertization has led to platform economies and service ecosystems. The Business Model patterns for I4.0 includes the following patterns ï Integration (crowdsource innovation; Production as a service; mass customization), Servitization (Product as a service; Result as a service; Life-long partnerships) and Expertization (Product- & Process-related consulting; Product-related platformization; Process-related platformization)(Weking et al., 2020)

Omar et al. (2019) explored the importance of business analytics and organizational cultural evolution into data-driven decision-making practices to enhance innovation in the End-to-End business functions in the manufacturing sector supply chains. This in the thesis authorôs opinion is applicable to every industry or market player that is undergoing digital transformation and wants to continually create value and stay competitive. Schumacher et al., 2016 explored the maturity models for assessing the readiness for I4.0 by including organizational aspects. Mohelska & Sokolova (2018) explored the managerial and organizational aspects of I4.0. Corporate values, norms, beliefs and attitudes shape organizational behavioural pattern which influences the adoption and implementation of SC 4.0. Executive Management Involvement and Governance style influences organizational culture.

Social Dimensions

There has been debates about technological advancement leading to unemployment. However, it can be seen that investment in ICT education and skill development initiatives in Science Technology Engineering and Mathematics (STEM) provide a counter argument as it provides a workforce with the required skills for global competitiveness. In a globally-connected and highly competitive market, capability to add value to products and services is enabled by ICT and this is a source of competitive advantage for individuals, enterprises and countries that has taken time to invest in digital skills and ICT. (Flynn et al., 2017). Studies have shown that the implementation of I4.0 processes and smart systems leads to supply chain resilience via capability enhancement and development of new skills for the workforce. (Ralston & Blackhurst, 2020).

Societal resistance to culture change and employee resistance can be a barrier to SC 4.0 implementation. Liboni et al. (2019) explored the socio-technical impact of I4.0 in Human Resource Management ï Human, Technology and Organization as each can interact (Human to organization; Human to Human and Human to Technology). Beyond the technical competences required in I4.0, personal competences and social competences are also important.

Technological Dimensions

Implementation of SC 4.0 goes beyond buying technical products off the shelf but a well-defined I4.0 strategy (linked to digital vision and digital strategy) that is aligned with business strategy and goals. The I4.0 strategy is a concatenation of the Supply Chain Strategy, Technology Strategy and Manufacturing strategy of an organization. (Sjøbakk, 2018). A barrier in the technological dimension is the fact that competing initiatives in several countries without proper standardization frameworks will create interoperability bottlenecks. (Rajput & Singh, 2019). Any technology is as good as its maturity level before its benefit can be fully harnessed. The benefit of a technology to the society is an important aspect that mitigates against resistance to change. I4.0 has some maturity models that can be used for assessing the implementation level. (Wagire et al., 2020; Facchini et al., 2020)

Haddud & Khare (2020) quantitatively demonstrated the influence of I4.0 in the end to end business functions in Supply Chain Management and Lean operations practices- Just-In-Time (JIT), Visual Management (VM), Total Productive Maintenance (TPM), Continuous Improvement (CI) and Autonomation.

Environmental Dimensions

Increasing government regulation is driving the adoption of environmentally friendly initiatives. Yadav et al. (2020) explored a Sustainable Supply Chain Management (SSCM) framework that addresses the sustainability adoption issues using industry 4.0 and Circular Economy (CE) based solution measures. The study identified a unique set of 28 SSCM challenges and 22 solution measures. In cold supply chains where Logistics Service Providers (LSPs) need to ensure the freshness of the products in transit, resource productivity, energy efficiency and eco-friendliness are priority areas in strategic implementation of Industry 4.0 (Ma et al., 2020). Rajput & Singh (2019) highlighted the I4.0 enablers and barriers in the implementation of CE based supply chains and established the link between I4.0 and CE. Some of the I4.0 design principles and concepts such as Modularity; Integration & Interoperability; Self-organizing/Self-optimizing/Self-adaptation; Flexibility; Value networks, etc were classified as contributing factors while barriers included need for data analytics, collaborative models, standards and specifications, cost, etc just to mention a few. (Rajput & Singh ,2019 pp 101- 102). The Scopus dataset has a lot of publications on sustainability which shows it as one of the most researched aspects in SC 4.0.

