Research on Risk Management for Healthcare Supply Chain in Hospital

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A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the Degree of Doctor of Philosophy

May 2018

Abstract

Purpose: Unlike the commercial industries, the risks arising from the healthcare industry's internal system and the surrounding environment may cause serious consequences, even the patients' health. Concerning the increasing emphasis on risk management in the healthcare supply chain environment, there is an urgent demand for a novel decision support method that supports supply chain risk management in the hospital setting. As the topic is still in the early stage and only a few systematic academic studies on this topic can be found over the last decades. This research aims to propose a novel comprehensive framework and integrated risk management model that takes explicit account of multiple types of risk factors in aiding decision-making as well as compares and ranks the current implemented alternative risk mitigation strategies using fuzzy set theory and multiple criteria decision analysis (MCDA) methods.

Methodology: In pursuit of meeting the requirements of the research objectives, this research conducts empirical studies from both China and UK healthcare industries and follows three steps of risk management procedure based on the proposed framework to conduct risk factors identification, assessment and risk mitigation strategies identification. In order to ensure that the analysis is systematic and inclusive, various types of risk factors are identified through a related systematic literature review and are validated through a set of empirical studies. Risk assessment is conducted through two stages of questionnaire surveys and evaluated through Fuzzy Analytic Hierarchy Process (AHP) and Interpretive Structural Modelling (ISM). Thereafter, risk mitigation strategies are identified through conducted empirical studies and evaluated through Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

Research Implications: This is the first study which has developed a comprehensive risk management framework in the healthcare supply chain that effectively integrates supply chain risk factors identification, risk assessment as well as mitigation strategy identification and evaluation. The novelty of the developed framework lies in the fact that a systematic and practical decision making tools are proposed supporting hospital managers making strategic decisions on healthcare supply chain risk management. Furthermore, compared with several

studies using secondary data, this thesis uses empirical data to conduct the identification and evaluation of risk mitigation strategies, enabling the results closes to the reality of the situation in the healthcare setting.

Practical Implications: The profile of risk sources, the priority weighting and inter-relationship among these risks and, the ranking of mitigation strategies provide a guideline for hospital managers to anticipate and proactively deal with potential risks. The proposed framework applies to both the UK and China healthcare industries, the finding can also be applied in other countries and regions.

Keywords: Supply Chain Risk Management (SCRM), Healthcare Industry, Hospital, Pharmaceutical/Medicine/Drugs Supply Chain, Multiple Criteria Decision Analysis (MCDA), Fuzzy Set theory, ISM.

Acknowledgements

Despite all the challenges and sufferings during my three-year PhD course, I have finally reached the moment for which I have desired. Since it was a long journey, intellectually and emotionally, I would not have stood here without kind supports and inspiration from the people around me. In particular, I would like to take this opportunity to express my deep appreciation to:

- Dr Jun Ren, Prof Jin Wang and Prof Charles Morecroft for providing me with illuminating ideas, constructive comments and encouraging me to keep going with confidence. Indeed I am lucky enough to be the student under their supervision for three years. I could not have imagined having better guidance for my PhD study.
- Prof Haiyan Wang, Prof Duangpun Kritchanchai, Dr Dimitrios Paraskevadakis, Dr Trakarn Prapaspongsa, Dr Dongmei Cao, Dr Di Zhang and Dr Wirachchaya Chanpuypetch for contributing their valuable suggestions and time to the quality of my research.
- Mr Steve Begley, Mr Ye Yang, Ms Sue Donaldson, Mrs Trudy Bown, Mr Jianwei Yang, Mr Bo Zhang, Mr Gang Yao, Mr Renshun Zhang, Mr Xiaoguo Yang, Mr Xuebin Xia, Mr Yanchao Sun, Ms Jie Fei, Mr Zong Yu and Ms Yuanyuan Tian for supporting me to conduct the empirical studies and collect the data from their organizations.
- Dr Zhisen Yang, Dr Chengpeng Wan, Dr Chaoyu Li, Ms Shiqi Fan, Mr Jun Hu, Dr Chengchun Li, Mr Haonan Cheng, Ms Jingjing Li, Mr Yuan Li for being my best friends whom I can lean on during the PhD journey.
- My colleagues in LOOM Research Institute and other researchers at Liverpool John Moores University for giving me wonderful times at Liverpool.
- Dr Robert Mason at Cardiff University and Mr Len Bird at Coventry University for providing me with confidence to finish this thesis.

Lastly, but not least by no means, I would like to extend my honest appreciation to my parents, my partner, Dr Xiao Yang, and her parents, uncle Yang and aunt Dong, for their

continuous support, encouragement and understanding throughout my doctoral research. Patience, sacrifice and love, intangible and invaluable assets provided by them kept me going during tough times in my life.

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Abbreviations

AHP	Analytic Hierarchy Process
AIDC	Automatic identification and Data Capture
B2B	Business-to-Business
CBA	Cost Benefit Analysis
CPD	Continuous Professional Development
CPFR	Collaborative Planning Forecasting and Replenishment
C.I.	Consistency Index
C.R.	Consistency Ratio
DEA	Data Envelopment Analysis
DH	Department of Health
DHL	Deutsche Post DHL
ED	Emergency Department
EDI	Electronic Data Interchange
EFPIA	European Federation of Pharmaceutical Industries and Associations
EPA	Environmental Protection Agency
ERP	Enterprise Resource Planning
ETA	Event Tree Analysis
EUC	European Union Commission
FAHP	Fuzzy Analytic Hierarchy Process
FEAHP	Fuzzy Extended Analytic Hierarchy Process
FFP	Fuzzy Failure Probability
FMEA	Failure Mode and Effect Analysis
FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
FST	Fuzzy Set Theory
FTA	Fault Tree Analysis
FTOPSIS	Fuzzy Technique for Order Preference by Similarity to Ideal Solutions
GDP	Gross Domestic product
GDSS	Global Data Synchronization Standards
GMP	Good Manufacturing Practice
GP	General Practice
GPO	Group Purchasing Organization
GSP	Good Supply Practice
GTINs	Global Trade Item Numbers
HAZID	HAZard Identification
HAZOP	HAZard and Operability
HCSCRM	Healthcare Supply Chain Risk Management
HL7	Health Level Seven
HTP	Hazard Totem Pole
ICT	Information Communication Technology
IDS	Intelligence Decision System

IDSs	Integrated Delivery Systems
IRM	Institute of Risk Management
ISM	Interpretive Structural Modelling
ISO	The International Organization for Standardisation
IT	Information Technology
IS	Information System
JIT	Just-in-Time
KPI	Key Performance Indicator
MADA	Multi-Attribute Decision-Analysis
MADM	Multi-Attribute Decision-Making
MCDM	Multi Criteria Decision-Making
MICMAC	Matriced'Impacts Croisés Multiplication Appliquéea'un Classement
NHS	National Health Service
PEPPOL	Pan European Public Procurement On Line
QSAM	Quick-Scan Audit Methodology
RFID	Radio Frequency IDentification
RM	Risk Management
R.I.	Random Index
S.D.	Standard Deviation
SEM	Structural Equation Modelling
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SCRM	Supply Chain Risk Management
SLR	Systematic Literature Review
SMEs	Small and Medium-size Enterprises
SWOT Analysis	Strengths, Weakness, opportunities and Threats analysis
TFN	Triangular Fuzzy Numbers
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
UCM	Uncertainty Circle Model
VMI	Vendor Managed Inventory
WHO	World Health Organization

CHAPTER ONE – INTRODUCTION

1.1 INTRODUCTION

This chapter introduces a general research background and specific research questions, followed by the research aims and objectives, scope of the research as well as the research methods. The thesis outline is provided to present different stages in the healthcare supply chain risk management process, including risk factors identification, risk assessment, risk mitigation strategies identification and evaluation.

1.2 RESEARCH BACKGROUND

In the past two or three decades, the expenditure in the healthcare sector across the globe has increased tremendously. UK National Health Service (NHS) is one of the largest employers in the world (Towill and Christoper, 2005), UK healthcare costs are expected to increase at a faster rate than the growth of the GDP, reaching about $4.6 trillion (equate to £2.95 trillion) and accounting for more than 19% of the GDP by 2019 (Centers for Medicare and Medicaid Services, 2010). More recent data indicates that supply chain related expenses, including the cost of all activities, assets, information, infrastructure, and labour related to the accurate procurement, delivery, storage, return, and disposal of products and materials necessary to provide healthcare services, account for 33% of the average healthcare provider's annual operating expense (Nachtmann and Pohl, 2009). It shows that though the delivery of services has generally improved, the cost incurred in providing the high quality is still high (Chandra *et al.,* 2009).

Research has revealed that the healthcare cost has soared to unprecedented levels threatening the sustainability of hospitals and the healthcare system in general (Vincent, 2006). Therefore, healthcare institutes and hospitals have been forced to adopting new models of operations (Bourlakis, 2011; Chakraborty, 2014). In particular, similar to other

industries, the healthcare sector (see Figure 1.1) generally consists of four main components: producers, purchasers, providers, and payers (Burns, 2008).

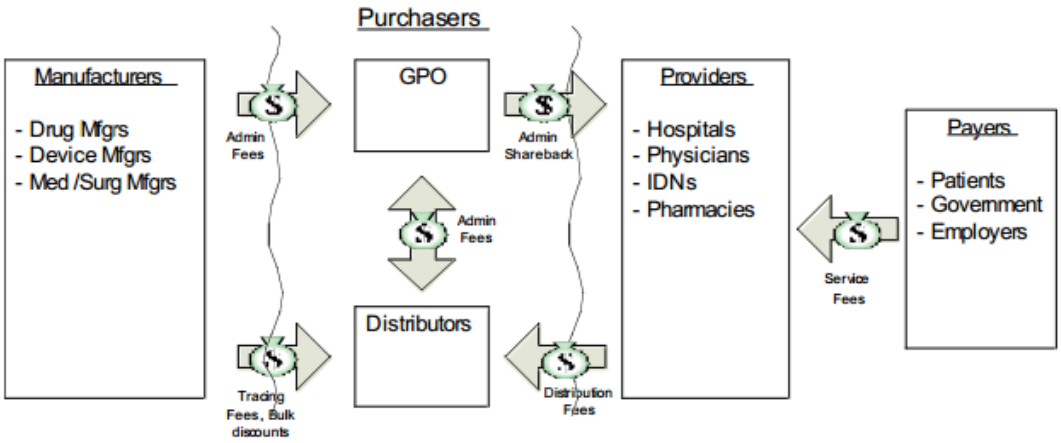


Figure 1-1: Health care value chain

(source adapted from ROi, Mercy case study and Burns, 2008)

The philosophy of supply chain management (SCM) is founded on the management of all activities from upstream to the downstream process, which including identification of the customer demand, solving problems of functional division that occur within and between each party, storage, distribution, redistribution, procurement (Colletti, 1994; Andraski, 1998; Stank *et al.,* 2001; Meijboom *et al.,* 2011; Aronsson *et al.,* 2011; Pinna *et al.,* 2015). Healthcare supply chain management (HCSCM) is unique and different from the traditional SCM as it handles a diversity of items in widely varying quantities in response to the larger number of diagnosis types and procedures (AbuKhousa *et al.,* 2014). Much of these items are of high value and require special handling to combat spoilage or obsolescence. Since clinical operations require adequate and accurate supplies according to the diverse needs of patients, healthcare supplies are mission critical to the health of the public (Beier, 1995). More importantly, healthcare supply selections are often driven by physician preference, which is largely based on medical training, experience with specific brands, and context-specific demands. This is in contrast to manufacturing and retail industries where supply selections are largely driven by production/sales forecasts and const considerations. As shown in Figure 1.1, the healthcare supply chain consists of both internal chain (patient care units, hospital pharmacies) and the external chain (producers, purchasers, distributors and

payers). Many researchers assert that implementing SCM would reduce organizational costs and cycle time as well as leading to higher performance without compromising quality of services. An efficient, user-friendly supply chain can also impact the healthcare provider's revenues by engendering physician loyalty and staff retention. However, studies have shown that the healthcare industry consistently lags commercial industry in adopting supply chain management. The topic of healthcare supply chain management is still in the early stage and its operational performance is immature, fragmented and more problematic (Kumar *et al.,* 2008; Mustaffa and Potter, 2009; Kwon *et al.,* 2016). D. Elmuti *et al.,* (2013) completed a survey of 700 organizations in the United States according to their familiarity and utilization of HCSCM initiatives. The results indicated that about 62% of the respondents reported that they did not have an existing HCSCM program. About 38% of the organizations surveyed reported that they were familiar with the HCSCM concept. The remaining organizations reported the duration of their HCSCM programs to be less than 1 year. Most of these companies are working to improve on only one aspect of the area of the total supply chain. Kwon *et al.,* (2016) indicated that the healthcare supply chain is struggling with misunderstanding of the fundamentals of supply chain concepts. The functions of the healthcare supply chain have been mistakenly identified as merely purchasing and contract management. Moreover, other hindrances for implementing SCM in the healthcare industry include the lack of standard nomenclature for healthcare products and the clinicians' preferences create further uncertainties (McKone-Sweet *et al.,* 2005), and lack of trust between hospitals and suppliers (Mustaffa and Potter, 2009). Despite the above, it is still perceived that there is significant scope for improving the overall performance of the supply chain in healthcare sector. Since 2005, there is a dramatically increasing number of publications about this topic. A number of different SCM tools have been also applied in practice, such as Just-In-Time (JIT), Vendor managed inventory (VMI) as well as Collaborative Planning, Forecasting and Replenishment (CPFR), *etc*.

Risks existing in the supply chain are referred to as the unexpected events which interrupt the operational process and have a negative impact on the whole system performance (Ho *et al.,* 2015). As a matter of fact, there is a growing number of disruptive cases with negative consequences on the performance of companies in recent years. There have been many cases of when disruption has paralysed the supply chain. For example, a fire

which lasted for only ten minutes in a Phillips semiconductor plant disrupted Ericsson's delivery of microchips for more than one month, which eventually led to a $400 million loss (Chopra and Sodhi 2004).The bankruptcy of a UK-based supplier, UPF-Thompson, forced Land Rover to make 1,400 workers redundant (Tang 2006). Similarly, nearly 420 KFC stores around UK were forced to close due to the delivery problems incurred by its delivery partner, a UK based food delivery specialist Bidvest Logistics in 2018. It is still possible to recall how the earthquake, tsunami and the subsequent nuclear crisis occurred in Japan in 2011 caused Toyota's production to drop by 55,000 vehicles, costing $72 million in profits per year (Pettit *et al.,* 2010). For the last decade, few areas of management interest have risen to prominence as rapidly as supply chain risk management (SCRM) (Colicchia and Strozzi, 2012).

From the hospital or healthcare perspective, Harris (2000) investigated the ultimate objective of managing risks as the ability to identify, assess, reduce and control risks to staff, patients and visitors. Essentially, the risks can be considered broadly as anything that compromise service delivery (Rafele *et al.,* 2005), for example, scarce service provision caused by inadequate resources or inefficient material management (Tomlin, 2009). The impact of risks accounts for the big proportion of hospital budgets hence risks management is a significant strategy to minimize expenditure and increase the service quality. Similarly, supply chain management must take account of risk management in hospital as there are many suppliers and customers with close interconnectivity. This often increases the risks in hospital supply chain because a disruption in one member may affect others. Usually, the supply chain capacity is decided by demand and supply (Tang, 2006) that are ever uncertain thus increasing the risk especially in healthcare where the resources are constrained. Organizations across supply chains may only focus on a given subset which is likely uncertain (Chopra *et al.,* 2004).

This thesis focuses on the risks in relation to the pharmaceutical products (*i.e.* medicine) in the hospital supply chain. It generally associated with medicine discontinuity, medicine shortages, poor performance, patient safety/dispensing errors, expiration and technological errors (*e.g.* causing stock shortages in pharmacies), all of which incur risk through disruption to the system. It is vital as medicines are a core input into healthcare treatment and are critical products (Breen, 2008). To tackle those risks, it is essential for the healthcare

providers (*i.e.* hospital) to understand what these risks are and how they affect the supply chain operations. Unless there is infinite resource that could be used to reduce such risks, healthcare providers will always have to prioritise their resources to deal with those risks that are most significant and imminent. This makes it important to evaluate the extent to which each risk factor affects the performance of the hospital supply chain and also to identify the relative importance of each risk factor. For the purpose of control and mitigation of the negative effects caused by multiple types of risks, a significant number of works in this field were undertaken in both practitioner and academic circles (Ho *et al.,* 2015). In essence, the SCRM process often includes risk factor identification, risk assessment and mitigation. The existing studies reveal that at least one of these processes are covered in the research to analyse SC risks and their management while taking various SC contexts into account (Blackhurst *et al.,* 2011; Christopher *et al.,* 2011). However, the findings of previous SCRM studies provide valuable insights, but little in a complete and systematic approach for the healthcare industry. According to the literature review, there are a small number of studies specifically focused on the healthcare supply chain risk management (HCSCRM), especially in hospital setting (Breen, 2008; Aguas *et al.,* 2013; Illie and virgil, 2013; Kanyoma *et al.,* 2013; Enyinda *et al.,* 2014; Elleuch *et al.,* 2014; Kim *et al.,* 2016; Zepeda *et al.,* 2016). Nevertheless, the finding of literature review reveals that the current healthcare systems' SCRM models are not capable of meeting challenges faced by hospitals (Mckinsey&Company, 2013). The risks and uncertainties in the healthcare supply chain network have yet to be fully explored. In addition, no research has been published to develop a thorough and sound risk management framework for evaluating integrated SCRM performance across the whole chain in the public healthcare sector, especially in respect of the medicine perspective. Furthermore, the attention that is given to systematic risk factors identification is fairly limited and needs further investigation. Currently, no published studies have examined the efficiency of currently implemented supply chain risk mitigation strategies in the public healthcare organizations. These issues will be further discussed in the literature review in Chapter two and will be addressed in this thesis.

This thesis, therefore, raises the following research questions and will answer them at the end of this research.

- RQ1. What is the most effective HCSCRM framework that can be implemented to deal with the HCSC risks?
- RQ2. What are the main sources of risk factors causing public sector healthcare supply chains vulnerable and how to address those risks?
- RQ3. Which risk factors are relatively more significant to a hospital's supply chain management performance?
- RQ4. How are these risk factors interacting with each other?
- RQ5. How can the hospitals from both UK and China effectively manage their supply chain related risks?
- RQ6. What are the main risk mitigation strategies to be considered?

1.3 RESEARCH AIM AND OBJECTIVES

In light of this, to address the practical needs and fulfil those research gaps, this thesis aims to propose a novel comprehensive framework and integrated risk management model that takes explicit account of multiple types of risk factors in aiding decision-making as well as comparing and ranking the current implemented alternative risk mitigation strategies using fuzzy set theory and multiple criteria decision analysis (MCDA) methods. The specific research objectives are:

- To review the existing and current status of implementation of risk management technology/theory in hospital supply chain, to explore the characteristics of the healthcare supply chain and review supply chain risk management methods.
- To develop a conceptual framework to identify, evaluate the risk level and mitigate the interrelated risk factors in the hospital supply chain operations.
- To develop an integrated supply chain risk management model to support the proposed framework using fuzzy set theory and multiple criteria decision analysis (MCDA) methods.

- To examine the applicability of the proposed model through empirically based cases in order to find out the best solution to manage the risk in hospital supply chain operations.
- To conduct case studies to justify and demonstrate applicability of the proposed model.

1.4 RESEARCH SCOPE

The diverse entities involved in the healthcare supply chain network, such as various flows (*i.e.* information, cash, service, material flow) and numerous stakeholders (*i.e.* manufacturers, suppliers, distributors, retailers, hospitals, governments and patients), are interweaved into a complex system, on the other hand, supply chain risk management is a broad topic that encompasses various aspects from which to look at the SC process. Therefore, it is essential to set the boundaries of the research at the early stage for the purpose of developing valuable insights.

Existing literature reveals that most studies have focused on the upstream of the healthcare supply chain, especially on pharmaceutical companies. Instead, the context of this thesis is confined to the general medicine flow in public hospital supply chain risk management. The major difference between the public and private healthcare providers is their main goals. The private hospital is profit oriented while the public sector is oriented toward quality service delivery. Furthermore, the enablers of supply chain management (SCM) (which include integration, collaboration, coordination and information systems) are applicable both to the private and public sectors. However, the rate of application in the public hospital in limited due to complex rules and procedures. Despite the comprehensive legislation and measures implemented by the public hospital, there are always challenges to manage the risks of fraud and corruption in the supply chain. Incidence of financial mismanagement which includes the SCM process remains prevalent in the public hospital. Korosec (2003) states “SCM is a procurement tool that, strategically integrates the whole procurement process.” Thus, SCM is thought to be narrow in a functional sense, an element of procurement rather than spanning multiple functional areas in the public hospital. By contrast, in the private hospital context, Mason-Jones (2004) argues that “procurement is a crucial central element of SCM”

and SCM covers “all functions throughout organizations, from marketing and production to procurement.” Therefore, a system of comtinuously monitoring and improvement of the supply chain is crucial for the success of the public hospital.

The research is mainly focusd on how to manage risks occurring from the upstream (*i.e.* manufacturer and distributor) to the downstream, end user (*i.e.* patients). More especially, it presumes that all supply chain activities (*i.e.* sourcing, distribution, storing, *etc*) within the interactions of different parties are carried out in association with material, finance and information flows to provide the medicine products to patients. Therefore, the risk types covered in this thesis are related to (1) the risks that are internal to the hospitals, (2) the risks external to the hospitals but internal to the supply chain networks and (3) the risks external to the supply chain networks. Comparing with other studies which only focus on one of the specific SCRM process, this thesis proposes an integrated method to identify the healthcare SC related risks, measure and analyse the risks, and evaluate the implemented risk mitigation strategies.

The geographical focus of the research within this thesis is both the United Kingdom (UK) and China. The UK provides a good case for the research relating to healthcare industry, as the NHS and its commercial partners are internationally renowned for running the world’s largest integrated health system. At the same time, healthcare reforms have been initiated by the Chinese government for seeking the development of a new system, which providing “safe, effective, convenient and affordable” healthcare to both rural and urban residents by 2020. Thus, the UK’s experience of providing high quality hospitals and efficient SC are capable to assist China to develop new systems for meeting the urgent needs for healthcare reforms. China has learned UK healthcare model since 2013 and spearheaded a series of initiatives to promote the international co-operation in healthcare education and information exchange between both countries. Although this is beneficial for sharing the experience among each other, it also means that both healthcare industries would face the same issues. Moreover, what is true of the analysis of supply chain related risks is becoming more imperative to both countries’ healthcare industries which pursue effectiveness and value in supply chain operations.

1.5 RESEARCH METHODS

This thesis follows a deductive research approach using data triangulation of both qualitative and quantitative research methods. The research mainly aims to develop a comprehensive framework and an integrated risk management model for identifying and assessing the risk factors in hospital supply chains. Particularly, it explores the efficiency of currently implemented risk mitigation strategy in the hospital setting. Thus, the empirical study was chosen to enhance the understanding of this complex healthcare supply chain system and to support the researcher as well as practitioner retain an in-depth analysis of this real-life situation.

Reporting of empirical in-depth studies on managing the medicine supply chain related risks in the hospital setting is rather scarce in scholarly work. Therefore, the empirical studies were conducted in both China and UK healthcare industries and data was collected via reviewing literature articles, official documentation and other published materials, direct observations, a series of interviews from industrial experts, consultants as well as academics with rich knowledge and experience of risk management, and questionnaire surveys. The questionnaires were pilot tested, with the results being used to modify the contents. In addition, the questionnaires were sent out via either email or web-link (*i.e.* eSurveyCreator) with a cover letter and content form to the targeted experts. The participant experts such as: Head of Procurement, Director of Hospital, Stock Manager, General Manager in Pharmaceutical Company, Chief Pharmacy Procurement IT Manager, Head of Supply Chain and E-commerce and academicians with industry experience are the knowledgeable individuals who are able to provide the valuable comments to all aspects of the survey.

Relevant literature review was used as a base to identify risk sources and risk mitigation strategies. A risk-factor questionnaire survey and semi-structured interviews with participant experts from both academic and industrial fields were conducted to validate the identified risk factors and relevant risk mitigation strategies that were extracted from the existing resources and explore other risk factors and mitigation strategies that have not been mentioned in the literature and other documentation. Moreover, a series of email and face-to-face interviews were distributed and conducted to further explore the appropriateness of the developed hierarchy model where the identified risk factors were summarized. For the purpose of assessing the risk factors, it is essential to measure the risks by determining their

priority weighting and evaluating their inter-relationships. Other questionnaire surveys (termed risk assessment survey) were conducted and analysed using Fuzzy Analytic Hierarchy Process (AHP) and Interpretive Structural Modelling (ISM). In order to better understand the significance of the identified risk mitigation strategies with regard to different risk factors, further questionnaire surveys was conducted to collect the relevant primary data. Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was then used to analyse the data and rank the relative importance of those mitigation strategies with respect to the performance under different risk contexts.

1.6 STRUCTURE OF THE THESIS

The thesis consists the following eight chapters:

Chapter One – Introduction: This chapter states a general overview of the research background, aim, objectives, the generated research questions, the scope of research, and methodological approach and structure of this thesis. It briefly reviews the requirement for this research and outlined how the research will be conducted.

Chapter Two – Literature review: This chapter extensively reviews the literature on the concepts of healthcare supply chain management, the status of risk management in the healthcare supply chain context and their development as well as definitions. This chapter discusses the current existing studies in association with supply chain risk management and assess the current knowledge on SCRM. Eventually, some research gaps are find out, particularly concerning the medicine supply chain related risks in the hospital sector.

