SCUOLA DI DOTTORATO
UNIVERSITÀ DEGLI STUDI *MEDITERRANEA* DI REGGIO CALABRIA

DIPARTIMENTO DI GIURISPRUDENZA, ECONOMIA E SCIENZE UMANE

DOTTORATO DI RICERCA IN
DIRITTO ED ECONOMIA

S.S.D. SECS-S/06 – SECS-P/08
XXXIV CICLO

ESSAYS IN SUPPLY CHAIN MANAGEMENT AND MODELING

DOTTORANDA:
Iside Rita Laganà

TUTOR:
Chiar.ma Prof.ssa Cinzia Colapinto (IPAG Business School, Francia)
Chiar.mo Prof. Massimiliano Ferrara (Unirc, Italia)
Chiar.mo Prof. Davide La Torre (SKEMA Business School, Francia)

COORDINATORE:
Chiar.mo Prof. Philipp Fabbio

ANNO ACCADEMICO 2020/2021

ISIDE RITA LAGANÁ

ESSAYS IN SUPPLY CHAIN MANAGEMENT AND MODELING

POR Calabria FESR/FSE 2014-2020
Regione Calabria - Dipartimento Presidenza, Settore Alta Formazione e Università –
Asse 12 Azione 10.5.6 - Linea A "Mobilità internazionale di dottorandi" XXXIV ciclo,
con periodo obbligatorio di 12 mesi all'estero
"La presente tesi di dottorato è cofinanziata con il sostegno
della Commissione Europea, Fondo Sociale Europeo e della Regione Calabria.
L'autore è il solo responsabile di questa tesi e la Commissione Europea e la Regione Calabria
declinano ogni responsabilità sull'uso che potrà essere fatto delle informazioni in essa contenute".

Essays in Supply Chain Management and Modeling

by

Iside Rita Laganà

A Thesis
Submitted to the Faculty of Ph.D. School
through the Department of Law, Economics, and Human Sciences
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy (Ph.D.)
in Law and Economics
and for the Award of the Additional Label of
"European Doctorate"

SSD SECS-S/06 & SECS-P/08

Mediterranea University of Reggio Calabria
Department of Law, Economics, and Human Sciences
Ph.D. Course in Law and Economics (XXXIV Cycle)
Italy

Academic Year 2020/2021

Ph.D. Candidate

Iside Rita Laganà

Department of Law, Economics, and Human Sciences (DiGiES)

Mediterranea University of Reggio Calabria, Italy

Iside Rita Laganà

Ph.D. Course Coordinator

Prof. Philipp Fabbio, Ph.D.

Department of Law, Economics, and Human Sciences (DiGiES)

Mediterranea University of Reggio Calabria, Italy

Supervised by:

Prof. Cinzia Colapinto, Ph.D. **(Supervisor Chapters: 1-2-3)**

Department of Strategy and Management, IPAG Business School, Nice Campus, France

Department of Management, *Ca' Foscari* University of Venice, Italy

Cinzia Colapinto

Prof. Massimiliano Ferrara, Ph.D. **(Supervisor Chapter: 4)**

Department of Law, Economics, and Human Sciences (DiGiES)

Mediterranea University of Reggio Calabria, Italy

Prof. Davide La Torre, Ph.D., HDR **(Supervisor Chapter: 5)**

SKEMA Business School and Université Côte d'Azur,

Sophia Antipolis Campus, France

Davide La Torre

DECLARATION OF AUTHORSHIP

This work was started during the research stay (October 2020 - July 2021) as a Ph.D. student at SKEMA Business School of Sophia Antipolis Campus (France) of Iside Rita Laganà under the supervision of Proff. Cinzia Colapinto and Davide La Torre.

The research is partially supported by POR Calabria FESR/FSE 2014 - 2020 Regione Calabria - Dipartimento Presidenza, Settore Alta Formazione e Università - Asse 12 Azione 10.5.6 - Linea A “Mobilità internazionale di dottorandi XXXIV ciclo, con periodo obbligatorio di 12 mesi all’estero”.

The author states that this work has also been submitted to the Faculty of the Ph.D. School through the Department of Law, Economics, and Human Sciences in partial fulfillment of the requirements for the additional label of "European Doctorate" (art. 21, Nuovo Regolamento di Ateneo in Materia di Dottorato di Ricerca - Allegato al D.R. n. 245 del 31 Luglio 2020). As required by the new university regulation on research doctorates, the compiler declares that this thesis has been submitted to the evaluation of two reviewers from two university institutions from two countries of the European Union, other than the one in which the thesis will be discussed.

The author declares that this is an original copy of his thesis, including any final revisions, approved by the thesis committee and the University Studies Office. She declares that this thesis is her original work, except for citations and quotations which have been duly acknowledged. The compiler also declares that he has not been previously, and not at the same time, presented for another degree at the *Mediterranea* University of Reggio Calabria or another University or Institution.

The compiler states that this work consists of five chapters. Each chapter has its supervisor: Chapters 1-2-3 have been supervised by Prof. Cinzia Colapinto from the Department of Strategy and Management of IPAG Business School, Nice Campus (France); Chapter 4 has been supervised by Prof. Massimiliano Ferrara from the Department of Law, Economics, and Human Science of the *Mediterranea* University of Reggio Calabria (Italy); Chapter 5 has been supervised by Prof. Davide La Torre from SKEMA Business School and Université Côte d’Azur of Sophia Antipolis Campus (France).

The author certifies that, to the best of her knowledge, this thesis does not infringe anyone's copyright or infringe any proprietary rights and that any ideas, techniques, quotes, or any other material from other people's work included in this thesis, published or otherwise, are fully recognized following standard referral practices.

Reggio Calabria, November 2021
Iside Rita Laganà

PURPOSE AND CONTENTS OF THE THESIS

Essays in Supply Chain Management and Modeling
Iside Rita Laganà, *Mediterranea* University of Reggio Calabria, Italy

In recent decades, supply chains have become highly sophisticated and crucial to ensure companies' competitiveness. Globalization is always profoundly impacting supply chains, making them even more interconnected and vulnerable to an ever-increasing range of risks. Recent events around the world have provided frequent reminders that we live in an unpredictable and changing world.

The economic turmoil caused by the outbreak of the COVID-19 pandemic in 2020 has exposed supply chains to various risks, raising doubts about globalization. Exposure to the COVID-19 pandemic has clearly shown the central function of supply chains in providing goods and services. The new coronavirus disease and the related crises have been inducing managers to redesign their supply networks offering an opportunity to understand their vulnerabilities and take actions to implement resilient activities to improve robustness and stabilization.

The purpose of this thesis is to present new information or, at least, a new perspective on Supply Chain Management. This thesis aims to be a contribution to support researchers, experts, and politicians' decisions to respond to the new business disruptions and supply chain challenges especially posed by the global spread of the COVID-19 pandemic.

This work is written in the format of a compilation thesis. This doctoral thesis consists of a collection of four joint papers published, approved, or submitted for publication. Clarification about how they are interrelated is included. The remainder of this thesis is divided into five chapters. An introductory research setting definition is presented to clarify the connection between the articles and emphasize aspects of the scientific work. The rest of the thesis is organized as follows:

Chapter 2 will present the most relevant definitions in the field of Supply Chain Management and associated terms establishing conceptual boundaries to enhance readers' understanding of the supply chain-related terminologies used in this thesis.

Chapter 3 will provide a systematic literature review of the application of multi-criteria decision-making methods in the healthcare supply chain. This paper has been revised and resubmitted in the *Journal of Multi-Criteria Decision Analysis* under the title "Multiple criteria decision-making in healthcare supply chain management: a state-of-the-art review and implications for future research". This paper has been written in collaboration with Prof. Cinzia Colapinto from the Department of Strategy and Management of IPAG Business School, Nice Campus (France).

Chapter 4 will study how to establish a reverse logistics (RL) system to collect unwanted medications (UMs) in households. In this chapter, a reverse supply chain (RSC) is proposed in a decentralized state including a manufacturer, a retailer, and a strategic consumer. The novelty of this article is that the model is investigated from the consumer's perspective. This chapter contains the joint paper entitled "Analysis of some incentives on two-echelon reverse supply chain with the strategic consumer: the case of unwanted medications in households" published in the *Journal of Multi-Criteria Decision Analysis*. This paper has been co-authored by Drs. Mehrnoosh Khademi, Somayeh Sharifi, and Mehdi Salimi, and Prof. Massimiliano Ferrara.

Chapter 5 aims at analyzing the impacts of COVID-19 pandemics on supply chain networks. In this chapter, the compiler collects the main results of the two joint works entitled respectively "Impact of epidemic dynamics on retail distribution networks" and "Modeling shock propagation on supply chain networks: a stochastic logistic-type approach". Both papers have been co-authored by Proff. Cinzia Colapinto and Davide La Torre, and Dr. Danilo Liuzzi. Both have been also submitted, accepted after a double-blind review process as conference papers, and presented respectively at the *"6th Colloquium on European Research in Retailing (CERR) 2021"* and the International Conference *"Advances in Production Management Systems (APMS) 2021"*.

Each chapter contains a statement of motivation explaining the main purposes of the study. Details about the paper's status and publication journal are provided. The references list is included at the end of each chapter.

ACKNOWLEDGMENTS

This thesis was not possible without the guidance, invaluable advice, constant inspiration, and motivation from the thesis supervisors Proff. Cinzia Colapinto and Davide La Torre. The author would like to express sincere gratitude to both of them. Their guidance and support are a source of inspiration for professional careers and life.

The compiler extends her gratitude to the supervisor Professor Massimiliano Ferrara for proposing this PhD project and for the scientific guidance.

The author also thanks the reviewers for evaluating this thesis, providing constructive comments to improve the quality.

For their suggestions and information, the compiler also thanks: Center for Dynamics (CfD), Technische Universität (TU) Dresden, Germany; Portsmouth Business School, University of Portsmouth, United Kingdom; Artificial Intelligence Institute and PRISM Research Center, SKEMA Business School, Sophia Antipolis Campus, France.

In addition, the author notes with appreciation the names of the following people who responded to an appeal made via the Internet or in person for the information pertinent to this effort: Maria Barbati, Xavier Brusset, Gafurjan Ibragimov, Mehrnoosh Khademi, Danilo Liuzzi, Mehdi Salimi, Somayeh Sharifi, and Stefan Siegmund.

The compiler also thanks all the professors, colleagues, and friends for the support received during these years.

Last, but certainly not least, the compiler expresses her greatest thanks to her family and her future husband, Giovanni, for love, encouragement, and confidence in achieving this important goal.

Reggio Calabria, November 2021

Iside Rita Laganà

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIDS	Acquired Immuno-Deficiency Syndrome
ANP	Analytic Network Process
APMS	Advances in Production Management Systems
B2B	Business to Business
B2C	Business to Consumer
CERR	Colloquium on European Research in Retailing
CfD	Center for Dynamics
CLM	Council of Logistics Management
COVID-19	Coronavirus Disease 2019
CSCMP	Council of Supply Chain Management Professionals
CSR	Corporate Social Responsibility
DEA	Data Envelopment Analysis
DM	Decision-making
ECD	Environmental Conscious Design
EU	European Union
FESR	Fondo europeo di sviluppo regionale
FSC	Forward Supply Chain
GP	Goal Programming
GSC	Green Supply Chain
GSCM	Green Supply Chain Management
HIV	Human Immunodeficiency Virus
HSC	Healthcare Supply Chain
HSCM	Healthcare Supply Chain Management
IF	Impact Factor
IF5	5 Years-Impact Factor
IFIP	International Federation for Information Processing

IT	Information Technology
IUCN	International Union for Conservation of Nature
JIT	Just-In-Time
LC	Life Cycle
LCA	Life Cycle Assessment
LM	Logistics Management
MCDA	Multicriteria Decision Analysis
MCDM	Multicriteria Decision Making
MERS	Middle East Respiratory Syndrome
MODA	Multi-objective Decision Analysis
MSEIR	Metapopulation Susceptible-Exposed-Infected-Removed
MSEIRS	Metapopulation Susceptible-Exposed-Infected-Removed-Susceptible
OM	Operations Management
OR	Operations Research
POR	Programma Operativo Regionale
PRISM	Project Information and Supply Management
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PSC	Pharmaceutical Supply Chain
RL	Reverse Logistics
ROA	Return on Assets
ROI	Return on Investment
RSC	Reverse Supply Chain
RSCM	Reverse Supply Chain Management
SARS	Severe Acute Respiratory Syndrome
SC	Supply Chain
SCM	Supply Chain Management
SEI	Susceptible-Exposed-Infectious
SEIR	Susceptible-Exposed-Infectious-Recovered

SEIRS	Susceptible-Exposed-Infectious-Recovered-Susceptible
SEIS	Susceptible-Exposed-Infectious-Susceptible
SI	Susceptible-Infectious
SIR	Susceptible-Infectious-Recovered
SIRS	Susceptible-Infectious-Recovered-Susceptible
SIS	Susceptible-Infectious-Susceptible
SSCM	Sustainable Supply Chain Management
TBL	Triple Bottom Line
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TU	Technische Universität
UCLA	University of California, Los Angeles
UM	Unwanted Medication
VIKOR	Vise Kriterijumska Optimizacija I Kompromisno Resenje
WEEE	Waste Electrical and Electronic Equipment Recycling
WHO	Word Health Organization

LIST OF PUBLICATIONS

Laganà, I.R. and Colapinto, C. (2021). Multiple criteria decision-making in healthcare supply chain management: a state-of-the-art review and implications for future research. *Journal of Multi-Criteria Decision Analysis* (Revised and resubmitted)

Laganà, I., Sharifi, S., Khademi, M., Salimi, M., and Ferrara, M. (2021). Analysis of some incentives on two-echelon reverse supply chain with a strategic consumer: The case of unwanted medications in households. *Journal of Multi-Criteria Decision Analysis*, pp. 1-12. doi: 10.1002/mcda.1736

Colapinto, C., La Torre, D., Laganà, I.R., and Liuzzi, D. (2021). Impact of epidemic dynamics on retail distribution networks. *Proceedings of the 6th Colloquium on European Research in Retailing (CERR) 2021*, SKEMA Business School, Sophia Antipolis Campus, France, July 15-17, 2021, pp. 199-204. ISBN 978-2-493066-00-8

Colapinto, C., La Torre, D., Laganà, I.R., and Liuzzi, D. (2021). Modeling shock propagation on supply chain networks: a stochastic logistic-type approach. In A. Dolgui *et al.* (Eds.), *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*, Springer, IFIP WG 5.7 International Conference 633, Nantes, France, September 5-9, 2021, pp. 23-31. doi: 10.1007/978-3-030-85910-7_3

CONTENTS

1. CHAPTER ONE – RESEARCH SETTING DEFINITION

1.1. Introduction

This chapter defines the research setting of this thesis, briefly indicating the aim, objectives, and scope of the work, as well as the structure and organization of the thesis. The background section provides general information on the topic and particularly explains why it is essential in catching the main aspects of the study, justifying the main need to conduct the research, and summarizing what the study aims to achieve. The remaining sections clarify the connection between all articles, emphasizing the main aspects of the scientific work.

1.2 Research Background

The term “supply chain” was first introduced by the newspaper “The Independent” in 1905, referring to the concept of a network of suppliers, producers/manufacturers, and consumers. “Supply chain management” wasn’t coined until the 1980s, so the field is still young compared to related areas such as procurement, logistics, and manufacturing, all of which play a role in supply chain management. Indeed, the term "supply chain" has been widely recognized mainly due to the globalization of manufacturing since the mid-1990s, particularly the growth of manufacturing in China (Vidrova, 2019).

A supply chain (SC) is the connected network of individuals, organizations, resources, activities, and technologies involved in the production and sale of a good or service. Supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product delivered to the end customer.

Supply Chain Management (SCM) is the centralized management of the flow of goods and services and includes all processes that transform raw materials into final products. Supply chain management is the practice of coordinating the various activities necessary to produce and deliver goods and services to the end-user (Ivanov *et al.*, 2019). SCM integrates supply and demand management within and between companies. SCM is often described as having five key elements: planning, procurement of raw materials, manufacturing, delivery, and returns. A traditional view of supply chains describes the flow of orders and goods between the following actors: supplier, manufacturer, wholesaler, retailer, and consumer.

The supply chain represents the backbone of most economies and successful multinational companies since it provides markets and society with goods and services throughout the world (Ivanov, 2021). Traditionally, global companies have based their supply chain on the assumption that materials flow freely globally, allowing them to source, produce, and distribute products at the lowest-cost locations around the world. Today, supply chains have become highly sophisticated and complex, with innumerable partners spread across multiple geographies as part of an unprecedented, intertwined global trade ecosystem.

The growing number of interconnections and the global nature makes the supply chain exposed to a wide range of risks that can disrupt the normal flows of the network, exposing organizations to economic, environmental, and social consequences. Indeed, supply chain disruptions have occurred more frequently in recent decades, representing a new challenge for supply chain managers. Furthermore, since 2020, the modern world has been stressed by an unprecedented and disruptive disease outbreak commonly known as COVID-19, an infectious disease caused by a newly discovered coronavirus and transmitted via droplets or contaminated objects, during close, unprotected contact between at least one infectious and one infected (La Torre *et al.,* 2021). The COVID-19 pandemic is seen as a new type of global upheaval quite unlike anything seen before that has created significant uncertainty between trade, finance, health and education systems, business, and society (Ivanov and Das, 2020). The current crisis and its widespread effects have clearly shown the significant role that supply chains play in the overall success and valuation of global societies, revealing vulnerability and fragility.

As the COVID-19 pandemic has shown, unforeseen events can cause major disruptions to the entire supply chain network: it is interesting to analyze how companies must focus much of their attention on managing the types of shocks, known as "unexpected disruptions", redesigning their supply chain, and implementing resilient activities that allow them to be able to mitigate risks, respond promptly to risk, and ensure faster stabilization and recovery (Ivanov *et al.,* 2019).

1.3 Research Aim and Objectives

The COVID-19 pandemic has had a devastating human impact and exerted unrelenting pressure on supply chains. This thesis aims to present new information or, at least, a new perspective on Supply Chain Management by identifying the key areas that have been most impacted by the pandemic and crises. The specific research objectives are:

P1. To review the existing and current status of the implementation of multicriteria decision making methods in the healthcare supply chain. To examine the applicability of these models in order to find out the best solution to manage the healthcare supply chain activities.

P2. To develop a reverse logistics (RL) system to collect unwanted medications (UMs) in households. To examine a reverse supply chain (RSC) in a decentralized state that includes a manufacturer, a retailer, and a strategic consumer. To investigate RSC from the consumer's perspective.

P3. To examine the applicability of mathematical models for infectious diseases to analyze the effects of epidemic outbreaks on supply chain networks. To develop stochastic Susceptible-Infected-Susceptible (SIS) frameworks to model the spread of new epidemics across different distribution networks and determine social distancing/treatment policies in the case of local and global networks.

1.4 Research Scope

This study is conducted to understand the areas of the supply chain that have been most affected by the pandemic and related crises. The scope of this thesis is to offer a fresh view of supply chain risk and resilience by covering management and modeling perspectives. This work is an attempt to inform researchers, experts, and policymakers on how to ingenerate organizations' preparedness to face supply chain disruptions and recovery.

1.5 Research Methods

The study methodology includes the following components:

Chapter three – Multi-Criteria Methods and Healthcare Supply Chain Management: A review of the relevant literature on the application of multi-criteria methods in the healthcare supply chain management is carried out by adopting a four-step methodology based on the practical guidelines provided by Frazão *et al.* (2018). The supply chain key areas of the MCDM implementation are identified by applying the decision matrix proposed by Ivanov *et al.* (2019:11).

Chapter four – Model Design and Methodology: Analysis of Some Incentives on Two-echelon Reverse Supply Chain with Strategic Consumer: The Case of Unwanted Medications in Households: In this article, a reverse logistics (RL) system is established to collect unwanted medications (UMs) in households. A three-person supply chain model is developed to analyze consumer behavior and preferences to achieve a more efficient RL system. As the manufacturer and retailer want to motivate the consumer, an RL system is designed consisting of advertising and exchange incentive from the manufacturer and retailer to motivate the consumer with the FSC for collecting UMs. The two-echelon supply chain consists of a pharmaceutical producer (manufacturer) and a pharmacy retailer who interact with a strategic consumer. The system possesses a forward supply channel where the manufacturer sells products to potential consumers through the retailers. Then, in a reverse supply channel, the retailers offer an exchange incentive, and the consumer decides whether to give the product based on her valuation and the utility function. Not only the exchange incentive can motivate householders to return UMs but also it can enhance sales in the FSC. Thereupon, the UMs collected are delivered to the manufacturer in order to dispose of appropriately. The disposal methods are associated with the properties of the collected UMs and the local government's policy (Laganà *et al.,* 2021:3). In order to analyze the effect of these strategies, a three-person RSC game theory approach is used. A three-person supply chain consists of a pharmaceutical manufacturer and retailer who will interact with a strategic consumer in several non-cooperative Stackelberg games. Three Stackelberg games are established and each member assumes the role of leader and the other two players assume the role of follower (Laganà *et al.,* 2021:1).

Chapter five – Modeling Supply Chain in the Era of Pandemics - A Dynamic Approach: In this chapter, a contribution to the current literature on applications of mathematical epidemiology in the field of Supply Chain Management is proposed by adopting a modified Susceptible-Infectious-Susceptible (SIS) framework. As regards the classic version of the SIS model which assumes a logistic formulation, this chapter first proceeds by focusing on the outbreak of the disease by using a simplified linearized version of the SIS model. Hence, a stochastic Susceptible-Infected-Susceptible (SIS) framework models the spread of new epidemics across different distribution networks in order to determine social distancing/treatment policies in the case of local and global networks, also highlighting the importance of adaptability. and the flexibility of decisions in unstable and unpredictable scenarios.

1.6 Thesis Organization

As said before, this work is compiled in the format of a collection thesis. It consists of four articles/papers that illuminate the collection of scientific problems previously proposed. Each chapter contains a statement of motivation explaining the main purposes of the related study. Details about the paper's status and publication journal are provided. Each chapter is framed by an introductory and a concluding/final discussion section. The references list is included at the end of each chapter.

The thesis consists of the following five chapters:

Chapter one – Research Setting Definition: This chapter provides a comprehensive introduction to the research study.

Chapter two – Theoretical Framework: This chapter presents the most relevant definitions in the field of Supply Chain Management and associated terms establishing conceptual boundaries to enhance readers' understanding of the supply chain-related terminologies used in this thesis.

Chapter three – Multi-Criteria Methods and Healthcare Supply Chain Management: This chapter has been supervised by Prof. Cinzia Colapinto from the Department of Strategy and Management of IPAG Business School, Nice Campus (France) and contains a joint paper written in collaboration with the supervisor. This work has been revised and resubmitted in the *Journal of Multi-Criteria Decision Analysis* under the title “Multiple criteria decision-making in healthcare supply chain management: a state-of-the-art review and implications for future research”. Results can inform decision-makers about multiple criteria decision methods in order to support decisions in the healthcare supply chain management.

Chapter four – Model Design and Methodology: Analysis of Some Incentives on Two-echelon Reverse Supply Chain with Strategic Consumer: The Case of Unwanted Medications in Households: this chapter has been supervised by Prof. Massimiliano Ferrara from the Department of Law, Economics, and Human Sciences of the *Mediterranea* University of Reggio Calabria (Italy) and contains the joint paper entitled “Analysis of some incentives on two-echelon reverse supply chain with the strategic consumer: the case of unwanted medications in households” published in the *Journal of Multi-Criteria Decision Analysis*. This paper has been co-authored by Drr. Mehrnoosh Khademi, Somayeh Sharifi, and Mehdi Salimi, and Prof. Massimiliano Ferrara.

This paper highlights the growing importance of environmental issues among researchers’ attention leading to an advancement in the green supply chains. The novelty of this article is that the model is investigated from the consumer's perspective. Indeed, the interesting point of this article is to investigate the result of having an appropriate RSC method from the consumer's perspective. The behavior and evaluation of the consumer on the proposed strategies affect both the manufacturer's and retailer's profits. Reversely, the decisions of the manufacturer and retailer have an influence on the consumer's benefit. So, this interaction has been investigated and resulted in a successful green activity. Moreover, the suggested RL system designed properly is beneficial for both FSC and RSC and, it showed how participating in green activities gives advantages to the members of the supply chain.

Chapter five – Modeling Supply Chain in the Era of Pandemics - A Dynamic Approach: This chapter has been supervised by Prof. Davide La Torre from SKEMA Business School and Université Côte d’Azur, Sophia Antipolis Campus (France).

In this chapter, the compiler collects the main results of the two joint works entitled respectively “Impact of epidemic dynamics on retail distribution networks” and “Modeling shock propagation on supply chain networks: a stochastic logistic-type approach”. Both papers have been co-authored by Proff. Cinzia Colapinto and Davide La Torre and Dr. Danilo Liuzzi. Both have been also submitted, accepted after a double-blind review process as conference papers, and presented respectively at the “6th Colloquium on European Research in Retailing (CERR) 2021” and at the International Conference “Advances in Production Management Systems (APMS) 2021”.
Findings and models can help global supply chain managers to understand the evolution of the epidemic and, therefore, determine the best counteractions to put in place in order to ingenerate resilience along the Supply Chain and support productivity, and thus the organizational performance.

1.7 References

Frazão, T.D.C., Camilo, D.G.G., Cabral, E.L.S., and Souza, R.P. (2018). Multicriteria decision analysis (MCDA) in healthcare: A systematic review of the mail characteristics and methodological steps. *BMC Medical Informatics and Decision Making,* 18, 90. doi: 10.1186/s12911-018-0663-1

Ivanov, D. (2021). *Introduction to Supply Chain Resilience: Management, Modelling, Technology.* Springer International Publishing. ISBN 3030704904, 9783030704902

Ivanov, D. and Das, A. (2020). Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: A research note. *International Journal of Integrated Supply Management*, 3(1), 90-102.

Ivanov, D., Tsipoulanidis, A., and Schönberger, J. (2019). *Global supply chain and operations management*. Springer Texts in Business and Economics. doi: 10.1007/978-3-319-94313-8_1

La Torre, D., Liuzzi, D., and Marsiglio, S. (2021). Epidemics and macroeconomic outcomes: Social distancing intensity and duration. *Journal of mathematical economics*, 93, 102473. doi: 10.1016/j.jmateco.2021.102473

Laganà, I., Sharifi, S., Khademi, M., Salimi, M., and Ferrara, M. (2021). Analysis of some incentives on two-echelon reverse supply chain with a strategic consumer: The case of unwanted medications in households. *Journal of Multi-Criteria Decision Analysis*, 1-12. doi: 10.1002/mcda.1736

Vidrova, Z. (2020). Supply chain management in the aspect of globalization. *Globalization and its Socio-Economic Consequences 2019. SHS Web of Conferences,* 74, 04031. doi: 10.1051/shsconf/20207404031

2. CHAPTER TWO – THEORETICAL FRAMEWORK

2.1 Introduction

The purpose of this chapter is to explore some of the most relevant definitions in the field of Supply Chain Management and associated terms, to establish conceptual boundaries to enhance readers' understanding of the supply chain-related terminologies used in this thesis. The definitions are compiled by the author from various books, research papers, journals, websites, and authors' experiences.

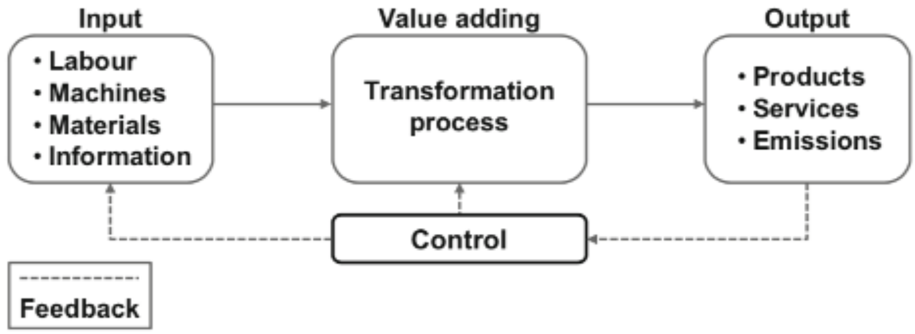
2.2 Basic concepts of Supply Chain Management

2.2.1 Operations management, Transformation process, and Value creation

Operations Management (OM) is the area of management concerned with designing and controlling of all the process involved in the transformation of inputs into finished products (goods and services). OM is the business function responsible for planning, organizing, coordinating, and controlling all the resources required to produce goods and services. Since OM is a management function, it also involves managing people, equipment, technology, information, and all other resources needed in the production of goods and services. OM is the central core function of any organization. OM's goal is to maximize efficiency throughout the transformation process. Consequently, operations are one of the strategic functions of any organization. OM includes strategic decisions with long-term business consequences, which also involve a large amount of expense and resource commitment. OM physically transforms inputs (e.g., labor, machines, materials, information, etc.) into outputs (e.g., products, services, emissions, etc.) adding value to the end customer or client.

The transformation process is critical to ensuring the matching between supply and demand and all organizations must strive to maximize the quality of their transforming approach to meet customer needs. Figure 2.1 summarizes the transformation process.

Figure 2.1: The transformation process



Source: Ivanov *et al.,* 2019:6

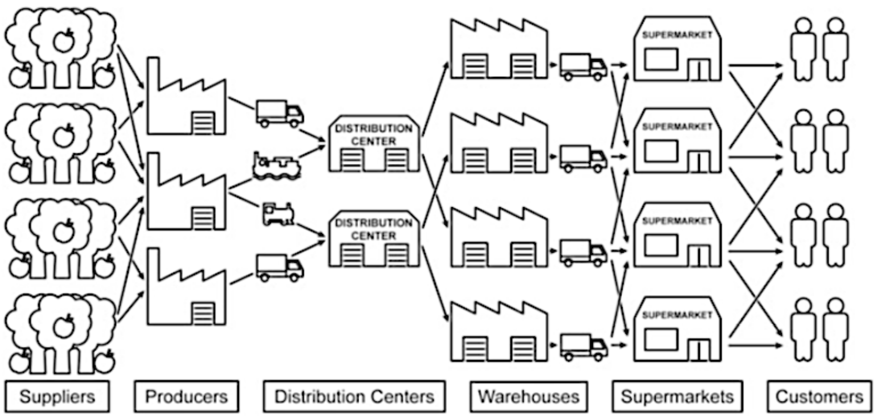
One of the basic elements in OM is the creation of value-added. Identifying the value of a product means understanding and specifying what the customer is expecting to receive (Ivanov *et al.,* 2019). In business, value-added generally refers to the increased utility that a company generates through the transformation process before offering semi-finished and then finished products to the end-customer or client. The increase in items' value can be due to labor, machine, materials, technology etc. Specifically, value-added concerns the extra features a company may add to a good or service, including either changing the product design or providing extra accompaniments primarily, with the main purpose of increasing consumer perceived value. Mathematically, value-added is defined as the difference between the total revenue and the total cost of materials, components, and services. Moreover, the value added at each stage is the difference between the cost of the input and the value of the output obtained from the stage. So providing value to end-customers is one of the main goals of any business. However, companies must guarantee to themselves a profit margin from the sale of goods and services. Consequently, a business is said to be profitable if the value that it creates or adds is greater than the cost to produce goods or services.

2.2.2 The Supply Chain

The Supply Chain (SC) is the connected network of individuals, organizations, resources, activities, and technologies, involved in the manufacturing and sale of a finished good or service.

SC activities involve the transformation of natural resources, raw materials, and components into a finished product then delivered to the end customer. A supply chain starts with the delivery of raw materials from a supplier to a manufacturer and ends with the delivery of a finished product or service to the customer or client. SC creates value in the form of products and services to end customers through various processes and activities carried out by the network of companies from upstream and downstream links (Christopher, 2005). SC is also described as a value chain, reflecting the idea that value is added along the chain (Stevenson, 2009). Specifically, the network, process, and activities underlying the SC are made up of suppliers, purchasing, manufacturing centers, warehouses, transportation, distribution centers, and retail outlets, as well as raw materials, inventory process, and finished products that flow between the structures. A simplified representation of the flow of materials, information, and services from the raw material, through manufacturers and distribution centers, to the end customer, is shown below.

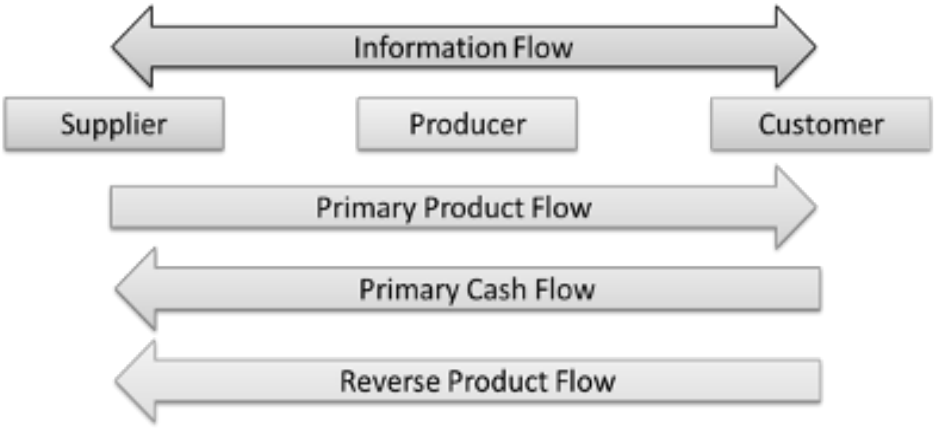
Figure 2.2: A simplified representation of a supply chain



Source: Ivanov *et al.,* 2019:8

Figure 2.3 illustrates a very simple supply chain with three entities: a supplier, a manufacturer, and a customer. Technically, a SC needs these three entities to exist. The supplier provides materials, energy, services, or components required in the transformation into products; the manufacturer, or producer, receives materials, supplies, energy, and components for use in the creation of finished products, and the end customer, or client, receives finished goods or services.

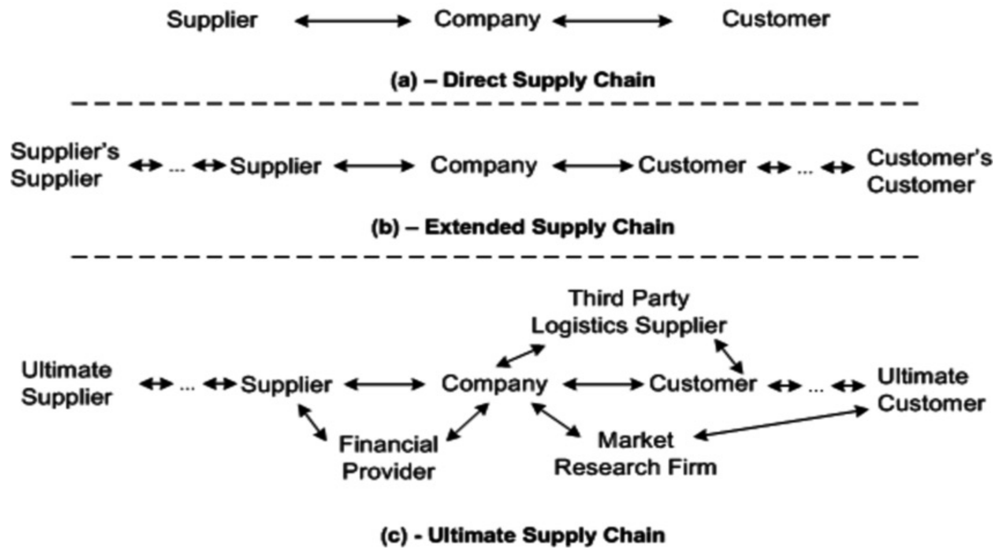
Figure 2.3: Supply chain with three entities



Source: Compiler's experience

Mentzer *et al.* (2001) describes a supply chain as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer. As stated by Mentzer *et al.* (2001), there are three degrees of supply chain complexity: a "direct supply chain," an "extended supply chain," and an "ultimate supply chain". The direct supply chain consists of a central organization, its suppliers and its customers. In addition, the extended supply chain includes suppliers of the immediate supplier and customers of the immediate customer. The ultimate supply chain includes all organizations that are involved in all flows of products, services, finance, and information from the ultimate suppliers to the ultimate customers. Also, the ultimate supply chain encompasses functional intermediaries such as market research firms, financial, and logistics services providers (Felea *et al.,* 2013).

Figure 2.4: Types of supply chain



Source: Mentzer *et al.,* 2001:4

An integrated supply chain model can generally contain three interrelated flows: physical material or primary product flow (which has itself three different stages: purchasing, transformation, and distribution), information flow (i.e., electronic data exchange or website linkages), and financial flow (which include the payment to suppliers and subcontractors for products and the payment by the customer to retailer for the final good or service) (Waller, 2003). The flow direction in the supply chain is not only forward, from first supplier to final customer or client. Goods can flow back up the supply chain for different reasons such as service, repair, remanufacturing, recycling, or disposal. The reverse chain plays a fundamental role in areas such as customer satisfaction, recycling, and environmental protection. Reverse logistics refers to a set of programs or competencies aimed at moving products in the reverse direction in the supply chain (i.e., from consumer to producer) and related activities may include handling product returns, recycling, reuse of materials, waste disposal, refurbishing or remanufacturing (Moise, 2008:198). Moreover, SCs can have multiple linked suppliers and different configurations. It is notable that an increasing number of companies coordinate in both upstream and downstream echelons in a supply network the material and information flows among a number of different suppliers, manufacturers, and distributors (Seifbarghy and Gilkalayeh, 2012).

2.2.3 Supply Chain Management

As we showed in the previous section, the supply chain consists of all the activities and processes associated with the flow of material, information, and money from the raw material stage to the final product and service. The integration of activities and processes among the members of the supply chain is frequently referred to the discipline of Supply Chain Management (Handfield and Nichols, 2003). The topic of Supply Chain Management (SCM) was first introduced to manage the flow of information, goods, and services across a network of customers, enterprises, and supply chain partners (Russel and Taylor, 2009). Since its introduction as a concept in the 1980s, SCM has undergone significant changes and extensions. Many authors attribute the foundations of SCM to the historical evolution of the logistics function and several consider that SCM and logistics are synonyms. As stated by Waters (2008:38), "logistics, or supply chain management, is the function responsible for the transport and storage of materials on their journey from original suppliers, through intermediate operations, to final customers". Even if SCM consists of logistics management activities, however, there is a difference between the concept of supply chain management and the traditional concept of logistics. Logistics is the management function responsible for all movement of materials within the boundaries of a single organization while SCM takes a broader view of movement through all related organizations that form the supply chain. SCM acknowledges all of traditional logistics and also includes activities such as marketing, new product development, finance, and customer's service (Hugos, 2006).

Thereby, over the past 30 years, the concept of SCM has been explored by various academic researchers and practitioners. Oliver and Webber (1982) define SCM as the process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible. Specifically, SCM spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption. Simchi-Levi, Kaminsky, and Simchi-Levi (2008) describes SCM as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantity, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements.

Literature reveals that there are various ways in defining Supply Chain Management. However, logistics and SCM academic textbooks and research papers typically adopt the widely used Council of Supply Chain Management Professionals (CSCMP) definition that defines SCM as the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities.

To sum up, Supply Chain Management is the centralized management of the flow of goods and services, including all the processes to transform raw materials into final products. SCM is the practice of coordinating the various activities necessary to produce and deliver products to the end customer. SCM is often described as having five key elements: planning, sourcing of raw materials, manufacturing, delivery, and returns. The planning phase refers to developing an overall strategy for the supply chain, while the other four elements specialize in the key requirements for executing on that plan. Companies must develop expertise in all five elements in order to have an efficient supply chain and avoid expensive bottlenecks. SCM also involves the oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer and then to the end customer. The three main flows of the supply chain are the primary product (or materials) flow, the information flow, and the financial flow. These occur across the following decision-making (DM) levels: strategic, tactical, and operational (Ivanov *et al.,* 2019). SCM includes the coordination and integration of these flows both within and among companies.