Legal Dimensions

Terms and Conditions require the consent of customers as balance of rights of data use tilts more to customers since the advent of the European General Data Protection Regulation (GDPR). There are also legal aspects related to Data governance, data ownership, data sharing and technology transfer across geographical borders, within organizations and in business alliances/partnerships. (Schröder, 2016)

6. Conclusions

There were key words in the Systematic Literature Review of Scopus database records that have the same or similar interpretations with the set of initial drivers that was developed from the literature review done by internet search. Co-word analysis as a similarity approach was utilized in the thesis. Some complementary terms to ñdriversò and ñbarriersò such as ñfactorsò/ ñenablersò and ñchallengesò were used by some of the authors in the search results of the SLR.

The final framework of prioritized drivers and barriers was developed considering Political, Economic, Socio-cultural, Technological, Environmental and Legal dimensions of the drivers and barriers in the adoption and implementation of Supply Chain 4.0.

The results which formed part of the conceptual framework answered the two Research questions in the thesis:

- RQ1: What are the drivers and barriers in the implementation of industry 4.0 in Supply Chain Management?
- RQ2: Which strategic dimensions should be considered in the adoption of industry 4.0 in Supply Chain Management?

This research provided valuable managerial implications that may support Business leaders and practitioners to have a better understanding of the strategic dimensions, drivers and barriers in the adoption and implementation of SC 4.0. It could be seen that there are Political, Economic, Socio-cultural, Technological, Environmental and Legal strategic dimensions that can influence the decision-making process in the adoption and implementation of industry 4.0 in Supply Chain Management. Also, some of the political and economic drivers and barriers are tightly coupled. Sustainability aspects of industry 4.0 in supply chain is a widely researched topic as seen in the Scopus dataset.

To the best of the authorôs knowledge, this is the first publication that analyzes the drivers and barriers in the adoption and implementation of I4.0 paradigm using PESTEL. Many frameworks in the press mainly used organization, technological and environmental dimensions in their analysis. The drivers and barriers in the political dimension as classified in this thesis maps with those classified in the organizational dimension in other authorsô frameworks. The bibliography list from this thesis can be utilized for further research in Supply Chain 4.0.

6.1 Managerial Implications

PESTEL is a strategic management tool that assists managers in decision-making by enhancing a holistic view of the internal and external drivers and/or barriers in the adoption of a concept, principle or technology. With protectionist policies and trade tensions elevated more than ever before, decision-makers need to consider all aspects ï Political, Economic, Socio-cultural, Technological, Environmental and Legal dimensions before proceeding on adoption and implementation of strategic initiatives.

The conceptual framework developed in this thesis can be utilized by the practitionersô community and academia to explore the key considerations in any country, organization, enterprises, etc before any global Supply Chain Management business engagement. The strong link between Political and Economic dimensions cannot be overlooked in the business landscape of today. The conceptual framework has to be properly internalized as some items on the framework can either be independently a driver or a barrier while some could be both a driver and a barrier simultaneously.

6.2 Proposal for Future Research

Industry 4.0 is an emerging research area which is applicable across several industries/sectors, geographical boundaries, political systems, economic systems and socio-cultural norms. A confirmatory quantitative research method from a strategic management perspective is proposed for future research. A good case for future research is a confirmatory research using Decision Making Trial and Evaluation Laboratory (DEMATEL) method or any other statistical method to analyze the cause and effect of the drivers and barriers proposed in the developed conceptual framework in this thesis.

Empirical investigations using a survey of practitioners in business R&D and participants from the academia could bring more insights into the research area. Also, exploratory methods such as Delphi or focus groups targeted at a diverse and multidisciplinary audience will help in providing more insights into the drivers and barriers in the adoption and implementation of SC 4.0.

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8. Appendices

This is the appendix. It captures some data used in the systematic literature review.