Chapter Three – Research methodology: This chapter explains the methodology, philosophy, approach, strategies and choices that established the foundation for the research work. After defining the overall research design, the chapter looks to justify the methodological choices to meet the research objectives by outlining the application of data collection and analysis methods.

Chapter Four – Conceptual famework and integrated risk management model: This chapter presents the novel risk management conceptual framework as a platform that attempts to incorporate the five main components, namely risk drivers and sources, decision-making, SC

strategies, supply chain risk management process and performance outcomes to address the industrial needs for practical decision support methodology. Based on the proposed framework, the integrated risk management model is developed by following three main risk management steps through organising and refining the previous methods.

Chapter Five – Healthcare supply chain risk factors identification: This chapter presents the first step of the risk management process, *i.e.* risk factors identification. In order to expand the coverage of the risk factors identification and classify the unstructured risk factors, this chapter reviewes relevant literature and other published materials. The questionnaire surveys is developed to make inferences about the attitudes and opinions from participant academic and industrial experts. Based on the survey results, the developed hierarchical structure of identified risk factors are modified and further validated through a serial of email and face-to-face interviews with the experts.

Chapter Six – Healthcare supply chain risk assessment: This chapter focuses on the assessment of identified risk factors in the hospital setting. It illustrates second-round questionnaire surveys conducted by empirical studies, where the data collected are analysed using Fuzzy AHP and ISM methods. This is carried out to determine the relative significance and highlight the interactions between each risk leading to the supply chain disruption.

Chapter Seven – Identification and evaluation of risk mitigation strategies: Instead of identifying the mitigation strategies based on the literature review, this research focuses on the current implemented strategies in the real-time context and identifies them through the empirical studies in both UK and China healthcare industries. The significant levels of risk mitigation strategies are evaluated through conducting the five-point Likert scale questionnaire survey and ranked by using a Fuzzy TOPSIS method. The chapter ends with the discussion and managerial implications.

Chapter Eight – Conclusion: This chapter summarises the findings on the risk factors identification, risk assessment and risk mitigation in the previous chapters. It also suggests the limitations of this thesis and provides the direction and recommendations for further research agenda. Figure 1.2 illustrates the overall thesis structure.

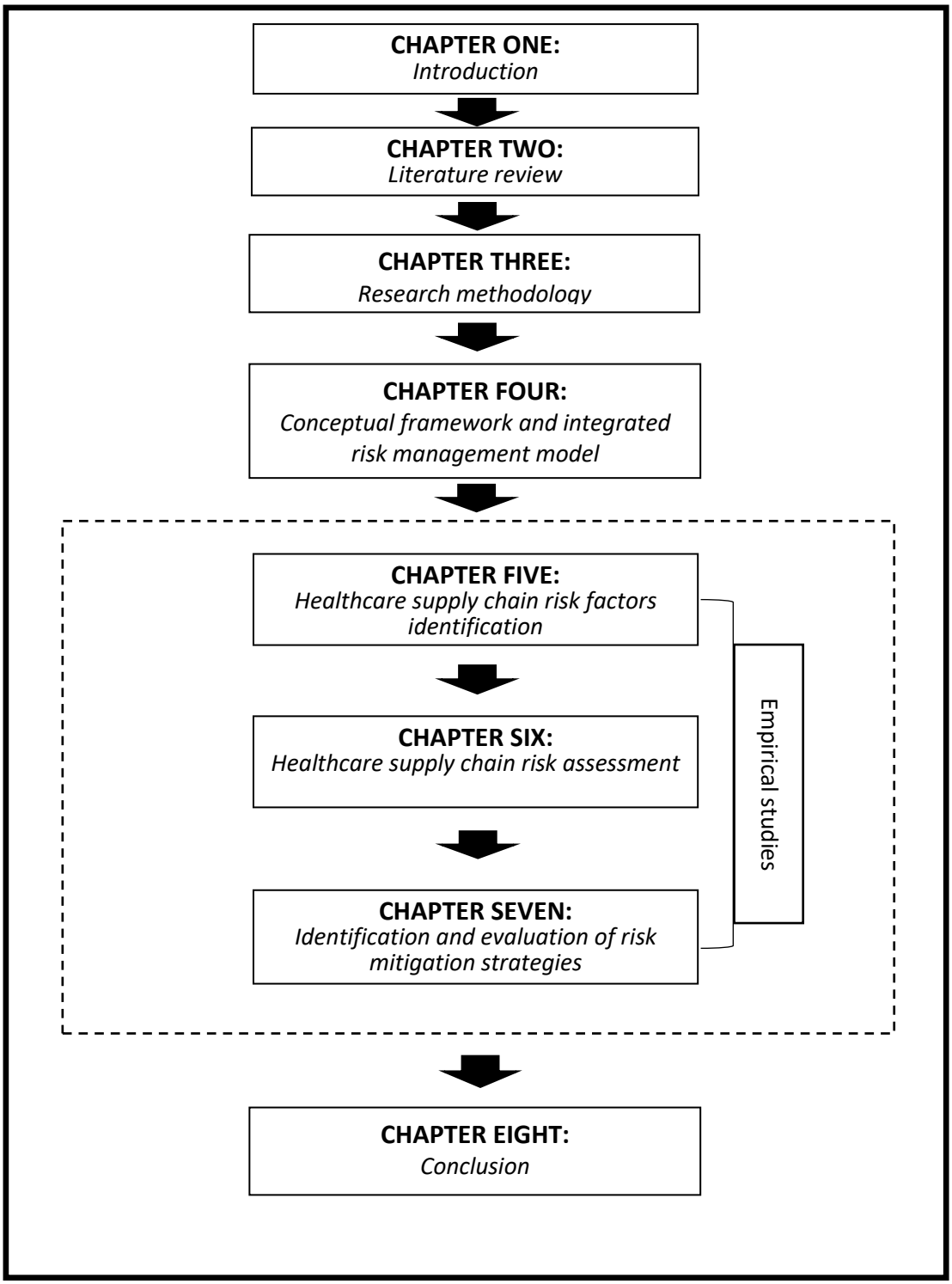


Figure 1-2: The structure of the thesis

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides details of how the rigorous systematic literature review are conducted, highlights the gaps allowing to clarify the research problems in the proposed study. The review of the literature comprises of three key areas, which are critical to the research including: healthcare supply chain management (HCSCM), supply chain risk management (SCRM) and healthcare supply chain risk management (HCSCRM) as shown in Figure 2.1.

It begins with the review of the current status of healthcare supply chain management and an introduction of the systematic review methodology. This is followed by the results section. The discussions of conceptual and research methodological issues are presented.

Thereafter, this chapter reviews the previous research on SCRM and identifies the research gaps, particularly with respect to the healthcare supply chain risk management (HCSCRM) in the hospital setting. Due to the lack of in-depth studies on HCSCRM, it leads to this literature review focusing on how SCRM knowledge has been built up in order for the findings to be applied to healthcare supply chain contexts. To understand the existing body of literature, the overview of conventional SCRM literature, SCRM methodologies as well as the status of supply chain risk management in the healthcare sector are presented.

The chapter concludes by summarising the key findings of the review, highlighting the contributions this study makes to the body of healthcare SCM and SCRM knowledge, and identifying the implications of the findings for practitioners and scholars. Thus, a future research agenda can be derived from the research gaps identified.

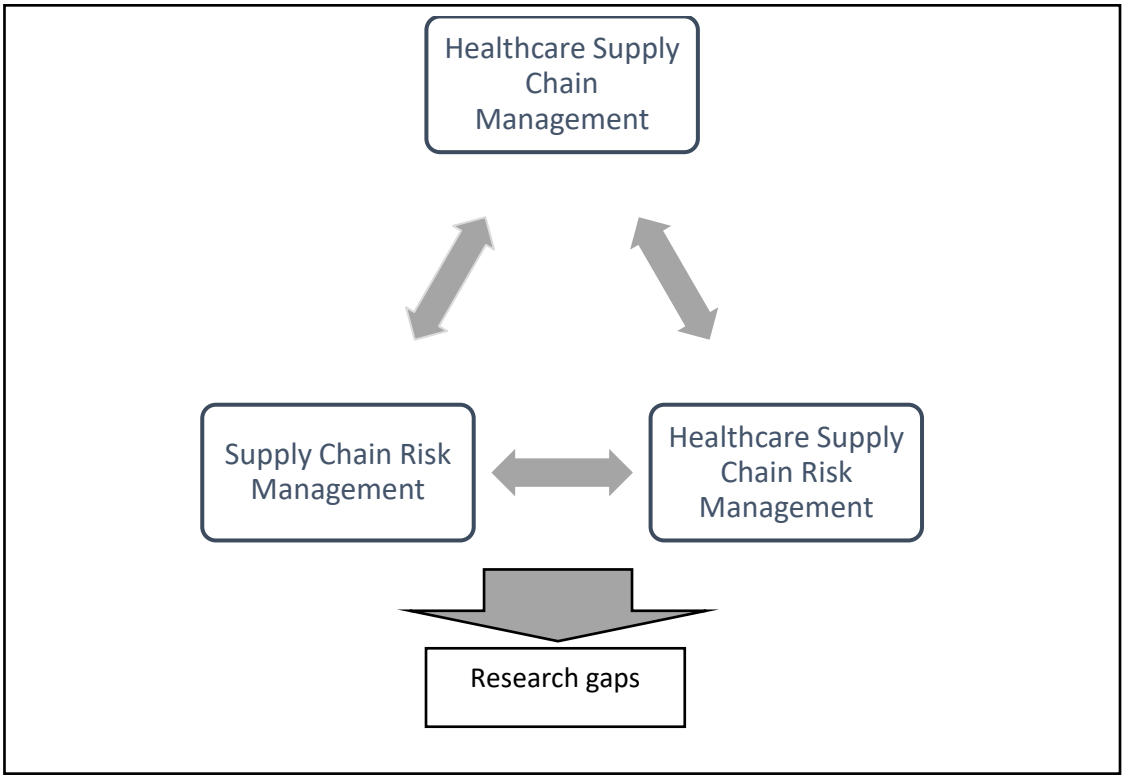


Figure 2-1: Three key areas of the literature review

2.2 HEALTHCARE SUPPLY CHAIN MANAGEMENT (HCSCM)

In recent years, healthcare and hospitals have been under increasing pressure to find ways of improving services and reducing costs. This is owing to the fact that competition in the healthcare sector has increased due to globalisation (Carter and Rogers, 2008), differentiation in customer demands, and resource pressure faced by private and public-service providers. Furthermore, the reforms have forced hospitals to find new ways to cut the costs of operation. Currently, statistics show that the healthcare sector loses approximately $5 billion annually in the implantable device supply chain due to waste, inefficiency, and sometimes inadequate visibility (Seuring and Müller, 2008).

In most healthcare institutions, supply chain cost is the second highest cost after labour. As a result, most hospitals are looking for ways to reduce their supply chain costs while improving their efficiency (Kumar *et al.,* 2009). There is evidence showing several opportunities where new thinking in commercial and industrial logistics and service supply chain management (SSCM) are being transformed into healthcare delivery to advantageous effect (Towill and

Christopher, 2003). Supply chain management (SCM) is a systematic approach to create a seamless and continuous process in supply chain operations (Mentzer *et al.,* 2001).

Harland (1997) suggested that the term supply chain management can be used to describe several concepts: the processes inside a manufacturing organisation, purchasing and supply management occurring within dyadic relationships, the total chain, and finally, a total firm network. Healthcare service providers are utilising SCM to reduce operation costs by automating manual processes, creating efficient trading partner's relationships, reducing waste and excess product, capturing all supply data for business requirements, and enabling automation among regional care networks (Seuring and Müller, 2008; Aronsson *et al.,* 2011). As an organisation, the hospital operations under certain supply chains are not only meant to increase the productivity of the hospitals but also to manage the risk associated with healthcare. There is no doubt that today's healthcare supply chain is more complex, and it involves technology, partnerships, and consolidation within the supply chain community (Haszlinna *et al.,* 2009). Healthcare and hospital operations are delivering goods and services from many suppliers to patients with a wide range of health requirements due to the need for hospitals to provide both planned and emergency care (Fenies *et al.,* 2006; MacVaugh, 2007). For example, some drugs require special temperature conditions for storing and delivery. Furthermore, a zero-defect condition is necessary for the healthcare delivery process to patients. Lillrank *et al.,* (2011) examined straightforward applications of manufacturing methodologies that fail to capture some essential features of healthcare.

In practice, performance measurement and process redesign have been proved as the two main approaches to improve hospital supply chain operation performance within the healthcare sector (Trautmann *et al.,* 2009). It is, however, important for researchers and practitioners to fully understand the process involved to benefit from the chosen methods. Likewise, it is essential to be knowledgeable about the associated issues inherent in the service delivery processes and the supply chain because, in business planning, quality, quantity, cost, and risk are all closely interrelated (Chakraborty *et al.,* 2014). In general, there is a vast and rapid change in the events in a hospital supply chain. It is vital to develop solutions that optimise profit by minimising wastage, while remaining flexible to the changing trends in the healthcare sector (Mustaffa and Potter, 2009). The objective of this section is two-fold. First, existing healthcare SCM research work between 1995 and 2016 is presented.

Second, a detailed review is undertaken associated with research developments in healthcare SCM.

2.2.1 HCSCM research methodology

A literature review is a major contribution to a research project, and it will provide a historical perspective of the different research areas and an in-depth account of independent research endeavors (Mentzer and Kahn, 1995). A systematic review procedure for retrieving and selecting the reviewed articles has been applied following Tranfield *et al.,* (2003) to avoid bias and improve the validity of the outcomes. The flowchart of the systematic research methodology outlines the review procedure step by step as illustrated in Figure 2.2 (Ho *et al.,* 2015).

2.2.1.1 Sourcing articles

The search strings used in the review, such as 'healthcare/hospital/pharmaceutical supply chain', 'healthcare service delivery', 'patient flow', 'logistics', and 'healthcare', and the search were directed to 'all fields', which does not limit the search to the title or keywords. In view of this, reviewed journal articles were selected being published between 1995 and 2016. The academic databases that were used to identify journal articles included Emerald insight, IEEExplore, ProQuest, ScienceDirect, Taylor and Francis, Web of Science, and ResearchGate. In addition, the literature search was supplemented by Google Scholar and OpenAuthors to improve completeness. Choosing these established databases also helped in minimising any form of publication bias or reviewer prejudices. Cronin *et al.,* (2008) maintained that some reviewers may refuse to publish some primary studies, particularly when they report findings that do not conform to their expectations. To achieve the highest level of relevance, as Moher *et al.,* (2009) suggested, peer-reviewed journal articles provide credible information because, for an article to be published in a journal, it must be reviewed by a team of specialised personnel to ascertain its authenticity. Journal articles also provide sources of up-to-date information as compared to books (Moher *et al.,* 2009). Thus, the peer-reviewed journal articles written in English were focused exclusively, whereas conference papers, master and doctoral dissertations, textbooks, book chapters, and notes were excluded in this review.

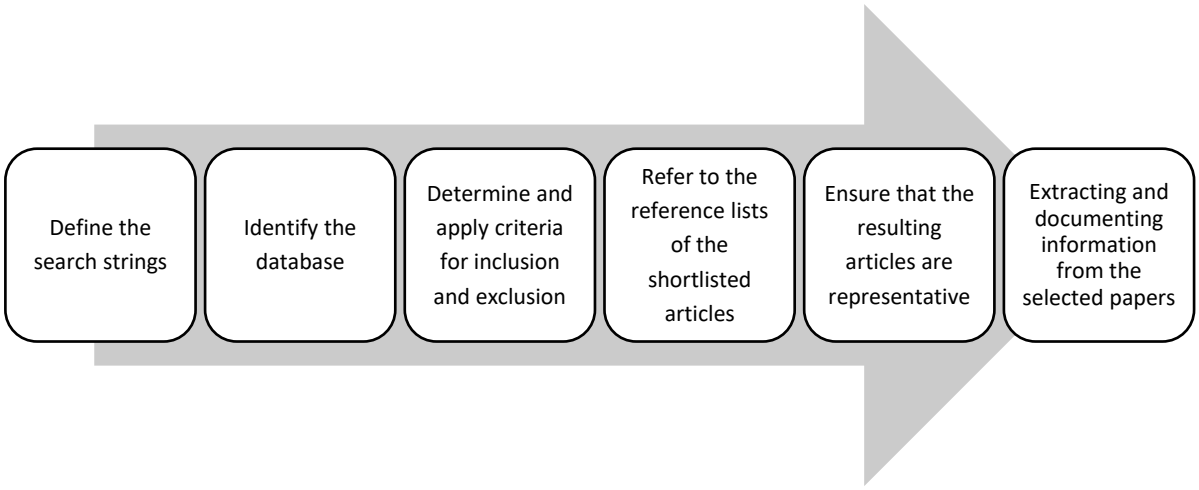


Figure 2-2: Flowchart of the HCSCM literature review methodology
(source adapted from Ho *et al.,* 2015).

The primary purpose for targeting databases was the fact that these databases contain a huge volume of peer-reviewed papers. A systematic review of the references cited in the resultant articles was also undertaken. The search retrieved a total of 369 papers. All the abstracts of the articles were examined to validate whether they covered one or more of the healthcare SCM topics, including material management, patient pathways, logistics, and research gap identification. Figure 2.3 illustrates a continuous increase in the number of papers focusing on the development of the healthcare supply chain in the past 20 years.

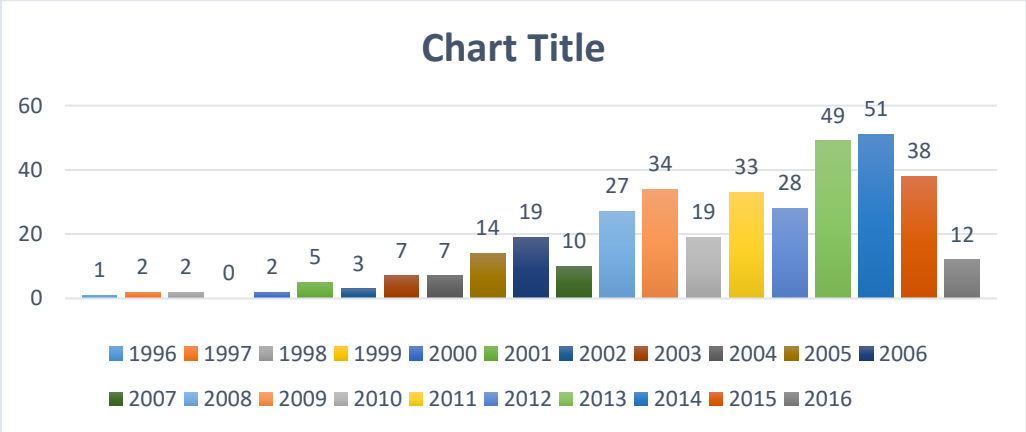


Figure 2-3: Distribution of the number of journal articles between 1995 and 2016 (369)

2.2.1.2 Screening articles

The retrieved articles were subjected to three stages of screening:

- The term *healthcare supply chain* is used to describe the flow of goods and services from the supplier to the end user (*i.e.* patients). Because the research only focused on the downstream supply chain of the healthcare industry, especially in the hospital setting, the papers related to the upstream part of the healthcare industry will be excluded. This reduced the number of articles from 369 to 227.
- Second, the retrieved articles based on the citations and the impact factor of each published journal were checked in order to ensure a high quality of articles. After this stage, a total of 87 papers were retained.
- Third, the reference lists of the shortlisted articles were also carefully cross-checked to ensure that there were no other articles of relevance that were omitted in the research. In all, 87 articles met the inclusion criteria for healthcare SCM. Furthermore, because SCM can be considered as the processes inside an organisation, some studies in terms of lean healthcare used for healthcare service delivery could also be included for the review. In the end, this analysis resulted in 87 articles.

2.2.1.3 Analysis and coding

Finally, this stage involved extracting and documenting information from each of the 87 sources. The seven dimensions along with the articles were analysed and integrated into a literature review framework suggested by Burgess *et al.,* (2006). As Table 2.1 shows, the classification framework is structured by four main components that enable a holistic and systematic literature review. More specifically, Grouping 1 conducted an analysis of the selected articles used and examined the trends of the research on healthcare SCM. Grouping 2 provided an evaluation of the consistent and various definitions in healthcare SCM from different researcher perspectives.

Table 2.1: HCSCM literature review classification framework
(source adapted from Burgess *et al.,* 2006)

Grouping	Content Covered	Rationale
1. Descriptive features of healthcare SCM literature	Time distribution of publications, journal names, contributing country	Describe characteristics of sample of articles
2. Definitional issues	Approaches to definitions and taxonomy for healthcare SCM	Explore consistency or variation in healthcare SCM definitions by researchers on a range of dimensions. Define the territory that the researchers claim falls within healthcare SCM
3. Theoretical concerns	Theoretical perspectives	Determine the range of theories that are used to inform healthcare SCM and the ends to which they are applied
4. Research methodological issues	Research methods	Determine the types of research methods that are used to explore healthcare SCM

Moreover, it classified the taxonomy of healthcare SCM from both physical and patient service views. Grouping 3 also classified the articles but dealt with issues within the theoretical bases. Finally, Grouping 4 examined issues associated with research methodology that are used to explore healthcare SCM. The framework was designed to assist in establishing a clear 'line of sight' from information sources to definitional matters, and then through to theoretical concerns and research approaches (Burgess *et al.,* 2006).

2.2.2 Results of HCSCM literature review

2.2.2.1 Descriptive features of HCSCM literature (grouping 1)

2.2.2.1.1 Time distribution of publication of articles

Owing to the limitation for exploring the trend of publication for healthcare SCM using the selected 87 papers, it provides an overview of the total retrieved 369 papers published in the last two decades, as shown in Figure 2.3. The first articles appeared in 1995. Until 2005, there

was a gradual increase in publications, with 334 out of 369 articles published between 2005 and mid-2016. The year 2014 represented a promising year in healthcare SCM research, contributing the most in the volume of papers published.

2.2.2.1.2 Journal titles

The 87 selected articles were reviewed to identify the journals and the number of articles published in each journal. As shown in Table 2.2, a total of 55 journals covering diverse perspectives of healthcare SCM were captured in the review. Three journals, *Production Planning and Control: The Management of Operations* (5), *International Journal of Health Care Quality Assurance* (4), and *Supply Chain Management: An International Journal* (11), accounted for 23% of the publications. The remaining 77% of articles were 'thinly' spread over the remaining 52 journals.

2.2.2.1.3 Contributing country

Descriptive analysis of countries contributing to healthcare SCM showed that US academics researchers contributed the most healthcare SCM papers, which comprise 88% in America and 28% in the world (Figure 2.4). The UK followed with 41% in Europe and 14% in the world. In Asia, India dominated one-third of the published articles compared to other countries. In Oceania, the Middle East, and Africa, the countries of Australia, Iran, and Ghana comprised 34%, 20%, and 34%, respectively, in those regions. In addition, there is collaborative research among co-authors representing more than two countries (*e.g.,* Laureani *et al.,* 2012; Aronsson *et al.,* 2011; Chireu *et al.,* 2014).