2.2.4 Basics of Logistics Management

The word logistics has originated from the Greek word "*logistikos*" and the Latin word "*logisticus*", meaning the science of computing and calculating. Originally, logistics was used as a military term in connection with the art of moving armies and supplies of food and armaments to the war front. Today, logistics refers to the part of an organization responsible for managing resources along the supply chain. Logistics is defined as the art and science of obtaining, producing, and distributing materials and products in the right place and in the right quantity. The Italian Logistics Association defines logistics as the set of all those organizational, managerial, and strategic processes within a company, from the supply to the final distribution of products.

Logistics Management (LM) is a subset of the larger supply chain management. According to the Council of Logistics Management (CLM), LM relates all the processes that refer to the planning, implementation, and control of the efficient, cost-effective flow, and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements.

The main goal of logistics relates to the concept of seven R's. It's about getting the right product, in the right quantity, in the right conditions, at the right time to the right customer, and in the right place.

Logistics and Supply Chain Management are terms often used interchangeably, but they actually refer to two aspects of the process. As mentioned above, a supply chain is a network of resources and distribution points that performs the functions of procurement of materials, transformation into intermediate and finished products, distribution, and delivery to customers, while logistics performs the function of planning and management of activities ranging from the procurement of raw materials to the distribution of finished products. In other words, SCM refers to the process of converting raw material to finished goods and services and getting it to the end customer, while logistics concerns the movement of raw materials or final product in the whole supply chain.

In general, logistics activities can be classified into two main groups: inbound and outbound logistics. Inbound logistics processes are linked to the inflow of raw materials from suppliers to production plants. Inbound logistics refers to the first stage of the value chain, involving different activities, such as the storage and delivery of raw materials or components used in production. Moreover, it includes the procurement of materials, inventory tracking, and optimization of the movement of products from suppliers to the store, warehouse, or production unit.

Outbound logistics involves the flow of finished products from a company to the end customer. These activities mainly concern distribution channels and customer service. Outbound logistics is the collection, storage, and distribution of final goods and related information flows, from the production plant to the end customer. It covers all those activities (i.e., sorting, packing, transporting, etc.) involved in the outflow of goods from the seller to the buyer.

Specifically, LM activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of Third-Party Logistics (3PLs) services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service activities. LM is evaluated as an integrating function, which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology (Council of Supply Chain Management Professionals, 2021).

Logistics can be split into five types by field: procurement logistics, production logistics, sales logistics, recovery logistics, and recycling logistics.

In more details, with procurement logistics we refer to the flow of goods when the raw materials and parts required for manufacturing are procured from suppliers. Companies are actively pursuing production by procuring the necessary materials in the proper amounts at the right times to reduce inventory costs. Production logistics is the flow of goods that includes the management of procured parts and materials, distribution inside a factory, product management, packaging, and shipping to warehouse. Delivery management, warehouse dispatch management, and shipping management can be optimized and the state of delivery vehicles can be managed by smoothly linking procurement logistics and sales logistics. Sales logistics relates to the delivery from delivery centers and logistics warehouses to distribution points such as wholesalers and retailers. Higher efficiency in transportation and delivery and shrinking inventory are indispensable for delivering the right product to the right customer in the necessary quantities and time. This also contributes to improving customer satisfaction. Finally, Recovery logistics and Recycling logistics respectively refers to a specialized segment of logistics focusing on the movement and management of products and resources after the sale and after delivery to the customer, including product returns for repair and/or credit, and on recycling of used products, containers, packaging, etc.

2.2.5 Global Supply Chain Management

In recent years, globalization has been a prevalent trend in almost every industry, as manufacturers and other companies attempt to take advantage of the abundant raw materials and low-cost manufacturing available in developing countries around the world. Global Supply Chain Management (GSCM) is directly linked to the growth of globalization. GSCM is widely discussed by academic and professional researchers, gaining wide worldwide recognition of global supply chain practices (Lambert and Cooper, 2000). GSCM refers to the design, planning, implementation, control and monitoring of supply chain activities with the aim of creating net value, building a competitive infrastructure, influencing world logistics, coordinating supply with demand, and measuring performance globally (Tiwari and Jain, 2013).

Global supply chains are the sophisticated networks of manufacturing, logistics, transportation and communications companies that move products and materials through production and distribution channels around the world. Global supply chain management is the process of ensuring the safe and timely delivery of everything from raw materials to finished consumer goods as they travel from manufacturers and suppliers to wholesalers, retailers and other distribution points. Global supply chains are networks that can span multiple continents and countries for the sourcing and supply of goods and services. Global supply chains involve the flow of information, processes and resources around the world. A global supply chain uses low-cost home procurement and refers to sourcing products and services from countries with lower labor rates and production costs than in the country of origin. The goals of supply chain managers are to reduce costs, improve efficiency, and mitigate risks.

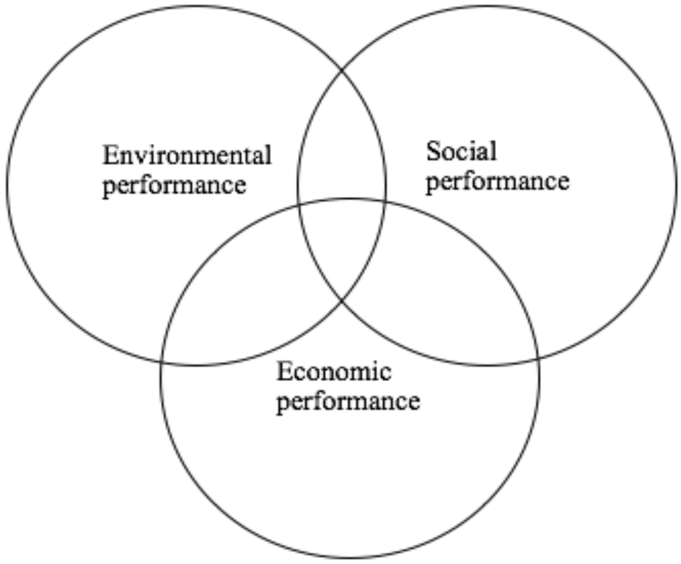
2.3 Green Supply Chain Management

2.3.1 Sustainability

In the last few decades, a growing number of large, medium, and even small companies are increasingly focused on sustainability issues. The most cited definition of sustainability comes from the United Nations World Commission for Environment and Development which defines sustainable development as that development aimed at satisfying the needs of the present without compromising the ability of future generations to meet their own needs. The UCLA Sustainability Committee defines sustainability as integrating environmental health, social equity, and economic vitality to create thriving, healthy, diverse, and resilient communities for present and future generations. Sustainable practices support ecological, human, and economic health and vitality. Sustainability assumes that resources are limited, so they should be used prudently and wisely, given the long-term priorities and the consequences of how resources are used.

The concept of sustainability is often made up using the concept of the Triple Bottom Line (TBL), coined by John Elkington in 1994 as his way of measuring performance in American corporations. The TBL is an accounting framework whose main purpose consists of measuring the financial, social, and environmental performance of a company over time. The number of companies, of all types and sizes, public and private, that share the concept of TBL, is in extraordinary increase. In fact, in recent years, companies are more than ever aware of their social and environmental responsibility, adopting or increasing their social programs. Moreover, consumers require companies to be more transparent about their environmental and social performance and are willing to pay more for goods and services if it means that workers receive a living wage and the environment is respected in the production process. Inspired by the illustration proposed by Brockhaus *et al.* (2013), TBL can be graphically interpreted as follows:

Figure 2.4: Illustration of Triple Bottom Line as "overlapping circles"



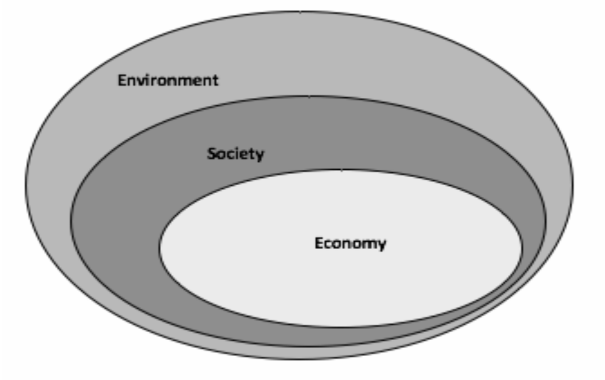
Source: Brockhaus *et al.,* 2013

As shown in the figure above, the TBL incorporates three dimensions of performance: social, environmental, and economic. In more details, environmental performance refers to the maintaining of ecological integrity, all of earth's environmental systems are kept in balance while natural resources within them are consumed by humans at a rate where they can replenish themselves. Social performance recognizes the importance of respecting universal human rights and the need for all people to have access to sufficient resources to keep their families and communities healthy and safe. Healthy communities want heads of government and business leaders who ensure respect for personal, labor, and cultural rights, and all people are protected from discrimination. Economic performance recognizes that human communities around the world must maintain their independence and have access to the resources they need, financial and otherwise, to meet their needs as secure sources of livelihood.

In 2005, IUCN mapped the three dimensions of TBL in three different ways: concentric circles, interlocking circles, and "pillars". This demonstrates that the three objectives need to be better integrated to ensure the balance between the dimensions of sustainability.

Figure 2.5: Three visual representations of sustainable development: concentric circles, overlapping circles, and pillars

a. The concentric circles of sustainability

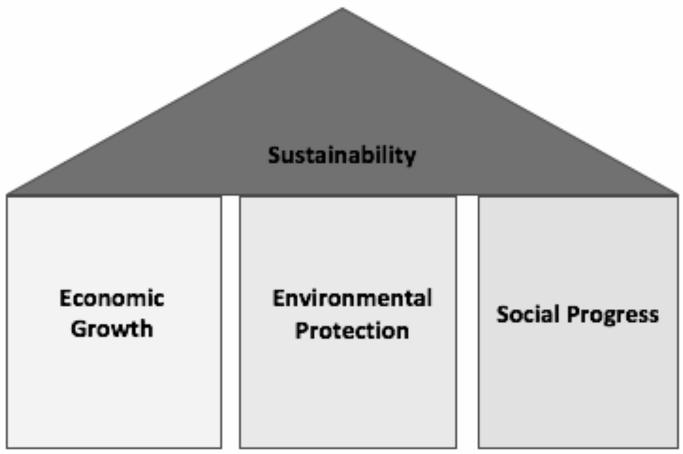


Source: http://www.sustainablecampus.cornell.edu/sustainability-intro.htm

b. The overlapping circles of sustainability

Source: http://www.iucn.org/programme/

c. The three pillars of sustainability



Source: http://www.vda.de/en/service/jahresbericht/auto2002/auto+umwelt/u_3.html

In 2005, the IUCN World Conservation Unit's annual report on the Business and Biodiversity program empathized the great attention demanded from governments, communities, and businesses in responding to the challenge of sustainability.

2.3.2 Linking Sustainability to Supply Chain

2.3.2.1 From Sustainable Supply Chain Management to Green Supply Chain Management

The supply chain considers the product from the initial processing of raw materials to distribution to the end customer, and then, if the loop is closed, from collection to the reintroduction in a new supply chain. Nowadays, there is an increasing recognition that companies must address the issue of sustainability in their own operations. The growing focus on the supply chain is a step towards wider adoption and development in the field of sustainability. The issue of sustainability in the context of SCM is discussed in the literature by using several terms.

Over the last few years, the issues of sustainability and SCM have been the subject of numerous debates (Seuring and Müller, 2008). Green Supply Chain Management (GSCM) and Sustainable Supply Chain Management (SSCM) are the two terms that most closely link the concepts of sustainability (Ashby *et al.,* 2012). A survey of the published definitions for SSCM and GSCM was proposed by Ahi and Searcy (2013). Carter and Rogers (2008) define SSCM as the strategic and transparent integration and achievement of the social, environmental, and economic objectives of an organization in the systemic coordination of key inter-organizational business processes to improve the long-term economic performance of the individual company and its supply chains. Ciliberti *et al.* (2008) describes it as the management of SCs in which all three dimensions of sustainability are taken into account, namely the economic, environmental, and social ones. Seuring (2008) defines SSCM as the integration between sustainable development and supply chain management (in which) by merging these two concepts, the environmental and social aspects along the supply chain must be taken into account, thus avoiding the related problems, more sustainable products, and processes. Seuring and

Müller (2008) interprets it as material, information, and capital flow management, as well as cooperation between companies along the supply chain, taking goals from all three dimensions of sustainable development, namely, economic, environmental, and social into account that derive from the requirements of the customer and interested parties. Haake and Seuring (2009) refers to SSCM as the set of supply chain management policies conducted, actions taken, and relationships formed in response to concerns related to the natural environment and social issues regarding design, acquisition, the production, distribution, use, reuse, and disposal of the company's goods and services. All these definitions explicitly take into account the concept of TBL as all of them integrate the concepts of economic, environmental, and social sustainability, while also fully agreeing on the multidimensional idea of sustainability. As regards the reference to Supply Chain Management, it is possible to note different versions: from integration and achievement of objectives to actions taken and relationships established regarding the design, acquisition, production, distribution, use, reuse, and disposal of goods and services. In this perspective, we can consider the definition proposed by Haake and Seuring (2009) as the most comprehensive. The greater emphasis on the environmental dimension of sustainability makes the GSCM definitions more focused than those for SSCM. This clearly shows that SSCM is usually interpreted as an extension of GSCM. One of the most adopted definitions of GSCM is given by Srivastava (2007) who integrating environmental thinking into SCM, including product design, material sourcing, and selection, manufacturing processes, delivery of the final product to the consumer as well as end-of-life management of the product after its useful life. Handfield *et al.* (1997) refer to the application of environmental management principles to the entire set of activities across the whole customer order cycle, including design, procurement, manufacturing and assembly, packaging, logistics, and distribution. Zhu and Sarkis (2004) state that GSCM is a new important archetype for companies to achieve profit and market share goals by reducing risks and environmental impacts by increasing their ecological efficiency. Wee *et al.* (2011) describe it as integrating environmental considerations into supply chain management, including product design, sourcing and material selection, manufacturing processes, delivering the final product to consumers, and managing the end-of-life of ecological products. Gnoni *et al.* (2011) refer to GSCM as an approach that aims to integrate the issue of the environmental dimension into supply chain procedures, starting with product design and continuing through procurement and selection of materials, production processes, delivery of the final product, and end-of-life management. Unlike in the case of SSCM, for GSCM there is broad agreement on the extension of SCM's activities, with some differences. In defining GSCM, Zhu *et al.* (2012) remark that the main goal is to achieve profit by increasing eco-efficiency. Handfield *et al.* (1997) consider the product life cycle from design to customer distribution, while Wee *et al.* (2011) also include reverse logistics. However, Gnoni *et al.* (2011) and Srivastava (2007) provide the most exhaustive definitions considering GSCM as the integration of SCM activities from product design to end-of-life management of the product after its useful life. According to this point of view, the life cycle of the product, from the cradle to the grave, is the subject of all the activities of GSCM, so that there is a full correspondence between the two concepts. Tseng *et al.* (2009) conduct an extensive literature review on GSCM, readapting the list of GSCM definitions introduced by Ahi and Searcy (2013).

Based on the discussion above, the process of integrating sustainability within the supply chain, the so-called Green Supply Chain Management, allows organizations to improve the flows, operations, and activities within the chain, gaining simultaneously economic, environmental, and social goals.

In addition, in recent years, improved environmental legislation and the wide range of green initiatives have provided some incentives for organizations to become more environmentally friendly. This underlines an increase in public awareness of environmental and social concerns and the growth of corporate social responsibility (CSR) within companies.

By providing some definitions of both SSCM and GSCM, it was possible to state that if SSCM simultaneously addresses the three pillars of sustainability (economic, environmental, and social dimension), GSCM emphasizes, in particular, the integration of the environmental dimension within the operations and activities of the SC, consequently promoting the achievement of social goals.

2.3.3 A brief history of Green Supply Chain Management

Environmentally conscious business practices have been receiving increasing notoriety among academic researchers and practitioners just in the early 20th century (Svensson, 2007). Some of the early modern supply chain practices, such as lean manufacturing and Just-In-Time (JIT), can be traced to Henry Ford's efforts to vertically integrate automotive supply chain and organizational practices. The concept of JIT and SCM at that time essentially focused on improving operational efficiency and minimizing waste. The main purpose of waste minimization was not related to environmental, but mostly to economic reasons. Waste is essentially described as a simple economic loss (Lai and Cheng, 2009). Furthermore, in recent years, industrial pollution has not been one of the main topics of investigation for economics or supply chain management researchers and practitioners. In the economy, the application of taxes for the management of externalities such as industrial pollution has been proposed (Pigou, 1920). At that time, the debate on the taxation of environmental pollution generated by industrial activities represented essentially the limit of the discussion. During this period, philosophical developments were taking place with the discussion of whether the natural environment deserved its rights and had its own intrinsic value (Fine and Leopold, 1933). In their work, Ayres and Kneese (1969) highlight that some of the earliest work, related to the current greening process of the supply chain, can be traced back even before the formation of the United States Environmental Protection Agency. During the 1970s, a further refinement of ideas about industrial metabolism and material flow balance occurred (Ayres, 1978). The discussion of how to use the mass balance for organizational and governmental decision making was also introduced in the early 1970s through a process chain assessment model estimates the cumulative (direct and hidden) costs of various processes or phases that form 'chains' that initiate a set of raw material inputs for a production that can be sold as semi-finished or consumer products (Stern *et al.,* 1973). At the same time, a further refinement of the philosophy of industrial ecosystems was taking place (Jelinski *et al.,* 1992) and further recognition of the concept of the supply chain as a competitive strategic weapon (Bhote, 1989). In the late 1960s, the environmental movement in the United

States was catalyzed due to growing consumer concerns about degradation. This led to the establishment, in the early 1970s, of the Environmental Protection Agency, with directives aimed at applying the regulations concerning the industrial production of all companies along the supply chain (Sarkis, 2012). This resulted in a growing need to enforce environmentally friendly decisions in supply chain management (SCM), shifting planning from reactive to proactive. As a result, environmental performance standards have increasingly been incorporated into contract guidelines for supply chain partners (Simpson and Samson, 2007). A company's response to the environmental requirements of external stakeholders is directly influenced by their level of commitment related to both environmental awareness and performance. In such environment-based scenarios, the supplier-customer relationship is affected by both the existing transaction cost requirements and the environmental commitment of both entities. Responding to growing environmental compliance needs, GSCM has evolved, reflecting an integration of environmental thinking. GSCM implies a global perspective, including product design, material sourcing, and selection, manufacturing processes, delivery of final products to consumers, as well as end-of-life product management (Srivastava, 2007). According to Srivastava (2007), the GSCM is growing in importance and is driven by increasing environmental degradation, decreasing natural resources, and increasing pollution levels.

2.3.4 Green Supply Chain Management definition and main topics

During the last two decades, Green Supply Chain Management has emerged as a result of the growing interest in integrating sustainability into supply chain practices.

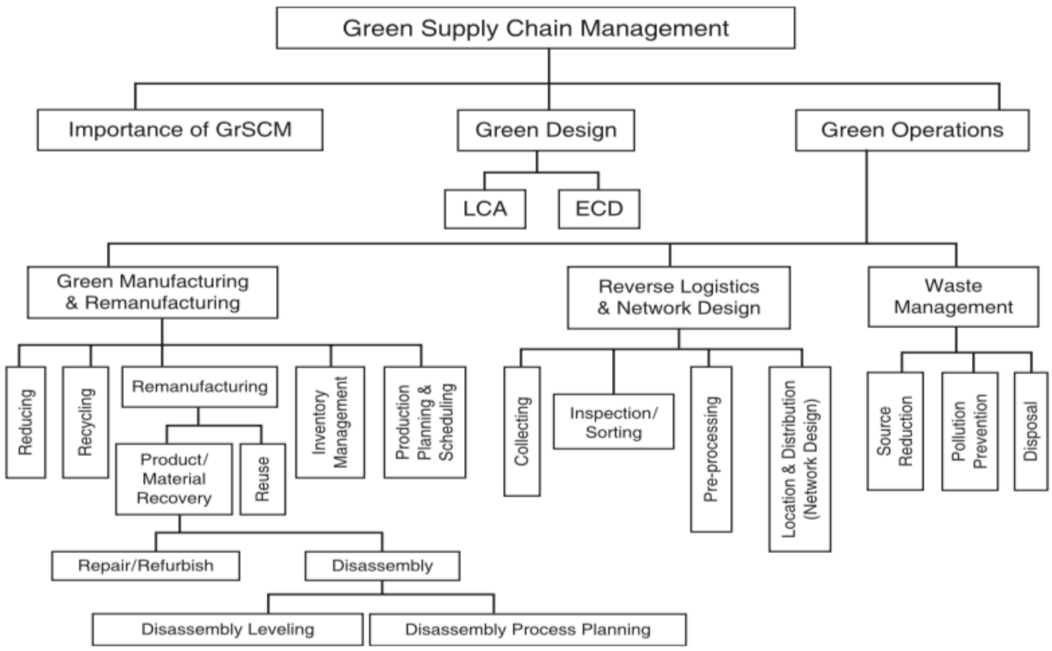
Green Supply Chain (GSC) arises from the integration between the concept of supply chain and green management. With SC, we refer to the complex flows of materials and information aimed at the production and transfer of a product on the market, while, with green management, we refer to the management strategies of the environmental and social impacts of a company.

With the term "Green Supply Chain", we define a management approach that aims to minimize the environmental impact of a good or service throughout its life cycle. In this definition, the concept of the Life Cycle (LC) of a product and process shifts the focus of attention from the organization itself to the entire system of relationships and actors who contribute, together with it, to the creation of value, opportunity, and the minimization of environmental impacts. Most organizations have so far considered their relationship with the environment as a problem essentially limited to its physical boundaries, manageable through the environmental compatibility of their processes and products, and the adoption of management models aimed at limiting negative impacts on the productivity of the site. However, such an approach is limiting, as the environmental impacts of a product, if traced back and related to the entire life cycle, accumulate together with the relationships that exist between the various customers and suppliers in the form of waste, emissions, and consumption generated along the value chain, from the extraction of raw materials to the end of life of the product. If we leave a model that sees the company responsible and able to act exclusively on the impacts generated by its internal operations (in particular, in the production process), we realize that a significant part of the negative externalities is generated in the nodes and connections that make up the supply chain. From these assumptions derives the need to consider extended management models, able to reduce the overall impacts through the involvement of all the players in the supply chain, creating sustainable value for stakeholders, minimizing inefficiencies and risks. From a management point of view, the application of a GSC involves the adoption of strategic supply chain measures that are numerous, including the reduction of environmental and economic risks, the increase in the operating efficiency of the system, and green innovation processes and products.

GSCM covers every stage of the supply chain from product design, procurement, sourcing and supplier selection, manufacturing and manufacturing processes, logistics, and final product delivery to consumers, together with the end of the life-product management (Emmet and Sood, 2010). As a whole, these phases cover: upstream, downstream, within organizations, and the logistics processes.

A green SC can be implemented in all four different areas of the supply chain, as mentioned above. Upstream, GSC can be implemented using green design, green procurement, and supplier environmental performance assessment. GSCM can be implemented in downstream activities by introducing any recovery and recycling opportunities after the product has provided its utility and also the disposal and sale of excess inventory. Within organizations, GSCM involves all activities related to green design, green packaging, and green manufacturing. Figure 2.6 is a representation of how and where an organization can adopt GSCM practices, from supplier to end customer.

Figure 2.6: Classification of Green Supply Chain Management main topics



Source: Srivastava, 2007:57

2.3.4.1 Green Design

Green Design is used to express the systematic consideration of design issues associated with environmental safety and health throughout the entire life cycle of the product. Srivastava (2007) proposes two main sub-themes: Life Cycle Assessment (LCA) and Environmental Conscious Design (ECD). Life Cycle Assessment, or analysis, (LCA) is described as a process to assess and evaluate the environmental, occupational health, and resource-related consequences of a product at all stages of its life, i.e. extraction and processing of raw materials, production, transport and distribution, use, regeneration, recycling, and final disposal. The purpose of the LCA is to monitor all material and energy flows of a product from the recovery of its raw materials from the environment to the disposal of the product in the environment. Attempts have also been made to develop operational models to help companies understand, monitor, and evaluate life cycle management (Srivastava, 2007). The Environmental Conscious Design (ECD) concept was adopted to support increased concerns about the environmental impact of products early in the design phase. This new trend requires that a product's design strategy be modified to integrate environmental constraints (Steven *et al.,* 2021).

2.3.4.2 Green Operations

Green Operations refer to the production/reproduction, use, handling, logistics, and waste management of the product and reverse logistics. Srivastava (2007) proposes three main themes related to Green Operations: Green Manufacturing and Remanufacturing, Reverse Logistics and Network Design, and Waste Management.

Green Manufacturing and Remanufacturing are some of the most important areas within green operations. It is about renewing production processes and establishing environmentally friendly operations within the manufacturing field. In essence, it is the "greening" of production, in which workers use fewer natural resources, reduce pollution and waste, recycle and reuse materials, and moderate emissions in their processes (Srivastava, 2007).

Reverse Logistics (RL) differs from Forwards Logistics (Tibben-Lembke and Rogers, 2002). Logistics has been defined as that part of the supply chain process that plans, implements, and controls the efficient and effective flow and storage of goods, services, and related information from the point of origin to the point of consumption to meet customer needs (Council of Logistics Management - CLM, 1999). Reverse logistics has been defined as the movement of products or materials in the opposite direction to create or recover value or for proper disposal (Tibben-Lembke and Rogers, 1999, 2001).

Network Design aims to accommodate returns and remanufacturing of products and the reuse of such parts and components (Closed-Loop Supply Chain Network Design).

Reverse Logistics differs from Waste Management in that the latter mainly refers to the collection and treatment of waste (products for which there is no new use) efficiently and effectively. The crux in this matter is the definition of waste. This is a major issue, as the term has serious legal consequences, e.g., it is often forbidden to import waste. Reverse Logistics focuses on those flows where there is value to be recovered and the results enter a (new) supply chain (De Brito and Dekker, 2002). Specifically, Waste Management refers to all the activities and actions necessary to manage waste from its birth to its disposal. It includes the collection, transportation, treatment, and disposal of waste, along with the monitoring and regulation of the waste management process.

2.4 Advanced Topics in Supply Chain Management: Supply Chain Risk Management and Resilience

2.4.1 Risk and Uncertainty in the Supply Chain

For the last few years, risk and uncertainty issues have become increasingly popular in the supply chain context (Davis, 1993; Prater, 2005; Sanchez-Rodrigues Vasco *et al.,* 2008; Simangunsong *et al.,* 2012). There are various ways to define uncertainty and risk (Wang and Jie, 2019). Van den Vorst and Beulens (2002) define supply chain uncertainty as follows: “Decision-making situations in the supply-chain in which the decision-maker does not know definitely what to decide as he/she is indistinct about the objectives; lacks information about (or understanding of) the supply-chain or its environment; lacks information processing capacities; is unable to accurately predict the impact of possible control actions on supply-chain behavior; or lacks effective control actions (non-controllability)” (Van den Vorst and Beulens, 2002:413).

Miller (1992) focuses on the difference between the notions of risk and uncertainty. Miller (1992) defines risks in business as unanticipated variation or negative variation that may influence business performance such as revenues, costs, profit, and market share; while uncertainty refers to the unpredictability of environmental or organizational variables that impact business performance or the insufficient information about these variables. There is a very close relationship between uncertainty and risk, because uncertainty increases the possibility of risk occurring, and risk is a consequence of uncertainty. In other words, risk occurs because of uncertainty about the future, and this uncertainty means that unexpected events may occur that cause some kind of damage. In practice, supply chain uncertainty is often used interchangeably with the term supply chain risk.

2.4.2 Supply Chain Risk Management

In recent decades, risk management has become one of the most important topics in academic research and practice. Risk management is a methodological approach to handle uncertainty (Ivanov *et al.,* 2019). From the organization's point of view, risk management is a continuous and systematic process to identify and treat risks attached to the organization's activities, aiming at securing the organization's existence and long-term success. A typical risk management process consists of four steps: i) risk identification; ii) risk estimation; iii) risk treatment; and iv) risk monitoring.

Specifically, risk identification is the first step in the risk management process. It aims at identifying an organization's exposure to uncertainty, and, thereby, being able to manage risks proactively. Therefore, risk identification is an important stage of the risk management process, since unidentified risks remain neglected in the subsequent steps; hence, it should be approached methodically. In a supply chain environment, risk identification must take into account the value stream of products and processes, assets and infrastructure, dependencies on other organizations, and the environment. The result of this process step is a list and description of the identified risks. Risk estimation aims to give a quantitative, semi-quantitative, or qualitative description of the probability and severity of each risk. This helps to focus attention on more severe risks and to choose suitable management options in the subsequent step. Risk treatment refers to the process to manage the identified risks by reducing the probability of occurrence, reducing the consequence, or accepting the risk. Its goal is not necessarily to minimize risk but to find an acceptable trade-off between risk and return for the organization. Risk treatment actions generally include risk transfer, risk-taking, risk elimination, risk reduction, and further analysis of individual risks. Moreover, risk treatment should define mitigation plans for reducing the effects of any adverse events. The fourth and last step refers to risk

monitoring. It includes a reporting and review structure for identified and newly emerging risks, and controlling the implementation of risk treatment strategies.
Risk Management in Supply Chain (SCRM) is the implementation of strategies to manage both every day and exceptional risks along the supply chain based on continuous risk assessment to reduce vulnerability and ensure continuity (Heckmann *et al.,* 2015).

2.4.2.1 Supply Chain Risk Classification

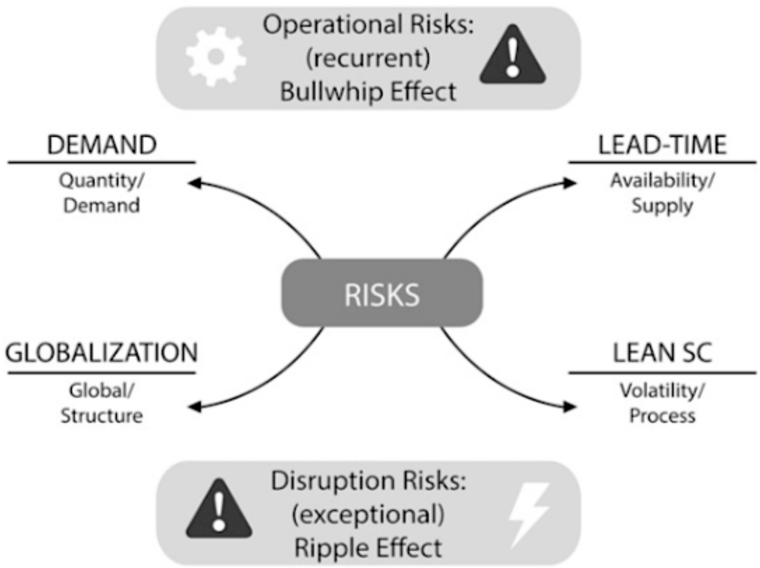
Recent literature introduced different classifications of supply chain risks (Chopra and Sodhi, 2004; Tang and Musa, 2011; Ho *et al.*, 2015; Quang and Hara, 2017). For example, Chopra and Sodhi (2004) categorize potential supply chain risks into nine categories: 1) Disruptions (e.g., natural disasters, terrorism, war, epidemics, etc.); 2) Delays (e.g., inflexibility of supply source); 3) Systems (e.g., information infrastructure breakdown); 4) Forecast (e.g., inaccurate forecast, bullwhip effect, etc.); 5) Intellectual property (e.g., vertical integration); 6) Procurement (e.g., exchange rate risk); 7) Receivables (e.g., several customers); 8) Inventory (e.g., inventory holding cost, demand, and supply uncertainty, etc.); 9) Capacity (e.g., cost of capacity). Moreover, Quang and Hara (2017) classify risks as the following: external risks which deal with threats from an external perspective of SC that can be caused by economical, socio-political or geographical reasons. examples are fire accidents, natural catastrophes, economic downturn, external legal issues, corruption, and cultural differentiation; time risks, referring to delays in SC processes; information risks (e.g., communication breakdown within the project team, information infrastructure complications, distorted information, and information leaks); financial risks (e.g., inflation, interest rate level, currency fluctuations, and stakeholder requests); supply risks (i.e., risks related to suppliers, e.g., supplier bankruptcy, price fluctuations, unstable quality and quantity of inputs); operational risks, caused by problems within the organizational boundaries of a firm (e.g., changes in design and technology, accidents, and labor disputes); demand risks that refer to demand variability, high market competition, customer bankruptcy, and customer fragmentation.

2.4.2.2 Operational and Disruption Risks

With the growth of global sourcing, the complex and interconnected structure of supply networks, and the increasing adoption of demand-driven and lean production practices, supply chains (SCs) have become increasingly exposed to several disruptions (Hosseini *et al.,* 2019). As a consequence of the increasing complexity of modern supply chains, the study of disruption management is continually developing, constituting a complicated and challenging field (Aldrighetti *et al.,* 2019).

Ivanov *et al.* (2019) classifies supply chain risks into demand, supply, process, and structure areas (Figure 2.7). Risks of demand and supply uncertainty are related to random uncertainty and business-as-usual situations. Such risks are also known as recurrent or operational risks.

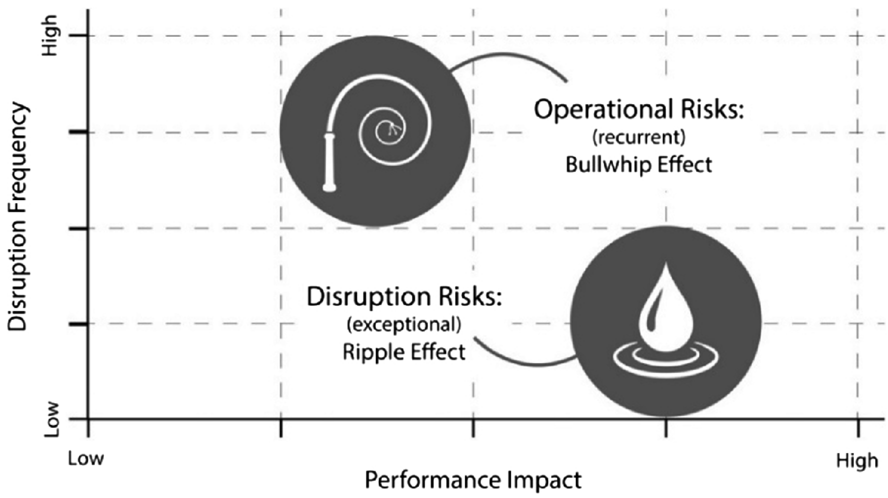
Figure 2.7: Operational and disruption risks in the supply chain



Source: Ivanov *et al.,* 2019:463

Disruption risks represent a new challenge for supply chain managers. Due to the unpredictability of the disruption appearance and the magnitude of the propagation of disruption consequences, the ripple effect has emerged in the supply chain. As stated by Hosseini *et al.* (2019), the ripple effect in the supply chain "refers to the structural dynamics and describes a downstream propagation of the disruption consequences, e.g., in the form of downscaling in demand fulfillment, downstream the SC as a result of a severe disruption (or a series of disruptions)". Recently, the supply chain disruption propagation of ripple effect, also known as "domino effect" or "snowball effect", has gained increasing attention from both academia and practitioners, because of the significant global economic loss caused by various disruption events such as the Thailand Flood in 2011, the Japan Earthquake in 2012, and now the Coronavirus Disease (COVID-19). Despite the growing number of contributions on disruption studies, the most recent overview of the ripple effect research in the supply chain has been provided by Ivanov and Dolgui (2020). The ripple effect is considered as "a specific area" of supply chain disruptions and "a strong stressor" to supply chain resilience (Dolgui and Ivanov, 2021). In recent years, the phenomenon of the ripple effect is widely present in practice. As stated by Dolgui *et al.* (2018), the ripple effect "occurs when a disruption, rather than remaining localized or being contained to one part of the SC, cascades downstream and impacts the performance of the entire SC" (Figure 2.8). For more details, please refer to the *Handbook on the Ripple Effects in Supply Chain* (Ivanov *et al.,* 2019).

Figure 2.8: Operational and disruption risks: The Bullwhip and the Ripple effects

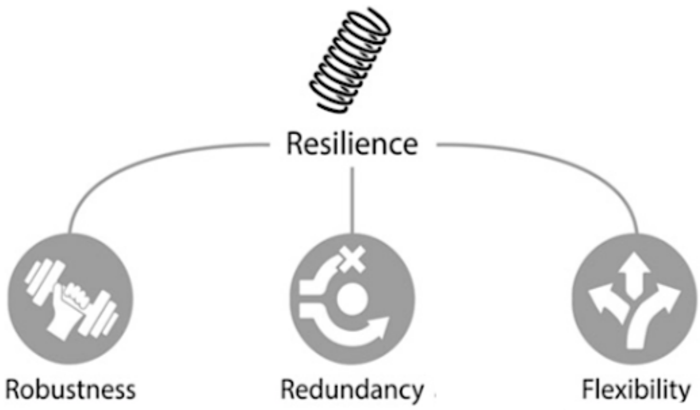


Source: Ivanov *et al.,* 2019:464

2.4.3 Supply Chain Resilience

In a changing world, where globalization is playing an increasing role and where supply chains are more and more exposed to disruption events, the resilience issue has been receiving increasing attention among researchers and practitioners. Resilience in the supply chain has been described in simpler and broader terms by different authors (For further information see Pires Ribeiro and Barbosa-Póvoa, 2020). According to Ivanov (2018), supply chain resilience is the "ability to maintain, execute and recover (adapt) planned execution along with achievement of the planned (or adapted, but yet still acceptable) performance is therefore the next objective property of the supply chain". One of the main objectives of supply chain management is to increase total supply chain output performance, which is basically referred to as supply chain effectiveness and efficiency. At the same time, achievement of planned performance can involve the impact of perturbations in a real-time execution environment. Supply chain execution is subject to uncertainty at the planning stage and disruption at the execution stage. This requires supply chain protection against an efficient reaction to disturbances and disruptions. As a consequence, supply chains need to be planned to be stable, robust and resilient enough to maintain their basic properties and ensure execution; and be able to adapt their behavior in the case of disturbances in order to achieve planned performance using recovery actions (Figure 2.9).

Figure 2.9: Resilience control elements



Source: Ivanov *et al.,* 2019:484

The robustness of supply chains is a complex characteristic of a non-failure operation, durability, recoverability, and the maintenance of supply chain processes and a supply chain as a whole. This is connected with the creation of a reserves system (the introduction of resource excessiveness) for the prevention of failures and deviations in supply chain processes. The flexibility of supply chains is a property concerning its ability to change itself quickly, structurally and functionally depending on the current execution state and reaching supply chain management goals by a change in supply chain structures and behavior. This is connected with the creation of an adaptation system (with regard to operations and resources) for the prevention, improvement, or acquisition of new characteristics for the achievement of goals under the current environmental conditions varying in time.

2.5 References

Ahi, P. and Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of Cleaner Production*, 52, 329-341.

Albastroiu, I. and Felea, M. (2013). Defining the concept of SCM and its relevance to Romanian academics and practitioners. *Amfiteatru Economic*, 15(33), 74-88.

Ashby, A., Leat, M., and Hudson Smith, M. (2012). Making connections: A review of supply chain management and sustainability literature. *Supply Chain Management: An International Journal*, 17. 497-516. doi: 10.1108/13598541211258573

Ayres, R.U. (1978). *Resources environment and economics; applications of the materials/energy principle*. New York, John Wiley and Sons.

Ayres, R.U. and Kneese, A.V. (1969). Production, consumption, and externalities. *American Economic Review*, 59(3), 282-297.

Bhote, K.R. (1989). *Strategic supply management a blueprint for revitalizing the manufacturer-supplier partnership.* American Management Association. New York.

Brockhaus, S., Kersten, W., and Knemeyer, A.M. (2013). Where do we go from here? Progressing sustainability implementation efforts across supply chains. *Journal of Business Logistics*, 34(2), 167-182.

Carter, C.R. and Rogers, S.S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, 38(5), 360-387.

Chopra, S. and Sodhi, M.S. (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*, 46, 52-61.

Christopher, M. (2005). *Logistics and supply chain management: Creating value-adding networks*. 3rd ed. Great Britain, Pearson Education Limited.