A. List of Keywords

id	keyword	occurrences	total link strength
712	industry 4.0	187	2269
1416	supply chains	94	1560
1391	supply chain management	73	1004
1374	supply chain	37	374
791	internet of things	26	332
700	industrial revolutions	23	374
893	manufacture	23	396
1427	sustainable development	22	405
346	decision making	21	406
698	industrial research	20	344
118	big data	17	275
456	embedded systems	16	297
1425	sustainability	16	241
738	information management	14	292
863	logistics	13	170
233	competition	12	213
129	blockchain	11	151
403	digital transformation	11	135
187	circular economy	10	170
849	life cycle	10	170
894	manufacturing	10	124
119	big data analytics	9	132
1318	smart manufacturing	9	71
351	decision support systems	8	189
689	industrial management	8	144
792	internet of things (iot)	8	132
856	literature review	8	96
906	manufacturing industries	8	132
1046	optimization	8	133
646	human	7	173
1313	smart factory	7	97
1450	systematic literature review	7	115
93	automation	6	115
321	data analytics	6	132
398	digital supply chain	6	84
407	digitalization	6	46
418	distributed computer systems	6	128

id	keyword	occurrences	total link strength
499	environmental impact	6	129
678	industrial economics	6	121
773	integration	6	99
803	iot	6	80
823	knowledge management	6	75
857	literature reviews	6	84
897	manufacturing companies	6	90
1254	scheduling	6	114
1424	surveys	6	103
1444	sustainable supply chains	6	140
214	collaborative manufacturing	5	83
225	commerce	5	84
234	competitive advantage	5	85
281	cost effectiveness	5	91
303	cyber physical system	5	107
315	cyber-physical systems	5	17
376	design/methodology/approach	5	99
402	digital technologies	5	86
410	digitization	5	72
479	engineering education	5	85
487	enterprise resource planning	5	78
506	environmental sustainability	5	94
507	environmental technology	5	85
565	food supply	5	95
650	human experiment	5	123
683	industrial internet of things	5	77
750	innovation	5	60
787	international trade	5	85
837	lean production	5	56
1147	production control	5	100
1163	production process	5	73
1299	simulation	5	78
1405	supply chain process	5	71
1407	supply chain resilience	5	41
1410	supply chain risk management	5	58
1441	sustainable supply chain	5	67
1493	thailand	5	15
1537	value chain	5	60
1545	virtual corporation	5	76

Table 9: *List of Keywords with ≥ 5 Occurrences*

B. Analysis of Publications in the SLR

From the 256 publications in the Scopus search results, 230 articles had their publication stage finalized while 26 were Articles in press. There was also a limitation of only 200 records whose citations could be extracted from Scopus. Also, from the list of publications, there were 14 records that did not have an author due to the fact that the result is a compendium of conference papers.

Publication Year	Total Number of Publications	Articles in Press (AIP) vs Articles Finalized (AF)	
2020	41	AIP	15
		AF	26
2019	106	AIP	10
		AF	96
2018	68	AIP	1
		AF	67
2017	27	AIP	0
		AF	27
2016	10	AIP	0
		AF	10
2015	4	AIP	0
		AF	4

Table 10: *Analysis of Scopus Search Result*

Advanced search string in Scopus that produced the result is shown below:

TITLE-ABS-KEY ("Supply Chain*" AND "Industry 4.0") AND (LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "DECI") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (LANGUAGE , "English"))

C. Top Citations from Scopus Dataset

Authors	Number of Citations	Source	Document Type
Ivanov et al. (2016)	186	International Journal of Production Research.	Article
Lopes de Sousa Jabbour et al. (2018)	89	Annals of Operations Research.	Article
Ivanov et al. (2019)	86	International Journal of Production Research.	Article
Frank et al. (2019)	84	International Journal of Production Economics.	Article
Tseng et al. (2018)	74	Resources, Conservation and Recycling.	Short Survey
Kovác & Kot (2016)	68	Polish Journal of Management Studies.	Article
Ben-Daya et al. (2019)	65	International Journal of Production Research.	Review
Luthra & Mangla (2018)	57	Process Safety and Environmental Protection.	Article
Prause, G (2015)	47	Journal of Security and Sustainability Issues.	Article
Dolgui et al. (2019)	41	International Journal of Production Research.	Review

Table 11: *Top 10 Cited Publications*