Table 2.2: List of journals publishing HCSCM research to date

Journal	No. of papers	Journal	No. of papers
Academy of Taiwan Business Review	1	*Journal of Service, Science and Management*	1
African Journal of Business and Economic Research	1	*Journal of Business Logistics*	2
Business Process Management Journal	2	*Journal of Risk Research*	1
Computers in Biology and Medicine	1	*Journal of Operations Management*	2
Computers and Operations Research	1	*Journal of Health Organization and Management*	3

Clinical Governance: An International Journal	1	*Journal of Management in Medicine*	1
Health Policy	1	*Journal of Purchasing and Supply Management*	1
Health Care Management Science	2	*Journal of Industrial Engineering and Management*	1
Health Marketing Quarterly	1	*Journal of Management and Strategy*	1
Health Care Management Review	2	*Journal of Health Service Research and Policy*	1
Healthcare Financial Management	1	*Journal of Healthcare Information Management*	1
Health Affairs	1	*Journal of Marketing Management*	1
International Journal for Quality in Health Care	1	*Leadership in Health Services*	3
International Journal of Innovation and Technology Management	1	*Management Review: An International Journal*	1
International Journal of Operations and Production Management	3	*Operations Research for Health Care*	2
International Journal of Logistics Management	2	*Production Planning & Control: The Management of Operations*	5
International Journal of Production Economics	2	*Public Money and Management*	1
International Journal of Health Care Quality Assurance	4	*Public Management Review*	1
International Journal of Value Chain Management	1	*Procedia Economics and Finance*	1
International Journal of Logistics Systems and Management	1	*Quality Management in Healthcare*	1
International Journal of Productivity and Performance Management	2	*Research Journal of Recent Sciences*	1
International Journal of Quality and Reliability Management	1	*Research in Social and Administrative Pharmacy*	1
International Journal of Physical Distribution and Logistics Management	2	*Supply Chain Management: An International Journal*	11
International Journal of Six Sigma and Competitive Advantage	1	*Strategic Outsourcing: An International Journal*	2
Ingenieria e Investigacion	1	*The International Journal of Human Resource Management*	1
Technology and Health Care	1	*The International Journal of Accounting*	1
The Journal of Applied Business Research	1		

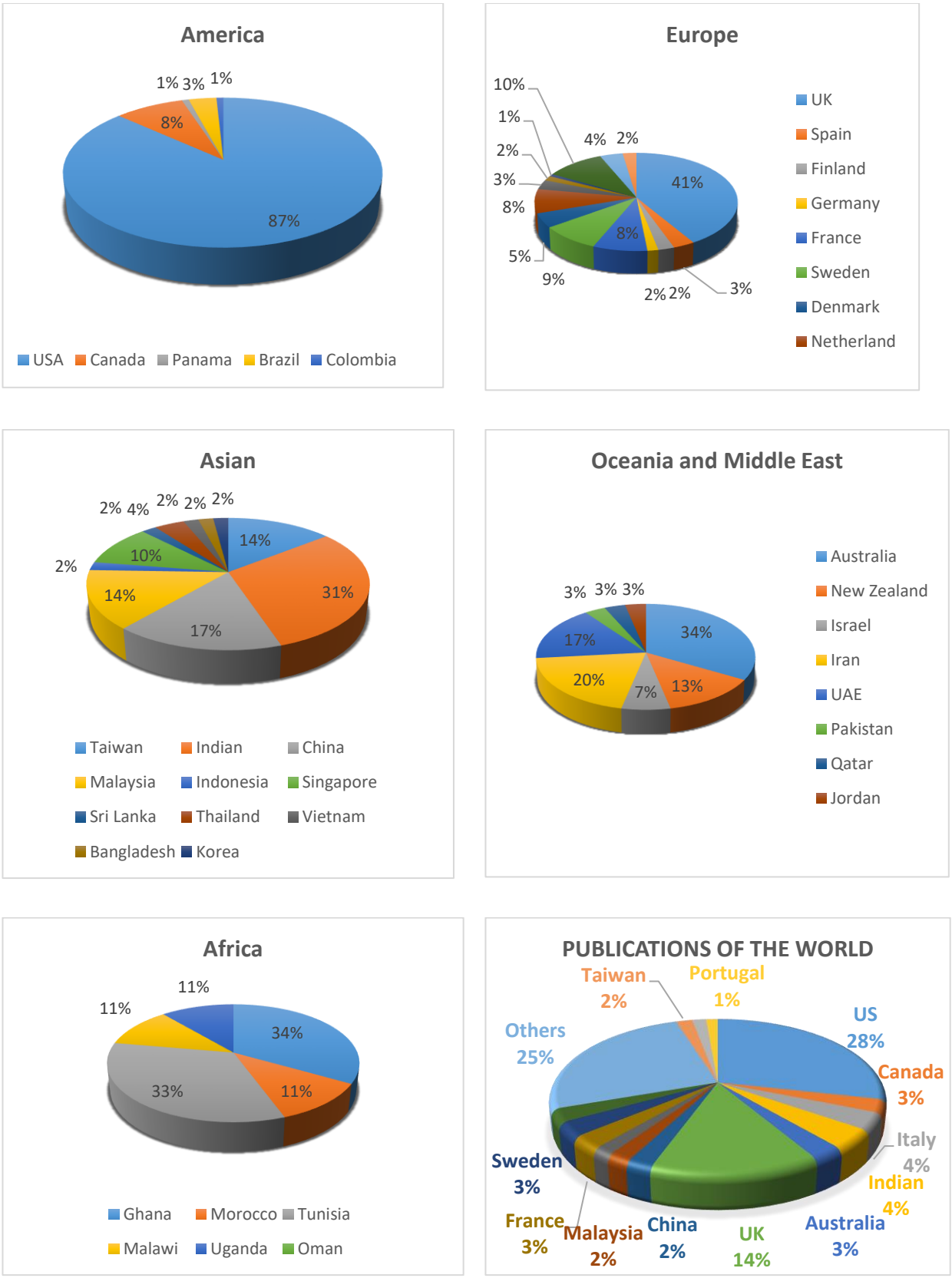


Figure 2-4: Distribution of contributing countries in HCSCM in the world

2.2.2.2 Definitional Issues (grouping 2)

2.2.2.2.1 Definition of healthcare supply chain management

As indicated in Figure 2.3, it appears that the development of the healthcare SCM is still in its early stage. The specific definition of the healthcare supply chain has emerged in the literature with diverse perspectives, as summarised in Table 2.3. It indicated that there is no consensus on the concepts of the healthcare supply chain. However, without a mutual understanding and clear definition, it will become difficult for researchers to communicate with practitioners and gain access to the industry to conduct empirical studies (Ho *et al.,* 2015).

It is impossible to build one's own definitions subjectively without any foundations based on the literature. Thus, a conservative approach has been suggested by Burgess *et al.,* (2006) who proposed that a definition must be explicitly stated, not merely implied, to be useful. As shown in Table 2.4, the literature has been classified into existing, modified, or original definitions. According to Table 2.4, about two-thirds of the articles (58) did not provide definitions. Moreover, 18 out of 87 used existing definitions. However, little consistency was found in the specific definitions used. Four of the 18 articles utilised the definition proposed by Burns (2008), who suggested the four main components in the healthcare supply chain (producer, purchaser, provider, and payer). The remaining articles only focus on the supply chain partially or on a specific aspect, such as the healthcare service delivery process. Only eight papers developed their own definitions in healthcare SCM. However, most of these have not been utilised or developed by other researchers.

Table 2.3: Definitions of HSC given by researchers

AUTHORS	Definitions of Healthcare SC	Scopes
Brennan (1998)	The supply chain is the chain of activities, information, and flow of funds that extends from manufacturers to the customer or patient.	Integrated delivery systems
Rivard-Royer *et al.,* (2002)	A major characteristic of the healthcare sector supply chain is the simultaneous presence of two chains: one external and the other internal. From the multitude of different supplies used by the institutions and the myriad distribution channels through which they flow, these supplies may come directly from the manufacturer or through a distributor. The healthcare institutions are not the end	Supply chain integrating

	customers. Hospitals must deploy their own logistics networks for delivering suppliers to the patient care units and users.	
Lina *et al.,* (2005)	Healthcare SCM is considered more problematic compared to the industrial sector. This is because the volume of diverse support services required to deliver the product (patient care) is unique, and the decision maker must consider information, material, and cash flows in the system.	Inventory management
Christopher and Towill (2005)	The authors defined the healthcare supply chain as the healthcare delivery pipelines, which refers to the flow of patients in pursuance of all phases of their treatment from referral to full recovery. In that sense, 'patient flow' is analogous to 'product flow' with corresponding value-added activities in the pipeline and similar valid concerns regarding quality management and delivery cycle times.	Pipeline differentiation
Kitsiou *et al.,* (2007)	The current healthcare supply chain is a multifaceted system consisting of several processes, tasks, intermediaries, and interfaces, where numerous responsibilities are highly segregated from the manufacturer to the end user: the patient.	Information systems
Samuel *et al.,* (2008)	The supply chain process is the essential link for all programs and services offered by a hospital. Hence, any improvement in managing the supply chain can positively affect the bottom line profitability of any hospital operations.	Performance improvement
Jan and Robert (2011)	The healthcare supply chain refers to the information, supplies, and finances involved with the acquisition and movement of goods and services from the supplier to the user to enhance clinical outcomes while controlling costs.	Integrated health supply chain
Shou (2013)	Healthcare SCM processes have three types of flows: physical product flow, information flow, and financial flow. The physical product flow manages customised products and services for the treatment of patients and their needs. Information and financial flows are related to supply chain design decisions for effective product flow and improved organisational performance.	Application of healthcare SCM in developing countries

Tillmann *et al.,* (2013)	Healthcare supply chains can be considered the 'value stream', which is defined as the special activities required to design, order, and provide a specific service to patients.	Performance measurement
Daniel *et al.,* (2013)	Hospital supply chains are unique and different from the typical industrial supply chains in many aspects, such as requiring accurate supplies, requiring special handling conditions for supplies, supply driven by physician preference, and rapid development of technology.	IT investment and hospital-supplier integration
Umang and Ramesh (2015)	Healthcare SCM is a set of approaches to link medicines, equipment, laundry, food, supplies, vendors, hospitals, and transport for efficient and effective use of resources to achieve total quality management.	Performance measurement
Abu *et al.,* (2015)	Hospital SCM ensures control of product flow through participation of three major stakeholders: producers, purchasers, and providers.	Value healthcare supply chain integrated hospital management
Chris *et al.,* (2014)	Healthcare supply chain represents the conduit in which pharmaceutical products take ingredients from the suppliers of active pharmaceuticals to the manufacturers of pharmaceuticals to the healthcare providers (hospitals and medical clinics) and clinicians to the ultimate end user: the patient.	Healthcare supply chain risk management
Schneller and Smeltzer (2006)	The healthcare supply chain is defined as 'the information, supplies, and finances involved in the acquisition and movement of goods and services from supplier to the end user in order to enhance clinical outcomes while controlling costs'.	

Table 2.4: Approaches to definitions of HCSCM

Approach to Definition	Articles	Count
Developed own definition	Kitsiou *et al.,* (2007); Vries and Huijsman (2011); Brennan (1998); Chen *et al.,* (2013); Breen (2008); Enyinda *et al.,* (2014); Bourlakis and Patten (2011); Langabeer (2005)	8
Used existing definitions	Elmuti *et al.,* (2013); Mustaffa and Potter (2009); Matopoulos and Michailidou (2013); Priyan and Uthayakumar (2013); Böhme *et al.,* (2013); Kumar *et al.,* (2008, 2009); Pan and Pokharel (2007); Kjos *et al.,* (2016); Rivard-Royer *et al.,* (2002); Meijboom *et al.,* (2011); Samuel *et al.,* (2010); Drupsteen *et al.,* (2013); Rahimnia	18

	and Moghadasian (2010); Hugo *et al.,* (2002); Narayana *et al.,* (2014); Kim and Kwon (2015); Aronsson *et al.,* (2011).	
Incrementally changed existing definitions	Villa *et al.,* (2014); Parnaby and Towill (2009); Towill (2005)	3
None used	Behzad *et al.,* (2011); McKone-Sweet *et al.,* (2005); Kumar and Blair (2013); Chakraborty *et al.,* (2014); Agwunobi and London (2009); Burns and Lee (2008); Jin *et al.,* (2008); Gebicki *et al.,* (2014); Guimaraes *et al.,* (2013); Heibuch (1995); Jurado *et al.,* (2016); Kelle *et al.,* (2012); Böhme *et al.,* (2014, 2016); Kumar *et al.,* (2005, 2008); Bakar *et al.,* (2009); Fernie and Rees (1995); Lega *et al.,* (2013); Bhaoo *et al.,* (2012); Rego *et al.,* (2014); Grose and Richardson (2014); Aptel and Pourjalali (2001); Jarrett (1998); Xie *et al.,* (2016); Elleuch *et al.,* (2014); Aguas *et al.,* (2013); Kanyoma *et al.,* (2013); Cullen and Taylor (2009); Ketikidis and Stalidis (2010); Lin and Ho (2014); Sampson *et al.,* (2015); Lillrank *et al.,* (2011); Ghorani (2015); Breen and Crawford (2005); Bendavid *et al.,* (2010); Chireu (2014); Laureani *et al.,* (2013); Radnor *et al.,* (2013); Al-Balushi *et al.,* (2014); Brandao de Sourza (2009); Chadha *et al.,* (2012); Stanton *et al.,* (2014); Joosten *et al.,* (2009); Curatolo *et al.,* (2014); Poksinska (2010); Souza and Pidd (2011); Guven-Uslu *et al.,* (2014); Guimaraes and Carvalho (2013); Burgess and Radnor (2013); Kollberg *et al.,* (2006); Olsson and Aronsson (2015); Dobrzykowski *et al.,* (2014); Machado *et al.,* (2015); Granlund and Wiktorsson (2013); Lapierre and Ruiz (2007); Vries (2011); Lent *et al.,* (2012).	58
Total		87

2.2.2.2.2 Taxonomy for healthcare SCM literature

Over the last few years, the literature on healthcare SCM has been broadening to include not only medical and surgical supplies but also a focus on patient flow i.e. the process in which patients enter the hospital until discharge (Jan *et al.,* 2011; Paul and Johan, 2011; Walley, 2007; Towill and Christopher, 2006; Cherian *et al.,* 2010; Olsson and Aronsson, 2015). The reviewed literature shows that different researchers studied this area through diverse perspectives. As it describes above, there is no consensus on the concept of the healthcare supply chain; most researchers only focus on the supply chain partially or on a specific aspect. These publications can be placed into three main categories: physical flow, patient flow, and whole supply chain. Further classification can be divided into seven sub-categories as follows: physical flow (logistics management, information communication system implementation,

performance measurement, process improvement orientation, risk management) and patient flow (performance measurement and process reengineering). Figure 2.5 illustrates this proposed taxonomy.

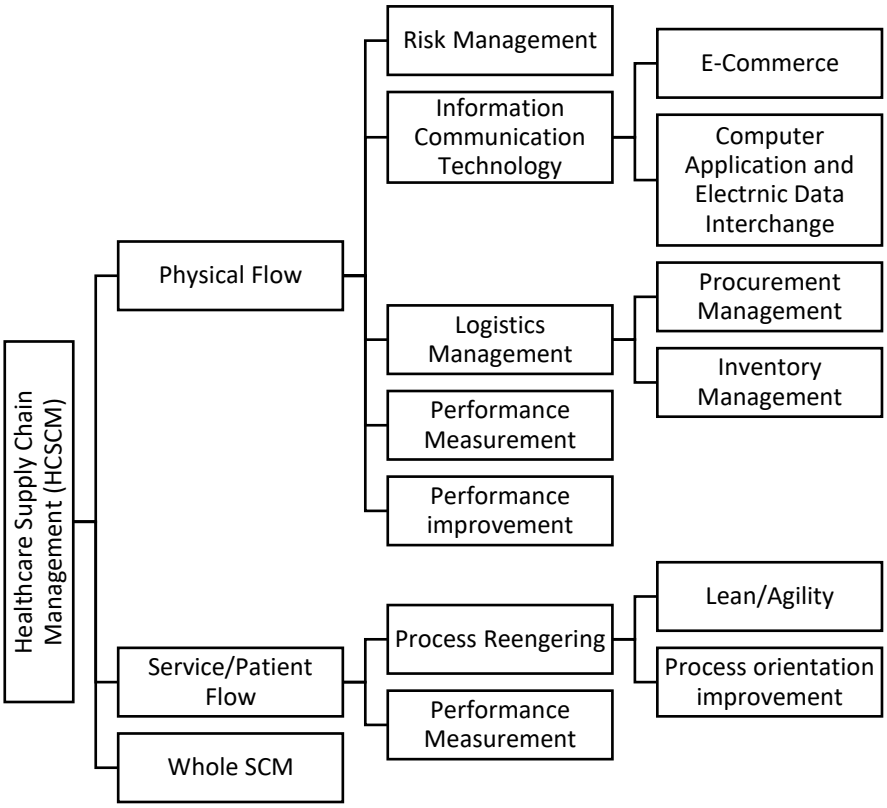


Figure 2-5: Taxonomy of HCSCM literature

2.2.2.3 Profiling published literature

2.2.2.3.1 Whole supply chain perspective

There is evidence of several opportunities where new thinking in commercial and industrial logistics and SCM are being transformed into healthcare delivery to advantageous effect (Towill and Christopher, 2003). According to Mentzer *et al.,* (2001), SCM can be defined as the systemic, strategic coordination of traditional business functions and tactics across these business functions within a company and across businesses within the supply chain to improve the long-term performance of individual companies and the supply chain.

Individual businesses no longer compete as stand-alone entities but as supply chains (Christopher, 2000). It is noteworthy that the great competitions in the future will not be between companies but rather between supply chains. Arthur Andersen and Co, (1990) developed a structure of a healthcare supply chain, as shown in Figure 2.6. They give the operational definition of the healthcare supply chain process: 'the vendor delivers products in 'eaches' (single), sorted by user department, to the hospital receiving dock where they are transported directly to the department, usually on a daily basis'. In addition to hospital, pharmacies are the final step on the healthcare supply chain before drugs reach the consumer/patient. Pharmacies purchase drugs from wholesalers, and occasionally directly from manufacturers, and then take physical possession of the drug products. After purchasing pharmaceuticals, pharmacies assume responsibility for their safe storage and dispensing to consumers. Pharmacy operations include maintaining an adequate stock of drug products, providing information to consumers about the safe and effective use of prescription drugs, and dacilitating billing and paument for consumers participating in group health benefit plans.

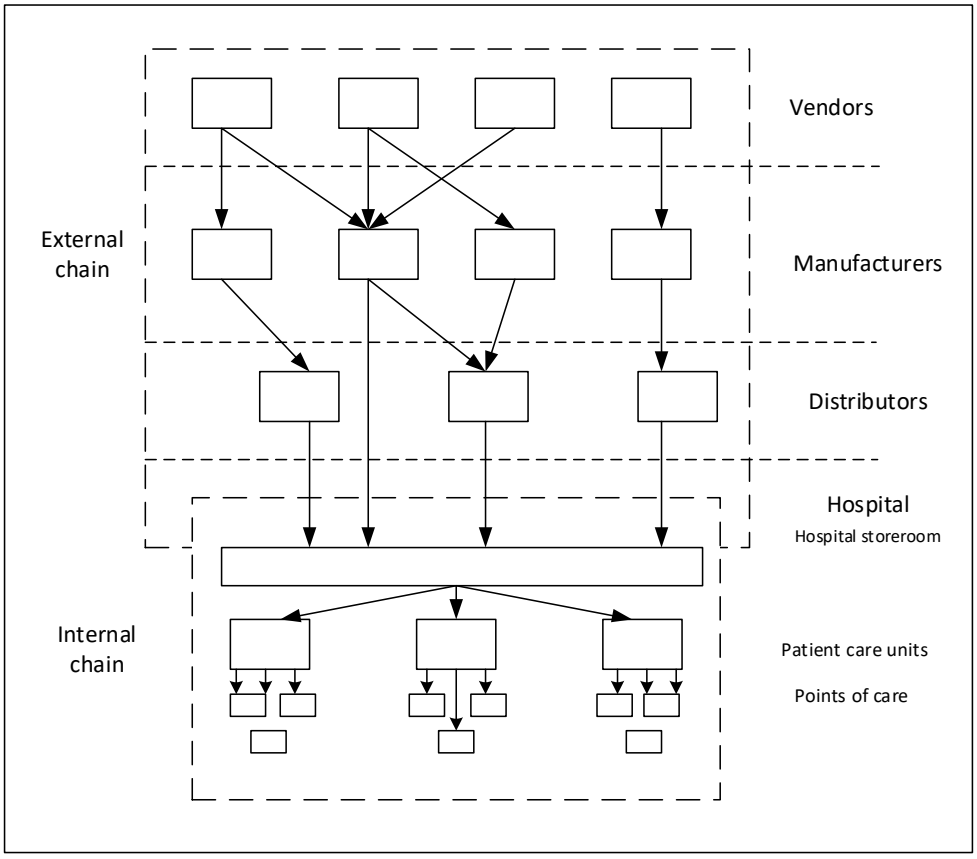


Figure 2-6: Healthcare supply chain structure

Due to the fact that, SCM is based on a systematic approach, only a few researchers have evaluated the healthcare supply chain through both physical and patient flows perspectives. Most studies have devoted the contributions into SCM partially or regarding a specific aspect. More specifically, Vries and Huijsman (2011) argued that the characteristics of the healthcare supply chain have some unique features, which make it difficult for the transition of the managerial knowledge directly from industrial to healthcare settings to take place. However, they have not denied that the healthcare sector can benefit from the knowledge learned in the industrial sector. They discussed the healthcare setting towards more process-oriented and greater integration of the healthcare supply chain through transformation. They suggested the healthcare processes might refer to physical products, such as pharmaceuticals, medical devices, and health aids as well as processes associated with the flow of patients. The authors produced a schematic overview of supply chain integrated development in Figure 2.7. In addition, de Vries and Huijsman (2011) discussed the following five main research areas with respect to healthcare supply chain integration development: (1) use of IT, (2) the influence of power and interest relationships between stakeholders, (3) lean and agile management practices, (4) performance measurements, and (5) applying SCM concepts to patient flows. Nevertheless, it lacks the empirical study to test the suggestion by the authors.

Figure 2-7: Stages of supply chain integration

(adopted from de Vries and Huijsman, 2011).

2.2.2.3.2 Physical flow perspective

a) Logistics management

Logistics activities involve planning, designing, implementing, and managing material flows in a supply chain to support functions such as procurement, distribution, inventory management, packaging, and manufacturing (Pokharel, 2005). In the healthcare sector, the demand for the items is quite difficult to predict (Jarrett, 1998). Moreover, Van Merode *et al.,* (2004) also mentioned that the stochasticity in the patient mix and the average length of in-patient stays are big problems in scheduling resources. The two main approaches used to plan the logistics activities in hospitals are inventory oriented and schedule oriented (Lapierre and Ruiz, 2007). The healthcare logistics aimed to deliver the right drugs and medical supplies in the right quantities and the right conditions at the right health service delivery points and at the right time for the right patients/users for the right cost (Chikumba, 2010).

b) Procurement management

Decision procurement professionals always play a vital role in influencing inventory levels and, ultimately, the service provided to the consumer of the hospital or clinic, as they tend to have control over many supplier relationships. Inefficient procurement will eventually be passed along to the patient as additional costs. Thus, any advances in efficiencies must first begin with procurement (Parker and Anderson, 2002). Based on a survey by the National Health Service (NHS, 2011), 30% of a hospital's budget is spent on procurement. The NHS aims to achieve £1.2 bn in efficiency savings through improved procurement.

According to Messelbeck and Sutherland (2000), the US Environmental Protection Agency (EPA) investigated medical waste as the fourth largest contributor of mercury in the environment. Therefore, better packaging could reduce medical waste and simultaneously lead to logistical efficiencies (Shah, 2004). However, the packaging of supplies is ignored as part of the purchasing decision-making process within the healthcare industry (Kumar *et al.,* 2008). Kumar *et al.,* (2008) studied the effect of packaging design on procurement decisions in hospitals and examined inefficiencies in the US hospital supply chain. The researchers conducted surveys of 75 hospitals across the US in different regions. The survey results revealed that packaging and environmental friendly supplier/medical products do not currently play a role in hospital procurement decisions. Nevertheless, it has effectively been shown that the opportunities for improvement in the packaging industry, engaged in supply

of products to the healthcare industry, require an environmentally conscious approach for long-term cost effectiveness.

c) Inventory management

An area of hospital SCM that particularly warrants close study is inventory (Zepeda *et al.,* 2016). However, the inventory and obsolescence in the healthcare sector are several times higher than in the retail/industrial sector. This is caused by the main driver of hospital inventory decisions, which is not cost but the need to meet service performance outcomes. It is a complex problem due to the uncertainty in the drug demands and the variety of constraints to be considered.

Nevertheless, the budget for healthcare organisations is under increasing strain. It faces a major challenge to reduce costs. Thus, some researchers assessed the best trade-off between cost savings and the high quality of service performance. Moreover, the risk associated with a stock out is also much higher because the demand is hard to predict (Kowalski, 1986). Thus, most researchers (Mustaffa and Potter, 2009; Matopoulos and Michailidou, 2013; Guimaraes *et al.,* 2013) suggested that a vendor-managed inventory approach appears to be the best solution for inventory control. Bhakoo *et al.,* (2012) extended the vendor-managed inventory implementation in the healthcare domain. Furthermore, they suggested that the hospital can participate in myriad collaborative arrangements with supply chain partners to manage inventory. The critical success factor for this arrangement is the compatibility of information systems technology between the third party and the hospital pharmacy.

In the 1980s, US distributors offered hospitals the inventory managerial method called the stockless system. According to Arthur Andersen and Co. (1990), the stockless method means a programme under which the vendor takes over the hospital's central distribution function and delivers products in 'eaches' (single), sorted by the user department, to the hospital receiving dock where they are transported directly to the department, usually daily. Further, by the late 1990s, the method seemed to be losing popularity.

Thus, Rivard-Royer *et al.,* (2002) examined a hybrid version of the stockless system, combining stockless material management and a conventional approach to patient care unit replenishment. The hybrid approach promised further benefits beyond the distributor-

patient care unit interface, to seek opportunities to reengineer the logistics processes for both internal and external unit logistics.

d) Performance measurement

According to Neely (1999), performance measurement can be considered the process of quantifying action, where measurement is the process of quantification and action, which leads to performance. The application of measurement would help organisations calibrate their capabilities and move forward via targeted continual improvement initiatives (Bakar, 2009). Fernie and Rees (1995) evaluated the performance of supply services from three perspectives: the NHS supply managers (service providers), trust hospital chief executives (purchasers of services), and companies supplying products to the NHS. The authors suggested that the establishment of a new internal market within the NHS in the wake of the 1990 legislation has had major implications for the members involved in SCM. Owing to the uncertainty that exists in the market environment, 'partnershipping' was introduced in the research.