Ciliberti, F., Pontrandolfo, P., and Scozzi, B. (2008). Logistics social responsibility: Standard adoption and practices in Italian companies. *International Journal of Production Economics*, 113, 88-106. doi: 10.1016/j.ijpe.2007.02.049

Council of Supply Chain Management Professionals, (2021). CSCMP Supply Chain Management Definitions. (online) Council of Supply Chain Management Professionals. (Online) Available at: http://cscmp.org/aboutcscmp/definitions.asp (Accessed March 2021).

Davis, T. (1993). Effective supply chain management. *Sloan Management Review*, 34(4).

De Brito, M. and Dekker, R. (2002). *Reverse Logistics: A framework*. Erasmus University Rotterdam, Econometric Institute, Econometric Institute Report.

Dolgui, A., Ivanov, D., and Sokolov, B. (2018). Ripple effect in the supply chain: An analysis and recent literature. *International Journal of Production Research*, 56(1-2), 414-430. doi: 10.1080/00207543.2017.1387680

Ivanov, D. and Dolgui, A. (2020). Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International Journal of Production Research*, 58(10), 2904–2915.

Elkington, J. (1994). Towards the sustainable corporation: Win-win-win business strategies for sustainable development. *California Management Review*, 36, 90-100. doi: 10.2307/41165746

Felea, M. and Albăstroiu, I. (2013). Defining the concept of supply chain management and its relevance to Romanian academics and practitioners. *Amfiteatru Economic Journal*, ISSN 2247-9104, The Bucharest University of Economic Studies, Bucharest, 15(33), 74-88.

Fine, B. and Leopold, E. (1993). *The world of consumption*. London; New York: Routledge.

Gnoni, M., De Felice, F., and Petrillo, A. (2011). A multi-criteria approach to strategic evaluation of environmental sustainability in a supply chain. *International Journal of Business Insights and Transformation*, 3, 54-61.

Haake, H. and Seuring, S. (2009). Sustainable procurement of minor items: Exploring limits to sustainability. *Sustainable Development*, 17, 284-294. doi: 10.1002/sd.424

Handfield, R.B. and Nichols, E.L. (2003). *Introduction to supply chain management*. 2nd edition. Upper Saddle River: Prentice Hall.

Handfield, R., Sroufe, R., and Walton, S. (2005). Integrating environmental management and supply chain strategies. *Business Strategy and the Environment*, 14, 1-19. doi: 10.1002/bse.422.

Ho, W., Zheng, T., Yildiz, H., and Talluri, S. (2015). Supply chain risk management: A literature review. *International Journal of Production Research*, 53(16), 5031-5069.

Hosseini, S. and Ivanov, D. (2019). A new resilience measure for supply networks with the ripple effect considerations: A Bayesian network approach. *Annals of Operations Research*. doi: 10.1007/s10479-019-03350-8.

Hugos, M.H., (2006). *Essentials of supply chain management*. 2nd ed. Hoboken: John Wiley & Sons.

Ivanov, D. (2018). Revealing interfaces of supply chain resilience and sustainability: A simulation study. *International Journal of Production Research*, 56(10), 3507-3523. doi: 10.1080/00207543.2017.1343507.

Ivanov, D., Dolgui, A., and Sokolov, B. (2019). *Handbook of ripple effects in the supply chain*. International Series in Operations Research and Management Science, 276. Springer Nature Switzerland. doi: 10.1007/978-3-030-14302-2

Ivanov, D., Tsipoulanidis, A., and Schönberger, J. (2019). *Global supply chain and operations management*. Springer Texts in Business and Economics. doi: 10.1007/978-3-319-94313-8_1

International Union for Conservation of Nature (IUCN) (2005), The IUCN Program 2005-2008 Many Voices, One Earth. (Online)
Available at: https://cmsdata.iucn.org/downloads/programme_english.pdf (Accessed March 2021)

Jelinski, L.W., Graedel, T.E, Laudise, W.D., McCall, D.W., and Patel, K.N. (1992). Industrial ecology's concepts and approaches. *Proceedings of the National Academy of Science Conference*, 89, 793-797.

Lai, K.H. and Cheng, T.C.E. (2009). *Just-in-time logistics*, Gower Publishing, Farnham, England.

Lambert D. M. and Cooper M. C. (2000). Issues in supply chain management. *Industrial Marketing Management*, 29(1), 65-83.

Mentzer, J., Dewitt, W., Keebler, J., Min, S., Nix, N., Smith, C., and Zacharia, Z. (2001). Defining Supply Chain Management. *Journal of Business Logistics*, 22(2), 1-25. doi: 10.1002/j.2158-1592.2001.tb00001.x.

Miller, K. D. (1992). A Framework for Integrated Risk Management in International Business. *Journal of International Business Studies*, 23, 311-331.

Moise, M., 2008. The importance of reverse logistics for retail activity. Amfiteatru Economic, 10 (24), 192-209.

Oliver, R.K. and Webber, M.D., (1982). Supply-chain management: Logistics catches up with strategy. In: M. Christopher, ed. 1992. *Logistics: The strategic issues.* London. Chapman & Hall, 63-75.

Pigou, A. C. (1920). *The economics of welfare*. London, Macmillan.

Pires Ribeiro, J. and Barbosa-Póvoa, A. (2018). Supply chain resilience: Definitions and quantitative modelling approaches – A literature review. *Computers & Industrial Engineering*, 115, 109-122. doi: 10.1016/j.cie.2017.11.006

Prater, E. (2005). A framework for understanding the interaction of uncertainty and information systems on supply chains. *International Journal of Physical Distribution and Logistics Management*, 35(524).

Quang, H.T. and Hara, Y. (2017). Risks and performance in supply chain: the push effect. *International Journal of Production Research*, 56(1369). doi: 10.1080/00207543.2017.1363429

Russel, R. S. and Taylor, B.W. (2009). *Operations management along the supply chain*. 6th ed. Hoboken: John Wiley & Sons.

Sanchez-Rodrigues, V., Stantchev, D., Potter, A., Naim, M., and Whiteing, A. (2008). Establishing a transport operation focused uncertainty model for the supply chain. *International Journal of Physical Distribution and Logistics Management*, 38(5), 388-411.

Sarkis, J. (2012). A boundaries and flows perspective of green supply chain management. *Supply Chain Management: An International Journal*, 7(2), 202-216.

Seifbarghy, M. and Gilkalayeh A.P. (2012). Supply chain integration under vendor managed inventory mode of operation considering stockout. *Economic Computation and Economic Cybernetics Studies and Research* – ECECSR, 46(1), 197-219.

Seuring, S. and Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, 16(15), 1699-1710. doi: 10.1016/j.jclepro.2008.04.020

Simangunsong, E., Hendry, L.C., and Stevenson, M. (2012). Supply-chain uncertainty: a review and theoretical foundation for future research. *International Journal of Production Research*, 50(16), 4493-523.

Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2008). *Designing and managing the supply chain: concepts, strategies, and case studies*. 3rd ed. New York: McGraw Hill.

Simpson, D. and Samson, D.A. (2008). *Developing strategies of green supply chain management*. Decision Line.

Srivastava, S.K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, 9(1), 53-80. doi: 10.1111/j.1468-2370.2007.00202.x

Stern, M.O., Ayres, R.U., and Saxton, J.C. (1973). *Tax strategies for industrial pollution abatement.* IEEE Transactions on Systems Man and Cybernetics, 3(6), 588-603.

Stevenson, W. J. (2009). *Operations management.* 10th ed., New York, McGraw-Hill/Irwin

Tibben-Lembke, R.S. and Rogers, D.S. (2002). Differences between forward and reverse logistics in a retail environment. *Supply Chain Management: An International Journal*, 7(5), 271-282. doi: 10.1108/13598540210447719

Tiwari A. and Jain M. (2013). Analysis of supply chain management in cloud computing. *International Journal of Innovative Technology and Exploring Engineering* (IJITEE), 3(5).

Stern, M.O., Ayres, R.U., and Saxton, J.C. (1973). *Tax strategies for industrial pollution abatement*. IEEE Transactions on Systems Man and Cybemetics, 3(6), 588-603.

Svensson, G. (2007). Aspects of sustainable supply chain management (SSCM): Conceptual framework and empirical example. *Supply Chain Management*, 12(4), 262-266. doi: 10.1108/13598540710759781

Tang, O. and Musa, S.N. (2011). Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economy*, 133,25-34.

Tseng, M.L., Divinagracia, L., and Divinagracia, R. (2009). Evaluating firm's sustainable production indicators in uncertainty. *Computers & Industrial Engineering*, 57, 1393-1403.

Van der Vorst, J. and Beulens, A. (2001). Identifying sources of uncertainty to generate supply chain redesign strategies. Int. J. Phys. Distrib. Logist. Manage. Decis.. 32. 409-430.

Waller, D.L. (2003). *Operations management: A supply chain approach*. 2nd ed. Thomson Learning. ISBN: 1861528035, 9781861528032

Wang, M. (2018). Impacts of supply chain uncertainty and risk on the logistics performance. *Asia Pacific Journal of Marketing and Logistics*, 30(3), 689-704. doi: 10.1108/APJML-04-2017-0065

Wang, M. and Jie, F. (2019). Managing supply chain uncertainty and risk in the pharmaceutical industry. *Health Services Management Research*, 33. doi: 10.1177/0951484819845305

Waters, D. (2008). *Supply chain risk management: vulnerability and resilience in logistics*. London: Kogan Page.

Wee, H.-M., Lee, M.-C., Yu, J. C. P., and Edward Wang, C. (2011). Optimal replenishment policy for a deteriorating green product: Life cycle costing analysis. *International Journal of Production Economics*, 133(2), 603-611. doi: 10.1016/j.ijpe.2011.05.001

Zaman, A.U. (2014). Measuring waste management performance using the "Zero Waste Index": The case of Adelaide, Australia. *Journal of Cleaner Production*, 66, 407-419. doi: 10.1016/j.jclepro.2013.10.032

Zhu, Q. and Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management*, 22(3), 265-289.

Zhu, Q., Sarkis, J., and Lai, K. (2012). Examining the effects of green supply chain management practices and their meditations on performance improvements. *International Journal of Production Research*, 50(5), 1377-1394.

3. CHAPTER THREE – MULTI-CRITERIA METHODS AND HEALTHCARE SUPPLY CHAIN MANAGEMENT

This chapter has been supervised by Prof. Cinzia Colapinto from the Department of Strategy and Management of IPAG Business School of Nice Campus (France) and contains the results of the state-of-the-art review conducted during the research stay as a Ph.D. student at SKEMA Business School of Sophia Antipolis Campus (France) with the co-authoring of the main supervisor of this thesis, Prof. Cinzia Colapinto. This work was first submitted in May 2021 for publication in the Journal of Multi-Criteria Decision Analysis. The Journal of Multi-Criteria Decision Analysis is indexed in Scopus and the Emerging Sources Citation Index of the Web of Science (Clarivate Analytics). This paper has undergone a thorough refereeing process, like papers submitted to regular issues. This paper is planned to be published by the end of 2021.
This chapter provides details of how the rigorous systematic literature review was conducted, highlights the gaps allowing to clarify the research problems in the proposed study. The review of the literature comprises two key areas: multicriteria decision making (MCDM) methods and healthcare supply chain management (HSCM). It begins with a review of the current status of healthcare supply chain management and an introduction to the systematic review methodology. This is followed by the results section. The discussions of conceptual and research methodological issues are presented. This chapter concludes by summarizing the key findings of the review, highlighting the contributions this study makes to the body of healthcare SCM and MCDM knowledge, also identifying the implications of the findings for academic researchers and practitioners. Thus, a future research agenda can be derived from the research gaps identified.

3.1 Introduction

In the last two decades, Supply Chain Management (SCM) has become pivotal in making business competitive in the market, gaining increasing and continuous attention from academic researchers and practitioners. Today, companies are facing significant challenges in identifying the best opportunity to meet customer expectations and containing costs. A Supply Chain (SC) is a network of organizations and processes used by various enterprises to deliver products and services from raw materials to end customers through material, information, and financial flows. Consequently, SCM can be defined as the design, planning, execution, control, and monitoring of supply chain activities to create net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally. SC is responsible for balancing demand supply along the entire value-adding chain. SCM is one of the key elements of any organization, responsible for matching supply and demand along the entire value-added chain, by integrating production and logistics processes at different levels. It is evident that decision-makers need to cope with different variables and conflicting objectives simultaneously. Consequently, mathematical modeling can come to support the decision-making process. Given the SCM characteristics described above, it is evident why MCDM models can be used in this area. Indeed, Multiple Criteria Decision Making (MCDM) models are important tools in Operation Research and Management Science (OR/MS) with extensive application in a variety of fields, including Supply Chain Management (Colapinto *et al.,* 2019). MCDM is a subfield of OR/MS to evaluate alternatives based on various and/or conflicting criteria by assigning weights to support the decision-making process. MCDM is appropriate for solving real-life problems by using quantitative and qualitative approaches, taking into account multiple conflicting objectives, and making the decision-making process more explicit, rational, and efficient. Since the 1960s, MCDM methods have been developed, proposed, and successfully implemented in many fields. The conceptualization of MDCM is beyond the scope of this work (for more information see Beck and Hofmann, 2012). In recent years, academic researchers have increasingly applied these techniques and approaches in the field of healthcare, with a particular focus on SCM. Although many literature reviews of such methods used to handle SCM issues already exist (e.g., Beck and Hafmann, 2012; Khan *et al.,* 2018), a literature review of MCDM methods with applications in HSCM does not exist to the best of our knowledge. This paper has two main objectives. First, we present a comprehensive review of the most significant literature on HSCM, classifying how and why MCDM models are becoming popular in this area. The intended purpose is to promote knowledge of the MCDM models that have been applied by researchers to the management of HSCM, highlighting which are the most common approaches adopted in searching for an optimal solution. Second, we use the literature review to identify gaps and thus contribute to the development of the theory and understanding of the latest techniques and applications. The choice of healthcare area as the subfield of application of SC is linked to its exponential growth due to increasing general awareness and globalization, to its potential negative impacts as a result of incorrect management, especially after the spread of the COVID-19 pandemic. In

2021, we aim to collect, analyze, and interpret data by using an inquiry model based on an appropriate analysis settled into two types of methods (qualitative and quantitative). The number of publications using MCDM and incorporating SC in the healthcare sector has mainly increased since 2006. The paper is organized as the following. In Section 2, we briefly introduce various HSCM and MCDM approaches and popular techniques used. In Section 3, we discuss the methodology we adopted to search, analyze, classify, and categorize the literature. In section 4, we present the results of this literature review. In section 5, we summarize our findings and identify future research directions. Section 6 concludes as usual.

3.2 Literature Review

In this section, a theoretical background is presented. We first introduce the topic of supply chain management in healthcare, followed by a general overview of MCDM methods in HSCM.

3.2.1 Healthcare Supply Chain Management

In general, Supply Chain (SC) refers to all the resources needed by an organization to provide goods or services to the end customers. Healthcare Supply Chain (HSC) has often been valued differently from conventional SC due to its high level of complexity, high-value goods, and because it involves human life (Aldrighetti *et al.,* 2019). Healthcare Supply Chain Management (HSCM) refers to the procurement and distribution of products and services as they move from the warehouse to the patient/customer. Healthcare is a hybrid sector that encompasses both products and services such as pharmaceutical, medical, equipment, waste management, information technology, et cetera. The management of the HSC is a very fragmented and complicated process, as it requires the management of special supplies and resources, and the provision of goods and services to healthcare practitioners and patients. There are various ways to define HSC. Dixit *et al.* (2019), define it as a special type of supply chain where medicines are produced, transported, and consumed. HSC takes place with the drug manufacturer's suppliers and ends with the patient (i.e., the customer) to meet demand through a defined distribution channel. Due to their properties and patient needs, various researchers have suggested different and specific models of SC for different health products such as drugs, vaccines, and other medical equipment (Dixit *et al.,* 2019). From the literature review, we can observe that academic researchers provide different terminologies for naming the supply chains exercised in the healthcare sector. In Dixit *et al.* (2019), a categorization is reported: healthcare SC (Kwon *et al.,* 2016; Azadeh *et al.,* 2016; Wijewardana and Rupasinghe, 2016; Ghorani, 2015; Kumar and Kumar, 2014; Guimarães and Carvalho, 2013; Al-Karaghouli *et al.,* 2013; Mathew *et al.,* 2013; Miah *et al.,* 2013; Kritchanchai, 2012; Mustaffa and Potter, 2009; Zheng *et al.,* 2006), pharmaceutical SC (Sabegh *et al.,* 2017; Papert *et al.,* 2016; Parmata *et al.,* 2016; Singh *et al.,* 2016; Papalexi *et al.,* 2016; Narayana *et al.,* 2014; Rossetti *et al.,* 2011; Wyld, 2008; Shah, 2004), hospital SC (Supeekit *et al.,* 2016; Chen *et al.,* 2013; Rachmania and Basri, 2013; Rego and de Sousa, 2009; Toba *et al.,* 2008), drug SC (Mensah *et al.,* 2015; Pinna *et al.,* 2015; Patel *et al.,* 2009), vaccine SC (Lee and Haidari, 2017; Sarley *et al.,* 2017; Kartoglu and Milstien, 2014), lean SC management in healthcare (Hatibu, 2015; Adebanjo *et al.,* 2016), and agile SC management in healthcare (Mehralian *et al.,* 2015).

3.2.2 Multiple Criteria Decision Making in Healthcare Supply Chain Management

Multiple Criteria Decision Making (MCDM) is a powerful tool that combines alternatives between numerous contradictory qualitative and/or quantitative criteria, resulting in a solution that requires consensus. Since the 1960s, many MCDM techniques and approaches have been successfully developed and implemented in many areas of application, requiring knowledge gathered from many fields, including behavioral decision theory, information technology (IT), economics, and mathematics. MCDM methods use multi-objective mathematical programming, multi-attribute utility theory, outranking or non-classical approaches to support decision model construction, respectively through the well-known MCDM approaches: Goal Programming (GP) or Data Envelopment Analysis (DEA), Analytic Hierarchy Process (AHP) or Analytic Network Process (ANP), PROMETHEE, and Fuzzy Sets Theory. However, a detailed analysis of the theoretical foundations of MCDM is beyond the scope of this article. For further information about MCDM see Khan *et al.* (2018). AHP and ANP have been evaluated as the most frequently used methods in healthcare due to the flexibility and ability to capture both subjective and objective characteristics of decisions-making, successfully supporting the managerial judgment and knowledge of healthcare practitioners. Over the past few decades, the healthcare sector has grown more and more rapidly due to the increased degree of general awareness and globalization. As a consequence, the number of MCDM applications has been developing to support HSCM decisions. We cannot ignore the effects and consequences brought by the coronavirus pandemic in 2020. In the last two years, Coronavirus disease (COVID-19) has been representing an extraordinary event that has been having a decisive impact on countries all over the world, businesses, and supply chains. The COVID-19 pandemic poses significant challenges in managing supply chains, including Healthcare Supply Chains: hospitals are often on the verge of collapse, supply chains are often disrupted in the production and distribution of products, and critical services, and federal and state agencies struggle to take preventive and palliative measures to counter the health, economic and social consequences. Of course, MCDM approaches appear to be appropriate in response to HSC management as they use quantitative and qualitative information, taking into account multiple conflicting objectives and performing a decision-making process as more explicit, rational, and efficient, by helping to determine performance metrics, driving preferences and exchanging criteria consistently and transparently. HSCM is an MCDM problem because, in the whole SC cycle, we have to examine various criteria. To manage the whole SC, we also necessitate identifying the relationship of each criterion that impacts the performance of the SC. This shows that decision-making is crucial in managing the SC cycle. Consequently, HSCM can be evaluated as an MCDM problem. Decisions are made based on conflicting criteria of maximizing profit and customer responsiveness while minimizing risk. MCDM in healthcare provides a comprehensive overview of multi-criteria optimization models and methods that can be used in the management of the related SC. Furthermore, with the involvement of internal and external stakeholders at the strategic, tactical, and operational levels (Ivanov *et al.,* 2019), the decision-making process provides alternatives that are usually of a conflictual nature. This situation increases the complexity of the decision-making process. Several academics have demonstrated the importance of applying MCDM methods and techniques in HSCM. A huge amount of literature review articles is focused on the applications and methodologies of MCDM in SC (e.g., Khan *et al.,* 2018; Govindan *et al.,* 2015; Razei, 2015). However, a systematic literature review in supply perspective of MCDM methods in the healthcare sector is not yet available, especially with the focus on DM levels. As a matter of fact, it is unclear which method is used for what function and at what level of DM. Furthermore, the categorization of MCDM methods and their application at different levels of SC decisions (strategic, tactical, and operational) are rather limited and are not evidently shown in the literature. For more information, see Adunlin *et al.* (2015). Here is a review of the literature that suggests increased awareness of MCDM methods and techniques as a robust and rigorous approach to support decision making in healthcare, especially due to the impact and complexity of healthcare decisions.

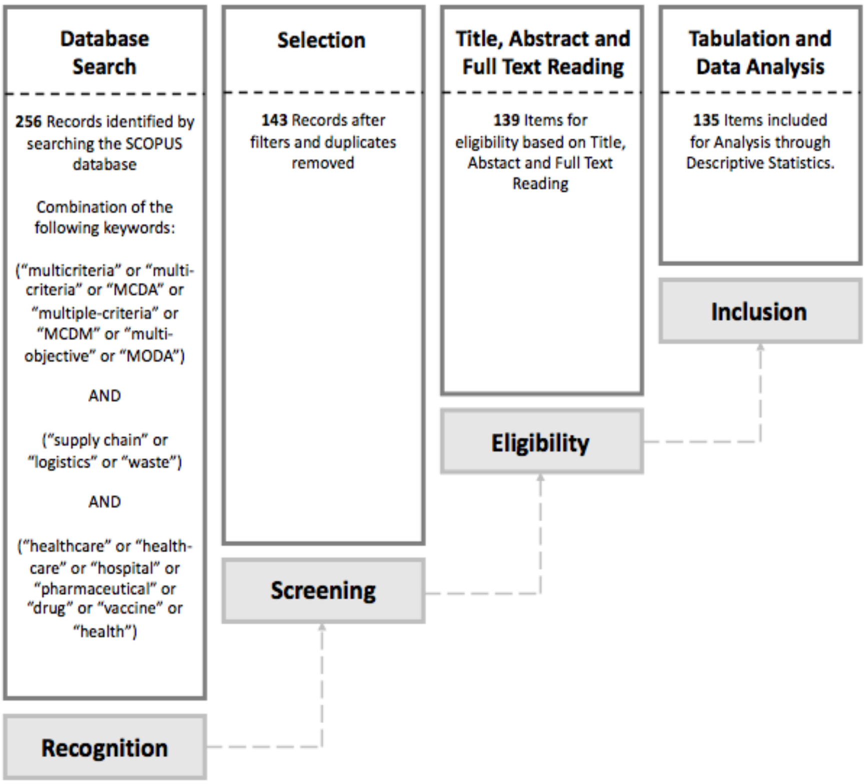
3.3 Methodology

In order to systematically perform our literature review and use content analysis in the process, we adopt a four-step methodology based on the practical guidelines provided by Frazão *et al.* (2018). The process model consists of the steps shown in Figure 3.1

3.3.1 General search data

Step 1 - Recognition This study presents a review of the literature based on the bibliographic database SCOPUS, which was searched on March 4, 2021. No language, publication date, or publication status restrictions were imposed to reach as many articles as possible. The main objective is to investigate how and for what purpose the researchers and practitioners (or government) use MCDM for the decision-making processes in Healthcare Supply Chain. The data for the literature review was obtained by keyword search using the search terms in combination with “multicriteria” or “multi-criteria” or “MCDA” or “multiple-criteria” or “MCDM” or “multi-objective” or “MODA”; and “supply chain” or “logistics” or “waste”; and “healthcare” or “health-care” or “hospital” or “pharmaceutical” or “drug” or “vaccine” or “health”. In the SCOPUS repository, the searches were given for “title, abstract and keywords”, the added filters are presented in Figure 3.1 The study was conducted in four phases (see Figure 3.1) obeying some inclusion and exclusion criteria, as shown in Table 3.1 The search was performed independently in a standardized non-blind manner by two reviewers and agreements among the reviewers were solved by consensus. We have developed a data extraction sheet. The searched items were not split between two authors for data extraction. Already, the disagreements were resolved by the discussion between two review authors.

Figure 3.1: Sequential steps for the collection and analysis of the data



Source: Frazão *et al.,* 2018:3

Step 2 – Screening For the first selection of studies, filters were applied and duplicate documents removed.

Step 3 – Eligibility After any duplicate documents were removed, article titles, abstracts, and full texts were read. This second step consisted of two phases: in the first one, article titles and abstracts were read. If they obeyed the prerequisite for inclusion criteria for title and abstract, the full text would be downloaded. For the second phase, inclusion criteria and exclusion criteria were determined as requirements to proceed with the reading of the pre-selected and downloaded document (see Table 3.1).

Table 3.1: Criteria used for inclusion and exclusion of the studies in the review

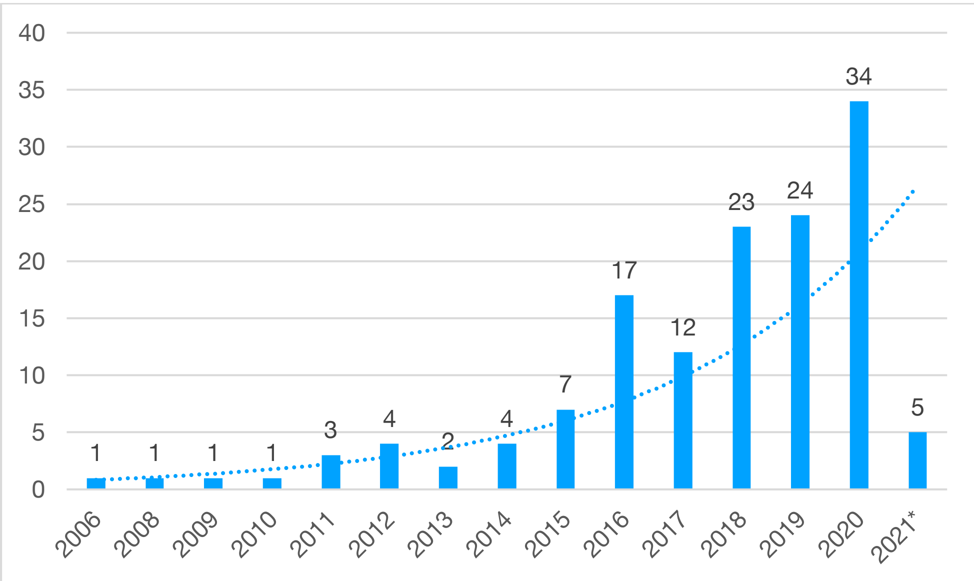
Inclusion criteria	
Inclusion criteria for title and abstract	**Inclusion criteria for full text**
Is a HSC intervention aided by the MCDM?	The MCDM method is applied to solve case studies in the healthcare SC.
Exclusion criteria	
Exclusion criteria for title and abstract	**Exclusion criteria for full text**
Does not present abstract; Does not present the full text available; Be a review article; Does not be an MCDA application and/nor Does; Not be MCDM application in the health sector.	Be an MCDM application, however: Does not make clear the structuring of the problem; Does not make clear the criteria and their origin; Presents a purely mathematical model.

Step 4 – Inclusion The obtained dataset consists of the articles that obeyed the inclusion pre-requisites (see Appendix).

3.4 Results

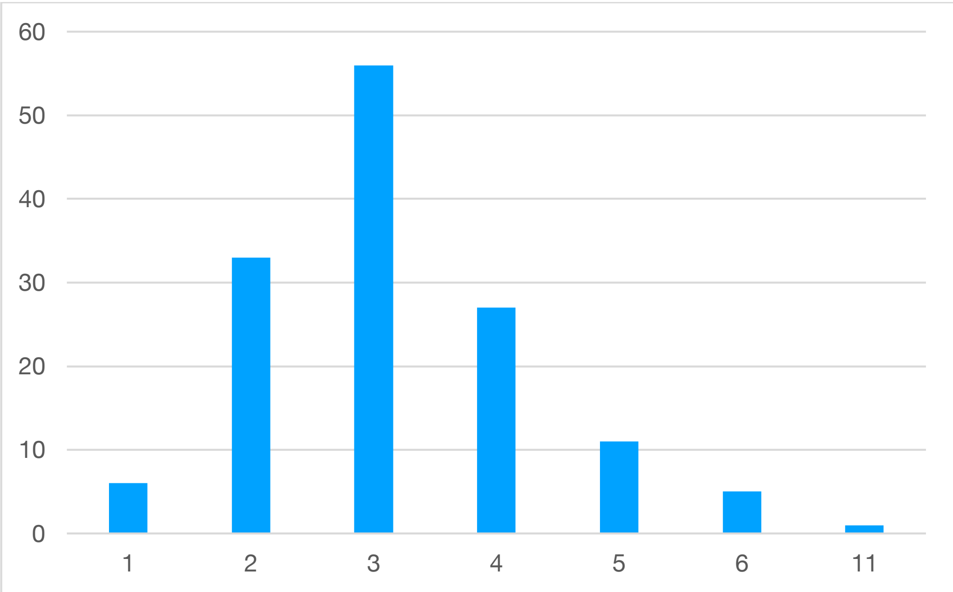
Methodologically, literature reviews can be comprehended as content analysis, combining quantitative and qualitative aspects to assess descriptive and content criteria. After preliminary screening and eliminating duplicates and qualitative and/or unrelated documents, 139 papers hit the scope of this review up to March 2021. Figure 3.2 shows how interest in the topic has grown over the past few years and decades.

Figure 3.2: Number of publications by year (2006–2021)*



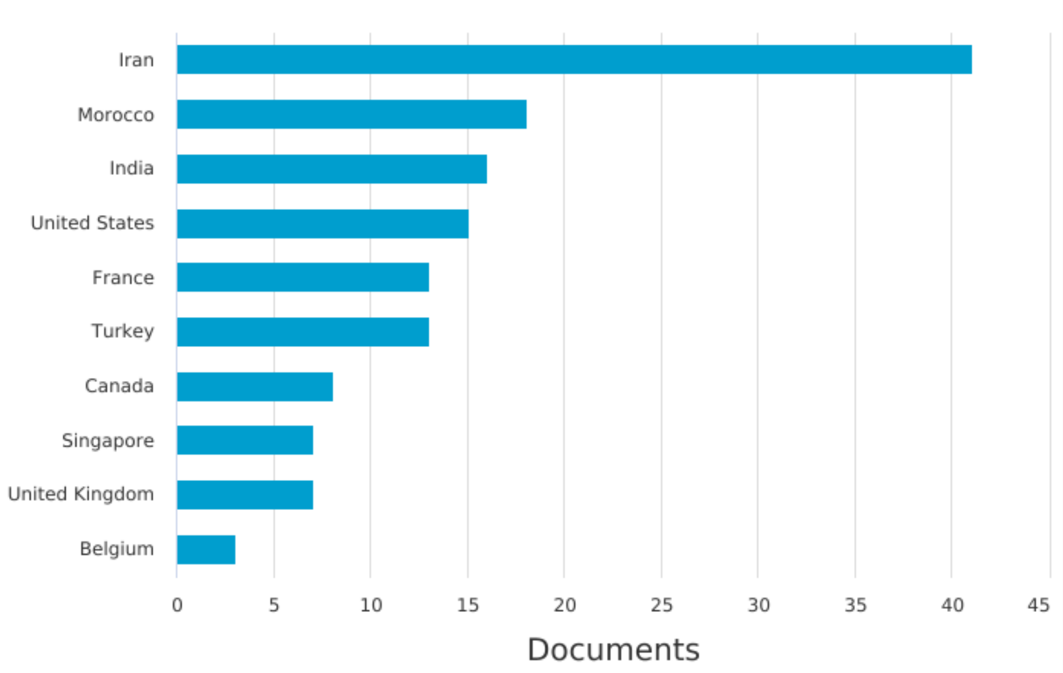
We can observe that the 2010s saw an upsurge in the publications. In terms of outputs, our research identified 139 articles, namely 105 journal articles (5 in press, 74%), 2 book chapters (1%), 32 conference papers (22%), and 4 literature reviews (3%). Most of the papers were co-authored by at least 3 researchers (40.3%; average 3.19; min=1; max=11) (see Figure 3.3).

Figure 3.3: Number of papers by co-authoring



Based on the geographical origin of the papers, it can be inferred that scientific contributions from Asian countries are pivotal in the area of HSCM. From a country point of view, it is apparent that most contributions are from Iran (41), followed by Morocco (18), India (16), United States (15), France (13), and Turkey (13). As a result Iran can be seen as the hub for the research concerning healthcare SC and MCDM (see Figure 3.4).

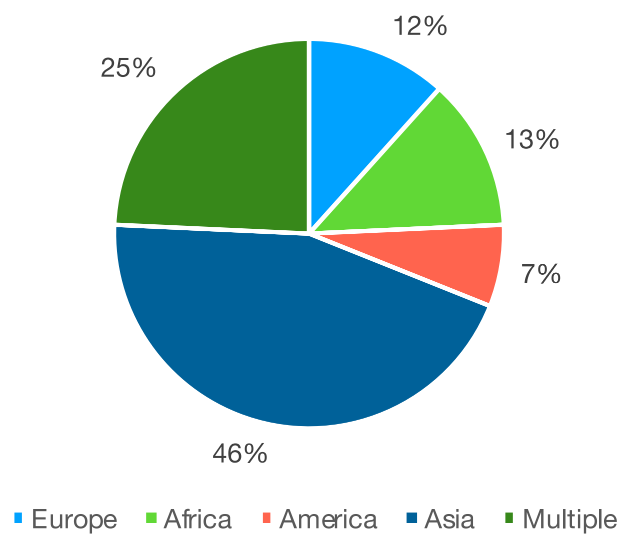
Figure 3.4: Number of documents by country (or territory)



Source: Scopus, 2021

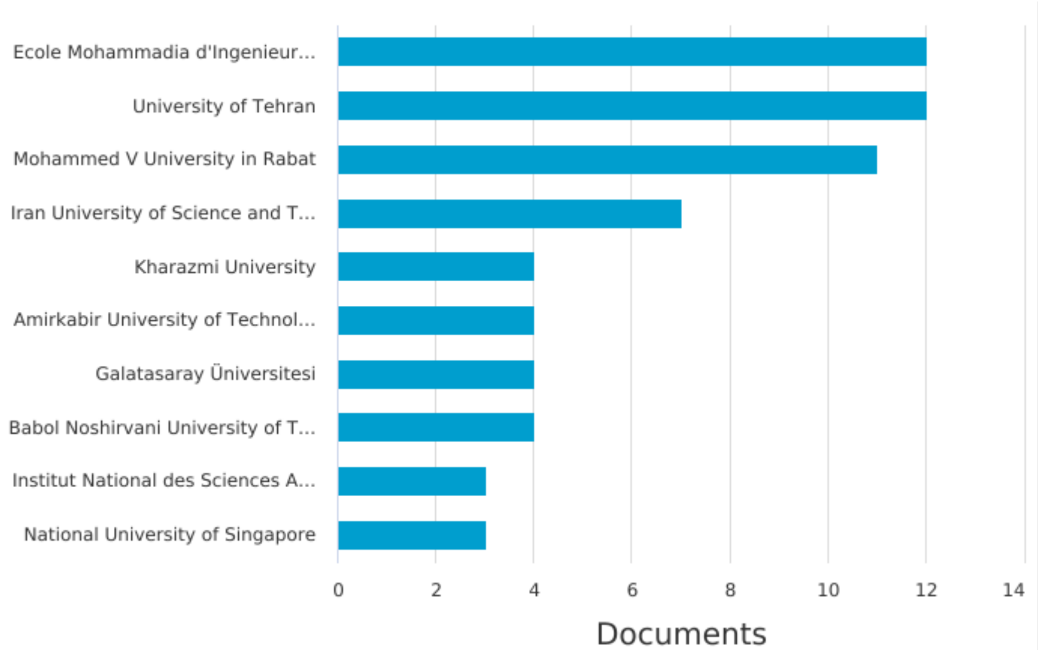
This is confirmed even if we look at the contributions by region (or continent): Asia dominates the stream of research (46%), followed by inter-continental collaborations (25%), whilst the research is still marginal in the remaining areas (Africa (13%), Europe (12%), and America (7%)).

Figure 3.5: Number of publications by region (or continent)



To confirm again the central role played by Asia, we can refer to the leading role of Asian universities as hosting institutions (Figure 3.6): 7 out of the top 10 university are Asian, namely University of Tehran (Iran), Iran University of Science and Technology (Iran), Kharazmi University (Iran), Amirkabir University of Technology (Iran), Galatasaray Üniversitesi (Turkey), Babol Noshirvani University of Technology (Iran), and National University of Singapore (Singapore). We can also consider the top authors in HSCM, namely A. Berrado (12, Morocco), L. Benabbou (10, Morocco), M. Dursun (4, Turkey), Hosseini-Motlagh (4, Iran), Paydar (4, Iran) and Tavakkoli-Moghaddam (4, Iran). One more time it is evident the top position of Asian scholars.

Figure 3.6: Number of documents by affiliations



Source: Scopus, 2021

Indeed, since 2015, we can observe an upsurge in the investment on this subject (Figure 3.6), and that the leading funding sponsor institution is the Iran National Science Foundation (3 investments), followed by the Baqiyatallah University of Medicine (Iran, Asia), Galatasaray Üniversitesi (Turkey), King Saud University (Saudi Arabia), Kumoh National Institute of Technology (South Korea), National Natural Science Foundation of China (China), Universitas Indonesia (Indonesia), and University of Tehran (Iran). Our list proves that half of funds are coming from Asian countries. Table 3.2 lists the journals that published most papers. The publications have appeared in top journals with an average IF of 4.14 and an average 5-Years

Impact Factor (IF5) of 4.22. IF5 is computed as a ratio over a 5-year window; more accurately, the numerator refers to the number of citations in the current year to all items published in a journal in the previous 5 years. As reported by Vanclay (2012), the IF5 provides to catch the impact of a journal in specific fields, that on average, might take longer than others to attract the majority of their citations (Colapinto *et al.,* 2019). Looking at the titles, we can observe that the topic is analyzed from a technical point of view not only considering the models' perspective. We can also state that the distribution of the titles is really fragmented. In fact, the maximum number of articles per journal is 4 (International Journal of Logistics System and Management), followed by Annals of Operations Research, Computer and Industrial Engineering, Expert Systems with Applications, and Journal of Cleaner Production with 3 published articles. There is no dominant journal covering these topics, as the leading journal accounts for 3% of all published articles.

Table 3.2: Top 5 journals based on number of publications

Journal	**Number of papers**	**IF**	**IF5**
International Journal of Logistics Systems and Management	4	1,304	1,295
Annals of Operations Research	3	2,583	2,574
Computers and Industrial Engineering	3	4,135	4,296
Expert Systems with Applications	3	5,452	5,448
Journal of Cleaner Production	3	7,246	7,491
		20,720	**21,1036**

In the broad area of the healthcare supply chain, SCOPUS identified the following as the main subject areas (or application domains) in which papers were published:

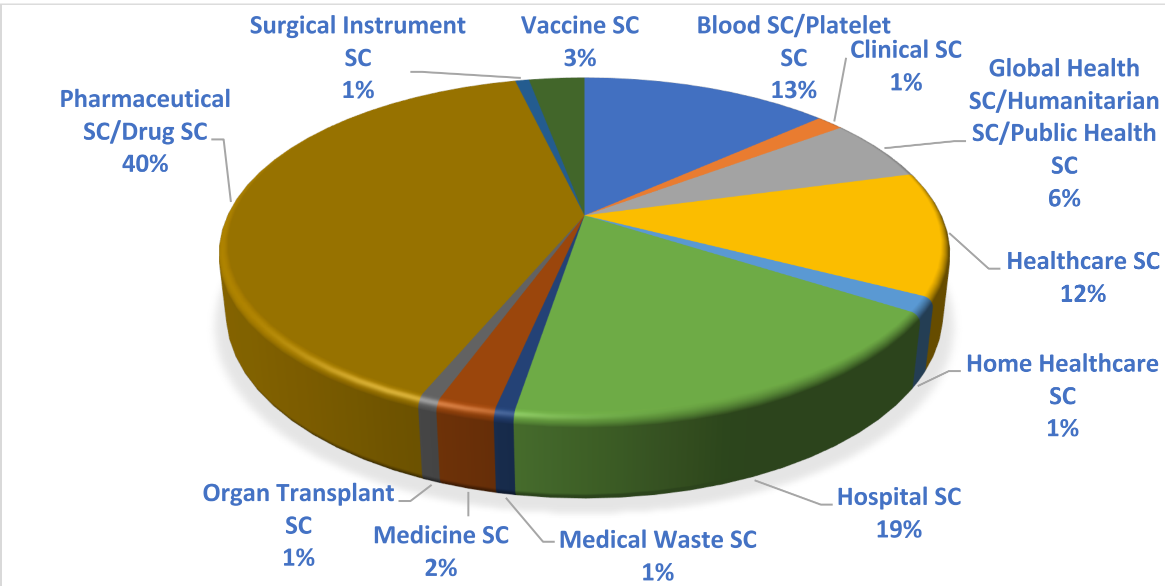
- Engineering: 54 papers (20.1%)
- Computer Science: 50 papers (18.2%)
- Business, Management, and Accountant: 47 papers (17.1%)
- Decision Sciences: 38 papers (13.8%)
- Mathematics: 19 papers (7.1%)
- Social Sciences: 13 papers (4.8%)
- Environmental Science: 10 papers (3,7%)
- Medicine: 9 papers (3%)

- Energy: 6 papers (2.2%)
- Chemical Engineering: 5 papers (1.5%)
- Others: 24 papers (8.6%)

3.4.1 Applications in the Healthcare Supply Chain Management

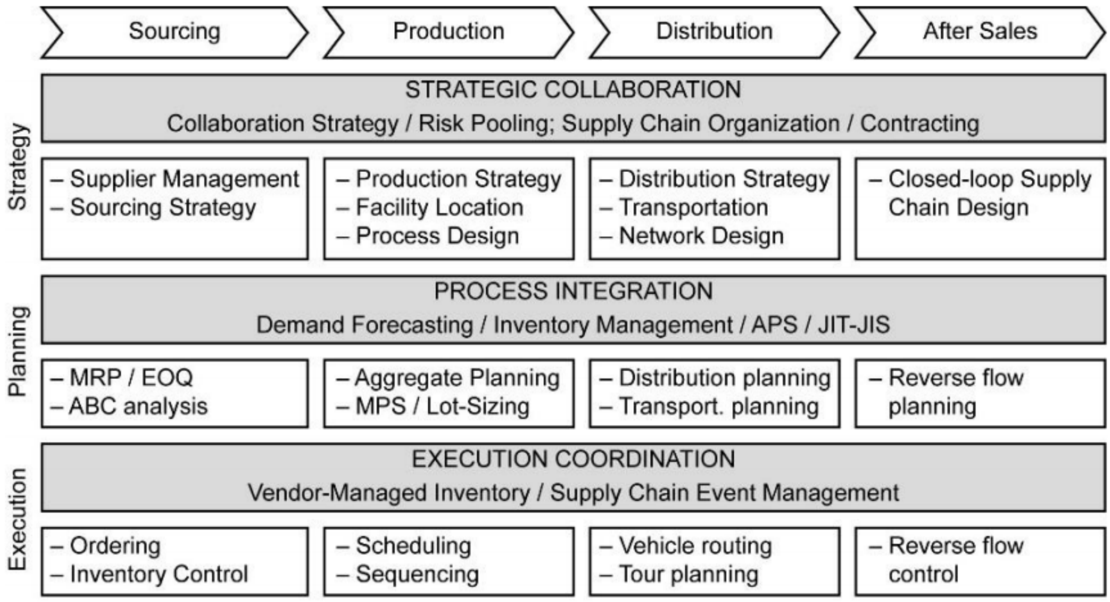
MCDM approaches are suitable for the study of different decision problems. Since the healthcare supply chain is a special and unusual type of SC, the nature of the factors influencing decisions, for example, raw material shortage, short product life, high-quality products and services, patient life care, risk prevention/mitigation, and seasonal demand are just some of the decision-making elements compliant with the MCDM modeling framework. Based on these observations, this section examines the updated applications of MCDM methodologies applied in the decision-making process in healthcare. Following Dixit *et al.* (2019), we can identify where MCDM models are more frequently applied (Figure 3.7): Pharmaceutical/Drug SC (40%) is the dominating area, followed by Hospital SC (19%), and Blood/Platelet SC (13%).

Figure 3.7: Number of papers by supply chain application areas



We decided to apply the decision matrix presented by Ivanov *et al.* (2019) to better illustrate the different approaches used to cope with specific challenges. Decision makers cope with multi-faceted responsibilities ranging from strategic to tactical and operative levels (Ivanov, 2010): strategic issues include, for example, plant location, decisions on the structure of service networks, and design of the SC, whilst tactical ones include decisions about production, transportation, and inventory planning. Operative issues relate to the execution thus they deal with production scheduling and control, vehicle routing, and equipment maintenance policies as examples (see Figure 3.8).

Figure 3.8: Decision matrix in supply chain and operations management



Source: Ivanov *et al.,* 2019:11

In our sample, most papers focus on strategic issues (69,6%), whilst the attention paid to tactical (19,3%), and operational issues (11,1%) is marginal. Following the decision matrix in supply chain and operations management proposed by Ivanov *et al.* (2019), we can divide searched items along the different SC activities: Sourcing, Production, Distribution, After Sales, and Other (mainly dealing with Performance measurement (e.g., Chorfi *et al.,* 2015; Khaoula and Abouabdellah, 2017) and Risk Management (e.g., El Mokrini *et al.,* 2016; Elamrani *et al.,* 2016; Kharisma and Ardi, 2020; Mokrini and Aouam, 2020; Sudarmin and Ardi, 2020). Looking at this SC classification, it is evident that Distribution (49 items) is the main application area followed by Sourcing (36 items), Production (18 items), Production/Distribution (1 items), and After sales (7 items). In the relevant category labeled "Other" (24 entries), researchers address issues related to supply chain performance management (e.g., Sahu and Kohli, 2019; Sahu and Sahu, 2019), Risk Management (e.g., Enyinda, 2018), Information Technology (e.g., Bouayad *et al.,* 2018), Resilience (e.g., Ganguly and Kumar, 2019) (see Table 3.3). Özkan *et al.* (2017)

focus on risk classification, prioritization, and minimization strategies related to demand planning, transport conditions, and storage in the pharmaceutical sector. It is interesting to see which are the main challenges identified by the researchers including in our matrix different application areas, decision-making level and SC activities. Most of the time, Distribution is the core of the analysis, except for Hospital SC and Pharmaceutical SC where it is possible to notice a homogeneous distribution of the published papers. Focusing on MCDM approaches, we observe the most used approach is Multi objective/Goal Programming (52 items), followed by Multi attribute utility theory (26 items), and Fuzzy logic theory (21 items). Focusing on the SC type, we can notice that Multi objective/Goal Programming approaches are widely used in Pharmaceutical SC (15 items), followed by Blood/Platelet SC (13 items), and Hospital SC (8 items). Multi attribute utility theory approaches are frequently applied to solve DM problems in Pharmaceutical SC (13 items), followed by Hospital SC (7 items), and Generic Healthcare SC (5 items). Furthermore, Fuzzy logic theory approaches are popular in supporting PSC decisions (12 items).

Table 3.3: Categorization by SC application areas and DM levels

	DM level			
	Strategic	**Tactical**	**Operation**	**Total**
Blood SC/Platelet SC	**15**	**3**		**18**
Sourcing	1	1		2
Production	1	2		3
Distribution	13			13
Clinical SC	**1**	**1**		**2**
Production	1	1		2
Global Health SC/Humanitarian SC/Public Health SC	**5**	**1**	**2**	**8**
Sourcing	1			1
Production		1		1
Distribution	4		2	6
Healthcare SC	**10**	**4**	**2**	**16**
Sourcing	3			3
Production		1	1	2
Distribution	5	2		7
After Sales	2	1		3
Other			1	1

Home Healthcare SC	**1**		**1**	**2**
Distribution			1	1
After Sales	1			1
Hospital SC	**14**	**6**	**5**	**25**
Sourcing	7	6		13
Production	1		2	3
Distribution	4			4
Other	2		3	5
Medical Waste SC	**1**			**1**
After Sales	1			1
Medicine SC	**2**	**1**		**3**
Production		1		1
Distribution	1			1
Other	1			1
Organ Transplant SC	**1**			**1**
Production	1			1
Pharmaceutical SC/Drug SC	**42**	**9**	**3**	**54**
Sourcing	13	2	1	16
Production	2	2	1	5
Production/Distribution		1		1
Distribution	12	1	1	14
After Sales	2			2
Other	13	3		16
Surgical Instrument SC			**1**	**1**
Distribution			1	1
Vaccine SC	**2**	**1**	**1**	**4**
Sourcing	1			1
Distribution		1	1	2
Other	1			1
TOTAL	**94**	**26**	**15**	**135**

Table 3.4: Categorization by MCDM approaches and DM levels

	DM level			
	Strategic	**Tactical**	**Operation**	**Total**
Blood SC/Platelet SC	**15**	**3**		**18**
Fuzzy Logic Theory	2			2
Multi/Hybrid MCDM Methods	1			1
Multi-Objective/GP (Goal Programming)	10	3		13
Other Methods	2			2
Clinical SC	**1**	**1**		**2**
Multi-Objective/GP (Goal Programming)	1			1
Other Methods		1		1
Global Health SC/Humanitarian SC/Public Health SC	**5**	**1**	**2**	**8**
MCDA	1			1
Multi Attribute Utility Theory		1		1
Multi-Objective/GP (Goal Programming)	3		2	5
Other Methods	1			1
Healthcare SC	**10**	**4**	**2**	**16**
Fuzzy Logic Theory	1		1	2
Multi Attribute Utility Theory	3	2		5
Multi/Hybrid MCDM Methods	1			1
Multiobjective/GP (Goal Programming)	5	2	1	8
Home Healthcare SC	1		1	2
Multiobjective/GP (Goal Programming)	1		1	2
Hospital SC	**14**	**6**	**5**	**25**
Fuzzy Logic Theory	4	1		5
MCDA	1		1	2
Multi Attribute Utility Theory	4	1	2	7
Multi/Hybrid MCDM Methods	1			1
Multi-Objective/GP (Goal Programming)	4	2	2	8
Other Methods		1		1
Outranking Relations		1		1
Medical Waste SC	**1**			**1**
Multi-Objective/GP (Goal Programming)	1			1
Medicine SC	2	1		3
Multi/Hybrid MCDM Methods	1			1
Multi-Objective Fuzzy Programming		1		1

Multi-Objective/GP (Goal Programming)	1			1
Organ Transplant SC	1			1
Multi-Objective/GP (Goal Programming)	1			1
Pharmaceutical SC/Drug SC	**42**	**9**	**3**	**54**
Fuzzy Logic Theory	12			12
MCDA		1		1
MCDM	2	1		3
Multi Attribute Utility Theory	12	1		13
Multi/Hybrid MCDM Methods	1		2	3
Multi-Objective/GP (Goal Programming)	10	4	1	15
Other Methods	1	2		3
Outranking Relations	3			3
Preference Disaggregation	1			1
Surgical Instrument SC			**1**	**1**
Multi-Objective Fuzzy Programming			1	1
Vaccine SC	**2**	**1**	**1**	**4**
MCDA	1			1
Multi-Objective/GP (Goal Programming)	1			1
Other Methods		1		1
Outranking Relations			1	1
TOTAL	**94**	**26**	**15**	**135**

From the above analysis, we decide to focus on Pharmaceutical SC. Even if we reduce our analysis to a subsample, strategic issues are still predominant, and they are equally associated with sourcing, distribution, and other activities. The latter category includes papers dealing with reducing risk assessment and management as well as performance measurement. Moving to consider the used methods, we see the relevance of fuzzy logic theory especially Fuzzy AHP models. Fuzzy sets theory is often incorporated with MCDM methods such as AHP, TOPSIS, and VIKOR, allowing to include uncertainty and subjectivity, and providing a more realistic decision-making framework (El Mokrini *et al.,* 2016). Pharmaceutical companies compete in a context characterized by multiple uncertainties and heterogenous data information, thus fuzzy logic can integrate it in the decision-making process. On the same line when we consider the Multi attribute utility theory models, AHP methods are still the most used: it appears that as the AHP approach is designed to help decision makers incorporate qualitative (intangible) and quantitative (tangible) aspects of complex problems, it is really suitable to decompose the structure of a HCSC problem. Finally, it is worthy to mention the use of Multi-objective/Goal Programming methods as well.

3.5 Discussion and Future Research Directions

As shown above, decision-making in the supply chain is influenced by various and often conflicting criteria/objectives. MCDM methods can support the creation of a clearer framework for solving SCM problems, particularly in the healthcare sector where the level of complexity is very high as it involves human life. Furthermore, in recent decades, the exponential increase in globalization and digitization has meant that the availability of data is constantly increasing, so the application of MCDM methods in dealing with SCM problems becomes inevitable, but also requires an adequate transformation. In particular we have observed that Pharmaceutical companies are more and more seeking the decision support model with computing techniques, which can improve their future performance and SC management. This has been reflected in the increasing number of publications in the last five years, partly supported by the development and diffusion of software. Our paper provides an overall presentation of the contributions and use of MCDM techniques in the supply chain, focusing on the methods used and their real-world applications in the healthcare area. As a result, we can summarize the main advantages that the MCDM paradigm provides in healthcare decision-making as follows: 1) the possibility of better structuring complex decision-making problems through the application of MCDM approaches; 2) the introduction of both quantitative and qualitative (human factor) criteria in evaluating DM process; 3) the introduction of sophisticated and/or hybrid MCDM methods in supporting decision makers in understanding peculiarities of healthcare SC real-world problems; 4) in conclusion, MCDM methods appear to have a promising future in the field of HSCM because they offer an efficient and realistic methodological framework for decision-making problems. As we are aware of some limitations of this study, we conclude highlighting some eventual future research directions:

The review can present a more in-depth analysis of all papers taking into consideration all the specific criteria considered by the DM in evaluating HSC.

Given the current unstable situation where digitalization has supported SC management during the COVID-19 crisis, further analysis on the inclusion and the relative contribution of Industry 4.0 and Digitalization (see Bouayad *et al.,* 2018) as tools to support better decisions in HSCM should be considered and discussed.

Appendix

Authors	Year	Source title
Abbassi A., Kharraja S., El Hilali Alaoui A., Boukachour J., Paras D.	2020	International Journal of Production Research
Abdel-Basset M., Mohamed R., Smarandache F., Elhoseny M.	2021	Computers, Materials and Continua
Adewara K.A.	2016	Spatial Information Research
Aghazadeh S.M., Mohammadi M., Naderi B.	2018	International Journal of Logistics Systems and Management
Ahlaqqach M., Benhra J., Mouatassim S., Lamrani S.	2020	Supply Chain Forum
Ahlaqqach M., Benhra J., Mouatassim S., Lamrani S.	2020	Communications in Computer and Information Science
Akcan S., Güldeş M.	2019	Journal of Healthcare Engineering
Al-Qatawneh L., Hafeez K.	2015	International Journal of Intelligent Enterprise
Antioch K.M., Drummond M.F., Niessen L.W., Vondeling H.	2017	Cost Effectiveness and Resource Allocation
Arani M., Chan Y., Liu X., Momenitabar M.	2021	Applied Mathematical Modelling
Arul Valan J., Baburaj E., Parthiban P.	2020	International Journal of Mathematics in Operational Research
Asghari M., Mirzapour Al-e-hashem S.M.J.	2020	Transportation Research Part E: Logistics and Transportation Review
Bahadori M., Hosseini S.M., Teymourzadeh E., Ravangard R., Raadabadi M., Alimohammadzadeh K.	2020	International Journal of Healthcare Management
Bertel S., Fenies P.	2013	Supply Chain Forum
Bornand B., Girardin L., Belfiore F., Robineau J.-L., Bottallo S., Maréchal F.	2020	Frontiers in Energy Research
Borumand A., Beheshtinia M.A.	2018	Kybernetes
Bouayad H., Benabbou L., Berrado A.	2018	ACM International Conference Proceeding Series
Carland C., Goentzel J., Montibeller G.	2018	European Journal of Operational Research
Carnero M.C., Gómez A.	2019	Sustainability (Switzerland)

Chorfi Z., Berrado A., Benabbou L.	2015	2015 10th International Conference on Intelligent Systems: Theories and Applications, SITA 2015
Debellut F., Jaber S., Bouzya Y., Sabbah J., Barham M., Abu-Awwad F., Hjaija D., Ramlawi A., Pecenka C., Clark A., Mvundura M.	2020	PLoS ONE
Delfani F., Samanipour H., Beiki H., Yumashev A.V., Akhmetshin E.M.	2020	International Journal of Systems Science: Operations and Logistics
Dey S., Kumar A., Ray A., Pradhan B.B.	2012	Procedia Engineering
Di Martinelly C., Duenas A., Pham D.	2018	ILS 2018 - Information Systems, Logistics and Supply Chain, Proceedings
Do Rosário Cabrita M., Frade R.	2016	International Journal of Business and Systems Research
Douissa M.R., Jabeur K.	2016	ILS 2016 - 6th International Conference on Information Systems, Logistics and Supply Chain
Dursun M.	2016	MATEC Web of Conferences
Dursun M., Goker N.	2017	Proceedings of International Conference on Computers and Industrial Engineering, CIE
El Mokrini A., Benabbou L., Berrado A.	2018	Supply Chain Forum
El Mokrini A., Dafaoui E., Berrado A., El Mhamedi A.	2016	IFAC-PapersOnLine
El Mokrini A., Kafa N., Dafaoui E., El Mhamedi A., Berrado A.	2016	IFAC-PapersOnLine
Elahi B., Franchetti M.	2015	IIE Annual Conference and Expo 2015
Elamrani A., Benabbou L., Berrado A.	2016	SITA 2016 - 11th International Conference on Intelligent Systems: Theories and Applications
Enyinda C.I.	2018	Operations and Supply Chain Management
Ertay T., Kahveci A., Tabanl R.M.	2011	International Journal of Computer Integrated Manufacturing
Eskandari-Khanghahi M., Tavakkoli-Moghaddam R., Taleizadeh A.A., Amin S.H.	2018	Engineering Applications of Artificial Intelligence
Fathollahi-Fard A.M., Govindan K., Hajiaghaei-Keshteli M., Ahmadi A.	2019	Journal of Cleaner Production

Fazli-Khalaf M., Khalilpourazari S., Mohammadi M.	2019	Annals of Operations Research
Feng Y.-Y., Wu I.-C., Chen T.-L.	2017	Health Care Management Science
Foroozesh N., Tavakkoli-Moghaddam R., Mousavi S.M.	2018	Neural Computing and Applications
Fors H.N., Harraz N.A., Abouali M.G.	2011	41st International Conference on Computers and Industrial Engineering 2011
Ganguly A., Kumar C.	2019	International Journal of the Analytic Hierarchy Process
Ganguly A., Kumar C., Chatterjee D.	2019	Journal of Health Management
Gardas B.B., D. Raut R., Narkhede B.E.	2019	International Journal of Productivity and Performance Management
Ghasemi P., Khalili-Damghani K., Hafezolkotob A., Raissi S.	2019	Applied Mathematics and Computation
Ghatari A.R., Mehralian G., Zarenezhad F., Rasekh H.	2013	Iranian Journal of Pharmaceutical Research
Ghorashi S.B., Hamedi M., Sadeghian R.	2020	Neural Computing and Applications
Gilani Larimi N., Yaghoubi S., Hosseini-Motlagh S.-M.	2019	Socio-Economic Planning Sciences
Goodarzian F., Hosseini-Nasab H., Muñuzuri J., Fakhrzad M.-B.	2020	Applied Soft Computing Journal
Goodarzian F., Taleizadeh A.A., Ghasemi P., Abraham A.	2021	Engineering Applications of Artificial Intelligence
Haghi M., Fatemi Ghomi S.M.T., Jolai F.	2017	Journal of Cleaner Production
Haial A., Berrado A., Benabbou L.	2020	International Journal of Logistics Systems and Management
Haial A., Berrado A., Benabbou L.	2016	Proceedings of the 3rd IEEE International Conference on Logistics Operations Management, GOL 2016
Halim I., Ang P., Adhitya A.	2019	Clean Technologies and Environmental Policy
Hassan T., Baboli A., Guinet A., Leboucher G., Brandon M.T.	2006	IFAC Proceedings Volumes (IFAC-PapersOnline)
Hossain M.K., Thakur V.	2020	Benchmarking
Hsieh C.-L.	2014	Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science)
Hu J., Zhao L.	2012	ICIC Express Letters

Imran M., Habib M.S., Hussain A., Ahmed N., Al-Ahmari A.M.	2020	Mathematics
Imran M., Kang C., Babar Ramzan M.	2018	Journal of Manufacturing Systems
Ivanova I.A., Glukhova T.V.	2020	International Journal of Supply Chain Management
Jabbarzadeh A., Haughton M., Pourmehdi F.	2019	International Journal of Production Economics
Jamshidiantehrani M., Ahmadzadeh A., Rahimisadr M., Abdolmohammadi M.	2020	Systematic Reviews in Pharmacy
Janatyan N., Zandieh M., Alem-Tabriz A., Rabieh M.	2018	International Journal of Supply and Operations Management
Jeong H.Y., Yu D.J., Min B.-C., Lee S.	2020	Transportation Research Part E: Logistics and Transportation Review
Jiang L., Liao H.	2020	Applied Soft Computing Journal
Kaabi H., Jabeur K., Enneifar L.	2015	Electronic Notes in Discrete Mathematics
Kargar S., Paydar M.M., Safaei A.S.	2020	Waste Management
Kargar S., Pourmehdi M., Paydar M.M.	2020	Science of the Total Environment
Karsak E.E., Dursun M.	2015	Computers and Industrial Engineering
Karsak E.E., Dursun M.	2014	Expert Systems with Applications
Kees M.C., Bandoni J.A., Moreno M.S.	2019	Industrial and Engineering Chemistry Research
Khalilpourazari S., Soltanzadeh S., Weber G.-W., Roy S.K.	2020	Annals of Operations Research
Khaoula K., Abouabdellah A.	2017	Proceedings of the International Conference on Industrial Engineering and Operations Management
Kharisma S.A., Ardi R.	2020	IEEE International Conference on Industrial Engineering and Engineering Management
Khlie K., Abouabdellah A.	2016	International Review on Modelling and Simulations
Laghrabli S., Benabbou L., Berrado A.	2016	SITA 2016 - 11th International Conference on Intelligent Systems: Theories and Applications
Laghrabli S., Benabbou L., Berrado A.	2016	Proceedings of the 3rd IEEE International Conference on Logistics Operations Management, GOL 2016
Lemmens S., Decouttere C., Vandaele N., Bernuzzi M.	2016	Chemical Engineering Research and Design

Longaray A., Ensslin L., Ensslin S., Alves G., Dutra A., Munhoz P.	2018	International Transactions in Operational Research
Low Y.S., Halim I., Adhitya A., Chew W., Sharratt P.	2016	Journal of Pharmaceutical Innovation
Mansoori S., Bozorgi-Amiri A., Pishvaee M.S.	2020	Neural Computing and Applications
Mathiyalagan P.	2015	2015 International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials, ICSTM 2015 - Proceedings
Mohammadian-Behbahani Z., Jabbarzadeh A., Pishvaee M.S.	2019	International Journal of Industrial and Systems Engineering
Mokrini A.E., Aouam T.	2020	Health Services Management Research
Moons K., Waeyenbergh G., Pintelon L.	2019	Omega (United Kingdom)
Moons K., Waeyenbergh G., Pintelon L., Timmermans P., De Ridder D.	2019	Operations Research for Health Care
Moons K., Waeyenbergh G., Timmermans P., De Ridder D., Pintelon L.	2020	Springer Proceedings in Mathematics and Statistics
Moradi M., Jolai F.	2018	International Journal of Supply and Operations Management
Moslemi S., Zavvar Sabegh M.H., Mirzazadeh A., Ozturkoglu Y., Maass E.	2017	International Journal of Systems Assurance Engineering and Management
Mouaky M., Berrado A., Benabbou L.	2016	SITA 2016 - 11th International Conference on Intelligent Systems: Theories and Applications
Nag K., Helal M.	2016	IEEE International Conference on Industrial Engineering and Engineering Management
Naghipour M., Bashiri M.	2019	Proceedings of 2019 15th Iran International Industrial Engineering Conference, IIIEC 2019
Nagurney A., Masoumi A.H., Yu M.	2012	Computational Management Science
Nasrollahi M., Razmi J., Ghodsi R.	2018	Promet - Traffic - Traffico
Nasrollahi M., Safaei M., Mahmoodi N.	2021	International Journal of Business Analytics
Nazeri A., Nosratpour M.	2016	International Journal of Pharmacy and Technology

Nematollahi M., Hosseini-Motlagh S.-M., Ignatius J., Goh M., Saghafi Nia M.	2018	Journal of Cleaner Production
Ng C.T., Cheng T.C.E., Tsadikovich D., Levner E., Elalouf A., Hovav S.	2018	Computers and Industrial Engineering
Nikhil E.V.S., Sai Ram V., Charan Yadav V., Kumar K.K., Nagaraju D.	2017	IOP Conference Series: Materials Science and Engineering
Niroomand S., Garg H., Mahmoodirad A.	2020	ISA Transactions
Onar S.C., Kahraman C., Oztaysi B.	2020	Journal of Intelligent and Fuzzy Systems
Osorio A.F., Brailsford S.C., Smith H.K.	2018	European Journal of Operational Research
Özkan B., Kaya I., Başligil H.	2017	Journal of Multiple-Valued Logic and Soft Computing
Pelissari R., Ben-Amor S., de Oliveira M.C.	2019	Lecture Notes in Logistics
Raut R.D.	2014	International Journal of Logistics Systems and Management
Razavi N., Gholizadeh H., Nayeria S., Ashrafi T.A.	2020	Journal of the Operational Research Society
Rodríguez González R., Álvarez Sánchez Y., León González J.L., Álvarez Migueles M., Rodríguez González Y., Santiago León Y.O.	2020	Universidad y Sociedad
Roshan M., Tavakkoli-Moghaddam R., Rahimi Y.	2019	Computers and Chemical Engineering
Rusnac C.M., Baboli A., Moyaux T., Botta-Genoulaz V.	2012	IFAC Proceedings Volumes (IFAC-PapersOnline)
Safaei A.S., Heidarpoor F., Paydar M.M.	2018	Computational and Applied Mathematics
Safaei A.S., Heidarpoor F., Paydar M.M.	2017	Operations Research for Health Care
Sahu K., Kohli S.	2019	International Journal of E-Entrepreneurship and Innovation
Sahu K., Sahu A.K.	2019	International Journal of Social Ecology and Sustainable Development

Samani M.R.G., Hosseini-Motlagh S.-M., Sheshkol M.I., Shetab-Boushehri S.-N.	2019	European Journal of Industrial Engineering
Santos L.F.D.O.M., Osiro L., Lima R.H.P.	2017	Expert Systems with Applications
Sazvar Z., Zokaee M., Tavakkoli-Moghaddam R., Salari S.A.-S., Nayeri S.	2021	Annals of Operations Research
Sbai N., Benabbou L., Berrado A.	2020	Proceedings - 2020 5th International Conference on Logistics Operations Management, GOL 2020
Schätter F., Wiens M., Schultmann F.	2015	Ecosystem Health and Sustainability
Shbool M.A., Rossetti M.D.	2020	Sustainability (Switzerland)
Singh S.K., Goh M.	2019	International Journal of Production Research
Sivakumar P., Ganesh K., Koh S.C.L.	2009	International Journal of Enterprise Network Management
Sudarmin A.C., Ardi R.	2020	IEEE International Conference on Industrial Engineering and Engineering Management
Suifan T., Alazab M., Alhyari S.	2019	International Journal of Advanced Operations Management
Tamir M., Chiheb R., Ouzayd F.	2018	International Journal of Advanced Computer Science and Applications
Topaloglu S., Selim H.	2010	Fuzzy Sets and Systems
Vishwakarma V., Prakash C., Barua M.K.	2016	International Journal of Logistics Systems and Management
Voigt K., Brüggemann R.	2008	Combinatorial Chemistry and High Throughput Screening
Wang X., Kong Q., Papathanasiou M.M., Shah N.	2018	Computer Aided Chemical Engineering
Wissem E., Ahmed F., Mounir B.	2011	2011 4th International Conference on Logistics, LOGISTIQUA'2011
Yaghoubi S., Hosseini-Motlagh S.-M., Cheraghi S., Gilani Larimi N.	2020	Journal of Ambient Intelligence and Humanized Computing
Yazdani M., Torkayesh A.E., Chatterjee P.	2020	Journal of Enterprise Information Management
Zahiri B., Torabi S.A., Mohammadi M., Aghabegloo M.	2018	Computers and Industrial Engineering
Zahiri B., Zhuang J., Mohammadi M.	2017	Transportation Research Part E: Logistics and Transportation Review

Zandi Atashbar N., Baboli A.	2014	CIE 2014 - 44th International Conference on Computers and Industrial Engineering and IMSS 2014 - 9th International Symposium on Intelligent Manufacturing and Service Systems, Joint International Symposium on "The Social Impacts of Developments in Information, Manufacturing and Service Systems" - Proceedings
Zavvar Sabegh M.H., Mohammadi M., Naderi B.	2017	International Journal of Systems Assurance Engineering and Management
Zhao H., Huang E., Dou R., Wu K.	2019	Expert Systems with Applications
Zhao H., Wu K., Huang E.	2018	IISE Transactions
Ziat A., Sefiani N., Reklaoui K., Azzouzi H.	2018	2018 International Colloquium on Logistics and Supply Chain Management, LOGISTIQUA 2018

3.6 References

Abbassi, A., Kharraja, S., El Hilali Alaoui, A., Boukachour, J., and Paras, D. (2020). Multi-objective two-echelon location-distribution of non-medical products. *International Journal of Production Research*. doi: 10.1080/00207543.2020.1777479

Abdel-Basset, M., Mohamed, R., Smarandache, F., and Elhoseny, M. (2021). A new decision-making model based on plithogenic set for supplier selection. *Computers, Materials and Continua*, 66(3), 2751-2769. doi: 10.32604/cmc.2021.013092

Adebanjo, D., Laosirihongthong, T., and Samaranayake, P. (2016). Prioritizing lean supply chain management initiatives in healthcare service operations: A fuzzy AHP approach. *Production Planning & Control*, 27(12), 953-966. doi: 10.1080/09537287.2016.1164909

Adewara, K. A. (2016). Evaluating open-source routing tools in vaccine delivery in Kano State, Northern Nigeria. *Spatial Information Research,* 24(3), 225-234. doi:10.1007/s41324-016-0021-2

Adunlin, G., Diaby, V., Montero, A.J., and Xiao, H. (2015). Multicriteria decision analysis in oncology. *Health Expectations: An International Journal of Public Participation in Health Care and Health Policy*, 18(6):1812-1826. doi: 10.1111/hex.12178.

Aghazadeh, S. M., Mohammadi, M., and Naderi, B. (2018). Robust bi-objective cost-effective, multi-period, location-allocation organ transplant supply chain. *International Journal of Logistics Systems and Management*, 29(1), 17-36. doi:10.1504/IJLSM.2018.088578

Ahlaqqach, M., Benhra, J., Mouatassim, S., and Lamrani, S. (2020). Closed loop location routing supply chain network design in the end-of-life pharmaceutical products. *Supply Chain Forum*, 21(2), 79-92. doi: 10.1080/16258312.2020.1752112

Ahlaqqach, M., Benhra, J., Mouatassim, S., and Lamrani, S. (2020). Multi-objective optimization of heterogeneous vehicles routing in the case of medical waste using genetic algorithms. doi: 10.1007/978-3-030-45183-7_20

Akcan, S. and Güldeş, M. (2019). Integrated multicriteria decision-making methods to solve supplier selection problem: A case study in a hospital. *Journal of Healthcare Engineering*. doi: 10.1155/2019/5614892

Al-Karaghouli, W., Ghoneim, A., Sharif, A., and Dwivedi, Y.K. (2013). The effect of knowledge management in enhancing the procurement process in the UK healthcare supply chain. *Information Systems Management,* 30(1), 35-49. doi: 10.1080/10580530.2013.739888

Aldrighetti, R., Zennaro, I., Battini, D., and Finco, S. (2019). Healthcare supply chain simulation with disruption considerations: A case study from Northern Italy. *Global Journal of Flexible System Management,* 20(1), 81-102. doi: 10.1007/s40171-019-00223-8

Al-Qatawneh, L. and Hafeez, K. (2015). Critical-to-life classification for managing inventory in a healthcare supply chain. *International Journal of Intelligent Enterprise*, 3(1), 54-78. doi: 10.1504/IJIE.2015.073491

Antioch, K. M., Drummond, M. F., Niessen, L. W., and Vondeling, H. (2017). International lessons in new methods for grading and integrating cost effectiveness evidence into clinical practice guidelines. *Cost Effectiveness and Resource Allocation*, 15(1). doi: 10.1186/s12962-017-0063-x

Arani, M., Chan, Y., Liu, X., and Momenitabar, M. (2021). A lateral resupply blood supply chain network design under uncertainties. *Applied Mathematical Modelling*, 93, 165-187. doi: 10.1016/j.apm.2020.12.010

Arul Valan, J., Baburaj, E., and Parthiban, P. (2020). Data analytics for relative ranking of factors to optimise blood bank supply chain. *International Journal of Mathematics in Operational Research*, 16(1), 98-117. doi: 10.1504/IJMOR.2020.104682

Asghari, M. and Mirzapour Al-e-hashem, S.M.J. (2020). A green delivery-pickup problem for home hemodialysis machines; sharing economy in distributing scarce resources. *Transportation Research Part E: Logistics and Transportation Review*, 134. doi: 10.1016/j.tre.2019.11.009

Azadeh, A., Haghighi, S.M., Gaeini, Z., and Shabanpour, N. (2016). Optimization of the healthcare supply chain in context of macro-ergonomics factors by a unique mathematical programming approach. *Applied Ergonomics*, 55, 46-55. doi: 10.1016/j.apergo.2016.01.002

Bahadori, M., Hosseini, S. M., Teymourzadeh, E., Ravangard, R., Raadabadi, M., and Alimohammadzadeh, K. (2020). A supplier selection model for hospitals using a combination of artificial neural network and fuzzy VIKOR. *International Journal of Healthcare Management*, 13(4), 286-294. doi: 10.1080/20479700.2017.1404730

Beck, P. and Hofmann, E. (2012). Multiple criteria decision making in supply chain management: Currently available methods and possibilities for future research. *Die Unternehmung*, 2, 182-217. doi: 10.5771/0042-059X-2012-2-180

Bertel, S. and Fenies, P. (2013). A multiple modeling for a healthcare supply chain: A case study with Clermont-Ferrand public dental hospital. *Supply Chain Forum*, 14(4), 10-20. doi: 10.1080/16258312.2013.11517324

Bornand, B., Girardin, L., Belfiore, F., Robineau, J.-., Bottallo, S., and Maréchal, F. (2020). Investment planning methodology for complex urban energy systems applied to a hospital site. *Frontiers in Energy Research*, 8. doi: 10.3389/fenrg.2020.537973

Borumand, A. and Beheshtinia, M. A. (2018). A developed genetic algorithm for solving the multi-objective supply chain scheduling problem. *Kybernetes*, 47(7), 1401-1419. doi: 10.1108/K-07-2017-0275

Bouayad, H., Benabbou, L., and Berrado, A. (2018). An analytic hierarchy process-based approach for information technology governance framework selection. Paper presented at the *ACM International Conference Proceeding Series.* doi: 10.1145/3289402.3289515

Carland, C., Goentzel, J., and Montibeller, G. (2018). Modeling the values of private sector agents in multi-echelon humanitarian supply chains. *European Journal of Operational Research*, 269(2), 532-543. doi: 10.1016/j.ejor.2018.02.010

Carnero, M. C. and Gómez, A. (2019). Optimization of decision making in the supply of medicinal gases used in health care. *Sustainability* (Switzerland), 11(10). doi: 10.3390/su11102952

Chen, D.Q., Preston, D.S., and Xia, W. (2013). Enhancing hospital supply chain performance: a relational view and empirical test. *Journal of Operations Management*, 31(6), 391-408. doi: 10.1016/j.jom.2013.07.012

Chorfi, Z., Berrado, A., and Benabbou, L. (2015). Selection of key performance indicators for supply chain monitoring using MCDA. Paper presented at the 2015 10th *International Conference on Intelligent Systems: Theories and Applications,* SITA 2015. doi: 10.1109/SITA.2015.7358395

Colapinto, C., Jayaraman, R., Ben Abdelaziz, F., and La Torre, D. (2019). Environmental sustainability and multifaceted development: Multi-criteria decision models with applications. *Annals of Operations Research*, 293(2), 405-432. doi: 10.1007/s10479-019-03403-y

Debellut, F., Jaber, S., Bouzya, Y., Sabbah, J., Barham, M., Abu-Awwad, F., and Mvundura, M. (2020). Introduction of rotavirus vaccination in Palestine: An evaluation of the costs, impact, and cost-effectiveness of ROTARIX and ROTAVAC. *PLoS ONE*, 15(2). doi: 10.1371/journal.pone.0228506

Delfani, F., Samanipour, H., Beiki, H., Yumashev, A. V., and Akhmetshin, E.M. (2020). A robust fuzzy optimization for a multi-objective pharmaceutical supply chain network design problem considering reliability and delivery time. *International Journal of Systems Science: Operations and Logistics*. doi: 10.1080/23302674.2020.1862936

Dey, S., Kumar, A., Ray, A., and Pradhan, B. B. (2012). Supplier selection: Integrated theory using DEMATEL and quality function deployment methodology. Paper presented at *Procedia Engineering*, 38, 2111-2116. doi: 10.1016/j.proeng.2012.06.253

Di Martinelly, C., Duenas, A., and Pham, D. (2018). Integration of operating room advance scheduling and allocation scheduling while considering the resource constraints: A multi-objective genetic algorithm approach. Paper presented at the *ILS 2018 - Information Systems, Logistics and Supply Chain, Proceedings*, 714-724.

Dixit, A., Routroy, S., and Kumar Dubey, S. (2019). A systematic literature review of healthcare supply chain and implications of future research. *International Journal of Pharmaceutical and Healthcare Marketing*, 13(4), 405-435. doi: 10.1108/IJPHM-05-2018-0028

Do Rosário Cabrita, M. and Frade, R. (2016). Supplier selection approach: Integrating analytic hierarchy process and supplier risk analysis. *International Journal of Business and Systems Research,* 10(2-4), 238-261. doi: 10.1504/IJBSR.2016.075743

Douissa, M. R. and Jabeur, K. (2016). A new multi-criteria ABC inventory classification model based on a simplified ELECTRE III method and the continuous variable neighborhood search. Paper presented at *the ILS 2016 - 6th International Conference on Information Systems, Logistics and Supply Chain*. doi: 10.1016/j.procs.2016.08.233

Dursun, M. (2016). Evaluation of agile suppliers using fuzzy MCDM approach. Paper presented at the *MATEC Web of Conferences*, 76. doi:10.1051/matecconf/20167602008

Dursun, M. and Goker, N. (2017). A 2-tuple fuzzy linguistic representation model-based decision framework for agile supplier selection. Paper presented at the *Proceedings of International Conference on Computers and Industrial Engineering, CIE.*

El Mokrini, A., Benabbou, L., and Berrado, A. (2018). Multi-criteria distribution network redesign: Case of the public sector pharmaceutical supply chain in Morocco. *Supply Chain Forum*, 19(1), 42-54. doi: 10.1080/16258312.2018.1433436

El Mokrini, A., Dafaoui, E., Berrado, A., and El Mhamedi, A. (2016). An approach to risk assessment for outsourcing logistics: Case of pharmaceutical industry. *IFAC-PapersOnLine*, 49(12), 1239-1244. doi: 10.1016/j.ifacol.2016.07.681

El Mokrini, A., Kafa, N., Dafaoui, E., El Mhamedi, A., and Berrado, A. (2016). Evaluating outsourcing risks in the pharmaceutical supply chain: Case of a multi-criteria combined fuzzy AHP-PROMETHEE approach. *IFAC-PapersOnLine*, 49(28), 114-119. doi: 10.1016/j.ifacol.2016.11.020

Elahi, B. and Franchetti, M. (2015). A multi-objective proposed mathematical model for a healthcare supply chain with perishable products. Paper presented at the *IIE Annual Conference and Expo 2015*, 1514-1523.