Some researchers (Lai *et al.,* 2002; Sharahi and Abedian, 2009) argued that one of the major problems of SCM is the lack of a relevant methodology for performance measures. Further, the Supply Chain Council developed the supply chain reference model (SCOR), which be used in the scientific literature and provides a useful framework for assessing supply chain performance (Lai *et al.,* 2002; Zanjirani *et al.,* 2009). However, Bolstorff (2006) argued that the SCOR model does not focus on the important dimensions of performance that characterise the value chain and thus suggested the use of the balanced scorecard framework (Kaplan and Norton, 1992). In addition, Kumar *et al.,* (2005) developed a procurement performance measurement model combining the generic measures (*e.g.,* efficiency, effectiveness, time, and IT system reliability), healthcare supply chain environment and structure, and procurement procedures. Further, a balanced scorecard is proposed by considering these three main components of the measurement model through six perspectives as follows: customer, supplier, process, IT system, learning, and growth overall.

e) Performance improvement

Brennan and Charles (1998) considered integrated delivery systems (IDSs) to be a key dimension of the integrated supply chain process, which aims to simplify clinical and business

processes within and across entire organisations. In this paper, the authors examined the need for IDSs to meet and exceed the 'best practice' performance in healthcare SCM for demand management, order management, supplier management, logistics management, and inventory management. Further, the limitation of IDSs in implementing service changes, such as user resistance, should be addressed by balancing the customer demand and plan objectives. In addition, IT systems and expertise, human resources, change management, organisational structure, and the relationship between the customer and supplier are the key enablers that can help prepare an organisation to transition to an integrated supply chain.

Healthcare organisations must overcome years of adversarial supplier relationships and dramatic internal and external inefficiencies to reengineer their supply chain (Toba *et al.,* 2008). Risk pooling among the hospitals could be a strategic policy to increase the cost effectiveness of hospitals (Pan and Pokharel, 2007). With the increasing requirement to rationalise healthcare services, there have been diverse attempts to improve the efficiency and effectiveness of hospital systems through vertical or horizontal and direct or indirect supply chain collaboration (Rego *et al.,* 2014).

Moreover, Nyaga *et al.,* (2015) conducted an evaluation of the effects of intra- and inter-organisational arrangements by examining the effect of incentive mechanisms for internal stakeholders and negotiating leverage with external partners on supply chain efficiency in the hospital sector. The result indicated that a higher percentage of physician employment and recruitment of supply chain professionals from the retail and industrial sectors will bring well-established best practices to enhance supply chain efficiency. According to Chakraborty *et al.,* (2014), supply chain collaboration has been established as an antecedent to value co-creation, which acts as a mediator role in the relationship between supply chain collaboration and firm performance. The novel conceptual framework has been proposed using a service dominant logic lens to conceptualise supply chain collaboration and its components in the context of the healthcare supply chain.

McKone-Sweet *et al.,* (2005) explored some barriers to the implementation of SCM practices, which include the lack of executive support, misaligned or conflicting incentives, the need for data collection and performance measurement, limited education about the supply chain, and inconsistent relationships with GPOs and other supply chain partners. Therefore, the authors conducted in-depth interviews with hospital executives and material managers, GPO

executives, distributors, and industry experts from November 2002 to June 2003 to obtain accurate information regarding the above barriers. Further, they divided the healthcare industry into three levels of the hospital supply chain: the environmental level (GPOs and distributors), the organisational level (hospital executives), and the operational level (material and supply chain managers). Then, the authors gave some recommendations for improving the healthcare supply chain regarding the levels, such as:

- Leveraging information systems to standardise, measure, analyse, and report performance metrics in a necessary step to streamline the healthcare supply chain.
- Building a long-term relationship with GPOs for potential advantages in reducing costs and achieving information sharing.
- Creating a structural training programme about supply chain knowledge is necessary for executives and material managers to develop good decision-making and planning capabilities.
- Supply chain performance (delivery performance, clinician and patient satisfaction, *etc*.) measurement plays a vital role for material/supply chain managers to track not only product costs but also other kind of costs.

f) Information communication systems

I. Computer application and electronic data interchange

Healthcare institutions are now adapting to supply chain information management systems to help them manage their procurements and increase efficiency (Zhu *et al.,* 2008). Various customised SCM software for the healthcare sector exists on the market (Gosling and Naim, 2009). Additionally, SCM helps procurement managers make informed decisions when it comes to matters related to the health supply chain. Various information management systems can be used in healthcare supply management data warehousing and analysis of healthcare big data (Carter and Rogers, 2008). However, education on healthcare SCM remains underdeveloped. For the world to achieve efficient healthcare SCM, more emphasis must be focused on healthcare SCM (Wisner *et al.,* 2015).

Kitsiou *et al.,* (2007) conducted the evaluation of various integration technology approaches that can be used as a potential guideline for assessing integration technology alternatives to

add value to a healthcare SCM system. In this study, the different information system technologies have been investigated, such as electronic data interchange (EDI), XML, Health Level Seven (HL7), common object request broker architecture, distributed healthcare environment, and web services.

The RFID technology is a wireless automatic identification and data capture technology (Wamba *et al.,* 2008) used to track and manage products, people, and assets with minimal human intervention. Clearly, RFID technology can provide many benefits for healthcare and pharmaceutical applications that allow service providers to design more efficient processes, reduce costs, and improve service and patient safety. In addition, pharmaceutical companies are using RFID to protect against counterfeit drugs (Kumar *et al.,* 2009). In fact, RFID spending in healthcare organisations was expected to increase rapidly from $474 million in 2008 to $3.1 billion in 2013 (Kalorama, 2008).

Bendavid *et al.,* (2011) examined the implementation of an RFID-based two-bin 'e-Kanban' replenishment system solution to improve the replenishment processes of medical supplies in a hospital distributed storage location through case study analysis. The results demonstrated that automating the nursing unit supply chain with the RFID system in conjunction with the redesign of the ward floor and of the roles and functions can substantially improve business and operational performance. However, the current RFID technology is too expensive for broad implementation within the healthcare sectors; thus, it must be calculated carefully to ensure proper investment for the organisations (Kumar *et al.,* 2009).

Pan and Pokharel (2007) investigated the motivators and barriers to the use of ICT in logistics in Singapore hospital settings. In this study, the authors mentioned that increasing efficiency, reducing data entry error, decreasing operational cost, and decreasing labour costs are some of the main reasons for ICT adoption in hospitals. In contrast, the cost of implementation, the availability of expertise to handle such new ICT, and a long period could be the main barriers.

II. E-commerce

The term e-commerce has been defined as 'the sharing of business information, maintaining business relationships, and conducting business transactions by means of telecommunication

networks (Dutta, 1997). While e-commerce is in its infancy in the hospital supply chain, it can be considered an important facet of SCM.

Breen and Crawford (2005) examined the role of e-commerce in a hospital pharmacy in the procurement of pharmaceuticals through EDI application. The researchers conducted an evaluation of the barriers and benefits for an applied EDI system in a hospital pharmacy, such as the lack of funding, security issues, and time saving. In addition, they suggested that internal customer satisfaction is central to the success of e-procurement deployment. The limitation of the study is that they only conducted a case study of a specific regional area of the NHS, which could have been applied to a larger national sample group. Cullen and Taylor (2009) determined five composite factors that are perceived by users to influence successful on-going use of e-commerce systems in business-to-business (B2B) buying and selling transactions in the UK NHS pharmaceutical supply chain. 'System quality', 'information quality', 'management and use', 'world wide web – assurance and empathy', and 'trust' were proposed as potential critical success factors. In a questionnaire based on this in the UK NHS pharmaceutical supply chain, all respondents ranked information quality, system quality, and trust as being the most crucial factors. However, they are not devoid of limitations, as they only focused on a single supply network.

2.2.2.3.3 Patient flow perspective

a) Process reengineering

I. Process orientation improvement

The redesign of supply chain processes for a smoother, faster response has become the main research topic since the classic contribution by Jay Forrester (1961) over 50 years ago. Most key ideas by Jay Forrester have been subsumed within business process reengineering. Berry *et al.,* (1995) further examined this approach in the electronic products supply chain for improving performance. According to Aronsson and Abrahamsson (2011), the healthcare supply chain can be considered the patient flow, which means the customer is part of the production process. Instead of going to the store to buy a finished product, a patient seeks medical help and is then a part of the entire process until the treatment is finished, as shown in Figure 2.8 (Bourlakis and Patten, 2011).

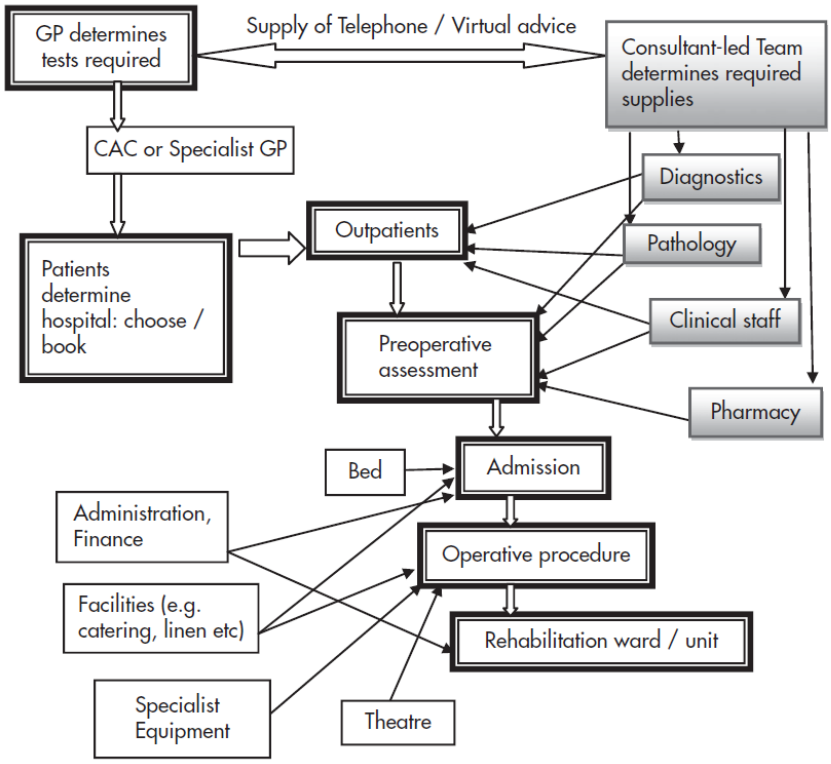


Figure 2-8: Hospital supply chain process for patient flow

(adopted from Bourlakis and Patten, 2011).

In terms of the viewpoint, the healthcare supply chain fits within the broader research discussion of the service supply chain, which should be managed differently because it has the following characteristics that are not found in manufacturing supply chains: intangibility, heterogeneity, simultaneous production and consumption, and perishability (Zeithaml *et al.,* 2009). Meijboom *et al.,* (2011) investigated the applicability of SCM in health services. In this study, they discussed four organisational problems (communication, patient safety, waiting times, and integration) that occur in situations that are complex because the patient treatment process requires multiple healthcare providers. Regarding these issues, they suggested breaking down the boundaries of each department, within healthcare providers and inter-organisationally, which is a necessary condition for enhanced patient-centred integration. Although it is necessary to implement the commercial SCM strategies into the healthcare sector, the research on the healthcare service supply chain is still in its infancy.

In the healthcare sector, improving patient flow is considered of immense importance in boosting hospital performance (Litvak, 2009; Villa *et al.,* 2009). Towill and Christopher (2005)

introduced a new concept of 'pipeline differentiation' as different supply chain strategies to deal with different requirements from patients in multiple situations. They argued that the perspective of 'one size does not fit all' should be adopted by the NHS system because they always meet different treatment processes. They cannot rely on the same pipeline to handle multiple demands, such as elective and emergency treatment. In the paper, four types of pipelines were implemented as follows: 1) *HOLPIP,* emergency care or multi-task activity requirements; 2) *PARPIP*, regular and high-volume elective surgery requirements; 3) *SINPIP*, GP services; and 4) *SEQPIP*, convalescent care.

II. Lean and Agile Practices

The use of technology and the changing medical field has given rise to the need to reduce waste and operation costs. From this perspective, lean SCM is beneficial. The lean concept originated from the Japanese manufacturing system, especially Toyota car manufacturing. The philosophy was developed to fit the Japanese post-war context, where natural resources were scarce, and the demand was very high (Kumar *et al.,* 2009). Due to its multinational status, the Toyota lean philosophy was spread to other countries and other fields (Fawcett *et al.,* 2014).

In fact, lean philosophy focuses on how to eliminate non-value-added activities in the chain to use less money to do more things. The five principles of lean (identify value, map the value stream, create flow, establish pull, and seek perfection) are utilised to identify and eliminate waste, improving the flow of activities to maximise the value for customers. It considers standardisation and specification of work processes, organisation of work in such a way that unexpected events are easy to spot, and deployment of activities that find and fix mistakes that could result in potential risks (Ohno, 1988; Womack and Jones, 2003). Therefore, lean tools, such as the fishbone diagram and failure mode and effect analysis (FMEA), can also be used for risk analysis and mitigation (Faisal and Ebrahim, 2014).

Instead of lean philosophy, the key to being agile is to accommodate unpredictable demand, including low volumes per individual 'product' and high levels of 'product variety' (Christopher and Towill, 2000). However, the following limitations of applying lean thinking in the healthcare sector have been argued by many researchers: narrow technical solutions, a limited system approach, and a focus on internal efficiency with limited consideration of

external effectiveness, which is insufficient for handling the increasingly turbulent external complexity that characterises the hospital setting (Mazzocato *et al.,* 2010; Radnor and Osborne, 2013). Thus, Dove (1999) described the concept of *agile* as the ability of an organisation to thrive in a continuously changing, unpredictable business environment.

The healthcare sector is characterised by high levels of uncertainty, complexity, and fragmentation. Organisations require agility in their supply chains to provide superior value and to manage risks and ensure uninterrupted service to patients (Michael and Nallan, 2009). The agile supply chain manufacturing programme was coined by researchers at the University of Leigh in 1991 (Kumar *et al.,* 2008). It described the various strategies that are crucial to enterprise success in environments of rapid and unpredictable changes (Melo *et al.,* 2009). Today, the healthcare landscape is at an inflection point where the two key issues that persist in the minds of healthcare providers are the changing reimbursement landscape and all the changes in the healthcare service delivery model.

In recent times, lean and agile supply management has considered supplements rather than alternatives. Some companies require implementing both lean and agile supply management for a successful SCM (Zsidisin and Ritchie, 2008). A hybrid of agile and lean SCM applies to a company that wishes to become a 'mass customizer' (Kumar *et al.,* 2009). A lean supply chain focuses mainly on adding value for business customers while reducing waste and cost. Being agile means that the supply chain can handle unpredictability. Whenever organisations choose to adopt a hybrid of lean and agile SCM, it is easier said than done since it has so many moving parts (Fawcett *et al.,* 2014). Several methods to combine agile and lean supply management methodologies exist, and the choice depends on the type and size of the business. Today's business environment is ever-changing, volatile, and very competitive, especially on the global front. As a result, it is important to adapt to an agile and lean supply chain (Lee and Schniederjans, 2011).

However, the lean principles that have been adopted in the healthcare context first appeared in a work published by the NHS Modernisation Agency (2001). Figure 2.9 illustrates the historical development of lean healthcare. Healthcare delivery is still far from achieving the level of excellence of lean applications in manufacturing (Berwick *et al.,* 2005). The lean healthcare supply chain is about simplifying the process by understanding what adds value and eliminating the non-value-added activities. The implementation in the healthcare setup

seeks to reduce patient delays in the emergency department (ED) and the number of return patient visits and to eliminate errors in the medical process (Melo *et al.,* 2009). Adaptation of lean in the healthcare context has been challenging since the redesign efforts expose patients and health service providers to unnecessary risks (Parker and DeLay, 2008).

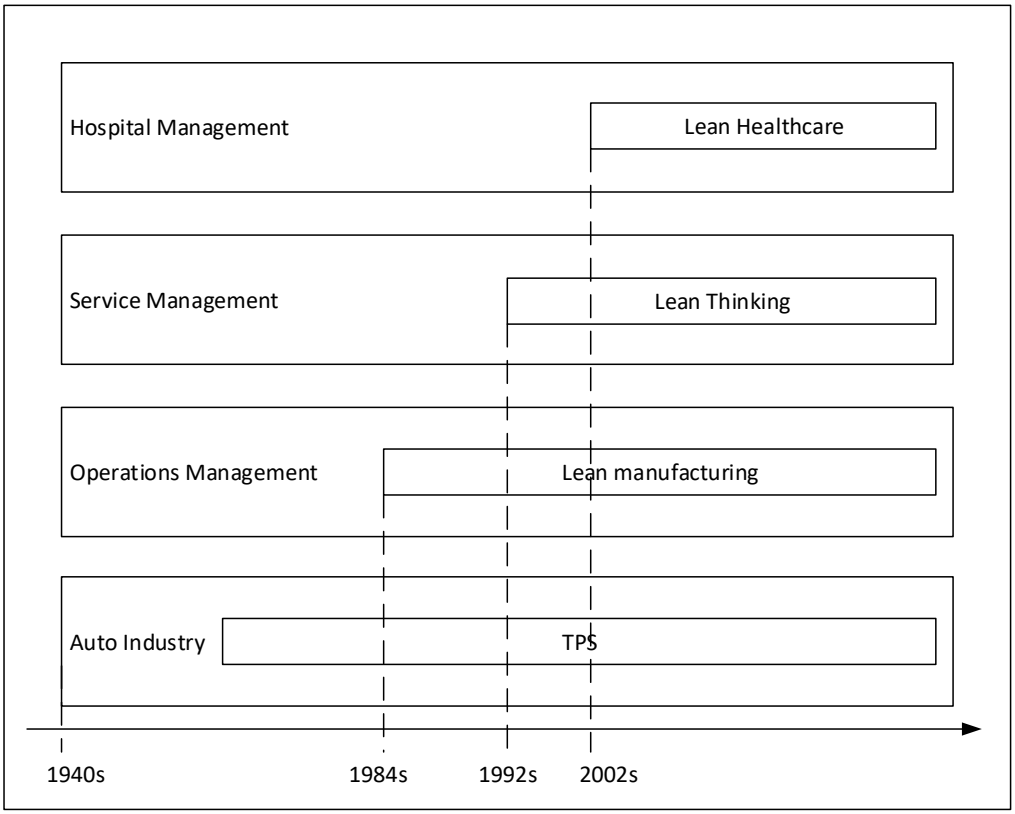


Figure 2-9: Historical development of research in lean healthcare

Chadha *et al.,* (2012) explored a lean healthcare transformation model that integrates queuing theory and lean methodology to improve the dynamic performance of the healthcare system. A system dynamic model and value stream mapping or other lean technologies were adapted in an ED at a hospital. The results that can be achieved include improved patient flow and decreased length of stay.

Laureani *et al.,* (2013) conducted a case study of the implementation of lean six sigma techniques (*e.g.,* 5S, DMAIC, process mapping, seven wastes, and control charts) through serious projects (*e.g.,* ward inventory, medical records, laboratory processes, fall prevention, and psychiatric clinic) in the Irish hospital sector. The results showed that support from top

management and regular communication with stakeholders were identified as key factors for success by three of the five project teams.

Similarly, Stanton *et al.,* (2014) explored a process improvement project based on lean six sigma techniques in the ED of a large Australian hospital. They found that the engagement of clinicians with the project and having extra resources provided improved patient flow from the ED to the hospital wards, leading to some changes having a positive effect on the work of staff. Burgess and Radnor (2013) evaluated the divergent approaches to lean implementation in English hospitals. In this study, they learned that implementation tends to be isolated rather than system-wide. The study reflects the perception of lean implementation in healthcare, which is fragmented, focusing on visible lean elements, tools and technology, but failing to address the less-visible strategic elements that relate to leadership and organisational readiness.

Nevertheless, Souza and Pidd (2011) identified and analysed the barriers to lean healthcare implementation in the UK NHS. In this study, they provided a list of barriers based on the experiences and interview results, such as perception, terminology, and organisational momentum and functional and professional resistance to change/scepticism. More specially, functional and professional silos can be found as major barriers to lean implementation because lean focuses on process improvement, which requires the elimination of impediments to the flow of patients.

Radnor and Osborne (2013) also found that the implementation of lean to data has been defective. They suggested that lean can only achieve its potential in public services when based within a public-service dominant business logic, which is context-specific to public services, embraces the true nature of services rather than products, and provides fertile rather than sterile directions for the evolution of public services that are both internally efficient and externally effective.

The redesign of the healthcare system depends on the lean paradigm that tends to focus on reducing waste processes and increasing efficiency. Lean SCM in the field of healthcare has experienced some opposition. According to Haszlinna *et al.,* (2009), lean SCM is not appropriate in a field with very high demand variability and high customisation demands. The healthcare sector is among these fields; thus, it is inappropriate to use lean supply

management. Agility is the fundamental characteristic of a successful supply chain faced with unprecedented and volatile demand (Martínez-Jurado and Moyano-Fuentes, 2014). The agile approach is the most promising paradigm for healthcare SCM. In the healthcare context, service supply chain integration is becoming more prevalent as the team-based care model is becoming standardised. The question of whether it is possible to combine lean and agile SCM in the healthcare context remains a major cause of disagreement since the experiments are expensive and risky for both the patient and service providers (Monczka *et al.,* 2008; Distelhorst *et al.,* 2014). Rahimnia and Moghadasian (2011) proposed that the decoupling point (DP) is the main concern in leagility to best suit the need to respond to downstream volatile demand while providing level scheduling upstream from the market place. The authors divided the healthcare service processes into three pipelines based on patient needs. According to the DP, they suggested that, from this point on, the treatment process is customised and specialised for each patient, as shown in Figure 2.10. However, Aronsson *et al.,* (2011) argued that leagility was not considered applicable in the studied healthcare organisations because the investigated processes had a high level of variety in demand and a high level of uncertainty. They concluded that it was not easy to define a DP among the processes, and they developed a hybrid strategy so that lean and agile methods could be efficiently applied throughout the system.

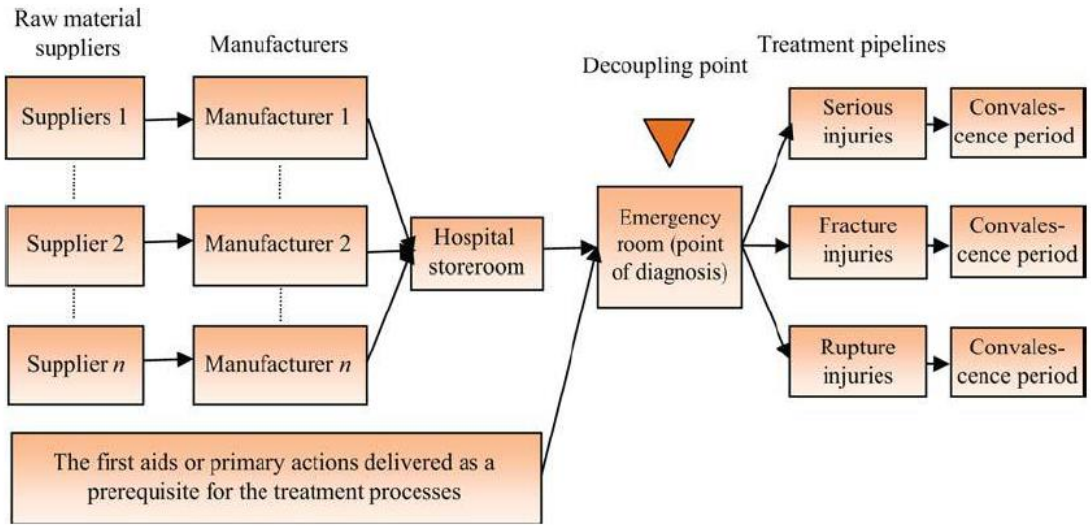


Figure 2-10. Healthcare delivery pipelines and location of the main DP

(adopted from Rahimnia and Moghadasian, 2011)

Guven-Uslu *et al.,* (2014) further indicated that a purposefully designed DP as a reference model can help improve integration between the processes, technology, and people components of service operations. They have a potential to help document the details of each sub-process so that people at various parts of the organisation can become aware of the technological and process-related necessities of the service.

b) Performance measurement

A considerable number of studies have examined patient satisfaction in various healthcare-related areas. However, few studies are focused on the performance measurement of doctor satisfaction. Bakar *et al.,* (2009) filled this gap and investigated the efficiency level of the decision-making units with hospital laboratories through the utilisation of resources to satisfy doctors' demands based on a data envelopment analysis. The study achieved its objective of evaluating the supply chain performance of two hospital laboratory supply chains in Singapore based on the important dimensions of doctor satisfaction and hospital laboratory inputs. The researcher observed that some dimensions are considered important that satisfy doctors and require more attention from hospital laboratory administrators, such as obtaining the necessary medical results and quality and services given by the laboratory staff.

Analysing hospital-wide patient flow performance, Villa *et al.,* (2014) developed a framework that adopts a system-wide approach to patient flow management. The conducted framework is structured into three distinct levels: the hospital, the pipeline (patient flow in hospital), and the production units (e.g., ED, operating rooms, or outpatient clinics). In this study, patient flow variability caused by a bad allocation of capacity represents a key problem concerning hospital patient flow problems. The authors suggested the creation of a standardised flow of data and information, which is an essential prerequisite for establishing effective patient flow.

2.2.2.4 Theoretical concerns (grouping 3)

Theoretical perspective

Theory development is an essential requirement for proper development of any field (Wacker, 1998). However, the theory building process is controversial. Some researchers suggest that theories should be built based on existing theories (Pfeffer, 1995), while other researchers encourage building new innovative theories (Van Maanen, 1995). For the field of healthcare

SCM, the exploration of which theories have been developed and where existing theories are being used is still limited. This study adapts an expanded version of theories suggested by Ammundan (1998) who offered a suitably comprehensive list to classify the theoretical stance. The existing theories can be classified into three types: economics (transaction costs and others that include agency), strategic management (resource-based view of the firm and competitive advantage), and psychology and sociology (organisational learning and inter-organisational networks). The results of classifying the articles based on the theoretical stance are summarised in Table 2.5.