Elamrani, A., Benabbou, L., and Berrado, A. (2016). A model for classification of outsourcing related organizational risks in a pharmaceutical supply chain. Paper presented at the *SITA 2016 - 11th International Conference on Intelligent Systems: Theories and Applications*. doi: 10.1109/SITA.2016.7772318

Enyinda, C.I. (2018). Modeling enterprise risk management in operations and supply chain: A pharmaceutical firm context. *Operations and Supply Chain Management*, 11(1), 1-12. doi: 10.31387/oscm0300195

Ertay, T., Kahveci, A., and Tabanl, R.M. (2011). An integrated multi-criteria group decision-making approach to efficient supplier selection and clustering using fuzzy preference relations. *International Journal of Computer Integrated Manufacturing*, 24(12), 1152-1167. doi: 10.1080/0951192X.2011.615342

Eskandari-Khanghahi, M., Tavakkoli-Moghaddam, R., Taleizadeh, A.A., and Amin, S.H. (2018). Designing and optimizing a sustainable supply chain network for a blood platelet bank under uncertainty. *Engineering Applications of Artificial Intelligence*, 71, 236-250. doi: 10.1016/j.engappai.2018.03.004

Fathollahi-Fard, A. M., Govindan, K., Hajiaghaei-Keshteli, M., and Ahmadi, A. (2019). A green home health care supply chain: New modified simulated annealing algorithms. *Journal of Cleaner Production,* 240. doi: 10.1016/j.jclepro.2019.118200

Fazli-Khalaf, M., Khalilpourazari, S., and Mohammadi, M. (2019). Mixed robust possibilistic flexible chance constraint optimization model for emergency blood supply chain network design. *Annals of Operations Research*, 283(1-2), 1079-1109. doi: 10.1007/s10479-017-2729-3

Feng, Y.-., Wu, I.-., and Chen, T.-. (2017). Stochastic resource allocation in emergency departments with a multi-objective simulation optimization algorithm. *Health Care Management Science*, 20(1), 55-75. doi: 10.1007/s10729-015-9335-1

Foroozesh, N., Tavakkoli-Moghaddam, R., and Mousavi, S.M. (2018). A novel group decision model based on mean-variance-skewness concepts and interval-valued fuzzy sets for a selection problem of the sustainable warehouse location under uncertainty. *Neural Computing and Applications*, 30(11), 3277-3293. doi: 10.1007/s00521-017- 2885-z

Fors, H. N., Harraz, N. A., and Abouali, M. G. (2011). Supplier selection and order allocation in supply chain management. Paper presented at the *41st International Conference on Computers and Industrial Engineering 2011*, 116-121.

Frazão, T.D.C., Camilo, D.G.G., Cabral, E.L.S., and Souza, R.P. (2018). Multicriteria decision analysis (MCDA) in healthcare: A systematic review of the mail characteristics and methodological steps. *BMC Medical Informatics and Decision Making,* 18, 90. doi: 10.1186/s12911-018-0663-1

Ganguly, A. and Kumar, C. (2019). Evaluating supply chain resiliency strategies in the Indian pharmaceutical sector: A fuzzy analytic hierarchy process (F-AHP) approach. *International Journal of the Analytic Hierarchy Process*, 11(2), 153-180. doi: 10.13033/ijahp.v11i2.620

Ganguly, A., Kumar, C., and Chatterjee, D. (2019). A decision-making model for supplier selection in Indian pharmaceutical organizations. *Journal of Health Management*, 21(3), 351-371. doi: 10.1177/0972063419868552

Gardas, B. B., D. Raut, R., and Narkhede, B. E. (2019). Analyzing the 3PL service provider's evaluation criteria through a sustainable approach. *International Journal of Productivity and Performance Management*, 68(5), 958-980. doi: 10.1108/IJPPM-04-2018-0154

Ghasemi, P., Khalili-Damghani, K., Hafezolkotob, A., and Raissi, S. (2019). Uncertain multi-objective multi-commodity multi-period multi-vehicle location-allocation model for earthquake evacuation planning. *Applied Mathematics and Computation*, 350, 105-132. doi: 10.1016/j.amc.2018.12.061

Ghatari, A. R., Mehralian, G., Zarenezhad, F., and Rasekh, H. (2013). Developing a model for agile supply: An empirical study from Iranian pharmaceutical supply chain. *Iranian Journal of Pharmaceutical Research,* 12(SUPPL.), 189-201.

Ghorashi, S.B., Hamedi, M., and Sadeghian, R. (2020). Modeling and optimization of a reliable blood supply chain network in crisis considering blood compatibility using MOGWO. *Neural Computing and Applications*, 32(16), 12173-12200. doi: 10.1007/s00521-019-04343-1

Gilani Larimi, N., Yaghoubi, S., and Hosseini-Motlagh, S.-. (2019). Itemized platelet supply chain with lateral transshipment under uncertainty evaluating inappropriate output in laboratories. *Socio-Economic Planning Sciences*, 68. doi: 10.1016/j.seps.2019.03.003

Goodarzian, F., Hosseini-Nasab, H., Muñuzuri, J., and Fakhrzad, M.-. (2020). A multi-objective pharmaceutical supply chain network based on a robust fuzzy model: A comparison of meta-heuristics. *Applied Soft Computing Journal*, 92. doi: 10.1016/j.asoc.2020.106331

Goodarzian, F., Taleizadeh, A. A., Ghasemi, P., and Abraham, A. (2021). An integrated sustainable medical supply chain network during COVID-19. *Engineering Applications of Artificial Intelligence*, 100. doi: 10.1016/j.engappai.2021.104188

Govindan, K., Soleimani, H., and Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research,* 240(3), 603-626. doi: 10.1016/j.ejor.2014.07.012

Ghorani, S.F. (2015). Model of healthcare supply chain agility based on information technology. *Research Journal of Recent Sciences*, 4(4), 54-60. doi: 10.1108/IJPHM-05-2018-0028

Guimarães, C.M. and Carvalho, J.C.D. (2013). Strategic outsourcing: a lean tool of healthcare supply chain management. *Strategic Outsourcing: An International Journal*, 6(2), 138-166. doi: 10.1108/SO-11-2011-0035

Haghi, M., Fatemi Ghomi, S. M. T., and Jolai, F. (2017). Developing a robust multi-objective model for pre/post disaster times under uncertainty in demand and resource. *Journal of Cleaner Production*, 154, 188-202. doi: 10.1016/j.jclepro.2017.03.102

Haial, A., Berrado, A., and Benabbou, L. (2016). A framework for designing a transportation strategy: The case of a pharmaceutical supply chain. Paper presented at the *Proceedings of the 3rd IEEE International Conference on Logistics Operations Management, GOL 2016.* doi: 10.1109/GOL.2016.7731680

Haial, A., Berrado, A., and Benabbou, L. (2020). Redesigning a transportation network: The case of a pharmaceutical supply chain. *International Journal of Logistics Systems and Managemen*t, 35(1), 90-118. doi: 10.1504/IJLSM.2020.103866

Halim, I., Ang, P., and Adhitya, A. (2019). A decision support framework and system for design of sustainable pharmaceutical supply chain network. *Clean Technologies and Environmental Policy*, 21(2), 431-446. doi: 10.1007/s10098-018-1646-8

Hassan, T., Baboli, A., Guinet, A., Leboucher, G., and Brandon, M. T. (2006). Re-organizing the pharmaceutical supply chain downstream: Implementation of a new pharmacy. Paper presented at the *IFAC Proceedings Volumes (IFAC- PapersOnline),* 12(PART 1).

doi: 10.3182/20060517-3-fr-2903.00365

Hatibu, M.N. (2015). Effect of lean supply chain management in organizational performance: a case of coastal provincial general hospital. *Asian Research Journal of Business Management Issue,* 2(3), 24-35.

Hossain, M.K., and Thakur, V. (2021). Benchmarking health-care supply chain by implementing industry 4.0: A fuzzy-AHP-DEMATEL approach. *Benchmarking*, 28(2), 556-581. doi: 10.1108/BIJ-05-2020-0268

Hsieh, C.-. (2014). An evolutionary-based optimization for a multi-objective blood banking supply chain model. Paper presented at the Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science), 8481 511-520. doi: 10.1007/978-3-319-07455-9_53

Hu, J. and Zhao, L. (2012). Emergency logistics network based on integrated supply chain response to public health emergencies. *ICIC Express Letters,* 6(1), 113-118.

Imran, M., Habib, M. S., Hussain, A., Ahmed, N., and Al-Ahmari, A. M. (2020). Inventory routing problem in supply chain of perishable products under cost uncertainty. *Mathematics*, 8(3). doi: 10.3390/math8030382

Imran, M., Kang, C., and Babar Ramzan, M. (2018). Medicine supply chain model for an integrated healthcare system with uncertain product complaints. *Journal of Manufacturing Systems*, 46, 13-28. doi: 10.1016/j.jmsy.2017.10.006

Ivanov, D., Tsipoulanidis, A., and Schönberger, J. (2019). *Global Supply Chain and Operations Management* (2nd ed.). Springer Text in Business and Economics.

Ivanova, I. A. and Glukhova, T. V. (2020). Aspects of information and analytical support for the supply chain management of healthcare customers' loyalty. *International Journal of Supply Chain Management,* 9(2), 622-629.

Jabbarzadeh, A., Haughton, M., and Pourmehdi, F. (2019). A robust optimization model for efficient and green supply chain planning with postponement strategy. *International Journal of Production Economics*, 214, 266-283. doi: 10.1016/j.ijpe.2018.06.013

Jamshidian-Tehrani, M., Ahmadzadeh, A., Rahimisadr, M., and Abdolmohammadi, M. (2020). Identifying and prioritizing the factors affecting the agility of the supply chain of pharmaceutical companies using multi-criteria decision-making methods in COVID-19 pandemic. *Systematic Reviews in Pharmacy*, 11(7), 371-381. doi: 10.31838/srp.2020.7.56

Janatyan, N., Zandieh, M., Alem-Tabriz, A., and Rabieh, M. (2018). Designing a sustainable distribution network in the pharmaceutical supply chain: A case study. *International Journal of Supply and Operations Management,* 5(2), 122-133. doi: 10.22034/2018.2.2

Jeong, H. Y., Yu, D. J., Min, B.-., and Lee, S. (2020). The humanitarian flying warehouse. *Transportation Research Part E: Logistics and Transportation Review*, 136. doi: 10.1016/j.tre.2020.101901

Jiang, L., and Liao, H. (2020). Cognitive fuzzy sets for decision making. *Applied Soft Computing Journal,* 93. doi: 10.1016/j.asoc.2020.106374

Kaabi, H., Jabeur, K., and Enneifar, L. (2015). Learning criteria weights with TOPSIS method and continuous VNS for multi-criteria inventory classification. *Electronic Notes in Discrete Mathematics,* 47, 197-204. doi: 10.1016/j.endm.2014.11.026

Kargar, S., Paydar, M. M., and Safaei, A. S. (2020). A reverse supply chain for medical waste: A case study in the babol healthcare sector. *Waste Management*, 113, 197-209. doi: 10.1016/j.wasman.2020.05.052

Kargar, S., Pourmehdi, M., and Paydar, M. M. (2020). Reverse logistics network design for medical waste management in the epidemic outbreak of the novel coronavirus (COVID-19). *Science of the Total Environment,* 746. doi: 10.1016/j.scitotenv.2020.141183

Karsak, E. E. and Dursun, M. (2015). An integrated fuzzy MCDM approach for supplier evaluation and selection. *Computers and Industrial Engineering,* 82, 82-93. doi: 10.1016/j.cie.2015.01.019

Karsak, E. E. and Dursun, M. (2014). An integrated supplier selection methodology incorporating QFD and DEA with imprecise data. *Expert Systems with Applications,* 41(16), 6995-7004. doi: 10.1016/j.eswa.2014.06.020

Kartoglu, U. and Milstien, J. (2014). Tools and approaches to ensure quality of vaccines throughout the cold chain. *Expert Review of Vaccines,* 13(7), 843-854. doi: 10.1586/14760584.2014.923761

Kees, M. C., Bandoni, J. A., and Moreno, M. S. (2019). An optimization model for managing the drug logistics process in a public hospital supply chain integrating physical and economic flows. *Industrial and Engineering Chemistry Research*, 58(9), 3767-3781. doi: 10.1021/acs.iecr.8b03968

Khalilpourazari, S., Soltanzadeh, S., Weber, G.-., and Roy, S.K. (2020). Designing an efficient blood supply chain network in crisis: Neural learning, optimization and case study. *Annals of Operations Research,* 289(1), 123-152. doi: 10.1007/s10479-019-03437-2

Khaoula, K. and Abouabdellah, A. (2017). Redesigning the hospital supply chain for enhanced performance using a lean methodology. Paper presented at the *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 917-927. doi: 10.15866/iremos.v9i6.10808

Kharisma, S. A. and Ardi, R. (2020). Supply chain risk assessment of generic medicine in Indonesia using DEMATEL-based ANP (DANP). Paper presented at the *IEEE International Conference on Industrial Engineering and Engineering Management*, 716-720. doi: 10.1109/IEEM45057.2020.9309793

Khlie, K. and Abouabdellah, A. (2016). Redesigning the hospital supply chain for enhanced performance using a lean methodology. *International Review on Modelling and Simulations,* 9(6), 407-413. doi: 10.15866/iremos.v9i6.10808

Kwon, I.G., Kim, S., and Martin, D.G. (2016). Healthcare supply chain management; strategic areas for quality and financial improvement. *Technological Forecasting and Social Change,* 113, 422-428. doi: 10.1016/j.techfore.2016.07.014

Kumar, D. and Kumar, D. (2014). Modelling rural healthcare supply chain in India using system dynamics. *Procedia Engineering,* 97, 2204-2212. doi: 10.1016/j.proeng.2014.12.464

Laghrabli, S., Benabbou, L., and Berrado, A. (2016). Multi-criteria decision aid model for transportation supplier selection: Case of a pharmaceutical supply chain. Paper presented at the *Proceedings of the 3rd IEEE International Conference on Logistics Operations Management, GOL 2016*. doi: 10.1109/GOL.2016.7731703

Laghrabli, S., Benabbou, L., and Berrado, A. (2016). Strategic decision processes classification framework using UTADIS. Paper presented at the *SITA 2016 -11th International Conference on Intelligent Systems: Theories and Applications*. doi: 10.1109/SITA.2016.7772317

Lee, B.Y. and Haidari, L.A. (2017). The importance of vaccine supply chains to everyone in the vaccine world. *Vaccine*, 35(35-A), 4475-4479. doi: 10.1016/j.vaccine.2017.05.096

Lemmens, S., Decouttere, C., Vandaele, N., and Bernuzzi, M. (2016). A review of integrated supply chain network design models: Key issues for vaccine supply chains. *Chemical Engineering Research and Design,* 109, 366-384. doi: 10.1016/j.cherd.2016.02.015

Longaray, A., Ensslin, L., Ensslin, S., Alves, G., Dutra, A., and Munhoz, P. (2018). Using MCDA to evaluate the performance of the logistics process in public hospitals: The case of a Brazilian teaching hospital. *International Transactions in Operational Research,* 25(1), 133-156. doi: 10.1111/itor.12387

Low, Y. S., Halim, I., Adhitya, A., Chew, W., and Sharratt, P. (2016). Systematic framework for design of environmentally sustainable pharmaceutical supply chain network. *Journal of Pharmaceutical Innovation,* 11(3), 250-263. doi: 10.1007/s12247-016-9255-8

Mansoori, S., Bozorgi-Amiri, A., and Pishvaee, M. S. (2020). A robust multi-objective humanitarian relief chain network design for earthquake response, with evacuation assumption under uncertainties. *Neural Computing and Applications,* 32(7), 2183-2203. doi: 10.1007/s00521-019-04193-x

Mathew, J., John, J., and Kumar, S. (2013). New trends in the healthcare supply chain. *POM 24th Annual Conference of the Production and Operations Management*, 1-10.

Mathiyalagan, P. (2015). Use of fuzzy TOPSIS techniques for selection of best alternatives of blood bank supply chain. Paper presented at the *International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials, ICSTM 2015 - Proceedings*, 644-649. doi: 10.1109/ICSTM.2015.7225492

Mehralian, G., Moosivand, A., Emadi, S., and Asgharian, R. (2015). Developing a coordination framework for the pharmaceutical supply chain: Using analytical hierarchy processes. *International Journal of Logistics Systems and Management,* 26(3), 277-293. doi: 10.1504/IJLSM.2017.10002596

Mensah, J., Annan, J., and Asamoah, D. (2015). Optimizing drug supply chain in hospital pharmacy department: Empirical evidence from a developing country. *Business and Economic Research,* 5(2), 153-164. doi: 10.5296/ber.v5i2.7789

Miah, S.J., Ahsan, K., and Msimangira, K.A.B. (2013) An approach of purchasing decision support in healthcare supply chain management. *Operations and Supply Chain Management*, 6(2), 43-53.

Mohammadian-Behbahani, Z., Jabbarzadeh, A., and Pishvaee, M. S. (2019). A robust optimization model for sustainable blood supply chain network design under uncertainty. *International Journal of Industrial and Systems Engineering,* 31(4), 475-494. doi: 10.1504/IJISE.2019.099190

Mokrini, A. E. and Aouam, T. (2020). A fuzzy multi-criteria decision analysis approach for risk evaluation in healthcare logistics outsourcing: Case of Morocco. *Health Services Management Research*, 33(3), 143-155. doi: 10.1177/0951484820901668

Moons, K., Waeyenbergh, G., and Pintelon, L. (2019). Measuring the logistics performance of internal hospital supply chains – A literature study. *Omega* (United Kingdom), 82, 205-217. doi: 10.1016/j.omega.2018.01.007

Moons, K., Waeyenbergh, G., Pintelon, L., Timmermans, P., and De Ridder, D. (2019). Performance indicator selection for operating room supply chains: An application of ANP. *Operations Research for Health Care,* 23. doi: 10.1016/j.orhc.2019.100229

Moons, K., Waeyenbergh, G., Timmermans, P., De Ridder, D., and Pintelon, L. (2020). Evaluating replenishment systems for disposable supplies at the operating theater: A simulation case study. Paper presented at the *Springer Proceedings in Mathematics and Statistics*, 316 147-162. doi: 10.1007/978-3-030-39694-7_12

Moradi, M. and Jolai, F. (2018). Purchasing planning and order allocation in the pharmaceutical sustainable supply chain using the theoretical-graph (GT-MP-DM) (Case study: Supplying the clotting factor for patients with hemophilia). *International Journal of Supply and Operations Management,* 5(4), 361-378. doi: 10.22034/2018.4.5

Moslemi, S., Zavvar Sabegh, M. H., Mirzazadeh, A., Ozturkoglu, Y., and Maass, E. (2017). A multi-objective model for multi-production and multi-echelon closed-loop pharmaceutical supply chain considering quality concepts: NSGAII approach. *International Journal of Systems Assurance Engineering and Management,* 8, 1717-1733. doi: 10.1007/s13198-017-0650-4

Mouaky, M., Berrado, A., and Benabbou, L. (2016). A MCDA approach to select a KANBAN system for multi-echelon inventory management in a pharmaceutical supply chain. Paper presented at the *SITA 2016 - 11th International Conference on Intelligent Systems: Theories and Applications*. doi: 10.1109/SITA.2016.7772316

Nag, K. and Helal, M. (2016). A fuzzy TOPSIS approach in multi-criteria decision making for supplier selection in a pharmaceutical distributor. Paper presented at the *IEEE International Conference on Industrial Engineering and Engineering Management*, 1126-1130. doi: 10.1109/IEEM.2016.7798053

Naghipour, M. and Bashiri, M. (2019). Designing a bi-objective stochastic blood supply chain network in a disaster. Paper presented at the *Proceedings of 2019 15th Iran International Industrial Engineering Conference, IIIEC 2019,* 171-177. doi: 10.1109/IIIEC.2019.8720727

Nagurney, A., Masoumi, A.H., and Yu, M. (2012). Supply chain network operations management of a blood banking system with cost and risk minimization. *Computational Management Science*, 9(2), 205-231. doi: 10.1007/s10287-011-0133-z

Narayana, S.A., Pati, R.K., and Vrat, P. (2014). Managerial research on the pharmaceutical supply chain – a critical review and some insights for future directions. *Journal of Purchasing and Supply Management,* 20(1), 18-40. doi: 10.1016/j.pursup.2013.09.001

Nasrollahi, M., Razmi, J., and Ghodsi, R. (2018). A computational method for measuring transport related carbon emissions in a healthcare supply network under mixed uncertainty: An empirical study. *Promet - Traffic - Traffico*, 30(6), 693-708. doi: 10.7307/ptt.v30i6.2779

Nasrollahi, M., Safaei, M., and Mahmoodi, N. (2021). A mathematical model for integrated green healthcare supply network design. *International Journal of Business Analytics*, 8(1), 58-86. doi: 10.4018/IJBAN.2021010104

Nazeri, A. and Nosratpour, M. (2016). A multi-objective model for supplier evaluation and selection and multi-product order allocation in the drug supply chain. *International Journal of Pharmacy and Technology,* 8(2), 12523-12536.

Nematollahi, M., Hosseini-Motlagh, S.-., Ignatius, J., Goh, M., and Saghafi Nia, M. (2018). Coordinating a socially responsible pharmaceutical supply chain under periodic review replenishment policies. *Journal of Cleaner Production,* 172, 2876-2891. doi: 10.1016/j.jclepro.2017.11.126

Ng, C. T., Cheng, T. C. E., Tsadikovich, D., Levner, E., Elalouf, A., and Hovav, S. (2018). A multi-criterion approach to optimal vaccination planning: Method and solution. *Computers and Industrial Engineering,* 126, 637-649. doi: 10.1016/j.cie.2018.10.018

Nikhil, E. V. S., Sai Ram, V., Charan Yadav, V., Kumar, K. K., and Nagaraju, D. (2017). Evaluation and selection of predicaments in the pharmaceutical supply chain using AHP under a fuzzy environment. Paper presented at the *IOP Conference Series: Materials Science and Engineering*, 197(1). doi: 10.1088/1757-899X/197/1/012061

Niroomand, S., Garg, H., and Mahmoodirad, A. (2020). An intuitionistic fuzzy two stage supply chain network design problem with multi-mode demand and multi-mode transportation. *ISA Transactions*, 107, 117-133. doi: 10.1016/j.isatra.2020.07.033

Onar, S. C., Kahraman, C., and Oztaysi, B. (2020). Multi-criteria spherical fuzzy regret-based evaluation of healthcare equipment stocks. *Journal of Intelligent and Fuzzy Systems,* 39(5), 5987-5997. doi: 10.3233/JIFS-189073

Osorio, A. F., Brailsford, S. C., and Smith, H. K. (2018). Whole blood or apheresis donations? A multi-objective stochastic optimization approach. *European Journal of Operational Research,* 266(1), 193-204. doi: 10.1016/j.ejor.2017.09.005

Özkan, B., Kaya, I., and Başligil, H. (2017). A fuzzy based goal programming methodology for minimizing the risk factors: A real case application in the pharmaceutical sector. *Journal of Multiple-Valued Logic and Soft Computing,* 28(4-5), 475-493.

Papalexi, M., Bamford, D., and Dehe, B. (2016). A case study of KANBAN implementation within the pharmaceutical supply chain. *International Journal of Logistics Research and Applications,* 19(4), 239-255. doi: 10.1080/13675567.2015.1075478

Papert, M., Rimpler, P., and Pflaum, A. (2016). Enhancing supply chain visibility in a pharmaceutical supply chain: Solutions based on automatic identification technology. *International Journal of Physical Distribution and Logistics Management,* 46(9), 859-884. doi: 10.1108/IJPDLM-06-2016-0151

Parmata, U.M.D., Sankara, R.B., and Rajashekhar, B. (2016). Measuring service quality from a pharmaceutical supply chain distributor's perspective. *International Journal of Pharmaceutical and Healthcare Marketing,* 10(3), 258-284. doi: 10.1108/ijphm-07-2015-0035

Patel, A., Norris, P., Gauld, R., and Rades, T. (2009). Drug quality in South Africa: Perceptions of key players involved in medicines distribution. *International Journal of Health Care Quality Assurance*, 22(5), 547-560. doi: 10.1108/09526860910975643

Pelissari, R., Ben-Amor, S., and de Oliveira, M.C. (2019). A multiple-criteria decision sorting model for pharmaceutical supplier classification under multiple uncertainties. doi: 10.1007/978-3-030-15398-4_17

Pinna, R., Carrus, P.P., and Marras, F. (2015). The drug logistics process: an innovative experience. *The TQM Journal,* 27(2), 214-230. doi: 10.1108/TQM-01-2015-0004

Rachmania, I.N. and Basri, M.H. (2013). Pharmaceutical inventory management issues in hospital supply chains. *Management*, 3(1), 1-5. doi: 10.5923/j.mm.20130301.01

Raut, R.D. (2014). An integrated Delphi-AHP-DEA-LPP multi criteria decision making approach for supplier selection and order quantity allocation system. *International Journal of Logistics Systems and Management,* 18(3), 366- 393. doi: 10.1504/IJLSM.2014.062823

Razaei, J. (2015). A systematic review of multi-criteria decision-making applications in reverse logistics. *Transportation Research Procedia,* 10, 766-776. doi: 10.1016/j.trpro.2015.09.030

Razavi, N., Gholizadeh, H., Nayeria, S., and Ashrafi, T.A. (2020). A robust optimization model of the field hospitals in the sustainable blood supply chain in crisis logistics. *Journal of the Operational Research Society.* doi: 10.1080/01605682.2020.1821586

Rego, N. and de Sousa, J.P. (2009). Supply chain coordination in hospitals. In Camarinha-Matos L.M., Paraskakis I. and Afsarmanesh H. (Eds), *Leveraging Knowledge for Innovation in Collaborative Networks Advances in Information and Communication Technology,* Springer, Berlin, Heidelberg, 307, 117-127. doi: 10.1007/978-3-642-04568-4_13

Rodríguez González, R., Álvarez Sánchez, Y., León González, J. L., Álvarez Migueles, M., Rodríguez González, Y., and Santiago León, Y. O. (2020). A multicriteria approach in the medicines inventory planning. *Universidad Y Sociedad*, 12(5), 152-164.

Roshan, M., Tavakkoli-Moghaddam, R., and Rahimi, Y. (2019). A two-stage approach to agile pharmaceutical supply chain management with product substitutability in crises. *Computers and Chemical Engineering,* 127, 200-217. doi: 10.1016/j.compchemeng.2019.05.014

Rossetti, C.L., Handfield, R., and Dooley, K.J. (2011). Forces, trends, and decisions in pharmaceutical supply chain management. *International Journal of Physical Distribution and Logistics Management,* 41(6), 601-622. doi: 10.1108/09600031111147835

Rusnac, C. M., Baboli, A., Moyaux, T., and Botta-Genoulaz, V. (2012). Downstream pharmaceutical supply chain reorganization by considering the sustainable development criteria. Paper presented at the *IFAC Proceedings Volumes (IFAC-PapersOnline),* 45(6 PART 1), 528-533. doi: 10.3182/20120523-3-RO-2023.00220

Sabegh, M.H.Z., Mohammadi, M., and Naderi, B. (2017). Multi-objective optimization considering quality concepts in a green healthcare supply chain for natural disaster response: neural network approaches. *International Journal System Assurance Engineering and Management,* 8(2), 1717-1733. doi: 10.1007/s13198-017-0645-1

Safaei, A.S., Heidarpoor, F., and Paydar, M.M. (2017). A novel mathematical model for group purchasing in healthcare. *Operations Research for Health Care*, 15, 82-90. doi: 10.1016/j.orhc.2017.09.005

Safaei, A.S., Heidarpoor, F., and Paydar, M.M. (2018). Group purchasing organization design: A clustering approach. *Computational and Applied Mathematics,* 37(2), 2065-2093. doi: 10.1007/s40314-017-0439-8

Sahu, K. and Kohli, S. (2019). Performance improvement tool towards the medicines manufacturing pharmaceutical companies under sustainable practices. *International Journal of E-Entrepreneurship and Innovation,* 9(2), 35-48. doi: 10.4018/IJEEI.2019070103

Sahu, K. and Sahu, A.K. (2019). Performance measurement of medicines delivery of pharmaceutical companies under chain of sustainable procurement. *International Journal of Social Ecology and Sustainable Development,* 10(3), 116-128. doi: 10.4018/IJSESD.2019070108

Samani, M.R.G., Hosseini-Motlagh, S.-., Sheshkol, M.I., and Shetab-Boushehri, S.-. (2019). A bi-objective integrated model for the uncertain blood network design with raising products quality. *European Journal of Industrial Engineering,* 13(5), 553-588. doi: 10.1504/EJIE.2019.102182

Santos, L.F.D.O.M., Osiro, L., and Lima, R.H.P. (2017). A model based on 2-tuple fuzzy linguistic representation and analytic hierarchy process for supplier segmentation using qualitative and quantitative criteria. *Expert Systems with Applications,* 79, 1339-1351. doi: 10.1016/j.eswa.2017.02.032

Sarley, D., Mahmud, M., Idris, J., Osunkiyesi, M., Dibosa-Osadolor, O., Okebukola, P., and Wiwa, O. (2017). Transforming vaccines supply chains in Nigeria. *Vaccine*, 35(17), 2167-2174. doi: 10.1016/j.vaccine.2016.11.068

Sazvar, Z., Zokaee, M., Tavakkoli-Moghaddam, R., Salari, S.A.-., and Nayeri, S. (2021). Designing a sustainable closed-loop pharmaceutical supply chain in a competitive market considering demand uncertainty, manufacturer's brand, and waste management. *Annals of Operations Research.* doi: 10.1007/s10479-021-03961- 0

Sbai, N., Benabbou, L., and Berrado, A. (2020). An AHP based approach for multi-echelon inventory system selection: Case of distribution systems. Paper presented at the *Proceedings - 2020 5th International Conference on Logistics Operations Management, GOL 2020.* doi: 10.1109/GOL49479.2020.9314711

Schätter, F., Wiens, M., and Schultmann, F. (2015). A new focus on risk reduction: An ad hoc decision support system for humanitarian relief logistics. *Ecosystem Health and Sustainability,* 1(3), 1-11. doi: 10.1890/EHS14-0020.1

Shah, N. (2004). Pharmaceutical supply chains: Key issues and strategies for optimization. *Computers and Chemical Engineering,* 28(6/7), 929-941. doi: 10.1016/j.compchemeng.2003.09.022

Shbool, M. A. and Rossetti, M. D. (2020). Decision-making framework for evaluating physicians' preference items using multi-objective decision analysis principles. *Sustainability* (Switzerland), 12(16). doi: 10.3390/SU12166415

Singh, S. K. and Goh, M. (2019). Multi-objective mixed integer programming and an application in a pharmaceutical supply chain. *International Journal of Production Research,* 57(4), 1214-1237. doi: 10.1080/00207543.2018.1504172

Singh, R.K., Kumar, R., and Kumar, P. (2016). Strategic issues in pharmaceutical supply chains: a review. *International Journal of Pharmaceutical and Healthcare Marketing,* 10(3), 234-257. doi: 10.1108/IJPHM-10-2015-0050

Sivakumar, P., Ganesh, K., and Koh, S.C.L. (2009). Multi-objective mathematical model for order quantity allocation in multiple discount environments for healthcare supply chain. *International Journal of Enterprise Network Management,* 3(2), 130-156. doi: 10.1504/IJENM.2009.029007

Sudarmin, A. C. and Ardi, R. (2020). DEMATEL-based analytic network process (ANP) approach to assess the vaccine supply chain risk in Indonesia. Paper presented at the *IEEE International Conference on Industrial Engineering and Engineering Management,* 726-730. doi: 10.1109/IEEM45057.2020.9309911

Suifan, T., Alazab, M., and Alhyari, S. (2019). Trade-off among lean, agile, resilient and green paradigms: An empirical study on the pharmaceutical industry in Jordan using a TOPSIS-entropy method. *International Journal of Advanced Operations Management,* 11(1-2), 69-101. doi: 10.1504/IJAOM.2019.098493

Supeekit, T., Somboonwiwat, T., and Kritchanchai, D. (2016). DEMATEL-modified ANP to evaluate internal hospital supply chain performance. *Computers and Industrial Engineering*, 102, 318-330. doi: 10.1016/j.cie.2016.07.019

Tamir, M., Chiheb, R., and Ouzayd, F. (2018). A decision support platform based on cross-sorting methods for the selection of modeling methods: Case of the hospital supply chain performance analysis. *International Journal of Advanced Computer Science and Applications,* 9(10), 475-484. doi: 10.14569/IJACSA.2018.091058

Toba, S., Tomasini, M., and Yang, Y.H. (2008). Supply chain management in hospital: A case study. *California Journal of Operations Management,* 6(1), 49-55.

Topaloglu, S. and Selim, H. (2010). Nurse scheduling using a fuzzy modeling approach. *Fuzzy Sets and Systems*, 161(11), 1543-1563. doi: 10.1016/j.fss.2009.10.003

Vishwakarma, V., Prakash, C., and Barua, M. K. (2016). A fuzzy-based multi criteria decision making approach for supply chain risk assessment in the Indian pharmaceutical industry. *International Journal of Logistics Systems and Management,* 25(2), 245-265. doi:10.1504/IJLSM.2016.078915

Voigt, K. and Brüggemann, R. (2008). Ranking of pharmaceuticals detected in the environment: Aggregation and weighting procedures. *Combinatorial Chemistry and High Throughput Screening,* 11(10), 770-782. doi: 10.2174/138620708786734299

Wang, X., Kong, Q., Papathanasiou, M. M., and Shah, N. (2018). Precision healthcare supply chain design through multi-objective stochastic programming. doi: 10.1016/B978-0-444-64241-7.50351-7

Wijewardana, A.R.L. and Rupasinghe, T.D. (2016). Lean healthcare framework for Sri Lankan healthcare supply chains: a case study of teaching hospitals. *Universal Journal of Management,* 4(10), 517-527. doi: 10.13189/ujm.2016.041001

Wyld, D.C. (2008). Genuine medicine?. *Competitiveness Review,* 18(3), 206-216. doi: 10.1108/10595420810905984

Wissem, E., Ahmed, F., and Mounir, B. (2011). Multicriteria method for a site selection of a new hospital in Sfax. Paper presented at *the 2011 4th International Conference on Logistics, LOGISTIQUA'2011*, 32-37. doi: 10.1109/LOGISTIQUA.2011.5939399

Yaghoubi, S., Hosseini-Motlagh, S.-., Cheraghi, S., and Gilani Larimi, N. (2020). Designing a robust demand-differentiated platelet supply chain network under disruption and uncertainty. *Journal of Ambient Intelligence and Humanized Computing,* 11(8), 3231-3258. doi: 10.1007/s12652-019-01501-0

Yazdani, M., Torkayesh, A. E., and Chatterjee, P. (2020). An integrated decision-making model for supplier evaluation in the public healthcare system: The case study of a Spanish hospital. *Journal of Enterprise Information Management,* 33(5), 965-989. doi: 10.1108/JEIM-09-2019-0294

Zahiri, B., Torabi, S. A., Mohammadi, M., and Aghabegloo, M. (2018). A multi-stage stochastic programming approach for blood supply chain planning. *Computers and Industrial Engineering,* 122, 1-14. doi: 10.1016/j.cie.2018.05.041

Zahiri, B., Zhuang, J., and Mohammadi, M. (2017). Toward an integrated sustainable-resilient supply chain: A pharmaceutical case study. *Transportation Research Part E: Logistics and Transportation Review,* 103, 109-142. doi: 10.1016/j.tre.2017.04.009

Zandi Atashbar, N., and Baboli, A. (2014). A multi-objective routing problem for perishable items in disaster relief. Paper presented at the *CIE 2014 - 44th International Conference on Computers and Industrial Engineering and IMSS 2014 - 9th International Symposium on Intelligent Manufacturing and Service Systems, Joint International Symposium on "the Social Impacts of Developments in Information, Manufacturing and Service Systems" - Proceedings,* 730-738.

Zavvar Sabegh, M. H., Mohammadi, M., and Naderi, B. (2017). Multi-objective optimization considering quality concepts in a green healthcare supply chain for natural disaster response: Neural network approaches. *International Journal of Systems Assurance Engineering and Management,* 8, 1689-1703. doi: 10.1007/s13198-017-0645-1

Zhao, H., Huang, E., Dou, R., and Wu, K. (2019). A multi-objective production planning problem with the consideration of time and cost in clinical trials. *Expert Systems with Applications*, 124, 25-38. doi: 10.1016/j.eswa.2019.01.038

Zhao, H., Wu, K., and Huang, E. (2018). Clinical trial supply chain design based on the pareto-optimal trade-off between time and cost. *IISE Transactions,* 50(6), 512-524. doi: 10.1080/24725854.2017.1395978

Ziat, A., Sefiani, N., Reklaoui, K., and Azzouzi, H. (2018). A SCOR based performance evaluation system of the hospital supply chain. Paper presented at *the 2018 International Colloquium on Logistics and Supply Chain Management, LOGISTIQUA 2018*, 182-187. doi: 10.1109/LOGISTIQUA.2018.8428273

Zheng, J., Bakker, E., Knight, L., Gilhespy, H., Harland, C., and Walker, H. (2006). A strategic case for e-adoption in healthcare supply chains. *International Journal of Information Management,* 26(4), 290-301. doi: 10.1016/j.ijinfomgt.2006.03.010

4. CHAPTER FOUR – MODEL DESIGN AND METHODOLOGY: ANALYSIS OF SOME INCENTIVES ON TWO-ECHELON REVERSE SUPPLY CHAIN WITH STRATEGIC CONSUMER: THE CASE OF UNWANTED MEDICATIONS IN HOUSEHOLDS

This chapter has been supervised by Prof. Massimiliano Ferrara from the Department of Law, Economics, and Human Sciences of the Mediterranea University of Reggio Calabria (Italy) and contains the joint work launched during the research stay as visiting professor (September 2019-February 2020) of Drr. Merhnoosh Khademi and Somayeh Sharifi at the Mediterranea University of Reggio Calabria under the supervision of the two senior co-authors Dr. Mehdi Salimi and Prof. Massimiliano Ferrara. This research has been partially supported by Department of Law, Economics, and Human Sciences through the "Piano Dipartimenti Universitari di Eccellenza L.232/2016". The reported paper is a special issue article published in February 2021 in the Journal of Multi-Criteria Decision Analysis (Wiley Online Library).

The aforementioned article was the compiler's first attempt to conduct joint research on Supply Chain Management issues. This article deserves to be included in this thesis as a starting point from which all the research activities were carried out during the stay at SKEMA Business School of Sophia Antipolis Campus (France).

In this article, there is established a reverse logistics (RL) system to collect unwanted medications (UMs) in households. A reverse supply chain (RSC) is proposed in a decentralized state including manufacturer, and retailer involving a strategic consumer. The novelty of this article is that the model is investigated from the consumer's perspective, whereas in the previous studies, the proposed models were from other upstream members' perspectives such as manufacturer and retailer. Furthermore, inducement and advertising strategies are proposed for stimulating consumers to engage more in an RSC. To analyze the effect of these two strategies, the three-person RSC game-theoretical approach is used. A three-person supply chain consists of a pharmaceutical manufacturer and a retailer who will interact with a strategic consumer in several non-cooperative Stackelberg games. Three Stackelberg games are established and each member takes a turn as a leadership role and the other two players assume the role of the follower.