Table 2.5 shows several articles that had no discernible theories for now (34%). All the remaining articles used existing theories, while none proposed an innovative healthcare SCM theory. Closer examination of specific theories that were utilised indicated that the organisational learning and inter-organisational network were most attractive to researchers (28% and 13%, respectively). In contrast, transaction cost, resource-based view, and competitive advantages were not as popular (9%, 9%, and 1%, respectively). Only two papers attempted multi-theory grounding.

Table 2.5: Articles classified by theory

Theory	Articles	Count
No discernible theories	Cullen and Taylor (2009); Aguas *et al.,* (2013); Enyinda *et al.,* (2014); Elleuch *et al.,* (2014); Breen (2008); Dobrzykowski *et al.,* (2014); Grose and Richardson (2014); Kjos *et al.,* (2016); Aptel and Pourjalali (2001); Heinbuch (1995); Gebicki *et al.,* (2014); Guimaraes *et al.,* (2013); Fernie and Rees (1995);Baker *et al.,* (2009); Samuel *et al.,* (2010); Lent *et al.,* (2012); Aronsson and Olsson (2015); Aronsson *et al.,* (2011); Souza and Pidd (2011); Poksinska (2010); Souza (2009); Balushi *et al.,* (2014); Bendavid *et al.,* (2010); Chircu *et al.,* (2014); Kumar *et al.,* (2009); Ghorani (2015);Narayana *et al.,* (2014); Machado *et al.,* (2015); Kim and Kwon (2015); Elmuti *et al.,* (2013);	30
New Healthcare SCM-specific Theories		
Economic		
transaction cost	Mustaffa and Potter (2009); Jarrett (1998); Kumar *et al.,* (2008); Burns and Lee (2008); Rego *et al.,* (2014); Breen and Crawford (2005); Kumar and Blair (2013); Agwunobi and London (2009)	8
Strategic Management		
Resource-based view of firm	Jin *et al.,* (2008); Uthayakumar and Priyan (2013); Kelle *et al.,* (2012); Jurado *et al.,* (2016); Drupsteen *et al.,* (2013); Lillrank *et al.,* (2011); Langabeer (2005); Kitsiou *et al.,* (2007)	8

Competitive advantage	Lega *et al.,* (2013); Bourlakis and Patten (2011); Guimaraes and Carvalho (2013); Guven-Uslu *et al.,* (2014)	4
Psychological/Sociological		
Organisational learning	Bhakoo *et al.,* (2012); Matopoulos and Michailidou (2013); Lin and Ho (2014); Granlund and Wiktorsson (2013); Lapierre and Ruiz (2007); Böhme *et al.,* (2013, 2014, 2016); Kumar *et al.,* (2005, 2008); Villa *et al.,* (2014); Sampson *et al.,* (2015); Behzad *et al.,* (2011); Radnor and Osborne (2013); Burgess and Radnor (2013); Curatolo *et al.,* (2014); Chadha *et al.,* (2012); Joosten *et al.,* (2009); Kollberg *et al.,* (2006); Laureani *et al.,* (2013); Stanton *et al.,* (2014); Rahimnia and Moghadasian (2010); Vries and Huijsman (2011); Xie *et al.,* (2016)	24
Inter-organisational networks	Vries (2011); Rivard-Royer *et al.,* (2002); Zepeda *et al.,* (2010); Kanyoma *et al.,* (2013); Meijboom *et al.,* (2011); Pan and Pokharel (2007); Charles (1998); Nyaga *et al.,* (2015); McKone-Sweet *et al.,* (2005); Chen *et al.,* (2013); Chakraborty *et al.,* (2014)	11
Multiple theories	Towill and Christopher (2005); Parnaby and Towill (2009)	2
Total		87

2.2.2.5 Research approaches (grouping 4)

Research methods

Researchers have a wide range of options, depending on the nature of knowledge and the certainty with which it is presented (Burgess *et al.,* 2006). According to Ghadge *et al.,* (2012), the research methodologies used for decision making in the healthcare SCM field were broadly classified as qualitative and quantitative methods. Qualitative research methods are further categorised as empirical study, conceptual theory/model, and literature review. Accordingly, quantitative research methods include mathematical modelling, probability and statistics theory, and simulation for detailed thematic analysis. Results of classifying the articles according to adopted research methods are shown in Table 2.6.

As Table 2.6 shows, most of the articles were classified as using qualitative methods (76 out of 87 articles or 87%). Within the utilised qualitative methods, empirical study has been conducted by researchers in 55 articles (63%). Obviously, the quantitative methods have attracted much less attention than qualitative methods (11 out of 87 or 13%). None of the articles used either probability or statistics theory. Regarding previous literature reviews in healthcare SCM, only six researchers conducted a literature review in healthcare SCM, as

shown in Table 2.7. A list of all past literature reviews with the adopted research methodologies and key findings/contributions is presented in Table 2.7.

Table 2.6: Articles classified by research methods

Research Methodologies	Articles	Count
Qualitative Methods		76
Empirical study	Heinbuch (1995); Elleuch *et al.,* (2014); Kjos *et al.,* (2016); Lent *et al.,* (2012); Vries (2011); Breen (2008); Enyinda *et al.,* (2014); Xie *et al.,* (2016); Laureani *et al.,* (2013); Granlund and Wiktorsson (2013); Böhme *et al.,* (2013, 2014, 2016); Elmuti *et al.,* (2013); Bhakoo *et al.,* (2012); Cullen and Taylor (2009); Aronsson *et al.,* (2011); Chen *et al.,* (2013); Burgess and Radnor (2013); Souza and Pidd (2011); Chircu *et al.,* (2014); Mustaffa and Potter (2009); Matopoulos and Michailidou (2013); Burns and Lee (2008); Rivard-Royer *et al.,* (2002); Standon *et al.,* (2014); Aptel and Pourjalali (2001); Breen and Crawford (2005); Guven-Uslu *et al.,* (2014); Drupsteen *et al.,* (2013); Charles (1998); Pan and Pokharel (2007); Olsson and Aronsson (2015); Kollberg *et al.,* (2006); Baker *et al.,* (2009); Ghorani (2015); Sampson *et al.,* (2015); Lillrank *et al.,* (2011); Kumar *et al.,* (2005, 2008); Bendavid *et al.,* (2010); Agwunobi and London (2009); Lapierre and Ruiz (2007); Jin *et al.,* (2008); Kanyoma *et al.,* (2013); Grose and Richardson (2014); Rahimnia and Moghadasian (2010); Vries and Huijsman (2011); McKone-Sweet *et al.,* (2005); Langabeer, (2004); Lin and Ho (2014); Kumar and Blair (2013); Bourlakis and Patten (2011); Guimaraes *et al.,* (2013)	55
Conceptual theory/model	Villa *et al.,* (2014); Nyaga *et al.,* (2015); Lega *et al.,* (2013); Towill and Christopher (2005); Joosten *et al.,* (2009); Parnaby and Towill (2009); Kitsiou *et al.,* (2007); Chakraborty *et al.,* (2014); Fernie and Rees (1995); Meijboom *et al.,* (2011)	10
Literature review	Curatolo *et al.,* (2014); Dobrzykowski *et al.,* (2014); Radnor and Osborne (2013); Jarrett (1998); Machado *et al.,* (2015); Narayana *et al.,* (2014); Al-Balushi *et al.,* (2014); Guimaraes and Carvalho (2013); Poksinska (2010); Kim and Kwon (2015); De Souza (2009)	11
Quantitative Methods		11
Mathematical modelling	Rego *et al.,* (2014); Chadha *et al.,* (2012); Behzad *et al.,* (2013); Priyan and Uthayakumar (2014); Uthayakumar and Priyan (2013); Kelle *et al.,* (2012); Jurado *et al.,* (2015)	7
Probability and statistics theory	None	0
Simulation	Gebicki *et al.,* (2014); Kumar *et al.,* (2009); Samuel *et al.,* (2010); Aguas *et al.,* (2013)	4

Total		87

Table 2.7: Summary of literature review in HCSCM research methods and findings

Author(s)	Research Methodology	Key Findings/Contributions
Vries and Huijsman (2011)	This paper adopted an exploratory, qualitative approach based on an analysis of existing literature in SCM in health services. Twenty-one papers were attracted based on the papers submitted to *Supply Chain Management: An International Journal*, and four papers were accepted for publication in this special issue.	Starting from a classification of existing research, five main research areas with respect to SCM in a healthcare setting are defined (IT, stakeholders, management philosophies, performance measurement, and patient flows). Additionally, next to studies with a non-disciplinary focus, an interdisciplinary focus on SCM issues in health services seems to be necessary.
Smith *et al.,* (2011)	Thorough review of the related literature focusing on management strategies, cost containment, IT, and collaboration in the healthcare supply chain.	The high cost and immaturity associated with the healthcare supply chain provides opportunities to make great strides towards supply chain excellence. The experience level of healthcare supply chain professionals and the collaborative nature of the industry are strong catalysts for improvement once the improvement opportunities and their associated barriers are revealed.
Shou (2013)	Literature review of broad literature on SCM in the healthcare industry.	Major managerial issues were identified and discussed, including healthcare supply chain performance, cost reduction, inventory management, the bullwhip effect, quality and security, and supply chain innovation. Some research methods were also discussed.
Dobrzykowski *et al.,* (2014)	Through a structured, analytical review and screening of 9,979 papers from 1982 to 2011 in healthcare operation management and SCM to explore the important trends and reporting on the current knowledge.	Use of quantitative methods to identify the current investigatory themes and quantifying methodological trends. A qualitative narrative description of the top research themes is provided and qualitatively described for future research.

Narayana *et al.,* (2014)	A systematic review of peer-reviewed academic journals in the pharmaceutical supply chain (PSC).	Research efforts depict a traditional focus on efficiency improvement, with an emerging interest in process analysis and technology implementation in the PSC. The review broadly outlines the scope for integrating research efforts from research and development to final healthcare delivery and for more studies in emerging economies.
Kim and Kwon (2015)	Review of the literature on healthcare SCM published in the United States for the most recent ten years (2004-2015), which ranges widely from hospital and pharmaceutical industries (cold chain) to public policy for healthcare.	The review has placed literature broadly under four categories: overviews of healthcare SCM, comparative studies on commercial SCM and healthcare SCM, major tools in SCM, and the barriers to adopting healthcare SCM.

2.2.2.6 Discussion

Description features of healthcare SCM literature (grouping 1)

The research focus was initially profound for UK researchers in 1995, followed by rapid growth from 2005, demonstrating that the topic is relatively new and with increasing attention from researchers. Especially from 2013 to mid-2016, the numbers of published articles rapidly rose to around 40% of publications in the last 20 years. This also reflects the fact that SCM is becoming a successful approach for improvement in the healthcare sector.

In terms of journal titles, while three journals comprise one-fifth of the articles, there is a broad range of journals that publish articles in the healthcare SCM area. This indicates that healthcare SCM is of interest to researchers from a vast array of backgrounds. In relation to the contributing countries, the field is growing at a fast pace in the USA and UK healthcare industries. This is believed to be driven by the fact that the healthcare system in the USA and Europe is more advanced than other countries. Publications from other continents are considerably fewer. Therefore, this is assumed to drive the interest of researchers from other countries.

Definitional issues (grouping 2)

Approaches to definitions of healthcare SCM

As Mentzer *et al.,* (2001) highlighted, the lack of clear definitions will inhibit SCM theoretical development. A good indication of the maturity level of a field is determined by researchers using existing standard definitions (Burgess *et al.,* 2006). However, as Table 2.3 shows, only 21% (18) of articles used existing standard definitions; in contrast, about 66% of researchers only followed the definition of the traditional SCM. Definitional consensus does not exist in this field. Furthermore, this suggests that healthcare SCM is still in the developmental mode and has not yet reached maturity. Thus, in the future, it can be expected that more new or modified definitions will be proposed.

Taxonomy of healthcare SCM

Among the selected articles, only four articles conducted an evaluation of the healthcare supply chain from both patient and physical flow perspectives. Many articles (53) focused on the performance of physical flow in the healthcare supply chain. They provided some improvement techniques from different perspectives, such as inventory management, procurement strategy, IT, and performance measurement. More specifically, within the improvement of physical flow in hospitals, logistics management in healthcare SCM has been the focus of strong research attention (22). In contrast, the remaining 30 articles focus on the service process in the supply chain. Moreover, 17 out of 30 reviewed journal articles applied lean and agile practices to improve the patient flow in the hospital setting. In addition, from the patient flow perspective, performance measurement has been the subject of few studies (2).

Theoretical concersn (grouping 3)

Theoretical perspective

Table 2.4 illustrates that the researchers did not propose original theories for the healthcare SCM body of knowledge. Thus, most researchers believed that healthcare SCM can be described through an extension of existing ideas. Nevertheless, since there are multiple theories being used in the field, Burgess *et al.,* (2006) suggested that a single existing theory could not demonstrate all that is embraced under SCM. Moreover, two theories are more popular than others: organisational learning and inter-organisational network theories. In contrast, a limited number of studies have proposed the competitive advantage, and this

suggests a specific feature of the healthcare industry. The current theories are insufficient to explain healthcare SCM completely, and the field requires further theory development.

Research methodological issues (grouping 4)

Research methods

It is evident that the most prevalent empirical research method is the case study. One of the key reasons is that an increasing number of practitioners seek collaboration opportunities with academics to find the optimal way to achieve competitive advantage in the healthcare industry. Thus, it is now much easier for researchers to communicate with practitioners and gain access to the industry to conduct empirical studies than before. Moreover, the absence of probability and statistics theory is similar to that found in other studies. For example, Burgess *et al.,* (2006) examined a similar pattern in traditional SCM literature. Until now, in terms of using of research methodologies, the focus has only been on a narrow range (Burgess *et al.,* 2006). Another issue of concern is the relative lack of quantitative research methods being used. Therefore, this could have an adverse effect on the development of the field.

2.3 SUPPLY CHAIN RISK MANAGEMENT

As an organisation, hospital operations under a certain supply chain are not only meant to increase productivity of the hospitals but also to manage the risk associated with healthcare. However, existing research on hospital supply chain management (SCM) indicates that healthcare and hospital operations are much more complex and fragmented than other industries. This is because the healthcare and hospital operations are delivering goods and services from several suppliers to patients with a wide range of health requirements according to the need for hospitals to provide both planned and emergency care (Fenies *et al.,* 2006; MacVaugh, 2007). For example, some drugs require special temperature conditions for storing and delivery. Furthermore, zero-defect conditions are necessary for the healthcare delivery process to patients.

In general, there is a vast and rapid change in the events in the hospital supply chain. It is vital to develop solutions that optimise profit by minimising waste while remaining flexible to the changing trends in the healthcare sector (Mustaffa and Potter, 2009). It is important for

researchers and practitioners to fully understand the process involved to benefit from the choice of methods. Likewise, it is essential to be knowledgeable about the associated issues inherent in the service delivery processes and the supply chain because, in business planning, quality, quantity, cost, and risk are all closely interrelated (Chakraborty *et al.,* 2014). From the hospital or healthcare perspective, Harris (2000) investigated the ultimate objective of managing risks as the ability to identify, assess, reduce, and control hazards to staff, patients, and visitors. Essentially, the hazards can be considered broadly as anything that compromises service delivery (Rafele *et al.,* 2005), such as scarce services caused by inadequate resources or inefficient material management (Tomlin, 2009).

In fact, the effect of risk accounts for the substantial proportion of hospital budgets, hence, risk management is a significant strategy to minimise expenditure and increase service quality (Scannell *et al.,* 2013). Similarly, SCM must cover risk management. In hospitals, there are so many supplies and customers with close interconnectivity. This often increases the risks in hospital supply chains because a disruption in one member may affect another. Usually, the supply chain capacity is decided by demand and supply (Tang, 2006), which are uncertain, thus increasing the risk, especially in healthcare, where the resources are constrained. Organisations across supply chains may only focus on a given subset, which is likely uncertain (Chopra *et al.,* 2005). However, the literature review reveals that the current healthcare systems' supply chain risk management (SCRM) model is not capable of meeting these challenges (McKinsey and Company, 2013).

To understand healthcare SCM, it is important to critically review the available literature about how conventional SCRM knowledge has been built up in order for the findings to be applied to healthcare supply chain contexts. In this regard, the purpose of this section is to explore the literature about SCRM to obtain the definition of some of the terms used, classify the risks, provide a comprehensive coverage of the risk management methodologies, and assess the status of risk management in the healthcare supply chain, especially for the pharmaceutical flow in the hospital setting.

2.3.1 SCRM literature review research methodology

As indicated in the introduction chapter, the purpose of this thesis was to critically analyse the available literature about conventional SCRM and its application in the healthcare industry. This implies that the review work is desk-based or is a literature-based study where

data from secondary sources, such as peer-reviewed journal articles, textbooks, previously conducted research studies, and published organisational reports have been used.

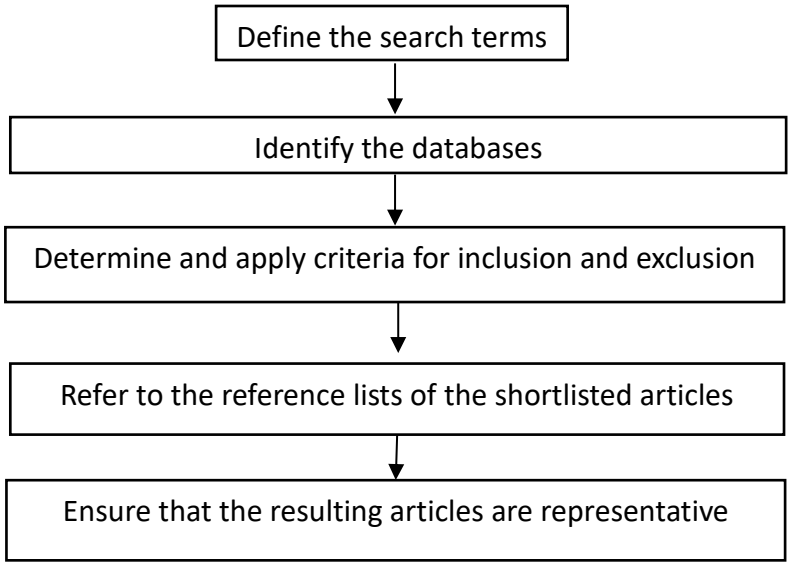


Figure 2-11: Flowchart of the SCRM research methodology for the present systematic literature review

(adapted from Ho *et al.,* 2015)

The research followed the SLR methodology suggested by Ho *et al.,* (2015) for developing an evidence-informed knowledge management process. The adapted SLR methodology for identifying the scope of literature is addressed in five distinctive phases, as shown in Figure 2.11. This section provides a presentation of the literature search procedures, databases used, search terms used, and the inclusion criteria and exclusion criteria used.

2.3.1.1 Literature search procedures and databases

A literature search was conducted to review the available literature regarding conventional SCRM and risk management in the downstream healthcare pharmaceutical supply chain, especially in the hospital setting. The literature search was restricted to peer-reviewed journal articles, textbooks, and organisational reports. As Moher *et al.,* (2009) suggested, peer-reviewed journal articles provide credible information because, for an article to be published in a journal, it must be reviewed by a team of specialised personnel to ascertain its authenticity. Journal articles also provide sources of up-to-date information compared to books (Moher *et al.,* 2009).

The literature search involved leading databases, such as Emerald Insight, Google Scholar, Science Direct, Springer, Taylor and Francis, Web of Science, and Wiley. The primary purpose for targeting these databases was the fact that these databases contain a huge volume of peer-reviewed papers. Choosing these established databases also minimised any form of publication bias or reviewer prejudices because, as Cronin *et al.,* (2008) maintained, some reviewers may refuse to publish certain primary studies, particularly when they report findings that do not conform to their expectations.

The researcher first conducted a systematic computer-assisted literature search in the above-mentioned databases, a process that was supplemented using a manual search. Combining the two literature search strategies facilitated the comprehensive analysis of journal issues, articles, and case studies that may not be published in the core databases. Footnote chasing or citation searching was applied to identify relevant studies captured during the database search. The researcher also used various database packages, such as Mendeley, to handle the bibliography list in a systematic manner. This made it easier to process, streamline, and produce a reference list in a straightforward way without duplication.

Search terms

Next, the chosen electronic subject databases were scanned to the defined keywords for articles published between 2003 and 2017. The search terms used in conducting this research included ‘risk management’ and ‘supply chain’. In additional, the search terms ‘supply chain risk(s)’ or ‘supply chain risk management’ were used in the article abstract with the keywords ‘hospital/healthcare/pharmaceutical’ in the abstract, keywords, and title search.

Inclusion and exclusion criteria

The researcher included studies that were published between 2003 and 2017. In addition, the included studies or peer-reviewed journal articles must be published in English. For a study to be included, it must be available in full, meaning that studies available in the form of a title and abstract were not included. Moreover, essays, letters, reports, conference papers, and comments were also disqualified. The abstracts and conclusions were reviewed to determine the relevance to hospital SCRM. Thus, after the examination, 32 references were excluded because they did not seem relevant to the topic. However, among the excluded papers, three were published as a conference paper but have been attracted by other researchers. Thus,

these papers were added to the retrieved reference lists. In the end, to ensure the comprehensiveness, the cross-checked references of the selected papers were further conducted and did not find any other relevant papers. Overall, 213 papers were included in this literature review. Among these 213 articles, 11 papers plus one official report are focused on the healthcare pharmaceutical supply chain in the hospital sector, which are relevant to this research.

2.3.2 Data analysis

2.3.2.1 Descriptive analysis

2.3.2.1.1 Year of Publication and journal

There is a continuous growth in the number of research works focusing on SCRM in the last 14 years, as seen in Figure 2.12. We can discern that more focus on this area was mainly triggered after disasters like the 9/11 terrorist attack in 2001. Until 2003, few researchers were dedicated to this field or indicated the potential of the future research agenda (Jüttner *et al.,* 2003; Harland *et al.,* 2003). After that, by 2004, the first peak was reached in this research field. The number of publications showed that some scholars made substantial contributions. Their findings laid the foundations for future work to understand the complexity of the risks in supply chain networks (Finch, 2004; Christopher and Peck, 2004; Chopra and Sodhi, 2004; Sinha *et al.,* 2004; Christopher and Lee, 2004; Norrman and Jansson, 2004; Hallikas *et al.,* 2004). In fact, most of the reviewed journal articles were published from 2012 onwards (60%, 127 out of 213). In 2012 20 (9%) were published, followed by 14 each in 2013 and 2014 (7% each), 20 in 2015 (9%), and 34 in 2016 (16%), which reached the peak. There are some special issues that can explain the reason for some peaks on these topics (Kilubi, 2016).

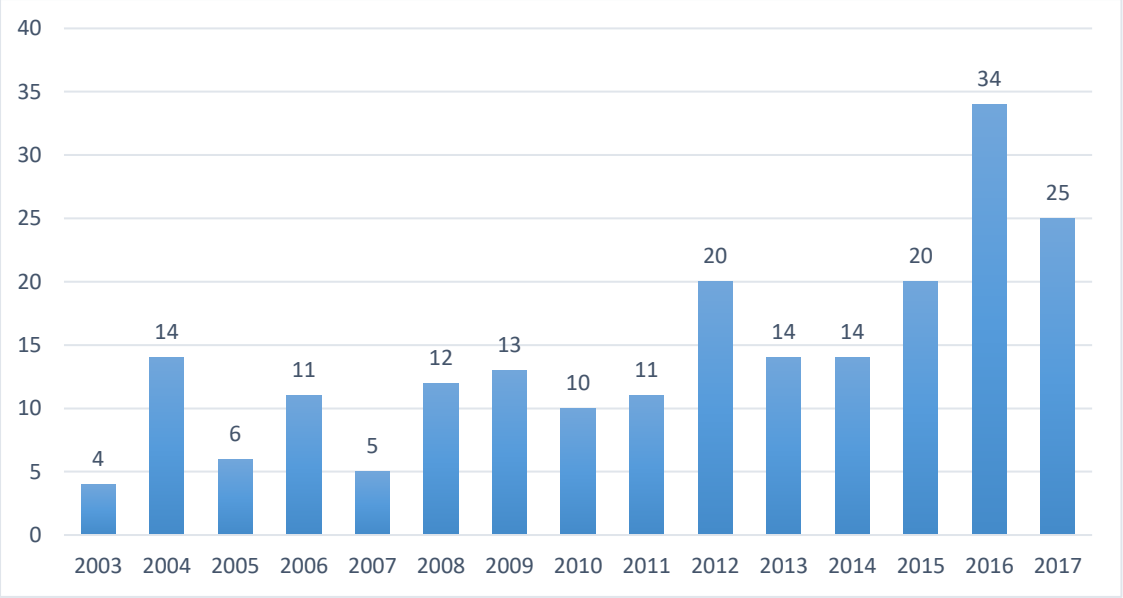


Figure 2-12: Distribution of the publication years

In this review, 213 articles were derived from 66 journals as shown in Table 2.8. In detail, the top eight journals were as follows: *International Journal of Production Economics* (39 papers), *International Journal of Production Research* (20 papers), *International Journal of Physical Distribution and Logistics Management* (15 papers), *International Journal of Logistics Research and Applications* (11 papers), *Journal of Operations Management* (9 papers), *Journal of Purchasing and Supply Management* (9 papers), *Supply Chain Management: An International Journal* (9 papers), and *European Journal of Operational Research* (8 papers on SCRM). That also indicates the prominent level of scientific relevance and significance of these journals. In addition, among these 66 published journals, the top eight journals had published about 56% of the articles. Besides the top eight ranking, it was also observed that 42 journals have published only one article related to SCRM.