4.1. Introduction

Environmental issues have taken considerable interest among researcher's attention leading to an advancement in the green supply chains. Many pharmaceutical industries have been forced to implement more green activities in their guidelines by imposing governmental policies and regulations as well as ecological awareness in the consumer society. Green supply chain management should be considered from two aspects: Forward Supply Chain (FSC) and Reverse Logistics (RL) process. Research on FSC networks studies the impact of enhancing the supply quality, such as energy and resource efficiency (Gong *et al.,* 2018; Horton *et al.,* 2016). RL gives all attention to recycling excess and unwanted products in households (Govindan and Popiuc, 2014; Walther *et al.,* 2008). One of the most vital recycling products is medications that are not being used including expired, unused, and spilled drugs, vaccines, and sera that should not be taken and need to be disposed of suitably (WHO, 2014). If leftover medications dispose of improperly, not only can damage the environment but also might cause harm to human health. Regards the price of medications, consumers are willing to keep large quantities of drugs in stock. Given the expiration date of the drugs, such a strategy will lead to irreparable consequences. Conversely, if unwanted medications (UMs) are returned to the pharmacies before their expiration date, they can be either sold in subsidiary markets or sent to the needful countries. This approach could have some positive results, such as improvement in the quality of health care in those societies. Hence, the consumer must be more involved in returning and recycling UMs and the companies employ proper methods to convince consumers to return UMs. The pharmaceutical companies are trying to be more active in improving RSC performance due to the government's regulations and policies imposed on them to dispose of and recover drugs and they also tend to create a decent image between their consumers. As the medications' recovery process is complex, in comparison with the numerous studies on forward-supply chain networks, the studies on the RSC networks are scant in some fields like UM. This complexity is chiefly due to the complicated recovery process in UMs in the sense that the producers always do not know information about the amount of money that they have to pay to collect and dispose of medications, available amounts of leftovers and the willingness of consumers to return medications.

This literature review shows inefficiency in the existing RL system. Although some regions such as the European Union (EU) have a collection system for collecting UM, in practice it is not effective (Jonjic and Vitale, 2014). In a real-world situation, UMs are still dumped into sewers and garbage cans in many countries (Al-Shareef *et al.,* 2016; Kozak *et al.,* 2016; Massoud *et al.,* 2016). Hence, current ER systems appear to be of little practical value. The process in RSC is doomed to fail unless there is a new RL system built for UM collection. In this research, we present a methodology to improve current methods for collecting unwanted products and increase consumer engagement in the RL system. Although the role of the consumer as a central figure is crucial in the Reverse Supply Chain (RSC), it has been ignored in previous studies. To establish the consumer will form an effective ER system, preferences should be taken into account. Motivated from this point of view, we consider the consumer as a strategic member with whom the other members of the supply chain interact.

The proposed RL system for the collection of UM integrates two strategies: an incentive with the advertising of the retailer and the manufacturer. We offer consumers some incentives to encourage them to collaborate and return UM messages. The incentive to trade is one of the incentive systems that have been examined in some recent studies on food waste and unwanted medicines. Additionally, advertising has been observed to bring more awareness of the environment, in turn, leading consumers to interact more (Tong *et al.,* 2011). As a result, the active consumer society will increase the return rate of unwanted products from households (Atasu *et al.,* 2009).

In the suggested RL system, the consumer plays a significant role in the Unified Messaging message collection process. The strategic consumer decides whether to return the UMs and his decision affects the main decision of the entire RL system suggested for the collection of UMs. The pharmacy retailer offers new drugs as an exchange offer to the consumer. The consumer evaluates the situation and based on some factors chooses to return the UMs or not. Then, the UMs collected are returned to the pharmaceutical manufacturer by the retailers and get financial benefits based on the amount collected. These activities are assumed to improve their reputation and green image for the manufacturer and retailer or other benefits, for example, obtaining subsidies, attracting more consumers, and increasing consumer loyalty (He and Li, 2011; Perez *et al.,* 2013; Pirsch *et al.,* 2007; Salmones *et al.,* 2005).

A game theory-based approach is considered to analyze the proposed RL system for the collection of UMs. The pharmaceutical manufacturer and retailer naturally want to maximize their individual net profit and the consumer's utility is vital to be considered by the proposed RL system. A two-tier supply chain designs a system consisting of a single strategic producer, retailer, and consumer. In a three-person non-cooperative game, each player individually acts as a self-maximizer to achieve a better result. Several models of game theory are established that include a manufacturer and a retailer, interacting with a strategic consumer. To address this situation, Stackelberg's game model is recommended and applied here to find an equilibrium point where the profit of the supply chain members is maximized considering the utility of consumption we use. We develop an uncooperative Stackelberg game by selecting the manufacturer as Stackelberg's leader, the retailer as Stackelberg's leader, and the consumer as the leader.

To acquaint readers unfamiliar with these topics, we have organized this article as follows: we dedicate the relevant short literature in Section 2 and the problem description and assumptions in Section 3. In Section 4, we formulate our model for each player. Section 5 deals with the Stackelberg game which is an essential part of this article, while section 6 provides numerical results. The notations and definitions are introduced in Section 7. Finally, we conclude this article with Section 8, where we give our conclusions.

4.2 Literature Review

In the last few years, Reverse Supply Chain Management (RSCM) has raised an increasing amount of attention and it is becoming an essential part of the business. The recovery process in the supply chain has been a favorable research topic when environmental regulations have been imposed by the government (Blackburn *et al.,* 2004). For instance, there have been some comprehensive reviews on RSC models in many studies such as Agrawal *et al.* (2015), Akcali et al. (2009), Aras *et al.* (2010), Govindan *et al.* (2013), Govindan *et al.* (2015), Guo *et al.* (2017), and Tang *et al.* (2012). Remanufacturing (recycle) plays a crucial role in the efforts of eco-efficiency, extended producer's responsibility, and concern for the environment. Recycling of surplus and unwanted products in households by using the RL process is described in Bing et al. (2016), Fehr and Santos (2009), Jalil *et al.* (2016), and Van Herpen and de Hooge (2019). Since the profitability of the recovery process in some industries, for example, cars, WEEE, and electronics industry, a great deal of literature on RSC focused on these industries (Govindan and Popiuc, 2014; Quariguasi Frota Neto *et al.* (2009).

However, the available literature in the pharmaceutical industry focuses on the FSC, while our principal focus is on the RSC. This inadequacy is caused by knowing the complexity of the medication recovery process. Moreover, collection and proper disposal UMs are assumed to require an extra investment by some companies (Xie and Breen, 2014). The available literature applied RSC as a theoretical framework for such supply chains or applied for recalling defective pharmaceutical products. Xie and Breen (2014) created a model for decreasing pharmaceutical waste in a green pharmaceutical supply chain. They considered an approach as a business strategy to reduce the impact of the companies in the pharmaceutical supply chain on the environment. Kumar *et al.* (2009) offered a structure to define each party's responsibility in the pharmaceutical RSC.

In some studies, an incentive is offered to consumers for stimulating them to collect unwanted products. Savaskan and Van Wassenhove (2006) presented an effective return incentive mechanism in the supply chain with competing retailers. Weraikat *et al.* (2016a) examined the use of coordination among all entities of RSC for medication recovery in the pharmaceutical industry. They involved consumers in the recovery process of pharmaceutical products by providing incentives. In addition to providing incentives, advertising can be used to educate people to participate in a green activity like collecting used products (Rai, 2013). It has an extreme impact on changing consumer's behavior. The advertising which has been used in the green supply chain was more in the FSC (Aust and Buscher, 2014) and a few studies were in RSC. In Hong *et al.* (2015), advertising was used for RSC by the local retailer. This article showed that local advertising forcefully affects channel members' pricing strategies, used-product collection decisions, and profits. Recently, experimental studies on strategic consumer behavior have increased. For example, Kremer *et al.* (2015) gave special attention to decision behavior of sellers which deal with strategic consumers. In Mak *et al.* (2014) were presented with laboratory experiments to study how strategic consumers decide to buy something under the accidental pricing policy. There is little literature on the interaction between the consumer and the upstream members in the supply chain management. Consumer's welfare has been investigated in Chesnokova (2007) based on the return policy. Su and Zhang (2008) presented the effect of strategic consumer behavior on the supply chain performance. However, all previous studies in the RSC have taken considerable interest in the interaction between supplier and retailer and paid no attention to the consumer behavior deliberately. So, the complex interactions that often occurred between consumer and upstream members were ignored. Hua *et al.* (2019) proposed an RL system for collecting UMs. They offered an RL system for collecting UMs. They joined the advertisement and incentive strategy. An exchange incentive for stimulating consumers to return UMs as well as an advertisement was from retailer and manufacturer. They used game theory to test the Nash and centralized game that they established for collecting UMs.

Ferrara *et al.* (2017) established a dynamic game to allocate Corporate Social Responsibility (CSR) to the members of a supply chain. They proposed a model of a supply chain in a decentralized state which includes a supplier and a manufacturer. The model was formulated through a dynamic discrete Stackelberg game. In the RL system, game theory was used as an effective method for supply chain management. Hua *et al.* used game theory to test and analyze their proposed RL model for collecting UMs (Hua *et al.,* 2019).

4.3 Problem Description and Assumptions

We provide the three-person supply chain model developed for analyzing consumer behavior and preference to obtain a more efficient RL system. As the manufacturer and retailer want to motivate the consumer, an RL system is designed consisting of advertising and exchange incentives from manufacturer and retailer to motivate the consumer with the FSC for collecting UMs. The two-echelon supply chain consists of a pharmaceutical producer (manufacturer) and a pharmacy retailer who interact with a strategic consumer. The system possesses a forward supply channel where the manufacturer sells products to potential consumers through the retailers. Then, in a reverse supply channel, the retailers offer an exchange incentive, and the consumer decides whether to give the product based on her valuation and the utility function. Not only the exchange incentive can motivate householders to return UMs but also it can enhance sales in the FSC. Thereupon, the UMs collected are delivered to the manufacturer in order to dispose of appropriately. The disposal methods are associated with the properties of the collected UMs and the local government's policy. Avoidance of penalty from environmental regulations, profit acquisition from the government's subsidy, resale of reusable medications, the reuse of disassembled recyclable parts and the growth of sales by the environmental image are the most common cause of collected UMs by the manufacturer; see Amaro and Barbosa-Povoa (2008), Huang *et al.* (2015), Weraikat *et al.* (2016a), and Weraikat *et al.* (2016b).

4.3.1 Assumptions

Assumption 1 - The suggested RL system is a three-person supply chain game composed of pharmaceutical manufacture, retailer, and a consumer under symmetric information structure and all members have perfect information regarding the supply chain. The products are sold to the consumers by the manufacturer through the retailer in the FSC. In the RSC, the retailer offers an incentive to motivate the consumer and collect more UMs, and the consumer evaluates the situation and decides whether to return the UMs and exchange them with new medicines, then the retailer sells back the collected UMs to the manufacturer. The state adopts a policy for a subsidy to the manufacturer for a unit of the medicines returned. The interactions between the members of the supply chain for collecting UMs are complicated due to the uncertainty distribution of the consumer decision and the channel power. In this situation, game theory is an effective tool to analyze the relationships between the members of the supply chain. Consequently, three Stackelberg games are studied based on the members who are the leader or follower in the games.

Assumption 2 - It is supposed that a unique pharmaceutical product is sold for simplifying the model. Another assumption is that P_r, the selling price of a medication, is constant in the FSC of time w and c_m remain fixed at reality medications' prices will not change commonly, because consumers purchasing the pharmaceutical product are often not price-sensitive consumers and the pharmaceutical market is completely competitive. In these conditions, the related parameters w and c_m also remain fixed. In Aust and Buscher (2012), Huang and Li (2001), Huang *et al.* (2007), and Zhang *et al.* (2013), the price was supposed to be invariant.

Assumption 3 - Let X_t, $t = 1, 2, \ldots, u$ be the quality perceived by the consumer and X_t are independent and they also distributed with cdf $F(.)$ and pdf $f(.) = F(.) > 0$ over the interval $[0,1]$.

Assumption 4 - There are some factors, for instance, price, quality, advertisement and warranty that have an influence on strategic consumers to decide about returning UMs. In this article, the manufacturer's advertising effort and retailer's exchange incentive proportion are the most important factors that influence the consumer's decision to exchange the UMs with the new products or not. The quality level R is uncertain and determined by the consumer is another factor. The amount of UM which have been collected, u, linearly depend on the manufacturer's advertising level, the retailer's exchange incentive proportion and quality level R.

$$u = k + \alpha_1 I + \beta_1 \varphi + \gamma_1 R, \tag{1}$$

where $k, \alpha_1,\ \beta_1, and\ \gamma_1$ are positive constants, such that the amount of the collection is always positive. $\alpha_1,\ \beta_1, and\ \gamma_1$ are the manufacturer's advertising effort, retailer's exchange proportion level and quality level elasticity, respectively.

Assumption 5 - In every part of this article, it is assumed that the measuring system of collecting UMs is based on the kilogram (kg) as units of weight. However, we can replace it with another measurement unit according to special situations. Hence, all related parameters $\alpha_0,\ \beta_0, \gamma_0,\ u, k,\ \alpha_1,\ \beta_1, \gamma_1, s, c_u, \rho_u,$ and ρ_m should be tied to the quantity (box). The amount of new medication that can be count for exchange is:

$$Q_P = \frac{\varphi}{P_r} u. \tag{2}$$

Assumption 6 - Let Q_f be the quantity of new products and Q_p be the quantity created to the consumer as an exchange incentive, if the consumer decides to return the UMs. Q_f is the selling quantity in the FSC which is positively affected by the manufacturer's advertising effort for collecting UMs, the retailer's exchange activity and the quality level defined by a consumer, because it is assumed that these activities not only can make more acceptable the enterprise green images for both the manufacturer and retailer but also can enhance consumer's understanding of the supply chain participants' corporate social responsibilities, to enhance consumer loyalty (He and Li, 2011; Perez *et al.,* 2013; Pirsch *et al.,* 2007; Salmones *et al.,* 2005) and attracts more consumers from their competitors, which can contribute to an increased amount of sales (Aksu, 2006). Thus, without a change in price, the demand is created as a deterministic model that is only affected by I which is the level of advertising effort and φ exchange incentive proportion in the collection activity and quality level R. Accordingly, the total quantity of new medications is obtained in this way

$$Q_f + Q_p = D + \alpha_0 I + \beta_0 \varphi + \gamma_0 R, \tag{3}$$

where D demonstrates the amount of basic market demand in the FSC without advertising and exchange incentive and quality level. $\alpha_0,\ \beta_0, and\ \gamma_0$ are either positive or zero and represent the sensitivity to the manufacturer's advertising effort and retailer's exchange proportion and consumer's quality level, respectively.

Assumption 7 - Both the amount of collected UMs u and the exchange quantity Q_p increase as φ, I, and R increase. For this reason, the larger $\varphi, I,$ and R are, the more UMs householders show desire to join in the collection activity which leads to an increase in the related cost. As a result, the related costs of effort are quadratic forms and are shown in this way $F\varphi^2$, EI^2, and LR^2 and concerning φ, I and R. This form of effort response models is also set in some studies; see Hong and Yeh (2012), Jorgensen and Zaccour (2014), Maiti and Giri (2017), Yang *et al.* (2013), and Zhou *et al.* (2016).

Assumption 8 - A consumer's valuation of a product is often highly personal and intrinsic (Zeithaml, 1988). The utility of the product evaluated by the consumer is related to her perception of what is received and what should be given back in return. Therefore, we suppose that the consumer's valuation function $V(X)$ is dependent on the perceived quality X.

$$\frac{dV(x)}{dx} > 0, \frac{d^2V(x)}{dx^2} < 0 \text{ and } lim_{x\to\infty}V(x) = V_{lim}$$

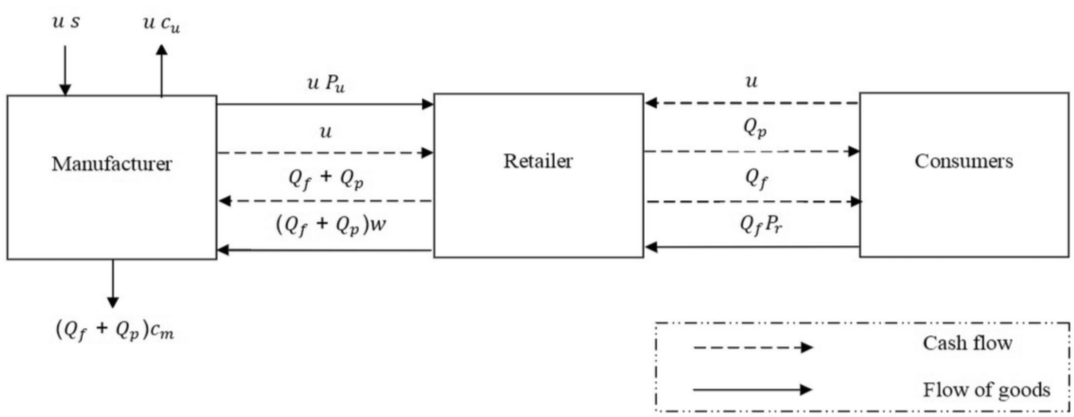
$$\frac{dV(x)}{dx} > 0, \frac{d^2V(x)}{dx^2} < 0 \text{ and } lim_{x\to\infty}V(x) = V$$

Assumption 9 - If the consumer does not accept an exchange offer and keeps UMs, a disutility cost will be incurred. Consequently, the consumer's satisfaction is affected adversely, denoted by s_0 and, it is assumed to be proportional to $V(X)$ according to $s_0 = \xi V(X)$ where $\xi \in [0,1]$. Note that the bounds imply that the disutility cost is positive and will not exceed the whole valuation of the product. Based on this condition, the higher the consumer's valuation of the product, the higher disutility will be incurred if the exchange offer is rejected.

4.4 Model Formulation for Each Player

In Figure 4.1, the closed loop supply chain (CLSC) is shown based on assumptions presented in the previous section.

Figure 4.1: Closed-loop supply chain with an exchange action



The mechanism is organized as follows: in the per production cycle, the collecting activity includes returning UMs from the consumer to the manufacturer and offering new products. The mechanism includes a manufacturer, a retailer and a strategic consumer, considering the consumer as an active member to appropriately investigate the performances of the whole chain. The procedure is the involvement of supply chain members in green activity, to transfer a product from the upstream to downstream or downstream to upstream. The upstream members and the consumer have interaction with each other, as the decision of the upstream may affect the consumer's decision and vice-versa. Based on the relation between the members mentioned in the above figure, the objective function of each member is presented. Moreover $m, r,$ and c are the symbol for the manufacturer, the retailer, and the consumer, respectively.

4.4.1 Retailer’s Model

The objective function of the retailer can be written as follows:

$$\pi_r = (P_u - w)Q_f - wQ_p - c_b F(R)u + P_u v - F\varphi^2 - \pi r_0, \tag{4}$$

where πr_0 represent profits without the collection activity and, $\pi r_0 = (P_r - w)D$. We substitute Equations (1) and (3) in Equation (4) and set $\pi r_0 = (P_r - w)D$ and $P_u - w = \rho_r,$ the decision function of the retailer yields.

$$\pi_r = \rho_r(\alpha_0 I + \beta_0\varphi + \gamma_0 R) + \big(P_u - \varphi - c_b F(R)\big)(k + \alpha_0 I + \beta_0\varphi + \gamma_0 R) - F\varphi^2, \tag{5}$$

where $c_b F(R)$ is the expected amount of product which the consumer will not return after evaluation due to its failure to reach the desired quality level, and they are unacceptable incentives from the consumer's valuation. When an incentive fails to reach the desired quality level of the consumer these will be given back to the manufacturer and $c_b F(R)$is lost cost due to consumer’s evaluation. The retailer's net profit margin m in the RSC is introduced as a new decision variable, $m = P_u - \varphi$ (Aust and Buscher, 2012). Therefore, replacing φ by $P_u - m$, we obtain

$$max\pi_r = \rho_r(\alpha_0 I + \beta_0(P_u - m) + \gamma_0 R) + \big(m - c_b F(R)\big)(k + \alpha_1 I + \beta_1\varphi + \gamma_1 R) - F(P_u - m)^2 \tag{6}$$

This decision problems can be solved by setting the first-order conditions $\frac{d\pi_r}{d\varphi} = 0$ and $\frac{d\pi_r}{dm} = 0$. The second-order conditions are $\frac{d^2\pi_r}{d\varphi^2} = -2(F + \beta_1)$. Therefore, π_r is concave. These yield the following equations

$$\varphi^* = \frac{-k - \alpha_1 I - \beta_1 c_b F(R) + \beta_1 P_u - \gamma_1 R + \beta_0 \rho_r}{2(F + \beta_1)} \tag{7}$$

and

$$m^* = \frac{k + 2FP_u + \alpha_1 I + \beta_1 c_b F(R) + \beta_1 P_u + \gamma_1 R - \beta_0 \rho_r}{2(F + \beta_1)} \tag{8}$$

Equations (7) and (8) imply that retailer's exchange incentive proportion from UMs to new medication is increasing in consumer's quality level R, but decreasing in I.

4.4.2 Manufacturer's Model

The profit of the manufacturer is the difference between the revenue and the costs. The revenue implies the income generated from selling new products that consumers buy in the FSC and new products for exchanging offers, the Government's subsidy for the returned products. The costs involve the disposal and transportation of UMs collected from the retailer to the manufacturer, the price that the manufacturer paid to the retailer for UMs returned and the manufacturer's unit cost incurred by the production of products. The manufacturer's annual profit function is:

$$\pi_m = (w - c_m)\big(Q_f + Q_p\big)\big(s - c_u - P_u - c_r F(R)\big)u - EI^2 - \pi_{m0}, \tag{9}$$

where π_{m0} represents the manufacturer's annual profit without considering the collection activity and $\pi_{m0} = (P_r - w)D$. We substitute Equations (1) and (3) in Equation (9) and set $\pi_{m0} = (w - c_m), w - cm = \rho_m ands - c_u - c_r F(R) = \rho_u$. We obtain the decision functions of the manufacturer as follows:

$$\pi_m = \rho_m(\alpha_0 I + \beta_0 \varphi + \gamma_0 R) + (\rho_u - P_u)(k + \alpha_1 I + \beta_1 \varphi + \gamma_1 R) - EI^2 \tag{10}$$

$c_r F(R)$ is the lost cost due to consumer's evaluation. The first order condition with respect to P_u and I yields

$$P_u^* = \frac{-k - \alpha_1 I + \beta_1 m - \beta_1 F(R) c_r - \gamma_1 R + \beta_0 \rho_m + \beta_1 \rho_u}{2\beta_1}, \tag{11}$$

and

$$I^* = \frac{-\alpha_1 P_u - \alpha_1 F(R) c_r + \alpha_0 \rho_m + \alpha_1 \rho_u}{2E}, \tag{12}$$

and since

$$\frac{d^2 \pi_m}{dI^2} = -2E < 0 \; and \; \frac{d^2 \pi_m}{d{P_u}^2} = -2\beta_1 < 0.$$

Therefore, π_m is concave. From Equation (11), we observe that the price paid by the manufacturer to the retailer for returned UMs is decreasing in I and R but increasing in ρ_m and ρ_u. Besides, from the Equation (12), we observe that manufacturer's advertising effort level is decreasing in P_u but increasing in ρ_m and ρ_u.

4.4.3 Consumer's Model

The consumer decides to return UMs after determining the quality level X. This decision is taken by the consumer based on her judgement of the product's overall excellence or superiority; see Zeithaml (1988). So the uncertain judgement of the quality determined by the consumer is represented by a probability distribution. The consumer is uncertain whether to return UMs or to keep them, her decision will be based on comparing X against a fixed quality level R, if the real quality $X > R$, the product will be returned, otherwise, the product will not be returned. The consumer decides whether to accept exchange offer Q_p ordered by the retailer for exchange incentives from the manufacturer. T_t is given by:

$$T_t = \begin{cases} 1 \; if \; X_t \geq R, \\ 0 \; if \; X_t < R \end{cases}$$

based on the quality X_t, $t = 1, \ldots, u$. The quantity returns by the consumer are

$$q = \sum_{i}^{u} I_j,$$

with expected value.

$$E(q) = u\big(1 - F(R)\big),$$

and the expected quantity does not return by the consumer is.

$$u - E(q) = uF(R).$$

The consumer's utility is

$$\pi_c = (E(V(x)E(q)) - E(s_0)(U - E(q))Q_f P_r - LI^2, \tag{13}$$

where $E\big(V(x)\big)$ is the consumer valuation and $E(s_0)$ is disutility due to not accepting the exchange offer by the consumer. Hence, the first order condition with respect to R yields

$$R' = \frac{(E(V(x) + E(s_0))(f(R)(k + \alpha_1 I + \beta_1\varphi + \gamma_1 F(R))) + \gamma_1(E(V(x) + \varphi) - \gamma_1 P_r}{(E(V(x) + E(s_0))\gamma_1 f(R) + 2L} \tag{14}$$

4.5 Stackelberg Games

4.5.1 Manufacturer–Stackelberg Game

In this game, the manufacturer could have more channel power to lead the game and take on the role of leader, the retailer and consumer are the followers. This model situation is solved by Stackelberg equilibrium (Xie and Neyret, 2009). The manufacturer as a leader is acquainted with the retailer's and consumer's reactions to his decision and makes the final decision on price pay to the retailer for returned UMs and advertising by selecting the optimal strategy among the best responses by the consumer and the retailer. The manufacturer's decision problem in the Stackelberg equilibrium is:

$$max\, \pi_m = \rho_m(\alpha_0 I + \beta_0\varphi + \gamma_0 R) + (\rho_u - P_u - c_r F(R))(k + \alpha_1 I + \beta_1\varphi + \gamma_1 R) - EI^2, \tag{15}$$

subject to

$$m = \frac{k + 2FP_u + \alpha_1 I + \beta_1 c_b F(R) + \beta_1 P_u + \gamma_1 R - \beta_0\rho_r}{2(F + \beta_1)} \tag{16}$$

and

$$R = \frac{-(E(V(x)) - E(s_0))(f(R)(k + \alpha_1 I + \beta_1 \varphi + \gamma_1 F(R) + \gamma_1(E(V(x) + \varphi) - \gamma_1 P_r}{(E(V(x) + E(s_0))\gamma_1 f(R) + 2L} \tag{17}$$

The optimal results are obtained after substituting the constraints into the objective function to eliminate the retailer's and consumer's decision variables and then setting the first-order derivatives of the manufacturer's variables to zero. The manufacturer makes the first move and selects I and P_u. The retailer replies with m that satisfies Equation (16) and, the consumer replies with R that satisfies Equation (17).

4.5.2 Retailer–Stackelberg Game

The situation where the retailer occupies more power to the other members is considered, which can be modelled as the retailer Stackelberg leader. The game's sequence proceeds in a similar manner outlined in Section 5.1. The retailer's decision problem in the Stackelberg equilibrium is:

$$max\ \pi_r = (P_u - w)Q_f - wQ_p - c_b F(R)u + P_u v - F\varphi^2 - \pi_{r0}, \tag{18}$$

subject to

$$P_u = \frac{-k - \alpha_1 I + \beta_1 m - \beta_1 c_b F(R) c_r - \gamma_1 R + \beta_0 \rho_m + \beta_1 \rho_u}{2\beta_1} \tag{19}$$

$$I = \frac{-\alpha_1 P_u - \alpha_1 F(R) c_r + a_0 \rho_m + \alpha_1 \rho_u}{2E}, \tag{20}$$

and

$$R = \frac{-(E(V(x)) - E(s_0))(f(R)(k + \alpha_1 I + \beta_1(\rho_u - m) + \gamma_1(E(V(x) + (P_u - m)) - \gamma_1 P_r}{(E(V(x) + E(s_0))\gamma_1 f(R) + 2L} \tag{21}$$

In this game, the problem is determining the most profitable incentive by the retailer as a leader, based on the manufacturer and consumer's best responses, so that his profit would be maximized. Substituting Equation (21) into Equation (20), then substituting Equation (20) into Equation (19) gives P_u and I based on m. It leads to an objective function without the constraints. By eliminating the manufacturer's and the consumer's variables, the retailer's variable m is obtained by setting the first-order derivatives of m to zero. Subsequently, the manufacturer and the consumer's variables and their objective functions will be obtained with having m.

4.5.3 Consumer–Stackelberg Game

The consumer has the role of leader, and the manufacturer and the retailer assume the role of followers in this game. The consumer's decision will be based on evaluating the exchange incentive to determine if the quality level is acceptable to him. Then the consumer decides whether to exchange the UMs or not. The consumer's optimization problem based on the manufacturer's and consumer's best responses is:

subject to:

$$max\, \pi_c = (E(V(x)E(q)) - E(s_0)(U - E(q))Q_f P_r - LI^2 \tag{22}$$

$$P_u = \frac{-k - \alpha_1 I + \beta_1 m - \beta_1 c_b F(R) c_r - \gamma_1 R + \beta_0 \rho_m + \beta_1 \rho_u}{2\beta_1} \tag{23}$$

$$I = \frac{-\alpha_1 P_u - \alpha_1 F(R) c_r + \alpha_0 \rho_m + \alpha_1 \rho_u}{2E}, \tag{24}$$

and

$$m = \frac{k + 2FP_u + \alpha_1 I + \beta_1 c_b F(R) + \beta_1 P_u + \gamma_1 R - \beta_0 \rho_r}{2(F + \beta_1)} \tag{25}$$

The optimal results are obtained after substituting the constraints into the objective function to eliminate the manufacturer and retailer's decision variables and then setting the first order derivatives of the consumer's variables to zero. Accordingly, we will have an optimization problem with no constraints that can be solved numerically for the optimal decision variable R.

4.6 Numerical Results

The focus of this section is on numerical examples to indicate the preceding Stackelberg and the implementation of the leadership role of each member. The classical utility function is considered as a consumer's valuation function which is

$$V(x) = \left(1 - e^{-\lambda x}\right)\tilde{V}, where\ \lambda > 0$$

Therefore, the consumer's disutility function is $s_0 = \xi V(x)$. The data shown in Table 5.1 are assumed in the example. The specific optimal solutions in three games are obtained by considering the manufacturer–Stackelberg game, retailer–Stackelberg game and consumer–Stackelberg game where the manufacturer, the retailer and the consumer are the leaders, respectively. The results of the games are listed in Table 4.2 The numerical results show that the consumer's utility obtained the best result when the manufacturer is considered as the leader. They show that among the three games, the manufacturer– Stackelberg game achieves the best total unwanted medicines. Besides, the consumer's utility obtained the best result when the manufacturer is considered as the leader. It is indicated that there is a positive relationship between consumer's utility and collecting unwanted medicines. The greater consumer's utility makes collecting more unwanted medicines. The manufacturer's and the retailer's profit and the consumer utility in three games have the following results. There is more profit when both the manufacturer and retailer are in the position of being the leader in the Stackelberg game. However, the consumer is better off when the manufacturer is the leader. Moreover, the manufacturer and retailer obtained the least payoff when the consumer is the leader. These observations result, it is likely the manufacturer will try to form a coalition with the retailer against the consumer. The decision variables in the three Stackelberg games have the following ordinal relationship:

$$I_r > I_m > I_c, \qquad \varphi_m > \varphi_r > \varphi_c, \qquad R_r > R_c > R_m, \qquad P_m > P_r > P_c$$

In the following, we analyze the FSC when the members of the supply chain do not participate in collection activity. The optimal results are shown in Table 4.3 The arrow ↑ denotes the value which increases in comparison to the basic example and ↓ denotes the opposite. The results are compared with the basic example. It shows that all variables decline except P_u.

The two members would not rather make more investment to take part in this activity, resulting in a barrier to collecting UMs. Hence, it is better for one that takes part in collection to look for its partner with the agreement that the collection activity could promote sales by establishing green enterprise images and increasing the customer awareness of the supply chain participants' corporate social responsibilities.

In the following, we analysis on how changing the parameters ρ_m and ρ_r affect supply chain members' profit. These two parameters are the manufacturer's profit margin and the retailer's profit margin, respectively. In the three Stackelberg games, these changes influence I, R and φ. The results show that in all three games I increases while R and φ decrease. From the results in Table 4.4, the retailer's and the consumer's profits regardless of who is the leader increase, whereas the manufacturer's profit declines in all three Stackelberg games.

We also evaluate the changing of the decision variables concerning initial voluntary. The results show that if the initial voluntary for giving back the UMs increases and the other parameters remain fixed, for both manufacturer–Stackelberg and retailer–Stackelberg games, two decision variables R and I decrease. It means using an exchange incentive is more favorable. In contrast, by decreasing the initial voluntary in the manufacturer–Stackelberg and the retailer–Stackelberg games, the decision variable φ decreases. In this situation, the supply chain prefers implementing advertising for collecting more UMs. Besides, the consumer quality level R increases.

Table 4.1: Parameters and their values

α_0	β_0	γ_0	c_b	α_1	β_1	γ_1	k
2	500	250	0.5	5	900	400	1000
c_r	ρ_r	ρ_m	ρ_u	D	P_r	400	E
0.1	15	1	1	100	5	400	0.5
L	F						
0.5	400						

The manufacturer, retailers and consumers' profit are delineated in Figures 4.2 to 4.4. On the one hand, the manufacturer's profit is descending on the other hand the profit for the retailer and consumer are ascending with respect to ρ_m.

Table 4.2. Optimal solutions in three games

	Manufacture-led	Retailer-led	Consumer-led
I	4.69	5.75	3.38
φ	1.23	1.09	0.8
R	5.045	4.63	3.22
U	3137.4519	2845.21875	2019.1878
P_u	0.45	0.55	0.85
π_r	7304.97625	7525.84875	6880.2395
π_m	3322.91895	2727.69875	1327.5418
π_c	3714.912237	3262.6853	2773.0653

Table 4.3. Optimal solutions in three games ($\alpha_0 = 0, \beta_0 = 0, and\ \gamma_0 = 0$)

	Manufacturer-led	Retailer-led	Consumer-led
I	↓	↓	↓
φ	↓	↓	↓
R	↓	↓	↓
U	↓	↓	↓
P_u	↑	↑	↑
π_r	↓	↓	↓
π_m	↓	↓	↓
π_c	↓	↓	↓

Table 4.4. Optimal solution in three games ($\rho_m = 2\ and\ \rho_r = 4$*) parameters*

	Manufacturer-led	Retailer-led	Consumer-led
I	↑	↑	↑
φ	↓	↓	↓
R	↓	↓	↓
U	↑	↑	↑
P_u	↑	↑	↑
π_r	↑	↑	↑
π_m	↓	↓	↓
π_c	↑	↑	↑

Figure 4.2. The profits of the manufacturer with respect to ρ_m

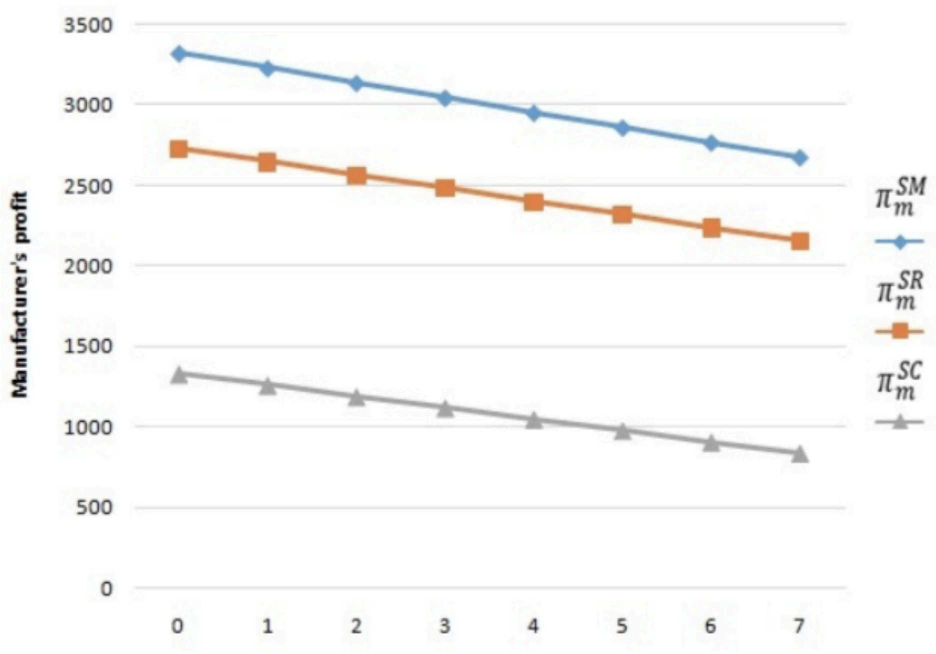


Figure 4.3. The profits of the retailer with respect to ρ_m

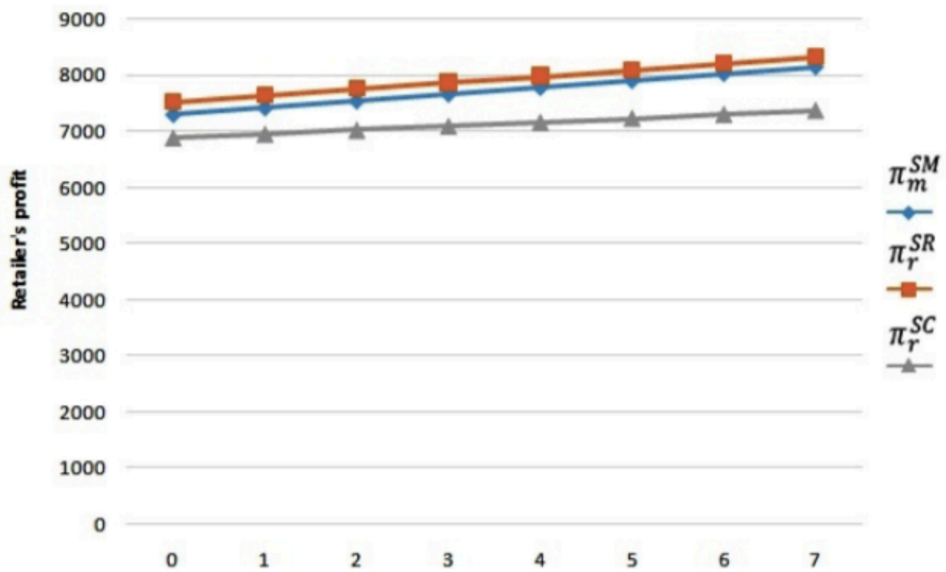
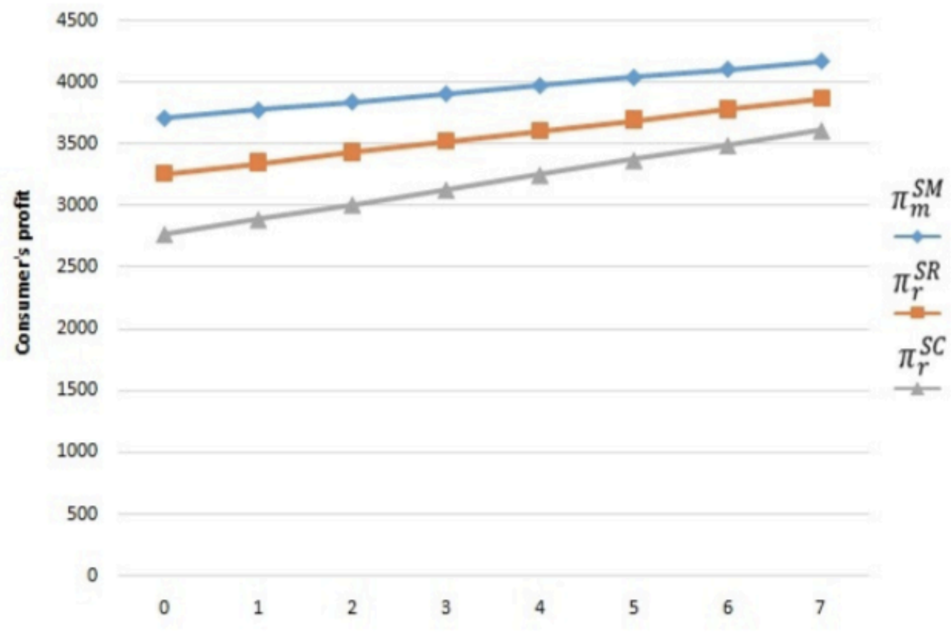


Figure 4.4. The profits of the consumer with respect to ρ_m



4.7 Notations and Definitions

By facilitating the model, certain parameters and decision variables are used. Notations and definitions used in our model are shown in Table 4.5.

Table 4.5. Notations and definitions

Parameters	
Q_f	Quantity of new medications which have been bought by the consumer in the FSC.
D	The basic market demand in the FSC without any incentive.
α_0	Coefficient of consumers' sensitivity toward the manufacturer's advertising effort level.
β_0	Coefficient of consumers' sensitivity toward the retailer's points-exchange incentive.
γ_0	Coefficient of consumers'sensitively toward the consumer's quality level.
c_m	Manufacturer's unit cost incurred by the production of medications.
w	Wholesale price of the manufacturer in the medication market.
P_r	Retailer's selling price of new medications.
ρ_m	Manufacturer's profit margin in the FSC (i.e., $\rho_m = w - c_m$).
ρ_r	Retailer's profit margin in the FSC (i.e., $\rho_r = Pr - w$).
ρ	Total profit margin of the two members in the FSC (i.e., $\rho = \rho_m + \rho_r$).
Q_p	Quantity of new medications for exchanging offer.
u	The quantity of UMs which have been collected and have been returned to the retailer.
d	Potential voluntary take-back Scale of UMs without any incentive.
α_1	Coefficient of UMs holders' sensitivity to manufacturer's advertising effort level.
β_1	Coefficient of UMs holders' sensitivity to retailer's points-exchange incentive proportion.
γ_1	Coefficient of UMs holders'sensitivity to consumer's quality level.
s	Government's subsidy for unit collected UMs incurred by disposal activity.
c_u	Manufacturer's cost per weight incurred by the disposal and transportation of collected UMs from the retailer to the manufacturer.
ρ_u	Manufacturer's unit net profit incurred by disposal activity (i.e., $\rho_u = s - c_m$).
m	Retailer's margin incurred by collection activity (i.e., $\rho_u = P_u - \varphi$).
E	Manufacturer's advertising effort level maintaining the coefficient of cost.
F	Retailer's exchange offer maintaining the coefficient of cost.
L	Consumers quality level maintaining the coefficient of cost.
ξ	Coefficient of disutility, where $\xi \in [0,\ 1]$.
c_b	Retailers unit lost due to consumer evaluation.
c_r	Manufacturers unit lost due to consumer evaluation.
I	Pharmaceutical manufacturer's advertising effort level.
φ	Retailer's points-exchange incentive proportion from UMs to new medication.
P_u	The price paid by a manufacturer to retailer for every unit of UMs which are returned.
X	The quality as perceived by the consumer, a random variable.
$V(X)$	The consumers valuation function.
V	Upper bound of the valuation function.
s_0	Consumers disutility function.
$F(.)$	Cumulative Distribution Function (cdf) of X.
$f(.)$	Probability Density Function (pdf) of X.
R	The quality level evaluated by the consumer.

4.8 Conclusions

In this article, we have created an RL system to collect UMs from households, that is, a model of a supply chain designed in a decentralized state including manufacturer, and retailer with a strategic consumer. Besides, an incentive scheme and advertising through an RL system have been suggested to stimulate consumers in RSC for collecting more UMs from households. Unlike other RL systems, which only focus on the upstream members of the RSC, this proposed RL system has involved the consumer as a strategic player in the supply chain model. In fact, this research has designed an RL system for collecting UMs with engaging the consumer. Despite the previous research, interaction with the consumer by considering the consumer's utility in the proposed RL system helps build an effective RL system. Not only does this interaction increase consumer's awareness of their corporate social responsibilities but also produces a green image for both manufacturer and retailer which in turn creates loyal customers. The interesting point of this article is that we have tried to investigate the result of having an appropriate RSC method from the consumer's perspective. The behavior and evaluation of the consumer on the proposed strategies affect both the manufacturer and retailer's profits. Reversely, the decisions of the manufacturer and retailer have an influence on the consumer's benefit. So, this interaction has been investigated and resulted in a successful green activity. Moreover, the suggested RL system designed properly is beneficial for both FSC and RSC and it showed how participating in green activities gives advantages to the members of the supply chain. Indeed, we applied the Stackelberg game by selecting retailer as the Stackelberg leader, manufacturer as the Stackelberg leader and consumer as a leader.

4.9 References

Agrawal, S., Singh, R. K., and Murtaza, Q. (2015). A literature review and perspectives in reverse logistics. Resources, Conservation and Recycling, 97, 76-92. doi: 10.1016/j.resconrec.2015.02.009

Akcali, E., Cetinkaya, S., and Uster, H. (2009). Network design for reverse and closed-loop supply chains: An annotated bibliography of models and solution approaches. *Networks*, 53, 231-248. doi: 10.1002/net.20267

Aksu, A. (2006). Gap analysis in customer loyalty: A research in 5-star hotels in the Antalya region of Turkey. *Quality and Quantity*, 40, 187-205. doi: 10.1007/s11135-005-5,357-y

Al-Shareef, F., Abu El-Asrar, S., Al-Bakr, L., Al-Amro, M., Alqahtani, F., Aleanizy, F., and Alrashood, S. (2016). Investigating the disposal of expired and unused medication in Riyadh, Saudi Arabia: A cross-sectional study. *International Journal of Clinical Pharmacy*, 38, 822-828. doi: 10.1007/s11096-016-0287-4

Amaro, A.C.S. and Barbosa-Povoa, A. (2008). Planning and scheduling of industrial supply chains with reverse flows: A real pharmaceutical case study. *Computers & Chemical Engineering,* 32, 2606-2625. doi: 10.1016/j.compchemeng.2008.03.006

Aras, N., Boyaci, T., and Verter, V. (2010). Designing the reverse logistics network. In Closed-loop supply chains: New developments to improve the sustainability of business practices, 67–97. *Boca Raton, FL: Auerbach Publications.*

Atasu, A., Van Wassenhove, L. N., and Sarvary, M. (2009). Efficient take-back legislation. Production and Operations Management, 18, 243-258. doi: 10.1111/j.1937-5.956.2009.01004.x

Aust, G. and Buscher, U. (2012). Vertical cooperative advertising and pricing decisions in a manufacturer-retailer supply chain: A game-theoretic approach. *European Journal of Operational Research*, 223, 473–482. doi: 10.1016/j.ejor.2012.06.042

Aust, G. and Buscher, U. (2014). Cooperative advertising models in supply chain management: A review. *European Journal of Operational Research*, 234, 1-14. doi: 10.1016/j.ejor.2013.08.010

Bing, X.Y., Bloemhof, J.M., Ramos, T.R.P., Barbosa-Povoa, A.P., Wong, C.Y., and Van der Vorst, J.G.A.J. (2016). Research challenges in municipal solid waste logistics management. *Waste Management*, 48, 584-592. doi: 10.1016/j.wasman.2015.11.025

Blackburn, J. D., Guide, V. D.R., Souza, G. C., and Van Wassenhove, L.N. (2004). Reverse supply chains for commercial returns. *California Management Review,* 46(2), 6-22. doi:10.2307/41166207

Chesnokova, T. (2007). Return policies, market outcomes, and consumer welfare. *Canadian Journal of Economics,* 40(1), 296-316. doi: 10.1111/j.1365-2.966.2007.00409.x

Fehr, M. and Santos, F.C. (2009). Landfill diversion: Moving from sanitary to economic targets. *Cities*, 26, 280-286. doi: 10.1016/j.cities.2009.07.007

Ferrara, M., Khademi, M., Salimi, M., and Sharifi, S. (2017). Dynamic Stackelberg game of supply chain for a corporate social responsibility. *Discrete Dynamics in Nature and Society*. doi: 10.1155/2017/8656174

Gong, Y., Jia, F., Brown, S., and Koh, S.C.L. (2018). Supply chain learning of sustainability in multi-tier supply chains: A resource orchestration perspective. *International Journal of Operations & Production Management*, 38(4), 1061-1090. doi:10.1108/IJOPM-05-2017-0306

Govindan, K. and Popiuc, M.N. (2014). Reverse supply chain coordination by revenue sharing contract: A case for the personal computers industry. *European Journal of Operational Research*, 233(2), 326-336. doi: 10.1016/j.ejor.2013.03.023

Govindan, K., Popiuc, M.N., and Diabat, A. (2013). Overview of coordination contracts within forward and reverse supply chains. *Journal of Cleaner Production*, 47, 319-334. doi: 10.1016/j.jclepro.2013.02.001

Govindan, K., Soleimani, H., and Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research,* 240, 603-626. doi: 10.1016/j.ejor.2014.07.012

Guo, S., Shen, B., Choi, T.M., and Jung, S. J. (2017). A review on supply chain contracts in reverse logistics: Supply chain structures and channel leaderships. *Journal of Cleaner Production*, 144, 387-402. doi: 10.1016/j.jclepro.2016.12.112

He, H.W. and Li, Y. (2011). CSR and service brand: The mediating effect of brand identification and moderating effect of service quality. *Journal of Business Ethics*, 100, 673-688. doi: 10.1007/s10551-010-0703-y

Hong, I.H. and Yeh, J.S. (2012). Modeling closed-loop supply chains in the electronics industry: A retailer collection application. *Transportation Research Part E: Logistics and Transportation Review*, 48, 817-829. doi: 10.1016/j.tre.2012.01.006

Hong, X., Xu, L., Du, P., and Wang, W. (2015). Joint advertising, pricing and collection decisions in a closed-loop supply chain. *International Journal of Production Economics*, 167, 12-22. doi: 10.1016/j.ijpe.2015.05.001

Horton, P., Koh, L., and Guang, V.S. (2016). An integrated theoretical frame- work to enhance resource efficiency, sustainability and human health in agri-food systems. *Journal of Cleaner Production*, 120, 164-169. doi: 10.1016/j.jclepro.2015.08.092

Hua, M., Lai, I.K.W., and Tangc, H. (2019). Analysis of advertising and a points-exchange incentive in a reverse supply chain for unwanted medications in households based on game theory. *International Journal of Production Economics*, 217, 259-268. doi: 10.1016/j.ijpe.2019.02.004

Huang, H., Li, Y., Huang, B., and Pi, X. (2015). An optimization model for expired drug recycling logistics networks and government subsidy policy design based on tri-level programming. *International Journal of Environmental Research and Public Health*, 12, 7738-7751. doi: 10.3390/ijerph120707738

Huang, Z.M. and Li, S.X. (2001). Co-op advertising models in manufacturer-retailer supply chains: A game theory approach. *European Journal of Operational Research,* 135, 527-544. doi: 10.1016/S0377- 2217(00)00327-1

Huang, Z.M., Li, S.X., and Mahajan, V. (2007). An analysis of manufacturer-retailer supply chain coordination in cooperative advertising. *Decision Sciences*, 33, 469-494. doi: 10.1111/j.1540-5,915.2002.tb01652.x

Jalil, E.E.A., Grant, D.B., Nicholson, J.D., and Deutz, P. (2016). Reverse logistics in household recycling and waste systems: A symbiosis perspective. *Supply Chain Management*, 21, 245-258. doi: 10.1108/SCM-02-2015-0056

Jonjic, D. and Vitale, K. (2014). Issues around household pharmaceutical waste disposal through community pharmacies in Croatia. *International Journal of Clinical Pharmacy,* 36, 556-563. doi: 10.1007/ s11096-014-9,936-7

Jorgensen, S. and Zaccour, G. (2014). A survey of game-theoretic models of cooperative advertising. *European Journal of Operational Research*, 237, 1-14. doi: 10.1016/j.ejor.2013.12.017

Kozak, M.A., Melton, J.R., Gernant, S.A., and Snyder, M.E. (2016). A needs assessment of unused and expired medication disposal practices: A study from the medication safety research network of Indiana. *Research in Social and Administrative Pharmacy*, 12, 336-340. doi: 10.1016/j.sapharm.2015.05.013

Kremer, M., Mantin, B., and Ovchinnikov, A. (2015). Dynamic pricing in the presence of myopic and strategic consumers: Theory and experiment. *Production and Operations Management*, 26(1), 116-133. doi: 10.1111/poms.12607

Kumar, S., Dieveney, E., and Dieveney, A. (2009). Reverse logistic process control measures for the pharmaceutical industry supply chain. *International Journal of Productivity and Performance Management,* 58(2), 188-204. doi: 10.1108/17410400910928761

Maiti, T. and Giri, B.C. (2017). Two-way product recovery in a closed-loop supply chain with variable markup under price and quality dependent demand. *International Journal of Production Economics*, 183, 259-272. doi: 10.1016/j.ijpe.2016.09.025

Mak, V., Rapoport, A., Gisches, E.J., and Han, J. (2014). Purchasing scarce products under dynamic pricing: An experimental investigation. *Manufacturing & Service Operations Management*, 16, 425-438. doi: 10.1287/msom.2014.0480

Massoud, M.A., Chami, G., Al-Hindi, M., and Alameddine, I. (2016). Assessment of household disposal of pharmaceuticals in Lebanon: Management options to protect water quality and public health. *Environmental Management*, 57, 1125-1137. doi: 10.1007/s00267-016- 0666-6

Perez, A., Salmones, M.d.M.G.d.L., and Bosque, I.R.D. (2013). The effect of corporate associations on consumer behavior. *European Journal of Marketing*, 47, 218-238. doi: 10.1108/03090561311285529

Pirsch, J., Gupta, S., and Grau, S. L. (2007). A framework for understanding corporate social responsibility programs as a continuum: An exploratory study. *Journal of Business Ethics*, 70, 125-140. doi: 10.1007/s10551-006-9,100-y

Quariguasi Frota Neto, J., Walther, G., Bloemhof, J., van Nunen, J. A. E. E., and Spengler, T. (2009). From closed-loop to sustainable supply chains: The WEEE case. *International Journal of Production Research*, 48, 4463-4481. doi: 10.1080/00207540902906151

Rai, N. (2013). Impact of advertising on consumer behavior and attitude with reference to consumer durables. *International Journal of Management and Business Strategy*, 2, 74-78.

Salmones, M.D.M.G.D.L., Crespo, A.H., and Bosque, I.R.D. (2005). Influence of corporate social responsibility on loyalty and valuation of services. *Journal of Business Ethics*, 61, 369-385. doi: 10.1007/s10551-005-5.841-2

Savaskan, R.C. and Van Wassenhove, L.N. (2006). Reverse channel design: The case of competing retailers. *Management Science*, 52(1), 1-14. doi: 10.1287/mnsc.1050.0454

Su, X.M. and Zhang, F.Q. (2008). Strategic customer behavior, commitment, and supply chain performance. *Management Science*, 54(10), 1759-1773. doi: 10.2139/ssrn.1010268

Tang, H.J., Cheng, T.C.E., and Ng, C.T. (2012). A note on the subtree ordered median problem in networks based on nestedness property. *Journal of Industrial and Management Optimization*, 8, 41-49. doi: 10.3934/jimo.2012.8.41

Tong, A.Y., Peake, B.M., and Braund, R. (2011). Disposal practices for unused medications around the world. *Environment International*, 37, 292-298. doi: 10.1016/j.envint.2010.10.002

Van Herpen, E., and de Hooge, I. E. (2019). When product attitudes go to waste: Wasting products with remaining utility decreases consumers' product attitudes. *Journal of Cleaner Production*, 210, 410-418. doi: 10.1016/j.jclepro.2018.10.331

Walther, G., Schmid, E., and Spengler, T.S. (2008). Negotiation-based coordination in product recovery networks. *International Journal of Production Economics*, 111(2), 334-350. doi: 10.1016/j.ijpe.2006. 12.069

Weraikat, D., Kazemi Zanjani, M., and Lehoux, N. (2016a). Two-echelon pharmaceutical reverse supply chain coordination with customers incentives. *International Journal of Production Economics,* 176, 41-52. doi: 10.1016/j.ijpe.2016.03.003

Weraikat, D., Kazemi Zanjani, M., and Lehoux, N. (2016b). Coordinating a green reverse supply chain in the pharmaceutical sector by negotiation. *Computers & Industrial Engineering*, 93, 67-77. doi: 10.1016/j.cie.2015.12.026

WHO (2014). Safe Management of Wastes from health-care activities. *World Health Organization*.

Xie, J. X. and Neyret, A. (2009). Co-op advertising and pricing models in manufacturer-retailer supply chains. *Computers & Industrial Engineering*, 56, 1375-1385. doi: 10.1016/j.cie.2008.08.017

Xie, Y. and Breen, L. (2014). Who cares wins? A comparative analysis of household waste medicines and batteries reverse logistics systems. *Supply Chain Management*, 19, 455-474. doi: 10.1108/ SCM-07-2013-0255

Yang, J., Xie, J., Deng, X., and Xiong, H. (2013). Cooperative advertising in a distribution channel with fairness concerns. *European Journal of Operational Research*, 227, 401-407. doi: 10.1016/j.ejor.2012.12.011

Zeithaml, V. A. (1988). Consumer perceptions of price, quality, and value: A means-end model and synthesis of evidence. *Journal of Marketing*, 52(3), 2-22. doi: 10.1177/002224298805200302

Zhang, J., Gou, Q. L., Liang, L., and Huang, Z. M. (2013). Supply chain coordination through cooperative advertising with reference price effect. *Omega*, 41, 345-353. doi: 10.1016/j.omega.2012.03.009

Zhou, Y., Bao, M., Chen, X., and Xu, X. (2016). Co-op advertising and emission reduction cost sharing contracts and coordination in low-carbon supply chain based on fairness concerns. *Journal of Cleaner Production*, 133, 402-413. doi: 10.1016/j.jclepro.2016.05.097

5. CHAPTER FIVE – MODELING SUPPLY CHAIN IN THE ERA OF PANDEMICS: A DYNAMIC APPROACH

This chapter has been supervised by Prof. Davide La Torre from SKEMA Business School and Université Côte d'Azur (Sophia Antipolis Campus, France) and contains the two joint works carried out during the research stay (October 2020 - July 2021) as a visiting Ph.D. student of Iside Rita Laganà at SKEMA Business School of Sophia Antipolis Campus (France). Both works are co-authored by Proff. Cinzia Colapinto (Department of Strategy and Management, IPAG Business School, Nice Campus, France) and Davide La Torre (SKEMA Business School and Université Côte d'Azur, Sophia Antipolis Campus, France), and Dr. Danilo Liuzzi (Department of Economics, Management, and Quantitative Methods, University of Milan, Italy). In this chapter, the compiler collects the main results of the two joint works entitled respectively "Impact of epidemic dynamics on retail distribution networks" and "Modeling shock propagation on supply chain networks: a stochastic logistic-type approach". Both were submitted and accepted after a double-blind review process as conference papers and presented respectively at the "6th Colloquium on European Research in Retailing (CERR) 2021", held from 15th to 17th of July 2021 on the SKEMA Business School of Sophia Antipolis Campus (France), and at the International Conference "Advances in Production Management Systems (APMS) 2021" organized by the International Federation for Information Processing (IFIP) and held online in Nantes (France) from 5th to 9th of September 2021.

5.1 Introduction

Supply chains (SCs) have been more and more suffering by unforeseen and disruptive events, such as terrorist attacks, economic crises, natural disasters, political conflicts, and epidemics, that could negatively impact the normal flow of materials, information, and money. Indeed, in recent years, studies on supply chain disruptions are receiving ever growing attention from academic researchers and practitioners.

Throughout the history of public health, Cholera Pandemics (1817-1923), Spanish Flu (1918-1919), HIV/AIDS (1981-present), SARS (2002-2003), Ebola (2014-2016), MERS (2015-present), and now COVID-19 are some of the most famous and brutal diseases that outbroke across international borders, often causing many deaths. The recent pandemic triggered by the outbreak of the new COVID-19 is considered a new type of disruption quite unlike any seen before (Ivanov and Das, 2020). Since the first days of the outbreak, its effects have been significantly and negatively impacting all business areas, affecting the efficiency of operations and showing the vulnerability of supply chain networks (Colapinto *et al.,* 2021b). The COVID-19 pandemic is a highly contagious virus-induced communicable disease caused by a newly discovered coronavirus, first identified in late 2019 in Wuhan, Hubei Province, China and spread in a very short time to all countries of the world. The virus spreads rapidly from human to human mainly due to the transmission that occurs when healthy individuals encounter respiratory droplets from an infected person's cough or sneeze or via contaminated objects or materials such as utensils, furniture, and cloths (La Torre *et al.,* 2020). As a consequence, scientists, policymakers, and managers around the world have tried to predict the evolution of the epidemic while keeping it under control by implementing traditional prevention and treatment measures (e.g., quarantine, voluntary isolation, use of masks, restrictions on mobility, social distancing, etc.) to manage and reduce the spread of the disease (Colapinto *et al.,* 2021b). The COVID-19 outbreak has notably revived the interest in mathematical epidemiology to describe the behavior of a disease (Ucakan *et al.,* 2021; La Torre *et al.,* 2021). In epidemiology, mathematical models are a useful tool for understanding the future course of an outbreak and helping to inform public health intervention in planning effective control strategies. Disease transmission models, or epidemic models for short, are an integral part of the epidemiologists' toolkit whose main goal can be summarized as the ability to accurately understand the mechanisms of spread of a disease affecting a population, to predict its future growth, and develop strategies to control it (Brauer, 2017; Nakamura and Martinez, 2019). Over the years, various approaches have been developed to model disease outbreaks, such as compartmental equations, stochastic equations, agent-based simulations, etc. Each approach suits a specific aspect of the outbreak studied, built upon hypotheses compatible with empirical records or based on a phenomenological context. Despite the significant advances obtained in the past few decades in describing the mechanism by which epidemics would spread, some control strategies (i.e., vaccination treatment, quarantine, social distancing, etc.) have been often neglected.

This chapter is structured as follows. Section 5.2 presents a general overview of mathematical modeling of infectious diseases to improve readers' understanding of the terminologies used in this chapter. The compiler also provides a brief description of the classic version of the Susceptible-Infectious-Susceptible (SIS) model. Discussion and main results section reports the methodology and results presented in Colapinto *et al.* (2021a) and Colapinto *et al.* (2021b).

5.2 Conceptual framework

5.2.1 Mathematical Modeling of Infectious Diseases

5.2.1.1 A brief history of Mathematical Epidemiology

The idea that the transmission and spread of infectious diseases follow laws that can be formulated in mathematical language dates back to 1766 (Kretzschmar and Wallinga, 2009). In his book "*Essai d'une nouvelle analyze de la mortalité causée par la petite vérole*", Daniel Bernoulli developed a mathematical model to analyze the effects of variolation of smallpox (a precursor of vaccination) on life expectancy in England, using mathematical analysis of the table of life (Siettos and Russo, 2013). Bernoulli used his model to show that inoculation against the virus would increase the life expectancy at birth by about three years. However, the primary study of communicable disease knowledge began with the work of John Graunt in his 1662 book "Natural and Political Observations created on Mortality Bills". Graunt analyzed the assorted causes of death, introducing a new technique for estimating the comparative risks of dying from numerous diseases and providing the primary approach to a theory of coincidental risks. It was only in the 20th century that the nonlinear dynamics of infectious disease transmission were really understood. At the turn of that century, there was much debate as to why an outbreak ended before all susceptible individuals were infected with assumptions about the pathogen's virulence changing during the outbreak. Hamer (1906) was one amongst the primary to acknowledge that solely the decrease within the density of susceptible individuals may stop the epidemic. Sir Ronald Ross, who received the honor in 1902 for instructing the life cycle of the Plasmodium vivax, used mathematical models to review the effectiveness of varied protozoal infection intervention ways. Sir Ronald Ross, who received the Nobel Prize in 1902 for clarifying the life cycle of the malaria parasite, used mathematical models to study the effectiveness of various malaria intervention strategies. In 1927, Kermack and McKendrick published a series of articles describing the dynamics of disease transmission in terms of a system of differential equations (Kermack and McKendrick, 1991a; Kermack and McKendrick, 1991b; Kermack and McKendrick, 1991c). Kermack and McKendrick are considered as the pioneers of the concept of a threshold quantity that separates different dynamic regimes. Only if the so-called basic reproduction number is above a threshold value can an infectious disease spread to a susceptible population. In the context of vaccination, this leads to the concept of herd immunity, stating that it is not necessary to vaccinate the entire population to eliminate infectious diseases. This theory proved its worth during the eradication of smallpox in the

1970s. A vaccination coverage of around 80% worldwide in combination with the ring vaccination was sufficient for the eradication of this virus. Only towards the end of the twentieth century did mathematical models become more widespread in public health policies. Modeling approaches were increasingly used during the first two decades of the AIDS pandemic to predict the further course of the epidemic and to try to identify the most effective prevention strategies. But the real impact of mathematical models on public health is the need to evaluate intervention strategies for emerging and re-emerging pathogens. First, it was the fear of a bioterror attack with the smallpox virus that triggered the use of mathematical models to combine his historical data on smallpox epidemics with questions about vaccination in modern societies (Ferguson et al., 2003). Subsequently, the SARS epidemic as an emerging pathogen initiated the use of mathematical models to analyze infectious disease epidemic data in real time to evaluate the effectiveness of intervention measures (Wallinga and Teunis, 2004). An epidemic outbreak has led to the important insight that the breeding number of the underlying influenza has been low in historical outbreaks, but the serial interval is short (Mills *et al.,* 2004). This implies that an influenza outbreak may be stopped with moderate levels of intervention, but measures must be taken very quickly to be effective. Conversely, for an infection such as measles with a high base reproduction number, very high levels of vaccination coverage are required for elimination. Such insights gained from mathematical analysis are extremely useful for designing appropriate intervention policies and evaluating interventions.

5.2.1.2 Basics of Mathematical Modeling of Infectious Disease

An infectious disease is commonly described as the result of a disharmonious ecological interaction between a microbial infectious agent (i.e., bacteria, fungi, parasites, or viruses) and a host. The dynamics of transmission of an infectious disease is constantly governed by various factors, such as the infectious agent, the mode of transmission, the host's susceptibility and resistance to the disease, as well as social, cultural, demographic, economic, and geographical factors which may enhance or mitigate the host's exposure to disease sources and consequently the transmission of the disease in the population. The identification of these factors is fundamental for a better understanding of transmission patterns and to support decision-making processes for the development of strategies for the prevention and control of infectious diseases (Costa *et al.,* 2021).

Mathematical models have become important tools in analyzing the spread and control of infectious diseases. Mathematical models are used in comparing, planning, implementing, evaluating, and optimizing various detection, prevention, therapy, and control programs. Epidemiology modeling can contribute to the design and analysis of epidemiological surveys, suggest crucial data that should be collected, identify trends, make general forecasts, and estimate the uncertainty in forecasts (Hethcote, 2000:600).
A mathematical model generally represents an abstraction of a phenomenon, commonly formulated by adopting equations that take into account various parameters involved in the genesis and evolution of the event studied. Specifically, an epidemiological model is defined as the mathematical and/or logical representations of the epidemiology of disease transmission and its associated processes. The methods used in epidemiology can be classified into two types: deterministic models and stochastic models (Garnett, 2002). Deterministic models represent the most practical way for conducting an approximate analysis of how an epidemic will behave in a closed system. The population N is divided into compartments that describe the disease states and the movements between these states are mathematically formulated by adopting ODEs that determine variations over time (Costa *et al.,* 2021). Stochastic models represent a more realistic approach to model the spread of infectious disease, taking into account the probability of influence of variables in the transmission dynamics, such as the probability of a susceptible individual being infected and the probability of transmitting the disease in the population (Britton, 2010; Costa *et al.,* 2021; Ndii and Supriatna, 2017).
In order to describe the spread of infectious diseases, some hypotheses must be adopted to simplify the mathematical simulation of its dynamics. These assumptions assume that the population N is subdivided into compartments. Compartmental models can be used to predict the properties of the spread of a disease, such as the prevalence (that is, the total number of infected) or the duration of an epidemic. Furthermore, the model allows us to understand how different situations may influence the outcome of the epidemic (e.g., what percentage of vaccinations in a given population provide herd immunity or what variation in the actual reproduction number produces an epidemic containment).
The most used mathematical models need to classify the population into compartments of which the most commonly used are: Susceptible (S); Infectious or Infected (I); Exposed (E), used when, for example, the disease takes some weeks to make the individual infectious; Recovered (R), or healed, i.e. not infectable because they are immune after contracting the disease (some

authors interpret them, as resistant or repressed, as not structured to the epidemic process, immune, or deceased). Other classifications can be used to formulate more accurate models: Passively immune infants (M); Exposed people in the latent period (E); Hospitalized (H); etc. The choice of which compartments to include in a model depends on the characteristics of the particular disease being modeled and the purpose of the model. Acronyms for epidemiology models are often based on the flow patterns between the compartments such as MSEIR, MSEIRS, SEIR, SEIRS, SIR, SIRS, SEI, SEIS, SI, and SIS (Hethcote, 2000:601).

Moreover, mathematical modeling contributes to quantifying possible disease control strategies by focusing on the important aspects of a disease and determining threshold quantities for evaluating disease survival. In epidemic models, the basic reproduction number, or basic reproductive ratio, (R_0) is one of the most important threshold quantities. The basic reproduction number helps to understand the extinction and persistence of a disease and expresses the average number of secondary infections produced when one infected individual is introduced into a host population where everyone is susceptible (Dietz, 1975; Olabode *et al.,* 2021). The value of R_0 for a specific disease depends on different variables, such as the location and the density of a population (Driessche, 2017). Specifically, values of $R_0 > 1$ indicate a high predictive risk of an epidemic event to occur, while values of $R_0 < 1$ indicate a low risk of the occurrence of an epidemic event (Kretzschmar and Wallinga, 2009). The R_0 is generally obtained by solving ordinary differential equations that consider the relation of the rate of infection (β) and the rate of recovery (γ), usually calculated by next-generation matrixes, or by the exponential growth rate method and maximum likelihood method, or by Bayesian statistics. Moreover, the R_0 is a parameter used to evaluate the efficacy of interventions such as quarantine, mask wearing, vaccination, washing hands in hospital sets, etc.; where if the intervention decreases the R_0 to values smaller than 1, it is considered effective, and ineffective if it does not change the R_0. It is also notable to point out that the value of R_0 is a dynamic parameter restricted to the time and space in which a given infection is occurring or occurred due to social and cultural factors that modulate the social contact rate between individuals, virulence factors from the pathogen, environmental conditions that enable the pathogen survival, treatment availability, as well as susceptibility of the pathogen to the antimicrobial drugs employed in the treatment along with other random factors present in the population.

5.3 Methodology

5.3.1 The Susceptible-Infectious-Susceptible Model

The Susceptible-Infectious-Susceptible (SIS) model is one of the simplest and most discussed frameworks in mathematical epidemiology, applicable to a wide range of diseases that do not confer permanent immunity, such as the seasonal flu, some sexually transmitted diseases, or some vector-borne diseases (La Torre *et al.,* 2021). According to its simplest formulation, the population N is assumed to be constant and normalized to unity without loss of generality, $N \equiv 1$. In an SIS model, a population, with N individuals, is categorized into two compartments "susceptible S" and "infected I", i.e., it is assumed to be composed of healthy individuals who are susceptible to the disease and the infectives who have already contracted the disease and can transmit it by getting in contact with susceptible. The disease is transmitted only when a susceptible individual is in contact with an infected individual. The SIS model can therefore be used for diseases that have the following properties:

- After recovering from the disease, each individual immediately returns to the healthy group and can be re-infected, i.e. for a SIS model, infected individuals return to the susceptible class on recovery because the disease confers no immunity against re-infection.
- Infected individuals are immediately contagious.
- Healthy people get sick with a linear rate of infection, β.
- Infected people recover with a linear cure rate, α.
- Each compartment interacts with the same probability. This justifies the assumption of linear relations.

The spread of the disease is usually formulated in the form of ordinary differential equations (ODE).

Let S be the number of susceptible individuals and let I be the number of infected individuals. At the time t, the number of susceptible $S(t)$ and the number of infected $I(t)$ are assumed to be constant, thus, $N(t)=S(t)+I(t)$. The simplest SIS model is given by:

$$\frac{dS}{dt} = -\beta SI + \alpha I,$$

$$\frac{dI}{dt} = \beta SI - \alpha I.$$

The term βSI refers to the average infected individual sufficient to infect others per unit time. Also, the probability that a given individual that each infected individual comes in contact with is susceptible is S/N. Thus, each infected individual cause $(\beta N)(S/N) = \beta S$ infections per unit time. Therefore, I infected individuals cause a total number of infections per unit time of βSI. The αI term refers to the fraction of infected individuals who recover (and re-entre the susceptible class) per unit time. We see that $\frac{d}{dt}(S + I) = 0$, so $S + I = N = constant.$ N is the total population. Substituting $I = N - S$ into $\frac{dI}{dt} = \beta SI - \alpha I$, we obtain

$$\frac{dI}{dt} = \beta I(N - I) - \alpha I = (\beta N - \alpha)I - \beta I^2.$$

Solving $\frac{d}{dt} = 0$, the SIS model has two possible equilibria when $I = 0$ and $I = N - \alpha/\beta$. This outcome can be also demonstrated in terms of the so-called "basic reproductive number", R_0. In the SIS framework, we assume the basic reproduction number given by the following expression:

$$R_0 = \frac{\beta N}{\alpha}$$

It can be shown that:

$$R_o < 1 \Rightarrow \textit{the equilibrium with } I = 0 \textit{ is stable},$$
$$R_o > 1 \Rightarrow \textit{the equilibrium with } I = N - \alpha/\beta \textit{ is stable}.$$

When $R_o < 1 (R_o > 1)$, in the long run, the disease will be completely eradicated (will persist) and thus the share of infectives will be zero (positive); this happens whenever the speed of recovery is faster (slower) than the speed of transmission. In the case of an epidemic outbreak in which $R_o > 1$, mitigating policies which affect the speed of recovery or the speed of transmission (or both) can be used to lower R_o and bring it below unity to achieve the long run eradication goal (for further information see La Torre *et al.,* 2020; La Torre *et al.,* 2021).

5.4 Results and Discussion

In this section, the data and the main methods presented in Colapinto *et al.* (2021a) and in Colapinto *et al.* (2021b) are reported.

5.4.1 Impact of Epidemics Dynamics on Retail Distribution Networks (Colapinto *et al.*, 2021a)

The exposure to the COVID-19 pandemic has clearly shown the central function of the retail distribution networks. The retail sector includes all activities aimed at distributing finished goods or services to the end-customer. The impacts of COVID-19 on the retail sector have been heterogeneous and can be considered essentially as a consequence of some factors, such as the lack of social distancing measures in the conduct of retail activities, the difficulty of moving from physical to "online" modalities given the nature of the activities carried out, and the lack of a timely response first from the company and then from the government to deal with such events.

The COVID-19 pandemics results as a test for supply chains robustness, flexibility, and recovery, pointing out the crucial role of resilience in managing them (Ivanov and Dolgui, 2021). Indeed, retail supply chain operations can be a source of vulnerability or resilience, depending on its effectiveness in monitoring risk, implementing mitigation strategies, and establishing business continuity plans. In the exceptional circumstance of the COVID-19 pandemic, companies should have grasped the importance of focusing much of their attention on managing the types of shocks, classified as "unexpected disruptions", redesigning their supply chain, and implementing resilient activities that enable them to be able to mitigate risks, respond promptly to risks, and ensure faster stabilization and recovery (Ivanov *et al.,* 2019b).

Colapinto *et al.* (2021a) proposes a Susceptible-Infectious-Susceptible (SIS) framework that abandons the classical version of the SIS model which assumes a logistic-type formulation, and focuses on the outbreak of the disease by adopting a simplified linearized version as suggested in La Torre *et al.* (2021). It supposes that the level of infected workers at each node of the distribution network is subject to shocks exogenous to the network driven by a classical Wiener process. This paper focuses on how the stochastic spread of the epidemic across the distribution network will generate a loss of productivity and, therefore, the capacity of the distribution network to serve potential customers. A numerical simulation is also proposed to analyze the dynamics of the infection over the network. In the case of a strict lockdown, Colapinto *et al.*

(2021a) provides a policy recommendation to generate resilience and therefore reduce productivity loss.

5.4.1.1 The outbreak of the disease

In the current literature, several contributions in mathematical epidemiology show that in the early phase of an epidemic the number of infectives tends to grow at a constant rate, and thus the evolution of the disease can be described through an exponential growth. With respect to the classical SIS model which assumes a logistic-type formulation, in this context the number of infected at the time t is described by the linear differential equation:

$$\dot{I}(t) = nI(t) - \delta I(t), \qquad I(0) = I^0$$

where n is the growth rate of the epidemic, δ is the recovery rate (La Torre *et al.,* 2021) (which also includes treatment and/or vaccination), and I^0 is the initial condition. The solution to this linear model is well known and provided by the expression:

$$I(t) = I(0)e^{(n-\delta)t}$$

If $n > \delta$ then the number of infected will be increasing, otherwise decreasing. The number of infected is subject to exogenous shocks driven by a Geometric Brownian Motion as follows:

$$dI_i(t) = (n-\delta)I(t)dt + \sigma I(t)dW(t), \qquad I(0) = I^0$$

The solution to this stochastic differential equation is known and provided by:

$$I(t) = I(0)e^{\left(n-\delta-\frac{\sigma^2}{2}\right)t+\sigma W(t)}$$

The expected value and the variance of $I(t)$ are also known and given by:

$$E\big(I(t)\big) = I(0)e^{(n-\delta)t}$$
$$Var\big(I(t)\big) = I(0)^2e^{2(n-\delta)t}\big(e^{\sigma^2 t} - 1\big)$$

5.4.1.2 Modeling and Control of Disruption Propagation

A distribution chain or network is modeled by a graph G, composed by N different nodes $x_i, i = 1, \dots, N$. At each node $i \in G$, the total number of infected is described by:

$$d\dot{I}_i(t) = \left[\left(n_i + \sum_{j \neq i} \gamma_{ij} I_j(t)\right) - \delta_i\right] I_i(t)dt + \sigma_i I_i(t)dW_i(t), \qquad I_i(t_0) = I_i^0$$

The above system of N stochastic differential equations describes the spread of the epidemic in the early stage.

The amount of infected people at the node i grows as consequence of two effects:

1. The local spread of the epidemics with the infection rate n_i
2. The immigration of infected people moving from the other nodes $j, j \neq i$, to the node i.

The amount of infected is also subject to exogenous shocks, all of them driven by a Geometric Wiener Process W_i where σ_i is the volatility term and the covariance is given by:

$$E\left(dW_i(t)dW_j(t)\right) = \rho_{i,j}$$

where $\rho_{i,i} = 1$. The spread of the epidemic causes a loss of productivity. If we define by $\theta_i, i = 1 \dots N$ the per-capita productivity at the node i, the total loss of productivity $L(t)$ is given by:

$$L(t) = -\sum_{i=1} \theta_i I_i(t)$$

subject to

$$d\dot{I}_i(t) = \left[\left(n_i + \sum_{j \neq i} \gamma_{ij} I_j(t)\right) - \delta_i\right] I_i(t)dt + \sigma_i I_i(t)dW_i(t), \qquad I_i(t_0) = I_i^0$$

where L is a stochastic process that describes the loss of productivity over time.