Table 2.8: Number of articles in alphabetical order (appearing at least twice)

Academic Journals	No. of Articles	%
Computers and Chemical Engineering	3	1.4
Computers in Industry	2	0.9
Computers and Industrial Engineering	4	1.9
Computers and Operations Research	2	0.9
European Journal of Operational Research	8	3.8
Expert Systems with Applications	3	1.4
International Journal of Production Research	20	9.4
International Journal of Production Economics	39	18

International Journal of Logistics Research and Applications	11	5.1
International Journal of Logistics Management	7	3.3
International Journal of Physical Distribution and Logistics Management	15	7
International Journal of Operations and Production Management	2	0.9
Journal of Business Logistics	2	0.9
Journal of Manufacturing Technology Management	4	1.9
Journal of Risk Research	4	1.9
Journal of Operations Management	9	4.2
Journal of the Operational Research Society	2	0.9
Journal of Purchasing and Supply Management	9	4.2
Omega	4	1.9
Production Planning and Control	2	0.9
Production and Operations Management	2	0.9
Safety Science	2	0.9
Supply Chain Management: An International Journal	9	4.2
Transportation Research	4	1.9

2.3.2.1.2 Demographics

With reference to the Figure 2.13, one-third of the contributions were from the USA (71 papers). Other leading countries, such as the UK (33 papers), China (23 papers), Germany (19 papers), and India (13 papers) also demonstrated their increasing attention to this topic. The finding is in line with that of Prakash *et al.,* (2017) who also found that developing countries, such as China and India, are working more on SCRM because Asian markets are being recognised as a source of economic activity for all sectors, especially manufacturing. Moreover, an increasing trend for co-author collaboration research has been observed all over the world.

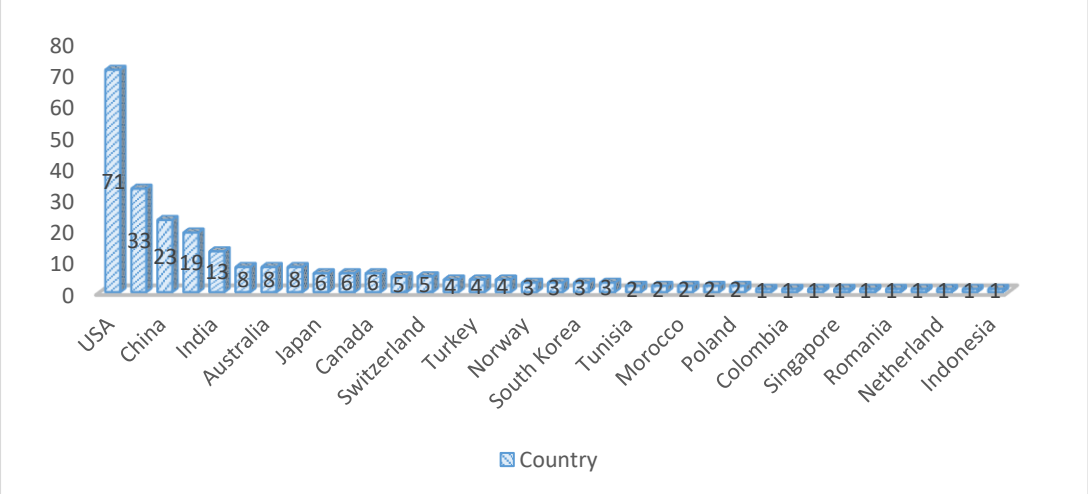


Figure 2-13: Distribution of the contributing countries

2.3.2.2 Thematic analysis

2.3.2.2.1 Evolving definitions for SCRM

In recent years, many companies are reporting increased concerns about the risk of supply chain vulnerability. Per Snyder and Shen (2006), 'for as long as there have been supply chains, there have been disruptions, and no supply chain, logistics system, or infrastructure network is immune to them'. According to a study conducted by the Computer Sciences Corporation, 60% of the surveyed companies recognised that their supply chains are vulnerable to disruptions (CSC, 2004). For example, a fire at a Phillips plant in 2000 disrupted production, leading to a $400 million loss (Chopra and Sodhi, 2004). Natural disasters, terrorist attacks, labour strikes, accidents, and inefficient management can all be the causes for supply chain disruption and delay (Berger *et al.,* 2004; Christopher and Lee, 2004; LaLonde, 2004; Norrman and Jansson, 2004; Poirier *et al.,* 2007; Quinn, 2006; Tang, 2006). The above examples show that any environmental, internal, and external risks with supply chain practices will cause delay and even disruption.

Few areas of management interest have risen to prominence as rapidly as SCRM, from the perspective of practitioners as a research area (Colicchia and Strozzi, 2012). Krajic (1983) is referred to as a pioneer in this research area. According to Haszlinna *et al.,* (2009), 'risk management refers to the identification, prioritisation and assessment of risks'. Risk management also encompasses coordination and economical application of resources with an aim of minimising, monitoring, and controlling the probability of unfortunate events (Kumar *et al.,* 2009).

Ghadge *et al.,* (2011) observed that there are considerable number of researchers that started researching SCRM in early 2000, according to their preliminary search. The 9/11 terrorist attack (2001) affected the major global supply chain, and this triggered interest in the SCRM field (Chopra and Sodhi, 2004; Sheffi, 2005), causing the increase in the number of articles on SCRM during 2003 and 2004 (Ghadge *et al.,* 2011).

The early research tended to be a reactive approach to risk management. They explored the improvement of the capability to respond to uncertain events. Moreover, the focus was on the supply chain network design to address a single company. Further, the business environment is becoming more unpredictable and increasingly unstable due to globalisation,

shorter product life time, and the series of crises and economic recessions. The risk management process has become more proactive and the focus goes beyond the boundaries of the single company until 2003, as the collaborative sharing of information and best practices among supply chain partners received increased attention. Accordingly, Jüttner *et al.,* (2003) built a foundation of effective SCRM as 'the specification and management of risks for the supply chain, through a co-ordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole'. Tang (2006) extended this definition by combining with others to define SCRM as 'the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity'. There is a slight difference in the managerial objectives for both definitions. In comparison with the former, Tang (2006) aimed not just to reduce risks but also to achieve business continuity. The author reviewed different quantitative models for managing supply chain risks and proposed four basic approaches: supply management, product management, demand management, and information management.

Ritchie and Brindley (2007) studied five main components of SCRM: risk drivers, risk management influencers, decision-maker characteristics, risk management responses, and performance outcomes. The performance and risk in SCM are interconnected and require the robust implementation of management tools and controls to maximise performance while controlling the consequential risks (Lonsdale and Cox, 1998). Thus, Ritchie and Brindley (2007) studied the supply chain performance in terms of efficiency and effectiveness, which is linked to risk drivers and risk management responses, and provided insight into managing and measuring risk in supply chains. However, this topic is still under considerable development for theory-building.

Furthermore, Vanany *et al.,* (2009) reviewed the current literature and found that SCRM was a relatively 'immature' stage from the academics' perspective. Until 2011, Wieland and Wallenburg (2011) found that SCRM helps supply chains proactively reduce vulnerabilities by supporting robustness reactively by supporting agility. Both approaches are identified to have an influence on the supply chain's customer value and on business performance.

Further, Abolghasemi *et al.,* (2015) also mentioned that SCRM has a close relationship with supply chain performance. They identified some key factors of supply chain performance based on the supply chain operation reference (SCOR) model through the predictive and

diagnostic abilities of Bayesian networks (BN). After a sensitivity analysis, the authors found that 'total cost' and its criteria, which include costs of labour, warranty, transportation, and inventory, have the widest range and most effect on supply chain performance; thus, managing them and controlling their related risk play a vital role for supply chain performance.

Heckmann *et al.,* (2015) demonstrated that the contributions in SCRM mainly focus on the identification of triggering events and the assessment of their likelihood of occurrence, although this risk perception might be limited for the supply chain. Nevertheless, Kilubi and Haasis (2015) found that the SCRM definition of Jüttner *et al.,* (2003) is the most frequently used in journal articles studying SCRM. Their definition is based on a synthesis of traditional risk management and SCM principles. Without incorporating the concepts of SCM into supply chain risk mitigation practices, the mitigation efforts are unlikely to be effective (Li *et al.,* 2015).

In SCM, risk management entails the implementation of various strategies to manage daily and exceptional risk along the supply chain (Carvalho and Cruz-Machado, 2011). However, there is no consensus for the researchers to define the meaning for SCRM (Jüttner, 2003; Sodhi, 2012). After reviewing the literature from 2000 to 2015, Kilubi and Haasis (2015) indicated that a definitional consensus does not exist and that SCRM is still in the evolving stage and has not yet reached maturity. Senior managers from Cisco (McMorrow, 2009) and Deloitte (Zhou, 2009) also realised the definition gap of SCRM among company executives and emphasised the need to develop a clear definition of SCRM.

Without a mutual understanding and clear definitions, researchers could be confused when communicating with practitioners. Alternatively, a consistent definition would help researchers estimate and evaluate the probability and consequences of the full set of supply chain risks and measure the effectiveness of SCRM methods (Ho *et al.,* 2015). One comprehensive definition of SCRM was suggested by Ho *et al.,* (2015) who defined SCRM as an inter-organisational collaborative endeavour using quantitative and qualitative risk management methodologies to identify, evaluate, mitigate, and monitor unexpected macro and micro level events or conditions that might adversely affect any part of a supply chain. Their definition is built on the existing literature (Jüttner *et al.,* 2003; Jutter, 2005; Norrman and Jansson, 2004; Tang, 2006; Thun, 2011).

2.3.2.2.2 Supply chain risk types and classification methods

Several studies demonstrated different definitions and types of risk in the supply chain (Jüttner *et al.,* 2003; Gaokar and Viswanadham, 2004; Tang, 2006; Manuj and Mentzer, 2008; Tummala and Schoenherr, 2011). These definitions have applicability to specific decision contexts and types. According to Tang and Musa (2011), a better definition of supply chain risk should refer to the events with a small probability that may occur abruptly and that can bring substantial negative consequences to the system. Ho *et al.,* (2015) defined supply chain risk as: 'the likelihood and impact of unexpected macro and/or micro level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities'. What most definitions of risk have in common are the three dimensions: (1) likelihood of occurrence of a particular event or outcome, (2) consequences of a particular event or outcome occurring, and (3) causal pathways leading to the event (Ritchie and Brindley, 2007).

Among the 213 reviewed journal articles, 45 articles discussed supply chain risk types as shown in Table 2.9. Rangel *et al.,* (2015) mentioned the lack of uniformity of the classification methods. According to some studies, supply chain risks can be divided into different perspectives. Specifically, some researchers simply classified the risk types into two categories, such as internal (*e.g.,* human errors, equipment failures, and material quality that can be controlled by the organisation) or external (*e.g.,* exchange rate changes, legislation, and natural events like earthquakes that cannot be controlled by the organisation). Some classified the risk types in terms of the controllable degree of the organisation (Trkman and McCormack, 2009; Cagliano *et al.,* 2012; Tukamuhabwa *et al.,* 2017), the supply-side risks and demand-side risks (Nagurney *et al.,* 2005; Manuj *et al.,* 2014), operational and disruption risks (Tang, 2006; Kőnig and Spinler, 2016), purchasing and demand risks (Thun and Hoenig, 2011), or macro and micro risks (Ho *et al.,* 2015). In addition, some scholars have added one or two more risk factors on the basis of the above studies (Wagner and Bode, 2006; Manuj and Mentzer, 2008; Jiang *et al.,* 2009; Oke and Gopalakrishnan, 2009; Cruz, 2013; Aguas *et al.*, 2013; Sreedevi and Saranga, 2017). Moreover, some researchers listed the risk types without explicit classification (Harland *et al.,* 2003; Chopra and Sodhi, 2004; Blackhurst *et al.,* 2008; Tummala and Schoenherr, 2011; Ghadge *et al.,* 2013; Aqlan and Lam, 2015; Rangel *et al.,* 2015; Blos *et al.,* 2016; Rogers *et al.,* 2016; Quang and Hara, 2017).

Moreover, some risk types have been extensively proposed and studied, such as supply risks (35 out of 45 papers), demand risks (27 out of 45 papers), and environmental risks (28 out of 45 papers) because their effects are observed more clearly within organisations that are configured in a supply chain array than in other organisations (Rangel *et al.,* 2015). In contrast, some risk types have obtained less attention from scholars (reputation, technology, and financial risks). Although the origins of risk research initially focused on the banking sector, most scholars have paid more attention to the physical and information flows rather than cash flow in SCM.

Table 2.9: Supply chain risk types identified by researchers

Authors	Risk Types
Harland *et al.,* (2003)	Strategic risks, operation risks, supply risks, customer risks, asset impairment risks, competitive risks, reputation risks, financial risks, fiscal risks, regulatory risks, and legal risks
Jüttner *et al.,* (2003)	Environmental risks, network-related risks, and organisational risks
Christopher and Peck (2004)	Internal to the firm: process and control risks, external to the firm but internal to the supply chain network: demand and supply risks, and external to the network: environmental risks
Chopra and Sodhi (2004)	Disruption, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity risks
Nagurney *et al.,* (2005)	Supply-side risks and demand-side risks
Tang (2006)	Operational risks and disruption risks
Wagner and Bode (2006)	Demand-side risks, supply-side risks, and catastrophic risks
Bogataj and Bogataj (2007)	Supply risks, process risks, demand risks, control risks, and environmental risks
Deleris and Erhun (2007)	Operational/technological risks, social risks, natural hazard, economy/competition risks, and legal/political risks
Cheng and Kam (2008)	Environmental risks, infrastructure risks, service delivery risks, and organisational and relationship risks
Manuj and Mentzer (2008)	Supply risks, demand risks, operational risks, and security risks
Blackhurst *et al.,* (2008)	Disruptions/disasters, logistics, supplier dependence, quality, information systems, forecast, legal, intellectual property, procurement, receivables (accounting) inventory, capacity, and management security
Tang and Tomlin (2008)	Supply risks, process risks, demand risks, intellectual property risks, behavioural risks, and political/social risks
Jiang *et al.,* (2009)	Cost risks, operational risks, and reputational risks

Oke and Gopalakrishnan (2009)	Supply related risks: imports, climate, man-made disasters, natural disasters, socio-economic, loss of key suppliers, demand related risks: economic, demand variability and unpredictability, and miscellaneous risks
Rao and Goldsby (2009)	Organisational risks, industry risks, and environment risks
Trkman and McCormack (2009)	Endogenous risks: market and technology turbulence and exogenous risks: discrete events (e.g., terrorist attacks, contagious diseases, workers' strikes), and continuous risks (e.g., inflation rate, consumer price index changes)
Thun and Hoenig (2011)	Purchasing risks and demand risks
Tummala and Schoenherr (2011)	Demand risks, delay risks, disruption risks, inventory risks, manufacturing (process) breakdown risks, physical plant (capacity) risks, supply (procurement) risks, system risks, sovereign risks, and transportation risks
Cagliano *et al.,* (2012)	External risks: catastrophic, political, economic, social, legal, culture, industrial, partner and internal risks: strategic, tactical, and operational
Jnandev *et al.,* (2012)	Regulatory risks, counterfeit risks, inventory risks, and financial risks
Lockamy and McCormack (2012)	Network risks, operational risks, and external risks
Vilko and Hallikas (2012)	Supply risks, operational risks, security risks, macro risks, policy risks, and environment risks
Ghadge *et al.,* (2013)	Product design information risks, distortion risks, demand risks, quality risks, disruption risks, operational risks, financial risks, skill/performance risks, poor management risks, safety/security risks, reputation risks, supply safety risks, geopolitical risks, supply capacity risks, intellectual property risks, regulatory/legal risks, information distortion risks, integration risk, network risks, and technology risks
Cruz (2013)	Supply-side risks, demand-side risks, exchange rate risks, and social risks
Aguas *et al.,* (2013)	Supply delays, disruptions in the supply, differences in quantities received, and demand forecast errors
Enyinda *et al.,* (2014)	Supply risks, operational risks, infrastructure risks, and political risks
Manuj *et al.,* (2014)	Supply-side risks and demand-side risks
Aqlan and Lam (2015)	Supplier risks, customer risks, process and control risks, technology risks, product risks, occupational risks, culture risks, transportation risks, and commodity risks
Jaberidoost *et al.,* (2015)	Supply and supplier risks, organisation and strategies risks, financial risks, market risks, political risks, logistics risks, and regulation risks
Rangel *et al.,* (2015)	Strategic risks, inertia risks, informational risks, capacity risks, demand risks, supply risks, financial risks, relational risks, operational risks,

	disruption risks, customer risks, legal risks, environmental risks, and culture risks
Ceryno *et al.,* (2015)	Organisational risks, network-related risks, industry risks, and environmental risks
Ho *et al.,* (2015)	Macro risks: man-made and natural risks, and micro risks: demand risks, manufacturing risks, supply risks, information risks, transportation risks, and financial risks
Aqlan and Lam (2015)	Demand risks, supply risks, process risks, control risks, and environmental risks
Blos *et al.,* (2016)	Water risks, raw material risks, ingredient risks, packaging risks, manufacturing process risks, infrastructure and nature hazard risks, energy risks, environmental risks, worker safety and health risks, people, skills and availability risks, information and systems risks, route to market and in market risks, legal, legislative, and regulatory risks, and workplace rights and social responsibility risks
Mokrini *et al.,* (2016)	Operational risks, financial risks, technology risks, information-related risks, relational risks, and internal risks
Torabi *et al.,* (2016)	Supplier risks, internal risks, environmental risks, and market risks
Govindan and Chaudhuri (2016)	Risk in internal operations of logistics service providers, financial risks, and customer-related risks
Rogers *et al.,* (2016)	Operational risks, infrastructure risks, legal risks, cultural risks, economic risks, supplier risks, forecasting risks, warehouse risks, transportation risks, labour risks, and natural disaster risks
Kőnig and Spinler (2016)	Operational risks: process risks, control risks, supply risks, demand risks, and disruption risks: man-made risks, and natural risks
Nakandala *et al.,* (2017)	Internal risks: process and control risks, operational risk external to the firm: supply and demand risks, and macro-level risks
Prakash *et al.,* (2017)	Environmental risks, supply risks, demand risks, and process risks
Quang and Hara (2017)	External risks, time risks, information risks, financial risks, supply risks, operational risks, and demand risks
Tukamuhabwa *et al.,* (2017)	Endogenous risks: supply-side, firm level, demand side, and exogenous risks: geopolitical and economic risks
Sreedevi and Saranga (2017)	Supply risks, manufacturing process risks, and delivery risks

2.3.2.2.3 Applied research methodologies

Generally, the research methodologies developed and applied for decision making in the SCRM field were broadly divided into two categories, as qualitative and quantitative methods. More specially, qualitative research methods were further divided based on research design, conceptual theory, empirical study (*e.g.,* case study, industrial survey, structured/informal

interview, and focus group methodologies), and literature review. Comparatively, quantitative methods were divided into mathematical modelling, simulation, and statistics and probabilistic theory for a more detailed thematic analysis (Ghadge *et al.,* 2012).

Figure 2.14 displays the distribution of the number of journal articles applying both methodologies and mixed methods between 2003 and 2017.The analysis found that empirical study was the primary methodology adopted to deal with contemporary industrial problems over the last few years (28%, 60 papers). Moreover, a wide range of studies have used the case study method to study supply chain risks. These studies focus on the various aspects and sectors, such as the risks in an uncertain global supply chain environment (Barry, 2004), strategies for the fragile food supply chain (Dani and Deep, 2010), managing the supply chain relational risk caused by cultural differences between China and the West (Jia and Rutherford, 2010), and mitigating supply chain risk through improved confidence (Christopher and Lee, 2004).

Additionally, Ghadge *et al.,* (2012) found that 80% of the case studies were focused on network-related risks. Mixed methods are the second most-used research methodology (25%, 54 papers), which shows that an increasing number of scholars pay more attention to using combined research to create new evidentiary knowledge. Figure 2.15 gives the growth trend of using mixed methods since 2012. This finding is also in line with the results by Tang and Musa (2010) and Ho *et al.,* (2015).

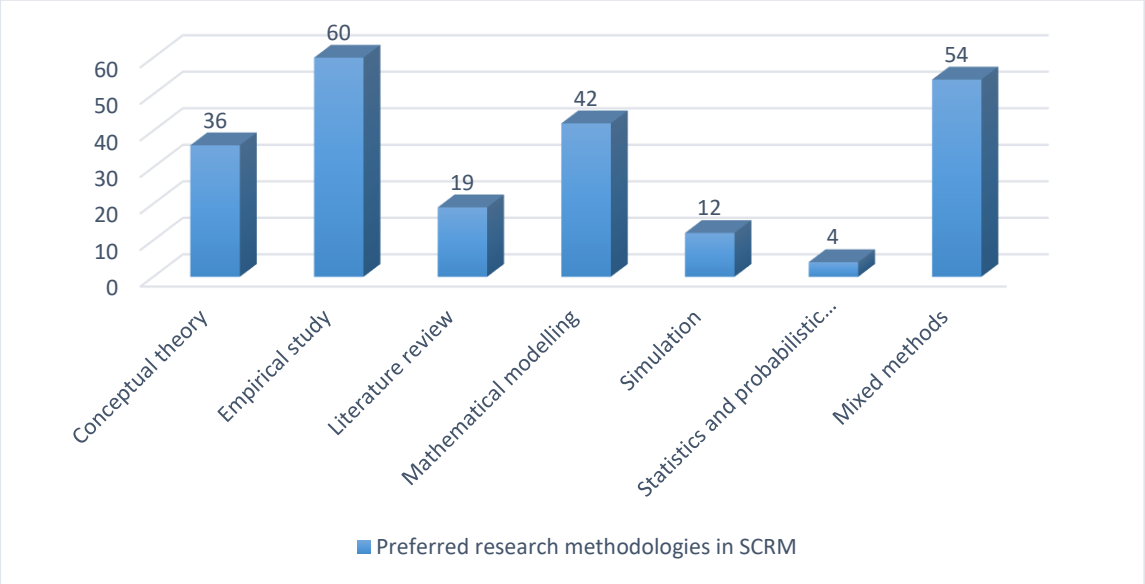
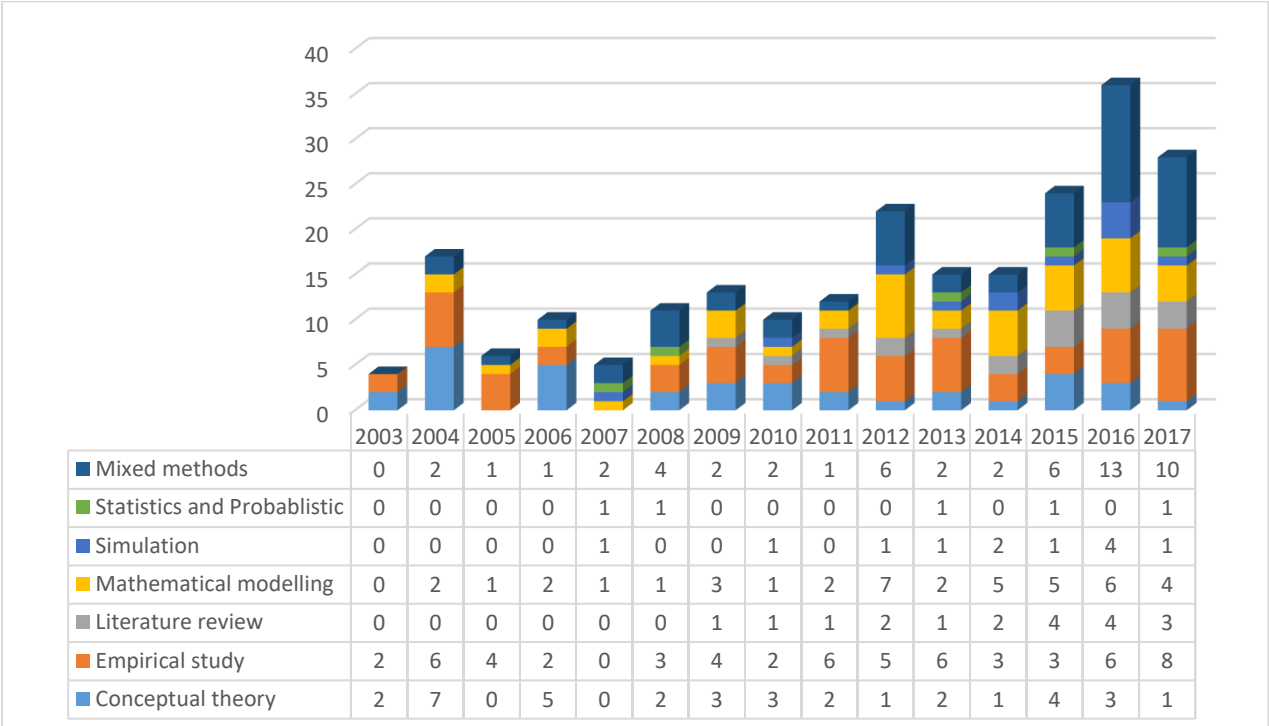


Figure 2-14: Distribution of research methodologies

Moreover, scholars have also frequently applied mathematical modelling (20%, 42 papers) to deal with SCRM strategy and policy formulation, followed by conceptual theory (17%, 36 papers). Mathematical modelling can be further divided into hard OR and soft OR techniques, which comprise multi-objective programming, linear and nonlinear programming, game theory, queuing theory, scenario planning, system thinking, etc.