When a strict lockdown policy is put in place each node of the network is isolated and, therefore, we can assume that $\gamma_{ij} = 0$. We can also suppose that the Wiener processes W_i are independent as the nodes are totally disconnected. In this scenario the above system boils down to:

$$dI_i(t) = (n_i - \delta_i)I_i(t)dt + \sigma_i I_i(t)dW_i(t), \qquad I_i(t_0) = I_i^0$$

In this particular case the expected loss of productivity over time is easy to be computed and it is given by:

$$E\big(L(t)\big) = -\sum_{i=1} \theta_i E\big(I_i(t)\big) = -\sum_{i=1} \theta_i I_i(0) e^{(n_i-\delta_i)t}$$

The volatility of $L(t)$ can also be easily calculated and it is provided by:

$$Var\big(L(t)\big) = \sum_{i=1} \theta_i^2 I_i(0)^2 e^{2(n_i-\delta_i)t}\left(e^{\sigma_i^2 t} - 1\right)$$

The continuing impact of COVID-19, as well as the potential for other global disruptions, on retail supply chains and its implications for 2021 and beyond has increasingly gained the attention among researchers and practitioners. The disruptions are largely due to the lockdown measures adopted and implemented by countries as a health strategy to mitigate the impact of the pandemic's spread on the human population: these choices led to production halts, movement restrictions of people and goods, border closures, logistical constraints, as well as the slowdown of trade and business activities. Colapinto *et al.* (2021a) analyzes the effects of the epidemic outbreak on the distribution network. The model proposed takes into account the flow of infection from one node to another of the network as well as the presence of exogenous shocks.

In this case, the resilience of the retail distribution network can be controlled by means of the result presented in the following proposition.

Proposition. Suppose that enough treatment and vaccination efforts δ_i are put in place such that $2\delta_i > \sigma^2{}_i + 2n_i$. Then the following results are true:

$$E\big(L(t)\big) = 0$$

and

$$Var\big(L(t)\big) = 0$$

The previous result states that, in the long run, both the loss of productivity and the risks are negligible and converge to zero.

5.4.1.3 Contributions and Practical Implications

This study applies a linearized Susceptible-Infectious-Susceptible (SIS) model able to capture the dynamics of the disease outbreak to retail networks, offering managers a strategy to cope with disruption risks and increase the resilience of the retail network. In the case of strict lockdown $(\gamma_{ij} = 0)$, it provides policy recommendations to generate resilience and therefore control the loss of productivity. Indeed, the numerical simulation shows that both treatment investments and lockdown measures are simultaneously necessary to invert the negative trend. It also simulates the effects on a medium retail network under (and not) lockdown measurements (Figures 5.1 and 5.2): it is evident that treatment investments alone are not able to sustain the productivity of the retail network.

Figure 5.1: Medium retail network

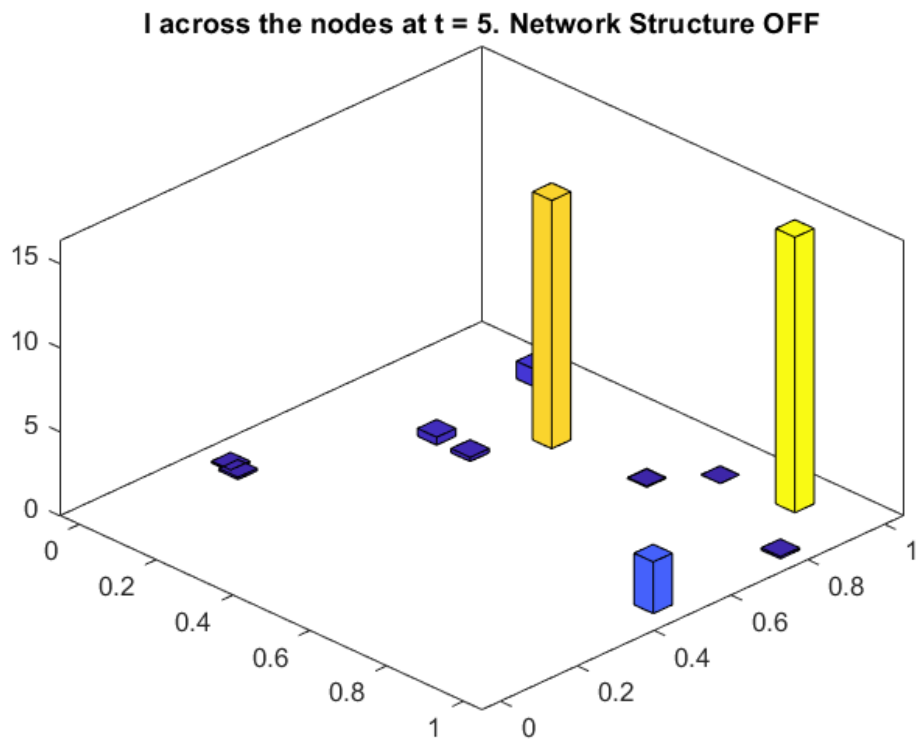
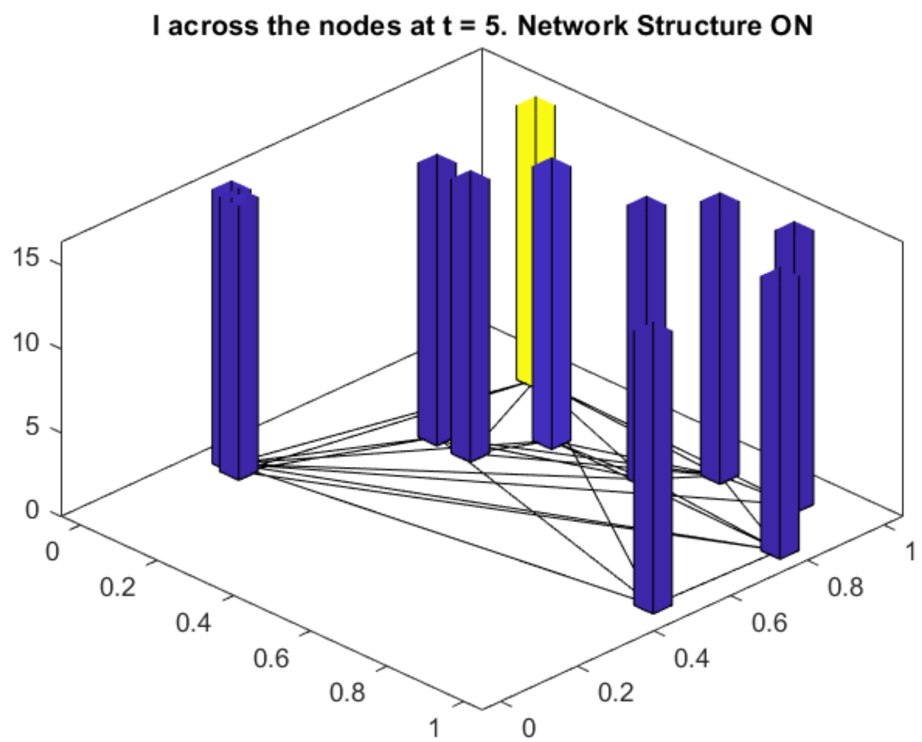


Figure 5.2: Medium retail network not in lockdown



5.4.2 Modeling Shock Propagation on Supply Chain Networks: A Stochastic Logistic-Type Approach (Colapinto *et al.,* 2021b)

Colapinto *et al.* (2021b) presents a stochastic Susceptible-Infected-Susceptible (SIS) framework to model the spread of new epidemics across different distribution networks and determine social distancing/treatment policies in the case of local and global networks. This paper highlights the relevance of adaptability and flexibility of decisions in unstable and unpredictable scenarios.

The Susceptible-Infected-Susceptible Model is one of the simplest and most widely used frameworks in mathematical epidemiology. It allows us to describe the evolution of a number of infectious diseases which do not confer permanent immunity after recovery as in the case of COVID-19. If we denote by N the total population, by $I(t)$ the number of infected people, and by $S(t) = N - I(t)$ the number of susceptible ones, the model reads as:

$$\begin{cases} \dot{I}(t) = \alpha I(t)S(t) - \delta I(t) \\ \dot{S}(t) = -\alpha I(t)S(t) + \delta I(t) \end{cases} \tag{1}$$

where α is the infection rate and δ is the recovery parameter. By doing the substitution $S(t) = N - I(t)$ the model boils down to:

$$\dot{I}(t) = \alpha I(t)\big(N - I(t)\big) - \delta I(t) \tag{2}$$

which is a Bernoulli differential equation whose solution is known and provided by the following expression:

$$I(t) = \frac{\left(1 - \frac{\delta}{\alpha}\right) Ce^{(\alpha-\delta)t}}{1 + Ce^{(\alpha-\delta)t}} \tag{3}$$

where $C = \frac{\left(1-\frac{\delta}{\alpha}\right)Ce^{(\alpha-\delta)t}}{1+Ce^{(\alpha-\delta)t}}$ (La Torre *et al.,* 2021). The SIS model can be used to analyze the spread of common diseases, such as the seasonal flu and the common cold, but also of emerging diseases. This model also applies to the analysis of as COVID-19 since thus far there exists no evidence that people who have recovered from COVID-19 and have antibodies are protected from a second infection (WHO, 2021). In the following we suppose that the total population N

is normalized to 1. Figure 5.3 shows the behavior of COVID infected with the following parameters' values: $\alpha = 0.1328$ and the recovery rate $\delta = 0.0476$ (see the formula above). In this scenario, the amount of infected converges to a plateau representing the long run endemic equilibrium. Figure 5.4, instead, shows the behavior of COVID-19 infected people with the following parameters' values: $\alpha = 0.1328$ and the recovery rate $\delta = 0.476$. This scenario corresponds to the case in which the adoption of treatment or vaccination campaigns produces an increment of the recovery parameter. As a result we can observe that the number of infected people gets reduced in the long run; we also notice that disease eradication is not possible in finite time.

Figure 5.3 Deterministic evolution of the number of infected $I(t)$

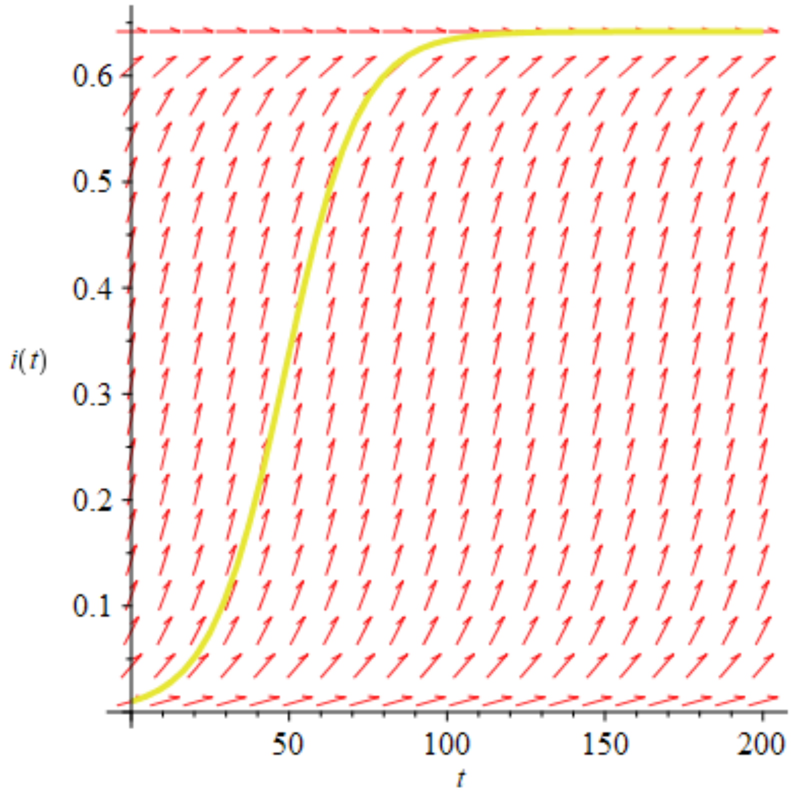
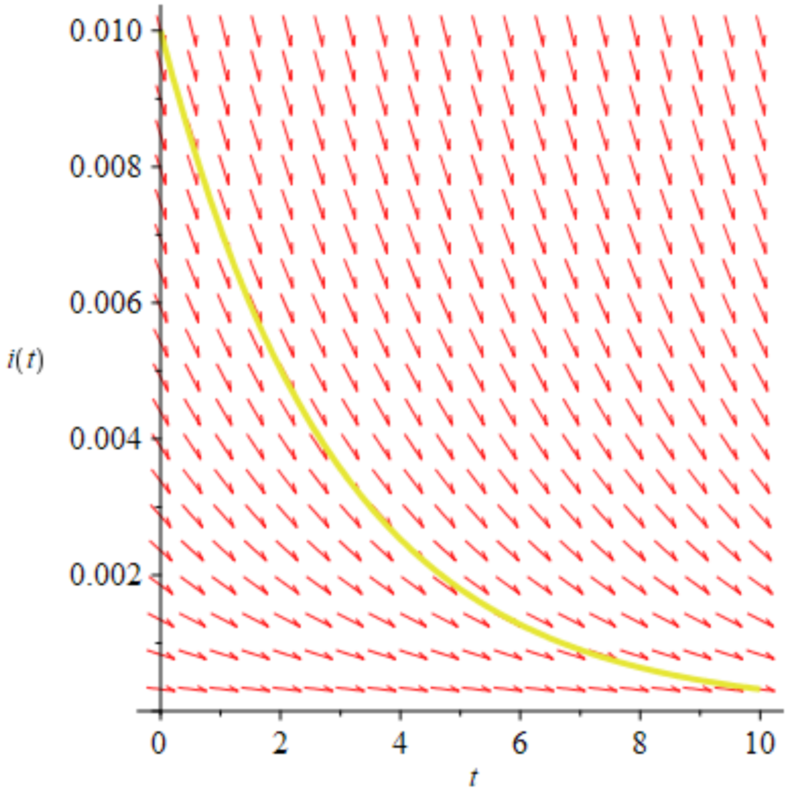


Figure 5.4 Deterministic evolution of the number of infected $I(t)$



5.4.2.1 SIS with Stochastic Shock

The previous section presented a fully deterministic SIS model. In the following paragraph we make an effort to model the effects of exogenous shocks on the epidemic evolution in order to present a more realistic scenario. Therefore we suppose that the number of infected people is subject to exogenous shocks driven by a Wiener process $W(t)$ as follows:

$$dI(t) = [\alpha - \delta - \alpha I(t)]I(t)dt + \sigma I(t)dW(t), \qquad I(0) = I^0 \tag{4}$$

Let's recall that a Wiener process is characterized by the following properties:

1. $W(0)$ is deterministic and given,
2. $W(t)$ has independent increments,
3. $W(s) - W(t)$ is normally distributed with zero mean and variance equal to $t - s$.

Other stochastic processes could be considered as well. For instance, Levy-type, or jump processes, could be used to model other possible non-continuous shocks. From the perspective of the extant literature, this model can be identified as the geometric stochastic Verhulst diffusion (Verhulst, 1838).

Verhulst's work was based on a previous paper by Malthus (1798) who was among the first to notice the existence of two different regimes in the growth of world population. Verhulst's model has been at the heart of an interdisciplinary work by researchers coming from many different fields.

In this context, the notion of deterministic equilibrium has to be replaced by the notion of steady state or stationary density. If we denote by $g[I(s), s; I(t), t]$ the probability density of $I(s)$ at time s, conditional upon its value $I(t)$ at time t, then it is well known that g satisfies the Fokker-Planck equation, which reads as:

$$\frac{\partial g(I,t)}{\partial t} = -\frac{\partial\big(g(I,t)I(\alpha - \delta - \alpha I)\big)}{\partial I} + \frac{1}{2}\sigma^2 \frac{\partial^2(g(I,t)I^2)}{\partial I^2}. \tag{5}$$

The steady state density $g(I(\infty), \infty, s; I(t), t)$can be found by solving the stationary equation $\frac{\partial g(I,t)}{\partial t} = 0$. This yields to a second order ordinary differential equation for g whose solution is provided by:

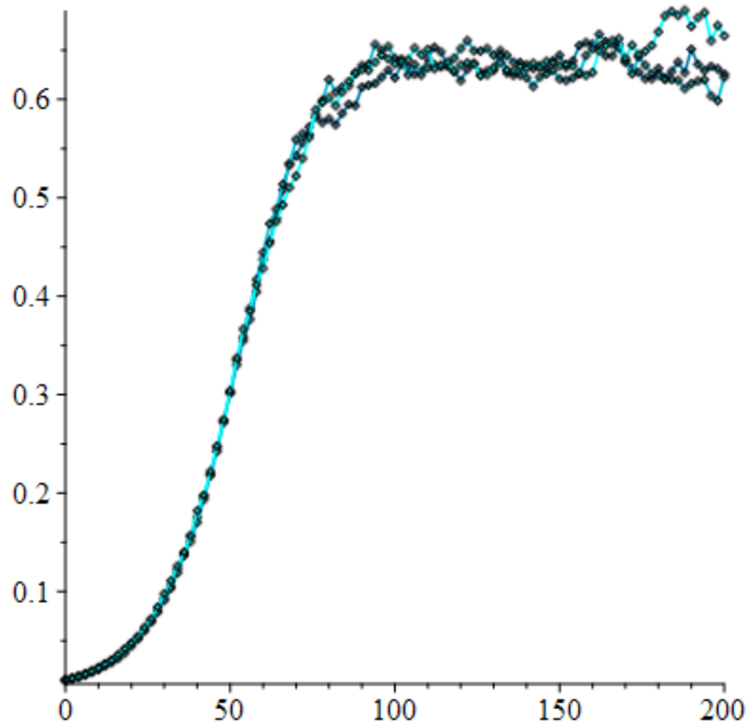
$$g[I(\infty), \infty, s: I(t), t] = \frac{I^{d-1} e^{-cI} (c)^d}{\Gamma(d)}$$

(6)

which is the Gamma distribution. Mean and variance of this distribution are known and provided by $\frac{v-1}{c} = \left(\theta - \frac{\sigma^2}{2\alpha}\right)$ and $\frac{\theta\sigma^2}{2\alpha} - \frac{\sigma^4}{4\alpha^2}$, respectively. Under the condition that $d = 2\frac{(\alpha-\delta)}{\sigma^2} - 1 > 0$, the previous quantities are strictly positive.

Figure 5.5 shows the stochastic behavior of COVID-19 infected people with the following parameters' values: $\alpha = 0.1328m$, $\delta = 0.0476$, and $\sigma^2 = 0.01$. This corresponds to the scenario in which the number of infected people fluctuates around an endemic equilibrium. Figure 5.6 shows the behavior of $I(t)$ with the following parameters' values: $\alpha = 0.1328m, \delta = 0.0476$, and $\sigma^2 = 0.05$. A greater value of the variance causes more amplified oscillations around the endemic equilibrium and thus more challenges for SC managers

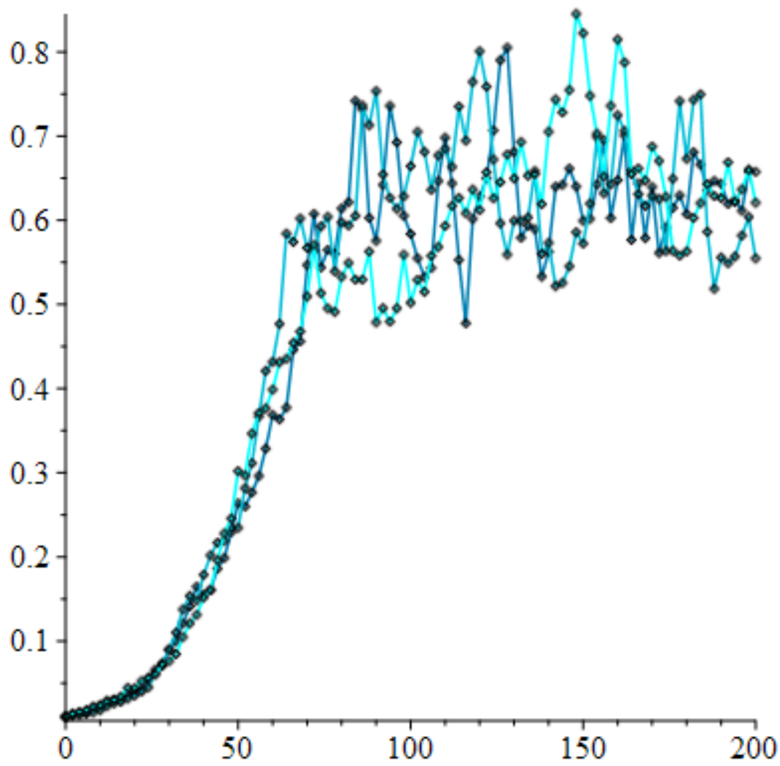
Figure 5.5: Stochastic evolution of the number of infected $I(t)$



5.4.2.2 Shock Propagation on a Network

As we are interested in analyzing the epidemic propagation over a supply chain, we refer to a network that is modeled by a graph G, composed by N different nodes $x_i, i = 1 \dots N$. Each pair of nodes (i, j) can or cannot be connected through an edge γ_{ij}. γ_{ij} will be zero if the nodes are disconnected and a positive number when the nodes are connected, with the number itself providing the linking intensity.

Figure 5.6 Stochastic evolution of the number of infected $I(t)$



At each node $i \in G$, the total number of infected people is described by:

$$dI_i(t) = \left(\alpha_i - \delta_i - \alpha_i I_i(t) + \sum_{j \neq i} \gamma_{ij} I_j(t) \right) I_i(t)dt + \sigma_i I_i(t) dW_i(t), \tag{7}$$

with initial conditions $I_i(t_0) = I_i^0$. The above system of N stochastic differential equations describes the spread of the epidemic across the network. The amount of infected people at the node i grows as consequence of two effects:

1. The local spread of the epidemics;
2. The immigration of infected people moving from the other nodes $j, j \neq i$, to the node i.

The amount of infected is also subject to exogenous shocks, all of them driven by a Geometric Wiener Process W_i where σ_i is the volatility term and the covariance is given by:

$$E\left(dW_i(t)dW_j(t)\right) = \rho_{i,j} \tag{8}$$

where $\rho_{i,j} = 1$. The spread of the epidemic causes a loss of productivity. If we define by $\theta_i, i = 1, \dots, N$ the per-capita productivity at the node i, the total loss of productivity $L(t)$ is given by:

$$L(t) = -\sum_{i=1} \theta_i I_i(t) \tag{9}$$

subject to

$$dI_i(t) = \left(\alpha_i - \delta_i - \alpha_i I_i(t) + \sum_{j \neq i} \gamma_{ij} I_j(t)\right) I_i(t)dt + \sigma_i I_i(t) dW_i(t), \qquad I_i(t_0) = I_i^0 \tag{10}$$

L is a stochastic process that describes the loss of productivity over time.

When a strict lockdown policy is put in place each node of the network is isolated and, therefore, we can assume that $\gamma_{ij} = 0$. We can also suppose that the Wiener processes W_i are independent as the nodes are totally disconnected.

In this scenario the above system boils down to:

$$dI_i(t) = \left(\alpha_i - \delta_i - \alpha_i I_i(t)\right) I_i(t)dt + \sigma_i I_i(t) dW_i(t), \qquad I_i(t_0) = I_i^0 \tag{11}$$

5.4.2.3 Numerical Simulations

As the number of infected people can affect the productivity level of a supply chain, our model enables decision makers to better understand the impact of lockdown measures. Through a numerical simulation we provide a visual representation of different scenarios. Indeed, the numerical simulations compare the behavior of the number of infected people over medium and large size networks. We consider two scenarios, which correspond either to the presence or to the absence of lockdown restrictions. We also report the average behavior and thus the impact on the supply chain networks. In particular, Figures 5.7 and 5.8 show the behavior over a medium size network with 11 nodes. One can immediately observe that the absence of lockdown restrictions allows internal flows among the different nodes thus it increases, on average, the number of infected people even in presence of exogenous shocks (negative or positive) and localized treatment policies. The same conclusion is supported by Figures 5.9 and 5.10 that show the behavior over a large network with 50 nodes.

This numerical simulation shows the effects of network connectivity on the spread of the disease at the global level. As the spread of exogenous shocks across the network might become relevant and not controllable in the case of connected networks. Thus it is crucial to intervene by combining flow barriers between different nodes and local intervention policies. In other words, connectivity might compromise the benefits of implementing local vaccination campaigns.

5.4.2.4 Contribution and Practical Implication

As the virus spread and most governments have imposed lockdown orders, supply chain disruptions increased. Indeed, COVID-19 illustrated that many companies are not fully aware of the vulnerability of their supply chain relationships to global shocks. SC managers need to balance and combine actions to serve their customers, as well as protect and support their workers. In this paper, we aim at analyzing the stochastic effects of the epidemic spread on a supply chain network. We present a stochastic SIS model which assumes the form of a stochastic logistic differential equation. Exogenous shocks are modeled by means of a stochastic Wiener process. We present a numerical simulation and we draw insights to support local supply chain managers to decide about the social distancing policy: he/she can take into account costs, governmental policies, and infection parameters. We also discuss the flow of infected people from one node to another and we provide some results to control the spread of the epidemics across the network. These results can help the global supply chain manager to understand the evolution of the epidemic and, therefore, determine the best counteractions to put in place: it is evident that lockdown policies and treatment measures have to coexist. Employees around the global supply chain need to receive the vaccine on the same timescale to ensure the best results for everyone. Further research involves the design of a stochastic optimal control model able to identify the best compromise between economic costs of lockdown restrictions and implementation costs of vaccination campaigns.

Figure 5.7: Evolution of infected people over a connected network with 11 nodes

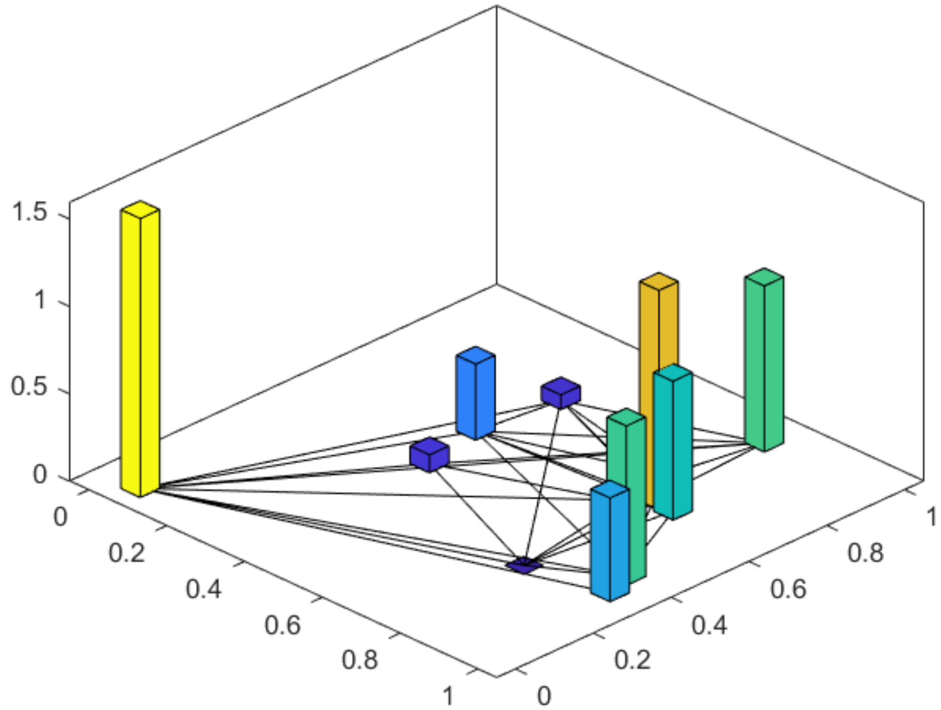


Figure 5.8: Evolution of infected people over a disconnected network with 11 nodes

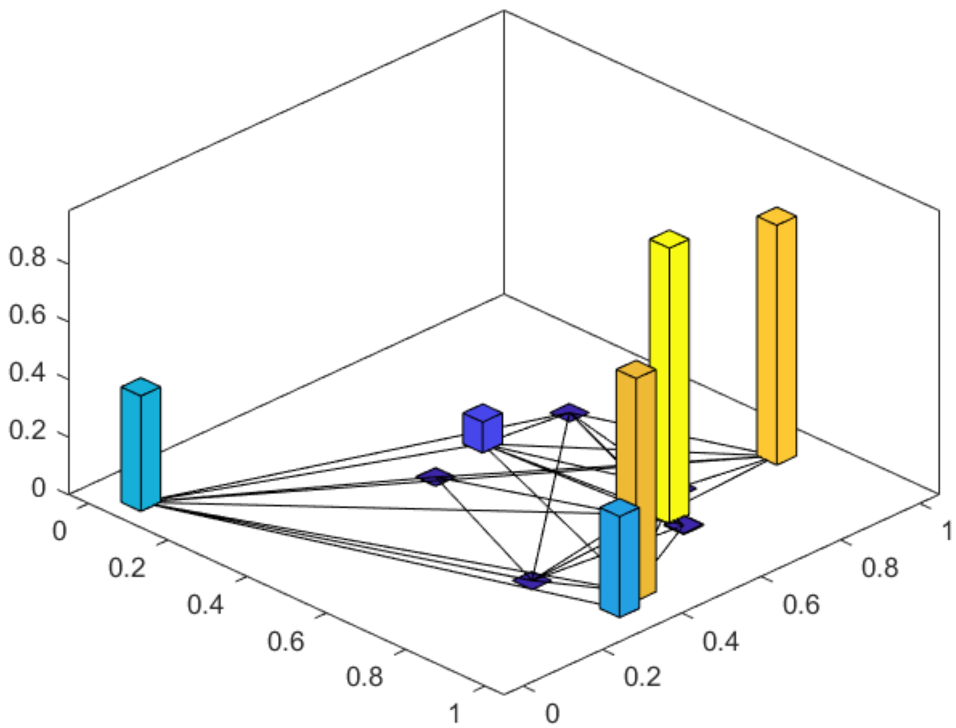


Figure 5.9: Evolution of infected people over a connected network with 50 nodes

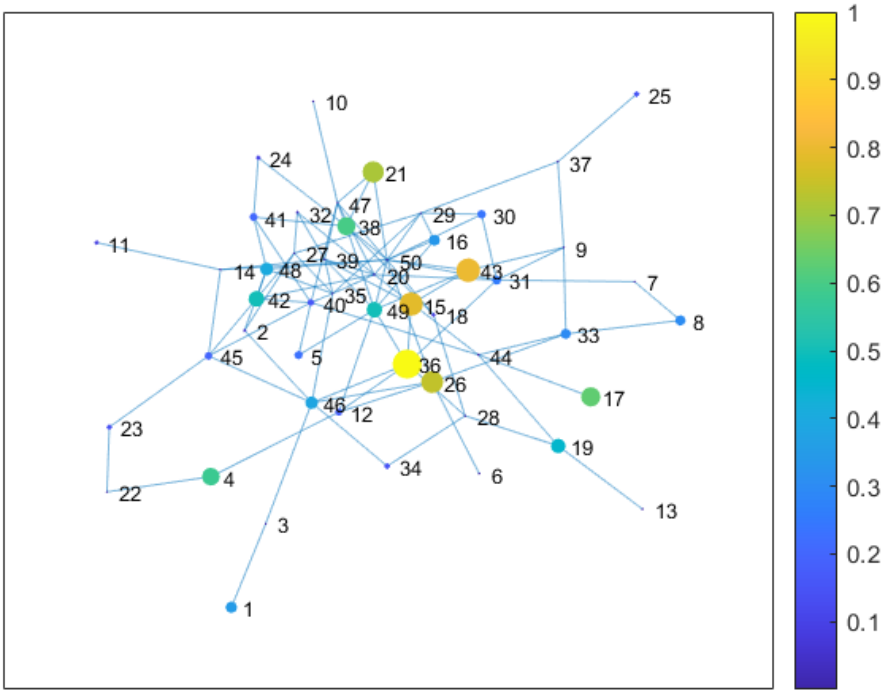
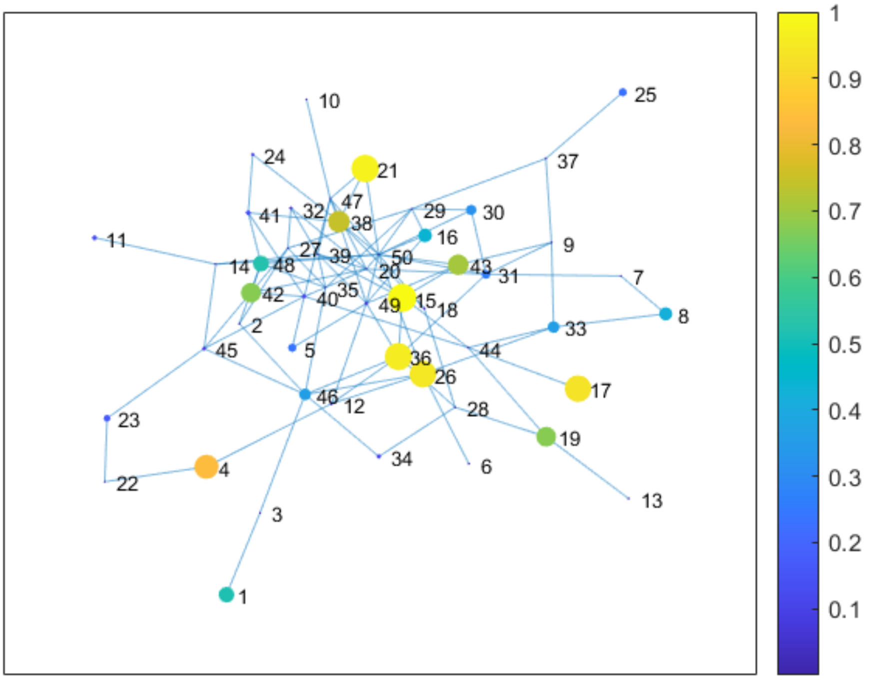


Figure 5.10: Evolution of infected people over a connected network with 50 nodes



5.5 References

Brauer, F. (2017). Mathematical epidemiology: Past, present, and future. *Infectious Disease Modelling*, 2, 113-127.

Britton. T, (2010). Stochastic epidemic models: A survey. *Mathematical Biosciences*, 225: 24-35.

Chopra, S. and Sodhi, M.S. (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*, 46(5), 2-61.

Chopra, S. and Sodhi, M.S. (2014). Reducing the risk of supply chain disruptions. *MIT Sloan Management Review Spring*, 3, 73-81.

Chowell, G., Sattenspiel, L., Bansal, S., and Viboud, C. (2016). Mathematical models to characterize early epidemic growth: A Review. *Phys Life Rev.* 18, 66-97.

Colapinto, C., Laganà, I.R., La Torre, D., and Liuzzi, D. (2021). Impact of epidemic dynamics on retail distribution networks. *Proceedings of the 6th Colloquium on European Research in Retailing (CERR) 2021*, SKEMA Business School, Sophia Antipolis Campus, France, July 15-17, 2021, 199-204. ISBN 978-2-493066-00-8

Colapinto, C., La Torre, D., Laganà, I.R., and Liuzzi, D. (2021). Modeling shock propagation on supply chain networks: A stochastic logistic-type approach. In A. Dolgui *et al.* (Eds.), *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*, Springer, IFIP WG 5.7 International Conference 633, Nantes, France, September 5-9, 2021, pp. 23-31. doi: 10.1007/978-3-030-85910-7_3

Costa, A.L.P., Pires, M.A., Resque, R.L., and Almeida, S.S.M.S. (2021). Mathematical modeling of infectious diseases: Key concepts and applications. *Journal of Infectious Disease Epidemiology*, 7:209.

Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J., and Handfield, R.B. (2007). The severity of supply chain disruptions: Design characteristics and mitigation capabilities. *Decision Sciences*, 38(1), 131-156.

Dietz, K. (1975). *Transmission and control of arbovirus diseases*, Epidemiology, K.L. Cooke, edSIAM, Philadelphia, 104-121.

Dolgui, A. and Ivanov, D. (2021). Ripple effect and supply chain disruption management: New trends and research directions. *International Journal of Production Research*, 59(1), 102-109.

Dolgui, A., Ivanov, D., and Sokolov B. (2018). Ripple effect in the supply chain: An analysis and recent literature. *International Journal of Production Research, Taylor Francis, Leading scholars in Production Research*, 56(1-2), 414-430.

Driessche, P. (2017). Reproduction numbers of infectious disease models. *Infectious Disease Modelling*, 2(3), 288-303.

Garnett, G.P. (2002). An introduction to mathematical models in sexually transmitted disease epidemiology. *Sexually Transmission Infections*, *BMJ Journal*, 78, 7-12.

Handfield, R.B and McCormack, K. (2017). *Supply chain risk management: Minimizing disruptions in global sourcing*. New York, Auerbach Publications.

Heckmann, I., Comes, T., and Nickel, S. (2014). A critical review on supply chain risk: Definition, measure, and modeling. *Omega*.

Hethcote, H.W. (2000). The mathematics of infectious diseases. *SIAM Review*, 42(4), 599-653.

Hethcote, H.W. (2008). The basic epidemiology models: models, expressions for R0, parameter estimation, and applications. In: Ma, S., Xia, Y. (Eds.), *Mathematical Understanding of Infectious Disease Dynamics*. Institute for Mathematical Sciences at the National University of Singapore, Singapore, 1-61.

Hosseini, S., Ivanov, D., and Dolgui A. (2020). Ripple effect modelling of supplier disruption: iIntegrated Markov chain and dynamic Bayesian network approach. *International Journal of Production Research*, 58(11), 3284-3303.

Hosseini, S., Morshedlou, N., Ivanov, D., Sarder, M. D., Barker, K., and Al Khaled, A. (2019). Resilient supplier selection and optimal order allocation under disruption risks. *International Journal of Production Economics*, 213, 124-137.

Ivanov, D. and Dolgui A. (2021). OR-methods for coping with the ripple effect in supply chains during COVID-19 pandemic: Managerial insights and research implications. *International Journal of Production Economics*.

Ivanov, D. and Das, A. (2020). Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: A research note. *International Journal of Integrated Supply Management*, 3(1), 90-102.

Ivanov, D., Dolgui, A., and Sokolov, B. (2019a). *Handbook of ripple effects in the supply chain*. International Series in Operations Research Management Science. Springer.

Ivanov, D., Tsipoulanidis, A., and Schönberger, J. (2019b). *Global supply chain and operations management: A decision-oriented introduction to the creation of value*. Springer Texts in Business and Economics. Springer International Publishing.

Khojasteh, Y. (2018). *Supply chain risk management: Advanced tools, models, and developments*. Singapore, Springer.

Kretzschmar, M. and Wallinga, J. (2009). Mathematical models in infectious disease epidemiology. In: Krämer A., Kretzschmar M., Krickeberg K. (eds). *Modern Infectious Disease Epidemiology.* Statistics for Biology and Health. Springer, New York, NY.

La Torre, D., Liuzzi, D., and Marsiglio, S. (2021). Epidemics and macroeconomic outcomes: social distancing, intensity, and duration. *Journal of Mathematical Economics.*

Øksendal, B.K. (2003). *Stochastic differential equations: An introduction with applications.* Springer-Verlag Berlin Heidelberg.

Malthus, T.R. (1798). *An essay on the principle of population*. J. Johnson, London.

Nakamura, G.M. and Martinez, A.S. (2019). Hamiltonian dynamics of the SIS epidemic model with stochastic fluctuations. *Scientific Reports*, Nature Research, 9.

Ndii, M.Z. and Supriatna, A.K. (2017). Stochastic mathematical models in epidemiology. *Information* (Japan), 20, 6185-6196.

Queiroz, M.M., Ivanov, D., Dolgui, A., and Fosso Wamb, S. (2020). Impacts of epidemic outbreaks on supply chains: Mapping a research agenda amid the COVID-19 pandemic through a structured literature review. *Annals of Operations Research.*

Siettos, C.I. and Russo, L. (2013). Mathematical modeling of infectious disease dynamics. *Virulence*, 4(4), 295-306.

Simchi-Levi, D., Schmidt, W., and Wei Y. (2014). From superstorms to factory fires: Managing unpredictable supply chain disruptions. *Harvard Business Review*, 92(1-2), 96.

Simchi-Levi, D., Wang, H., Wei, Y. (2018). Increasing supply chain robustness through process flexibility and inventory. *Production and Operations Management*, 27(8), 1476-1491.

Verhulst, P.F. (1838). Notice sur la loi que la population suit dans son accroissement. *Correspondance Mathématique et Physique,* 10, 113-121.

Ucakan Y., Gulen S., Koklu K. (2021). Analyzing Tuberculosis in Turkey through SIR, SEIR, and BSEIR. *Mathematical Models, Mathematical and Computer Modeling of Dynamical System*, 27(1), 179-202.