The most popular approach is fuzzy-based multi-objective mathematical programming (Oliveira *et al.,* 2013; Yu and Goh, 2014; Nooraie and Parast, 2015). For example, Oliveira *et al.,* (2013) used the multi-objective mathematic modelling method to weigh the priority of risk-reduction investments through the financial perspective to deal with optimised decision making under demand uncertainty.

Fuzzy TOPSIS and Fuzzy analytical hierarchy/network process also have attracted more attention in the SCRM literature to easily quantify risk in many cases (Wang *et al.,* 2012; Samvedi *et al.,* 2013; Jaberidoost *et al.,* 2015; Li *et al.,* 2015). Using conceptual theory, researchers could represent a research methodology describing fundamental concepts on SCRM (Vanany *et al.,* 2009).



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Mixed methods	0	2	1	1	2	4	2	2	1	6	2	2	6	13	10
Statistics and Probablistic	0	0	0	0	1	1	0	0	0	0	1	0	1	0	1
Simulation	0	0	0	0	1	0	0	1	0	1	1	2	1	4	1
Mathematical modelling	0	2	1	2	1	1	3	1	2	7	2	5	5	6	4
Literature review	0	0	0	0	0	0	1	1	1	2	1	2	4	4	3
Empirical study	2	6	4	2	0	3	4	2	6	5	6	3	3	6	8
Conceptual theory	2	7	0	5	0	2	3	3	2	1	2	1	4	3	1

Figure 2-15: Distribution of quantitative and qualitative methods over the last decades

Based on the above findings, most scholars made outstanding contributions to this field, laying the foundation for future research in the initial stage (Jüttner *et al.,* 2003; Harland *et al.,* 2003; Finch, 2004; Christopher and Peck, 2004; Chopra and Sodhi, 2004; Sinha *et al.,* 2004; Christopher and Lee, 2004; Hallikas *et al.,* 2004; Tang, 2006). Thus, several conceptual theories or framework developments were frequently attempted by these scholars. As Figure 2.15 shows, the first SCRM literature review was published in 2009. At this stage, a large number of scholars had been dedicated to this topic for many years. It is necessary to provide the whole picture of associated issues in past works, which serves as a basis and guide to proposed future research. Although simulation (6%, 12 papers) and statistics/probability (2%, 4 papers) have attracted less attention in the literature, some researchers have argued that simulation will play a key role in SCRM, as it is able to devise decision options for well-defined risk-mitigating techniques (Talluri *et al.,* 2013; Kilubi, 2016).

2.3.2.2.4 Supply chain risk management process

In most cases, SCRM involves four processes that include identification, assessment, and controlling and monitoring of supply chain risks (Sarac *et al.,* 2010). The complexities of some supply chains make it difficult to apply these processes in preparing for all eventualities (Ganeshan and Magazine, 2012).

Tummala and Schoenherr (2011) extended the previous studies (Tummala *et al.,* 1994; Tummala and Mak, 2001) based on the structured risk management process (RMP), consisting of the following five phases: risk factors identification, risk measurement, risk assessment, risk evaluation, and risk control and monitoring. They also extracted further studies conducted by Ellegaard (2008), Finch (2004), Manuj and Mentzer (2008), and Schoenherr *et al.,* (2008) who proposed an approach consisting of a modified RMP to identify, assess, and manage supply chain risks. The final modified approach is an SCRM process including three phases, which are risk identification, risk measurement, and risk assessment in Phase I; risk evaluation, risk mitigation, and contingency plans in Phase II; and risk control and monitoring in Phase III. This approach provides a foundation of the SCRM process framework for supply chain managers for strategic decision making, considering the different supply chain risk profiles associated with a given situation.

More specifically, various processes make up the process of risk management in the supply chain. The process of risk management usually begins with identifying internal and external factors in the supply chain environment (Walker *et al.,* 2008). For example, in the manufacturing industry, some industries are faced with climatic risk, such as severe weather, while others experience the risk of the high cost of transporting goods.

Organisations can identify their supply chain risks by mapping the supply chain. Supply chain mapping also helps an organisation to prioritise various risks and address them effectively (Sarac *et al.,* 2010). In most cases, the starting point in supply chain mapping is the product or service that can greatly affect a company or organisation's profitability (Mollenkopf *et al.,* 2010). After understanding how to identify risk types, factors or both, the next steps involve risk assessment. The process involves prioritising risks according to the threat they pose to the well-being of a business. Risk assessment is associated with the occurrence of the trigger event and the severity of the consequences (Harland *et al.,* 2003). After identification and assessment of the risk, the next step entails devising risk treatment plans. At this point, it is important to devise measures that can protect the supply chain from risks, creating plans to respond to events that may be caused by the identified risks and developing plans to help continue operations in the case of disruptions (Gosling and Naim, 2009).

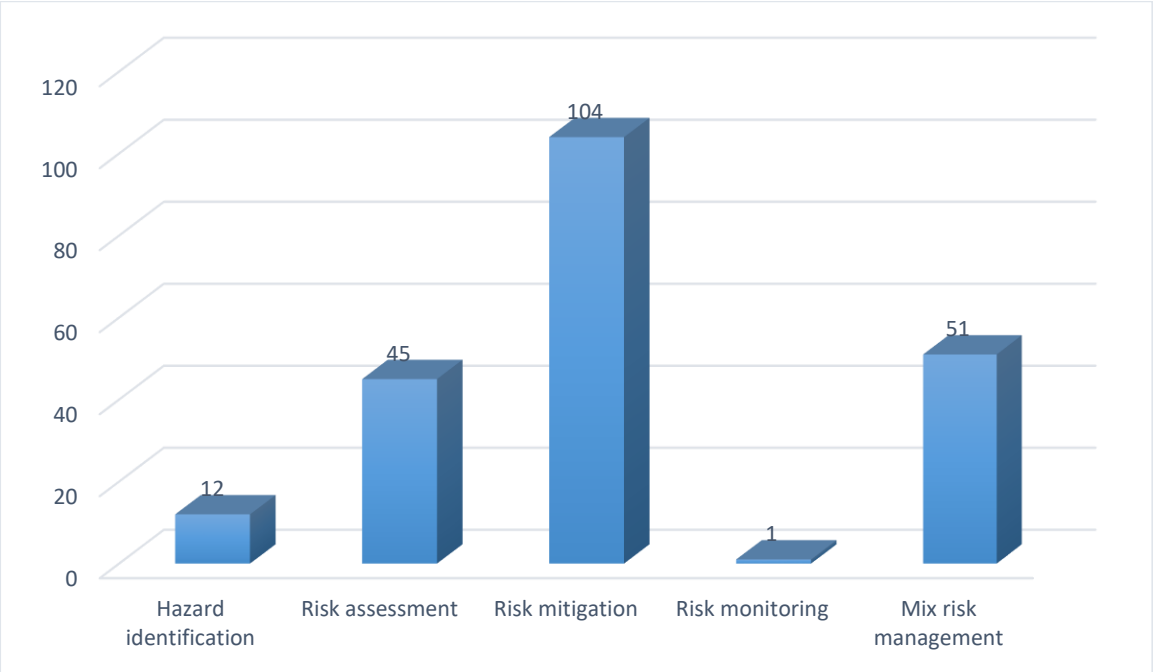


Figure 2-16: Number of categories of papers by the associated research areas

Finally, the process can also entail determining metrics and ways of measuring risk and the effectiveness of various plans put in place to mitigate risk (Fawcett *et al.,* 2014). By analysing the data based on the reviewed articles, most of the studies were focused on risk mitigation activity (49%, 104 papers). This indicated the relative maturity stage of researchers in SCRM.

The RMP is not complete without monitoring and review. Risk monitoring can be defined as monitoring developments in the supply chain that may increase or decrease risks on an on-going basis (Zsidisn *et al.,* 2005). The four main principles of SCRM include leadership, governance, management of change, and the development of a business case (Carter and Rogers, 2008). Monitoring and review not only entails checking the effectiveness of risk management practice but also maintaining various plans to meet changes in processes and suppliers and the regulation of any other elements that influence the supply chain (Walker *et al.,* 2008). Less focus has been centred on the last stage of the SCRM process, risk monitoring, which embeds risk management into the daily practices of organisations (1 paper). As shown in Figure 2.16, many articles studied a specific or individual SCRM process, while a few researchers considered holistic RMPs (24%, 51 papers).

2.3.2.2.5 Supply chain risk sources identification

As a decision-making support tool, the analytic hierarchy process (AHP) method has been applied by several researchers. It can support managers in setting up a priority hierarchy of risk management. Gaudenzi and Borghesi (2006) proposed the AHP method to identify supply chain risk factors with a view to improving the objective of customer value. However, the limitation of the research is the focus on the single focal company; thus, the risk indicators would not be applicable to other industries. Besides this, the following approaches can help in the identification of potential supply chain risks: supply chain mapping, checklists or check sheets, event tree analysis, fault tree analysis, Ishikawa cause and effect analysis (Tummala *et al.,* 1994), and failure mode and effect analysis (FMEA) (Tuncel and Alpan, 2010). According to Adhitya *et al.,* (2009), the hazard and operability analysis method from chemical process risk management has been employed for risk factors identification and consequence analysis.

Blos *et al.,* (2009) identified the supply chain risks in the automotive and electronic industries in Brazil by implementing a supply chain vulnerability map. The drawback of their study comes from the small sample size. A fishbone diagram has been used as an efficient method to

identify and visually depict the potential causes of common problems in the supply chain (Desai *et al.,* 2015). Four categories of potential effects have been examined in their study, such as defects, delays, counterfeits, and general errors. However, the lack of a case study is the main drawback for this research.

2.3.2.2.6 Supply chain risk assessment

An increasing number of risk assessment methods have been developed in the last two decades, especially for supply risk assessment (Ho *et al.,* 2015). Techniques such as the Delphi method, expert focus groups, five-point estimation, or Monte Carlo simulation can aid in the assessment of the probabilities of the risks (Tummala *et al.,* 1994).

There are plenty of research studies focused on the financial risk assessment in the supply chain. Value at risk and conditional value at risk are common methods that have been used in portfolio theory as percentile measures of downside-risk associated with undesirable outcomes (Chen and Yano, 2010; Hahn and Kuhn, 2012; Lockamy and McCormack, 2010; Poojari *et al.,* 2008; Sawik, 2013; Soleimani and Govindan, 2014). Furthermore, variance or standard deviation are largely used as a measure of supply chain financial risks as well (Azaron *et al.,* 2008; Babazadeh and Razmi, 2012; Hahn and Kuhn, 2012).

However, some articles argued that deviation-based measures are problematic measures of risk in general (Cox, 2008; Pedersen and Satchell, 1998). Cigolini and Rossi (2010) conducted a fault tree method to assess the operational risk at three stages of the oil supply chain (drilling, primary transport, and refining). The limitation of the study is ignoring operational risk assessment at other important stages like design, construction, and outsourcing.

Wagner and Neshat (2010) applied graph theory to convert the 'fuzzy' construct of supply chain vulnerability to an index (the SCVI). They revealed that graphs can be used as visual maps that facilitate the understanding of supply chain vulnerability and support decision making in SCRM. However, the proposed approach heavily depends on the expert judgements and availability of data that quantifies the drivers of SCV.

Ruiz-Torres *et al.,* (2013) proposed the model to utilise the decision tree approach to consider the possible situation in which one or more suppliers fail and develop contingency plans. However, the research did not consider the dynamic characteristics of the supply chain

network and all the input parameters and supplier characteristics were considered deterministic.

Kumar *et al.,* (2010) applied the artificial bee colony technique, genetic algorithms, and particle swarm optimisation to identify operational risk factors, their expected value, the probability of occurrence, and the associated additional cost. However, they are not devoid of limitations, as they only focused on a single-product supply chain network.

Tummala and Schoenherr (2011) suggested the hazard totem pole (HTP) analysis for the systematic evaluation of supply chain risks, integrating the risk assessment aspects of their severity, probability, and cost. Ramkumar (2016) proposed a risk assessment methodology for in-house and third-party type of e-procurement implementation based on a modified analytic network process (ANP) coupled with fuzzy inference systems. They investigated the technological implementation risks, which are found to be higher for both in-house and third-party e-procurement systems. However, the above two methods are also mostly depending on the assumption and subjective nature of the rankings and evaluations.

Moreover, there is a substantial number of quantitative methods that have been broadly proposed for the risk assessment, such as multicriteria decision-making and AHP approaches (Gaudenzi and Borghesi, 2006; Kull and Talluri, 2008; Levary, 2008; Kamath *et al.,* 2012; Wang *et al.,* 2012; Ling, 2014; Li *et al.,* 2015; Jaberidoost *et al.,* 2015; Dong and Cooper, 2016; Mu and Carroll, 2016), MRP-DRP stochastic modelling (Bogataj and Bogataj, 2007), fuzzy TOPSIS (Chatterjee and Kar, 2016), BNs (Lockamy and McCormack, 2012; Badurdeen *et al.,* 2014), modified FMEA method (Chen and Wu, 2013), and hierarchical holographic modelling (Nakandala *et al.,* 2017). It is obvious that there is a large body of literature on risk assessment focused on the priority of risk factors.

Nevertheless, it is also necessary to identify cause-effect relations between each risk factor in terms of their direct and indirect influence in the network. Hence, approaches such as interpretive structural modelling (ISM) or decision-making trial and evaluation laboratory can be used to present a hierarchical model showing the interrelationships between the risk sources (Hachicha and Elmsalmi, 2014; Govindan and Chaudhuri, 2016). The main drawback of those approaches is the lack of capability to deal with the complex system, while only considering a limited number of variables in the development of the model.

2.3.2.2.7 Supply chain risk mitigation and control strategies

As discussed above, among the 213 reviewed journal articles, 104 articles discussed risk mitigation strategies. According to Grötsh *et al.,* (2013), the research found that supplier insolvencies are a major source of interruption of the supply chain. Regarding these issues, they explored a mechanistic management control system, a rational cognitive style, and relational buyer-supplier relationships, which have positive effects on proactively managing supplier insolvency risks.

Yu *et al.,* (2015) proposed a novel conceptual model combining two variables: supply chain integration and organisational risk propensity for mitigating supply chain risk. The mechanism of supply chain risk on company performance through supply chain integration and organisational risk propensity can also help firms solve the problem of strategy choice under such a risk.

Ghadge *et al.,* (2012) surveyed the articles and found that, at a strategic level, contingency planning and risk-sharing outsourcing contracts are prominently used as risk mitigation strategies. Likewise, Li *et al.,* (2015) identified risk information sharing and risk-sharing mechanisms as two important joint SCRM practices in improving financial performance that can be strengthened by collaborative relationship characteristics, including relationship length, supplier trust, and shared SCRM understanding.

Bayesian networks are graphical models that display a set of possible variables and their conditional dependencies as a decision-making tool that can help managers mitigate risks within different fields (Abolghasemi *et al.,* 2015). An evaluation technique, the HTP analysis, has already been applied by Tummala *et al.,* (1994; Tummala and Mak, 2001). However, the limitations of the method must be noted regarding the assumptions and subjective nature of the ranking and evaluations.

Some similar strategies were stressed by different studies, which showed that supply chain risks can be mitigated by implementing flexibility (Chang *et al.,* 2015; Tang, 2006; Miller, 1992; Wieland and Wallenburg, 2012), redundancy (Chang *et al.,* 2015; Manuj *et al.,* 2014; Miller, 1992; Bucklin, 1965), hedging (Manuj *et al.,* 2014; Achrol *et al.,* 1983; Agrawal and Seshadri, 2000; Cachon, 2004; Miller, 1992; Tang, 2006), robustness (Wieland and Wallenburg, 2012; Tang, 2006; Downey, 2004), postponement (Manuj *et al.,* 2008; Tang, 2006; Bucklin, 1965;

Chiou *et al.,* 2002; Zinn and Bowersox, 1988), co-operation (Miller, 1992; Nooraie and Parast, 2015; Manuj *et al.,* 2008; Tang, 2006; Manuj *et al.,* 2014), and information technology (Tang, 2006).

There are limitations associated with the above articles. Wieland and Wallenburg (2012), Grötsh *et al.,* (2013), and Li *et al.,* (2015) surveyed samples that are geographically limited to only one country (*i.e.,* Germany or China) and have a small sample size. Manuj and Mentzer (2008) only focused on internal stakeholders. The proposed risk mitigation model was based on stable demand instead of fluctuating demand (Nooraie *et al.,* 2015). Chang *et al.,* (2015) proposed the conceptual framework mainly considers risk mitigation approaches rather than more fine-grained strategic options and contexts. Yu *et al.,* (2015) have not applied an empirical study to test the model.

Risk mitigation and control strategies that have been proposed by several researchers were mainly classified into two approaches: proactive and reactive. Furthermore, many more researchers have conducted proactive mitigation strategies than those that have proposed reactive strategies (Perry, 2007; Hopp *et al.,* 2012; Richey, 2009; Kumar and Havey, 2013).

Grötsh *et al.,* (2013) also learned that scholars have continuously suggested managing SCRM proactively to mitigate risks. After reviewing 87 peer-reviewed academic articles from 2000 to mid-2015, Kilubi and Haasis (2015) classified the most frequently mentioned enablers on SCRM based on two risk-mitigating methods: preventive and responsive. For the preventive approach, the strategy constitutes the enablers of visibility, relationships, collaboration, multiple sourcing, postponement, and redundancy. For the responsive methods, the strategy comprises visibility, flexibility, multiple sourcing, redundancy, and coordination. Proactive SCRM can be defined as planning and operating ahead to mitigate risks before they emerge (Mitroff and Alpaslan, 2003; Knemeyer *et al.,* 2009) while reactive SCRM are applied after a disruption has occurred to respond to or aid recovery (Tukamuhabwa *et al.,* 2017).

Moreover, few researchers use other classifications of strategies that focus on whether they support the robustness and/or agility of the supply chain under uncertainty (Wieland and Wallenburg, 2013). Some strategies could be proactive or reactive based on when and why they are applied, such as collaboration, agility, and postponement.

Agility, for example, can help to mitigate the emergency incident when the disruption occurs or afterward. However, agility also helps to manage the hazards before disruption occurs by investing in people and information (Jüttner *et al.,* 2003; Schmitt and Singh, 2012). Meanwhile, some strategies should be planned before a disruption, such as building a risk management culture (Tang, 2006; Dani and Deep, 2010; Diabat *et al.,* 2012; Grötsh *et al.,* 2013; Yu *et al.,* 2015; Oliva, 2016).

In Table 2.10, the SCRM strategies that have been put forward by researchers are summarised based on whether they are employed proactively or reactively. Table 2.10 represents visibility and transparency; collaboration and agility have been frequently adopted to mitigate risks. The findings are in line with findings by other scholars. For example, Kilubi (2016) found that the top three identified SCRM strategies were visibility and transparency, relationship/partnerships, and flexibility. Flexibility can be defined as a primary component of agility (Saravanapandi and Kumaran, 2015). However, the research deals with these strategies individually rather than collectively.

Some strategies can facilitate each other. For example, increasing visibility and transparency can improve collaboration within the organisation or with other supply chain members by sharing the risk information. In addition, although some strategies appear to complement each other dramatically, they can also conflict. For instance, horizontal collaboration between suppliers may increase supply chain risk through collusion (Choi and Krause, 2006). Moreover, a wide range of studies are adopting a 'one size fits all' approach to risk mitigation strategies. There are few research studies that consider the efficiency of alternative supply chain risk mitigation strategies under related contexts (Chang *et al.,* 2015). Consequently, the spread of disruption can be due to the lack of effective mitigation strategies (Ghadge *et al.,* 2012).

Table 2.10: Summary of reviewed risk mitigation strategies

SCRM Strategies	References
Proactive strategies	

Increasing visibility and transparency, for example, information sharing (risk-related information) between supply chain members and intra-organisational departments (information sharing mechanism), communication, use of information technology to enhance connectivity and traceability, etc.	Jüttner *et al.,* (2003); Christopher and Peck (2004); Christopher and Lee (2004); Giunipero and Eltantawy (2004); Hallikas *et al.,* (2004); Blackhurst *et al.,* (2005); Faisal *et al.,* (2006); Tang (2006); Ritchie and Brindley (2007); Enyinda and Szmerekovsky (2008); Chen and Huang (2010); Dani and Deep (2010); Giannakis and Louis (2011); Thun and Hoenig (2011); Diabat *et al.,* (2012); Groznik and Trkman (2012); Lavastre *et al.,* (2012); Lei *et al.,* (2012); Tse and Tan (2012); Zou and Couani (2012); Ilie and Popa (2013); Maryland (2013); Xue *et al.,* (2013); Yu and Goh (2014); Chang *et al.,* (2015); Li *et al.,* (2015); Nooraie and Parast (2015); Rajesh and Ravi (2015); Singh (2015); Choi *et al.,* (2016); Mishra *et al.,* (2016); Oliva (2016); Riley *et al.,* (2016); Yang and Fan (2016); Fan *et al.,* (2017); Kurniswan *et al.,* (2017); Namdar *et al.,* (2017); Nguyen *et al.,* (2017); Tsai (2017); Tukamuhabwa *et al.,* (2017); Urciuoli and Hintsa (2017)
Collaboration: The ability to work effectively with either other supply chain entities or within the organisation for mutual benefit, for example, sharing information and other resources to reduce vulnerability, participative management, cross functional involvement, risk sharing, etc.	Jüttner *et al.,* (2003); Christopher and Peck (2004); Giunipero and Eltantawy (2004); Hallikas *et al.,* (2004); Spekman and Davis (2004); Kleindorfer and Saad (2005); Cucchiella and Gastaldi (2006); Faisal *et al.,* (2006); Blackhurst *et al.,* (2008); Jiang *et al.,* (2008); Khan *et al.,* (2008); Lai *et al.,* (2009); Scheller-Wolf and Tayur (2009); Dani and Deep (2010); Jia and Rutherford (2010); Thun and Hoenig (2011); Lavastre *et al.,* (2012); Zou and Couani (2012); Elzarka (2013); Grötsh *et al.,* (2013); Maryland (2013); Bandaly *et al.,* (2014); Kim and park (2014); Lavastre *et al.,* (2014); Scholten *et al.,* (2014); Ellinger *et al.,* (2015); Gao (2015); Li *et al.,* (2015); Yu *et al.,* (2015); Cheng and Chen (2016); Mishra *et al.,* (2016); Oliva (2016); Riley *et al.,* (2016); Zepeda *et al.,* (2016); Tukamuhabwa *et al.,* (2017); Wiengarten *et al.,* (2016); Fan *et al.,* (2017); Ghadge *et al.,* (2017); Revilla and Saenz (2017); Wang *et al.,* (2017)
Postponement: The manufacturer produces a generic product, which can be modified at the later stages before the final transport to the customer.	Jüttner *et al.,* (2003)

Agility: The ability to efficiently change operating states in response to uncertain and changing market conditions, for example, flexibility to adapt to changing requirements with minimum time and effort, visibility, joint planning, customer responsiveness, etc.	Jüttner *et al.,* (2003); Schmitt and Singh (2012)
Knowledge management: The exploitation of computational systems that can store, process, and transmit knowledge from one individual to another, to facilitate daily operations within the supply chain (e.g., staff training, etc.)	Hallikas *et al.,* (2004); Sinha *et al.,* (2004); Faisal *et al.,* (2006); Maryland (2013); Scholten *et al.,* (2014); Riley *et al.,* (2016)
Multiple sourcing and flexible contractual agreements	Zsidisin and Ellram (2003); Christopher and Peck (2004); Tang (2006); Trkman and McCormack (2009); Diabat *et al.,* (2012); Wieland and Wallenburg (2012); Xanthopoulos *et al.,* (2012); Fang *et al.,* (2013); Kanyoma *et al.,* (2013); Gaudenzi *et al.,* (2017); Lücker and Seifert (2017); Tukamuhabwa *et al.,* (2017); Wang *et al.,* (2017)
Redundancy or buffering strategy, for example, buffer (emergency) stock, excess productive capability, back sourcing, etc.	Jüttner *et al.,* (2003); Zsidisin and Ellram (2003); Chopra and Sodhi (2004); Colicchia *et al.,* (2011); Chang *et al.,* (2015); Aven (2016); Mishra *et al.,* (2016); Park *et al.,* (2016); Mohammaddust *et al.,* (2017)
Building risk management culture, for example, managers' attitude towards risks, top management support, firm integration/team work, risk governance, etc.	Eltantawy (2004); Faisal *et al.,* (2006); Tang (2006); Dani and Deep (2010); Diabat *et al.,* (2012); Grötsh *et al.,* (2013); Yu *et al.,* (2015); Oliva (2016); Park *et al.,* (2016); Fattahi *et al.,* (2017); Urciuoli and Hintsa (2017)
Increasing logistics capabilities, for example, increasing transportation equipment capability, inventory management, investment in new facilities, etc.	Chopra and Sodhi (2004); Sinha *et al.,* (2004); Kleindorfer and Saad (2005); Schmitt (2011); Wieland and Wallenburg (2012); Maryland (2013); Micheli *et al.,* (2014); Gao (2015); Choi *et al.,* (2016); Li *et al.,* (2016); Tsai (2017); Tukamuhabwa *et al.,* (2017); Urciuoli and Hintsa (2017)
Supplier development, for example, supplier assessment; supplier certification; quality management programmes; financial, training, and technical knowledge to improve efficiency, commitment, reliability, etc.	Zsidisin and Ellram (2003); Christopher and Peck (2004); Blackhurst *et al.,* (2005); Blackhurst *et al.,* (2008); Thun and Hoenig (2011); Diabat *et al.,* (2012); Micheli *et al.,* (2014); Kurniswan *et al.,* (2017); Tukamuhabwa *et al.,* (2017)

Increasing innovativeness: The motivation and capability to seek and invest in new business ideas, for example, research and development, technologies, processes, and strategies that can reduce vulnerability, etc.	Norrman and Jansson (2004); Scholten *et al.,* (2014); Bandaly *et al.,* (2016); Prakash *et al.,* (2017)
Outsourcing: Outsourcing non-core product offshore and insourcing core products and developing offshore insourcing capabilities.	Huq *et al.,* (2016); Tukamuhabwa *et al.,* (2017)
Financial management, for example, financial hedging, borrowing from customers, effective credit management, insurance, etc.	Elleuch *et al.,* (2014); Tukamuhabwa *et al.,* (2017)
Reactive Strategies	
Collaboration: The ability to work effectively with either other supply chain entities or within the organisation for mutual benefit, for example, sharing information and other resources to reduce vulnerability, participative management, cross functional involvement, risk sharing, etc.	Ojala and Hallikas (2006); Oke and Gopalakrishnan (2009); Simchi-Levi *et al.,* (2013); Rajesh and Ravi (2015)
Agility: The ability to efficiently change operating states in response to uncertain and changing market conditions, for example, flexibility to adapt to changing requirements with minimum time and effort, visibility, joint planning, customer responsiveness, etc.	Christopher and Peck (2004); Chopra *et al.,* (2004); Sodhi (2004); Blackhurst *et al.,* (2005); Kleindorfer and Saad (2005); Cucchiella and Gastaldi (2006); Faisal *et al.,* (2006); Tang (2006); Tomlin (2006); Enyinda *et al.,* (2008); Khan *et al.,* (2008); Tang and Tomlin (2008); Braunscheidel and Suresh (2009); Narasimhan and Talluri (2009); Oke and Gopalakrishnan (2009); Chen and Huang (2010); Dani and Deep (2010); Christopher and Holweg (2011); Thun and Hoenig (2011); Wallace and Choi (2011); Diabat *et al.,* (2012); Wieland and Wallenburg (2012); Zou and Couani (2012); Simchi-Levi *et al.,* (2013); Scholten *et al.,* (2014); Varzandeh *et al.,* (2014); Abolghasemi *et al.,* (2015); Chang *et al.,* (2015); Rajesh and Ravi (2015); Singh (2015); Sahay and Ierapetritou (2015); Kurniswan *et al.,* (2017); Lücker and Seifert (2017); Sreedevi and Saranga (2017); Wang *et al.,* (2017)

Redundancy or buffering strategy, for example, buffer (emergency) stock, excess productive capability, back sourcing, investments in a back-up IT system, etc.	Schmitt (2011); Thun and Hoenig (2011); Schmitt and Singh (2012); Simchi-Levi *et al.,* (2013)
Increasing logistics capabilities, for example, increasing transportation equipment capability; inventory management; investment in new facilities, etc.	Nooraie and Parast (2016)
Business contingency planning	Norrman and Jansson (2004); Finch (2004); Kleindorfer and Saad (2005); Oke and Gopalakrishnan (2009); Colicchia *et al.,* (2011); Diabat *et al.,* (2012); Wieland and Wallenburg (2012)
Demand management, for example, silent product rollover; dynamic assortment planning, creating customer flexibility, customer incentives, demand forecasting, etc.	Chopra and Sodhi (2004); Diabat *et al.,* (2012); Elleuch *et al.,* (2014); Rajesh and Ravi (2015); Tukamuhabwa *et al.,* (2017); Urciuoli and Hintsa (2017)
Financial management, for example, financial hedging, borrowing from customers, effective credit management, insurance, etc.	Gaudenzi *et al.,* (2017); Tukamuhabwa *et al.,* (2017)
Multiple sourcing and flexible contractual agreements	Jüttner *et al.,* (2003); Oke and Gopalakrishnan (2009); Thun and Hoenig (2011); Mohammaddust *et al.,* (2017); Namdar *et al.,* (2017)
Postponement: The manufacturer produces a generic product, which can be modified at the later stages before the final transport to the customer.	Jüttner *et al.,* (2003); Tang (2006); Manuj and Mentzer (2008); Yang and Yang (2010); Wieland and Wallenburg (2012); Manuj *et al.,* (2014); Rajesh and Ravi (2015); Wang *et al.,* (2017)

2.3.2.2.8 Supply Chain Risk Monitoring and Review

Compared with risk assessment and mitigation strategies, there is only one article that assessed risk monitoring and review so far. However, in the growing research based on supply chain risk, some studies have developed an SCRM framework and stress the need for risk monitoring (Hallikas *et al.,* 2004; Norrman and Jansson, 2004; Zsidisin and Ellram, 1999). The current business environment is becoming more uncertain. To identify new types of risk requires monitoring changes in the network, customer needs, technology, partner strategies, and competitors and updating the risk assessment correspondingly (Hallikas *et al.,* 2004).

Blome *et al.,* (2011) found that most of their surveyed sample firms incorporated risk monitoring into their regular supplier monitoring activities, shortened the assessment cycle, and increased the monitoring depth during the financial crises. Moreover, the existing disruption is not only determined by the nature of the disruption but is also influenced by the organisational maturity level to handle such disruption issues (Qzai *et al.,* 2015).

Tummala and Schoenherr (2011) determined that data management systems can be utilised in the risk control and monitoring process for storing and updating the related risk information. This would help the organisation implement risk response action plans and provide guidelines for future improvement. In addition, there are plenty of sophisticated SCRM software applications that offer commercial solutions for risk management.

Zhang *et al.,* (2011) developed an integrated mathematical abnormality diagnosis model by combining radial base function neural network, fuzzy control, and statistical analysis methods to propose a pre-warning system of production quality issues in the food supply chain. The pre-warning system can effectively identify abnormal data types and accurately determine whether a warning should be issued. The drawback of the study is the narrow focus on quality risk in the food supply chain.

2.3.2.2.9 Integrated SCRM processes

A wide variety of studies focused on more than one stage of the SCRM process (24%, 51 papers). Ritchie and Brindley (2007) proposed a conceptual framework for SCRM consisting of five major components: risk sources and profile, risk and performance drivers, risk and performance consequences, risk management responses, and risk and performance outcomes. Tummala and Schoenherr (2011) modified the previous RMP to identify, assess, and manage supply chain risks. The complete SCRM process constitutes three phases: Phase I (risk factors identification, risk measurement, risk assessment), Phase II (risk evaluation, risk mitigation, and contingency plans), and Phase III (risk control and monitoring).

Bandaly *et al.,* (2014) developed an integrated approach to SCRM using operational methods and financial instruments. They suggested that the SCRM process requires the collaboration of supply chain members (*e.g.,* suppliers, manufacturers, and distributors) and the collaboration of functional units (operations and finance) of these members. In addition,

some research only covered two SCRM processes, such as risk identification and assessment (4%, 9 papers) or risk assessment and mitigation (8%, 18 papers). For instance, Jennifer et al. (2008) explored a proposed supplier risk assessment and monitoring framework related to a project with a US-based automotive manufacturer. A multi-criterion scoring procedure is proposed to evaluate part and supplier risk indices.

Tuncel and Alpan (2010) presented a failure mode, effects, and criticality analysis (FMECA) technique to examine the disruption factors in the supply chain network and proposed a timed Petri nets framework to analyse the effectiveness and efficiency of various risk mitigation actions. Abolghasemi *et al.,* (2015) proposed a novel approach for SCRM, which combined SCOR metrics and BNs to measure the supply chain performance for selecting the best alternative to mitigate risks.

There are limitations associated with the above studies. Abolghasemi *et al.,* (2015) only focused on a single industry with limited real data for the performance metrics. Tuncel and Alpan (2010) focused only on the perspective of the manufacturer. Tummala and Schoenherr (2011) demonstrated only the phases of the SCRM approaches but did not explain how the approach could be applied in practice. Ritchie and Brindley (2007) and Bandaly *et al.,* (2014) only conducted a single-case study. The development of alternative risk assessment approaches would increase the sensitivity of the risk analysis (Jennifer *et al.,* 2008), and there was a lack of empirical study to test the proposed risk management concept (Hofmann *et al.,* 2014).

2.3.3 Status of risk management in the healthcare supply chain

All activities in the health supply chain have risks to a certain extent. In the health supply chain, members of staff work in the procurement department, storage, distribution, and inventory with the aim of ensuring that all clients and customers in the health sector obtain all the services they need. A potential problem that can erupt from this process is called supply chain risks (Kumar *et al.,* 2009). Like other industries, the healthcare industry is not immune from both predictable and unpredictable supply chain disruptions, which have significant effects on costs and patient care (e.g., losses due to downtime, shortage of essential drugs, and loss of life; Enyinda *et al.,* 2014).

However, the biggest difference compared to other industries is that risk has a direct serious effect on the patient's life. Research has indicated that, in Europe, medicine can travel through as many as 20 to 30 pairs of hands before it finally reaches the patient (Haigh, 2004). Consequently, operational failures in hospitals can result from the inability of a hospital's work system to reliably provide supplies when, where, and to whom they are needed (Tucker, 2004). Therefore, successful SCM is a significant element of an organisation's ability to increase efficiency and ensure the safety of the patients' lives.

To manage the healthcare supply chain, most organisations identify the types and sources of risk and then derive effective strategies to mitigate the effects of the risk in their operations (Wisner *et al.,* 2015). Risk management from a healthcare perspective refers to a formal approach that is employed to identify and mitigate all sources of disruption and dysfunction within the healthcare supply chain (Gosling and Naim, 2009).

There are various benefits of risk management in the healthcare supply chain. First, effective risk management helps a firm or organisation achieve its supply chain objective. Risk management enables organisations to reduce the cost of enhancing efficiency in the healthcare supply chain operations. Risk management in the healthcare supply chain helps to improve the governance and leadership of the supply chain (Haszlinna *et al.,* 2009). In addition, risk management in the healthcare supply chain can help to improve the confidence and trust in the supply chain of various stakeholders and customers (Tummala and Schoenherr, 2011). Finally, effective risk management in the healthcare supply chain helps supply chain managers focus more on proactive risk management rather than reacting to unforeseen events (Kumar *et al.,* 2009).

Risk management in the healthcare supply chain has continued to improve (Simpson *et al.,* 2015). Various enablers of risk management in the healthcare supply chain have been identified; they include information sharing, building trust among supply chain partners, building a responsive supply chain, collaborative relationships among healthcare supply chain partners, strategic risk planning, aligning initiatives, and risk sharing in the healthcare supply chain. Other enablers of healthcare SCRM include knowledge about risks in the healthcare supply chain and continual risk assessment and benchmarking of various healthcare SCM practices (Tummala and Schoenherr, 2011).

Healthcare institutions are now adapting to supply chain information management systems to help them manage their procurement and increase efficiency (Zhu *et al.,* 2008). Various customised SCM software packages for the healthcare sector exist in the market (Gosling and Naim, 2009). The SCM helps procurement managers make informed decisions in matters related to the health supply chain. Various information management systems can also be used in healthcare supply management data warehousing and analysis of healthcare big data (Carter and Rogers, 2008). However, education on healthcare SCRM remains underdeveloped.

According to Burn (2008), the healthcare supply chain consists of four main components: producer, purchaser, provider, and patient. In this study, particular focus is placed on the downstream chain (e.g., hospital), from the sourcing of the pharmaceutical products and materials from distributors/suppliers to the dispensation of medication in the care department. There is scarce research data on risk management within the healthcare supply chain pertaining to hospitals. Thus, in this study, after reviewing 213 quality papers in the SCRM field, only 11 papers and one official report were selected that were related to the hospital pharmaceutical SCRM. Similarly, there is no consensus on the concepts of healthcare SCRM as there are in SCRM in traditional industries. Among the reviewed articles, only one researcher defined healthcare SCRM as: 'Risk management in the healthcare supply chain represents a systematic approach of identifying, analysing, treating and monitoring the risks that affect patient care process' (Enyinda *et al.,* 2014). To provide a meaningful analysis, Table 2.11 summarises the selected papers in terms of the title, authors, publication year, research objectives, research methodology, and key findings.

Table 2.11: Summary of 12 selected research papers

Paper Citation	Focus	Method Type	Key Finding
'A Preliminary Examination of Risk in The Pharmaceutical Supply Chain (PSC) In the National Health Service (NHS)(UK)' (Breen, 2008)	Gain a more realistic understanding of the nature and prevalence of risk in the PSC in the UK NHS.	Qualitative	Thirty-five prevalent risks have been identified, similar to those prevalent in industrial supply chains, regardless of the idiosyncrasies of the PSC, via a workshop forum held in November 2005. Suggesting that caution must be applied in how such risks are addressed, there are aspects

			of the product that highlight its uniqueness (e.g., criticality).
'Evaluation of Different types of Risks in Pharmaceutical Supply Chain' (Kamath *et al.,* 2012)	Analysing and mitigating four major risks affecting the PSC.	Hybrid	Outsourcing, incorporating the latest anti-counterfeiting technologies, inventory management logistics planning, and good warehousing practices, insurance of products, and facilities and proper risk management strategies are suggested by the authors to mitigate risks.
'Summary of the executive session on critical threats to the pharmacy supply chain and the effects on patient care' (Maryland, 2012)	Focusing on the viable solutions to various critical threats to the PSC.	Qualitative	A discussion group taken by various stakeholders in the PSC on August 2012 in Bethesda, Maryland. Viable solutions to critical threats to the PSC were suggested during the discussion. Collaboration among all stakeholders involved in the PSC is needed to ensure a reliable PSC and to protect public safety.
'Supply risk analysis: applying system dynamics to the Colombian healthcare sector' (Aguas *et al.,* 2013)	This paper addresses supply risk in the oncological medicine supply chain in Colombia. A system dynamics model was developed for assessing supply risk effect on supply chain operation and performance.	Quantitative	The results show the market response level, implying a deficit in the medication system. Logistics service supply present delays in delivery times. It was found that the waiting time for receiving treatment was longer than three months in most cases. On average, it is known that only few patients requiring drugs will receive them in normal conditions.
'Efficient Healthcare Consumer Supply Chain Optimization' (Ilie and Popa, 2013)	The article aims to present the supply chain of the Romanian public healthcare system to determine if the end results of this work are positive and meet current requirements and	Qualitative	Romanians will require more money to buy a vaccine because imported drugs have a higher price than domestic production. Another conclusion is that policies developed by local healthcare institutions remain faithful to the MS to protect the interests

	challenges faced by society.		of patients and consumers and to build a safer future.
'Sourcing Strategy and Supply Chain Risk Management in the Healthcare Sector: A Case Study of Malawi's Public Healthcare Delivery Supply Chain' (Kanyoma *et al.,* 2013)	The study primarily investigated the role of a single sourcing strategy in either exacerbating or mitigating persistent supply failure in Malawi's public healthcare delivery supply chain.	Qualitative	The study findings confirmed that single sourcing exacerbates the risk of supply failure, evidenced by persistent stock outs of drugs in hospitals that consequently risk the lives of many patients who rely on the public healthcare system.
'An Analytical Model for Healthcare Supply Chain Risk Management' (Enyinda *et al.,* 2014)	This research is concerned with the quantification of risk in the healthcare supply chain using AHP.	Hybrid	The results indicated that infrastructure is the most important risk in the healthcare supply chain, followed by operational, supply, and political risk. Moreover, risk reduction is the overall best risk management option rather than risk avoidance, risk acceptance, and risk transfer.
'A combined approach for supply chain risk management: description and application to a real hospital pharmaceutical case study' (Elleuch *et al.,* 2014)	The paper describes a supply network risk approach to assist supply chain decision makers to risk identification, assessment, and management.	Hybrid	The proposed approach is based on combining many techniques and methods include the following: 1) FMECA to identify risk and its current location and assess risks, 2) design of experiment to design risks mitigation and action scenarios, 3) discrete event simulation to assess risks mitigation action scenario, 4) AHP method to evaluate risk management scenarios, and 5) desirability optimisation to perform the best risk scenario.
'Supply chain risk management and hospital	In this study, the authors examine the effects of horizontal	Quantitative	Results suggest that, while affiliation with local, regional, and national systems has

inventory: Effects of system affiliation' (Zepeda *et al.,* 2016)	inter-organisational arrangements on inventory costs for hospitals facing two key environmental conditions: the logistics services infrastructure at the hospital and the demand uncertainty for clinical requirements that a hospital experiences.		mitigating effects under weak logistics services infrastructure, the mitigating effect is greatest for affiliation with local systems.
'i-RM: An intelligent risk management framework for context-aware ubiquitous cold chain logistics' (Kim *et al.,* 2016)	The research focus is on a special type of logistics in the healthcare setting, called ubiquitous cold chain logistics (UCCL).	Quantitative	An intelligent risk management framework for UCCL, namely, i-RM was suggested to automatically handle risks.
'How internal integration, information sharing and training affect supply chain risk management capabilities' (Riley *et al.,* 2016)	The research determined if internal integration, information sharing, and training constitute direct antecedents to organisations' warning and recovery capabilities.	Hybrid	The findings suggested that building SCRM capabilities and their antecedents can better address an array of supply chain risks. They examined internal integration and training competencies as abilities to strengthen organisations' warning and recovery capabilities.
'Operational productivity and performance in English NHS acute hospitals: Unwarranted variations' (Lord Carter's report, 2016)	Lord Carter of Coles' final report sets out how non-specialist acute trusts can reduce unwarranted variation in productivity and efficiency across every area in the hospital to save the NHS £5 billion each year by 2020/2021.	Qualitative	The 15 core recommendations on hospital productivity were designed to tackle unwarranted variation and help NHS trusts improve their performance.

2.3.3.1 Supply chain risk management methodologies in healthcare setting

Risk management in the healthcare supply chain represents a systematic approach of identifying, analysing, treating, and monitoring the risks that affect the patient care process (Enyinda *et al.,* 2014). To do so, risk factors identification, assessment, mitigation, and monitoring processes were reviewed along with the selected papers. As shown in Table 2.12, the divergent strategies explored by researchers are summarised.

Table 2.12: Classification of the SCRM process in the healthcare setting

Articles	Risk Factors Identification	Risk Assessment	Risk Mitigation	Risk Monitoring
Breen (2008)	X			
Kamath, *et al.,* (2012)	X	X	X	
Maryland (2012)			X	
Ilie and Popa (2013)			X	
Kanyoma *et al.,* (2013)	X	X	X	
Aguas *et al.,* (2013)	X	X		
Elleuch *et al.,* (2014)	X	X	X	
Enyinda *et al.,* (2014)	X	X		
Kim *et al.,* (2016)	X	X	X	
Zepeda *et al.,* (2016)			X	
Riley *et al.,* (2016)				
Lord Carter's report (2016)	X		X	

2.3.3.1.1 Healthcare supply chain risk factors identification

Risk factors identification defines the cause of accidents in the healthcare supply chain. It is a first and essential step in SCRM. Brainstorming is employed to define the risk factors according to the perception of decision makers (Elleuch *et al.,* 2014).

As a pioneer of studying risk management in the UK NHS pharmaceutical supply chain (PSC), Breen (2008) conducted a workshop forum that focused on risk factors identification within

the PSC. The outputs of the workshop showed that there were 35 prevalent risks with varying levels of criticality. The participants were split into two groups to rate the criticality of the selected risk factors and to produce a general structure of the PSC. Furthermore, those identified risk factors have been divided into three distinct sections: supply chain structure, controllability, and strategy. The fragmentation of the supply chain has the highest rating due to a lack of uniformity in decision making within the PSC. This was followed by the lack of visibility of stock, unexpected increases in demand, demand versus capacity, and lack of information, which also have high ratings.

Maryland (2012) discussed the fragmentation of the drug distribution processes and the use of restricted drug distribution systems, grey-market activity, counterfeiting, and drug shortage, which are critical threats to the PSC in the healthcare setting. Fake medicines range from useless to highly dangerous, and they often contain the wrong level of active ingredient or an active ingredient intended for a different purpose. The individuals taking counterfeit medicine put their health and even their lives at high risk. These risk factors are also mentioned by other researchers (Breen, 2008; Kamath *et al.,* 2012; Enyinda *et al.,* 2014).

Moreover, several researchers also found that the shortage of drugs is another high-risk factor in the healthcare supply chain (Breen, 2008; Ilie and Popa, 2013; Aguas *et al.,* 2013; Elleuch *et al.,* 2014). With nearly 40% of hospital budgets dedicated to inventory (McKone-Sweet *et al.,* 2005), managers must explore available SCRM techniques to reduce inventory-related risks. In a review of over 500,000 medication incidents reported to the National Reporting and Learning System between 2005 and 2010, omitted and delayed medicine was the category with the greatest number (16%) of reported medicine incidents (David, 2012). Colombian pharmaceutical policy shows that some of the main problems in the Colombian health systems are related to the availability of essential medicines (Aguas *et al.,* 2013).

Kanyoma and Khomba (2013) also revealed that stock outs have paralysed healthcare delivery systems and caused the deaths of patients, delays in medical surgery, and worsened medical conditions of patients, among other effects. Furthermore, Kanyoma *et al.,* (2013) also learned of the major causes of medicine shortage in complementary empirical studies of Malawi's public hospitals. The risk factors have been identified as follows: single sourcing strategy, insufficient inventory at the Central Medical Store (CMS), delays by procurement staff, and withholding of funds by donors. Moreover, other risk factors mentioned in their study that

are potential causes of recurrent stock outs include wrong demand forecasting, unexpected disease outbreaks, lack of funds at the hospital level, poor inventory management, and unavailability of drugs on the market. In this study, they found that the government instituted only a single supplier, namely, the 'Central Medical Stores', which is the main cause of medicine shortages. Moreover, variation in demand is another major factor influencing inventory management. Because of the higher demand uncertainty for alternative clinical services, the risk of stock out of needed items has higher uncertainty, which makes it difficult to reliably forecast (Davis, 1993; Lee *et al.,* 1997; Sodhi and Lee, 2007).

Supplier failure is another important risk factor that would lead to high cost or other serious consequences. It could be caused by either the location of the manufacture/supplier (not domestic based) or contract problems with hospitals, and so on (Breen, 2008; Kanyoma *et al.,* 2013; Ilie and Popa, 2013; Elleuch *et al.,* 2014; Enyinda *et al.,* 2014). Some researchers also identified the risk factors associated with regulation and political issues because the healthcare supply chain is regulated and monitored by various parties, such as the Department of Health, National Institute for Health and Clinical Effectiveness (NICE), Medicine and Healthcare Products Regulatory Agency, and the NHS Purchasing and Supply Agency (NHS PASA), to name but a few (Breen, 2008; Kamath *et al.,* 2012; Kanyoma *et al.,* 2013; Ilie and Popa, 2013).

Inventory risks could incur significant costs to healthcare providers. Kamath *et al.,* (2012) and Enyinda *et al.,* (2014) investigated the effects of inventory risk in the Indian and Nigerian healthcare industries, respectively. In general, inventory accumulation and obsolescence in the hospital sector are several times higher than in the retail/industrial sector (Ebel *et al.,* 2013). This is due to the unique characteristics of the healthcare industry, which does not regard the supply chain costs as the main driver of inventory decisions. Instead, inventory level is dictated by the need to meet service performance outcomes (Zepeda *et al.,* 2016). Several researchers have determined that organisations encounter issues in managing inventory due to the different types of supply chain risks; demand exceeds supply, resulting in stock outs, or supply exceeds demand, resulting in surplus inventory (Craighead *et al.,* 2007; Kremer and Wassenhove, 2014; Sodhi *et al.,* 2012; Talluri *et al.,* 2013).

Some researchers stated that information-related risks have been a threat to the healthcare industry for many years (Breen 2008; Ilie and Popa, 2013; Aguas *et al.,* 2013). They identified

several information-related issues including 'Slow information transmission and single channel', 'asymmetries of the information', 'information flow or lack of demand information', 'too much information', 'fragmentation of SC-no single source, multiple channels, no communication, unilateral decisions', 'lack of data standardisation (common codes)'. It was reported that the lack of data standardisation (common codes) is the top pharmaceutical information-related risk factor in terms of risk severity.

As described above, supply chain risk refers to the 'variation in the distribution of possible supply chain outcomes, their likelihoods, and their subjective values' (Jüttner *et al.,* 2003). Labour Peer Lord Carter (2016) produced a report for the government that reviewed what could be done to eliminate the unwarranted variations, to improve efficiency in hospitals in England. In this report, the various unwarranted variations can be considered as the risk factors. Since 2015, Lord Carter has engaged with 136 acute hospitals in England and further conducted empirical studies in 40 of those hospitals about the challenges in delivering improved productivity and improving efficiency. Nevertheless, this report disclosed some major issues related to the NHS SCM. In this report, Lord Carter found an astonishing variety in the numbers of products and suppliers used across and within NHS trusts. A sample of 22 trusts used 30,000 suppliers, 20,000 different product brands, over 400,000 manufacturer products codes, and more than 7,000 people can place orders. There is a dramatic increase in the average price paid for procurements each year. Lord Carter also mentioned the significant variation in inadequate medicine stockholding between 11 and 36 days, holding £200 m of stock at any one time. Additionally, Lord Carter found that about 50% of medicine deliveries come from a small number of wholesalers, while the other 50% come directly from the manufacturers. That can mean that an NHS trust will receive up to 30 medicine deliveries every day, which would lead to dispensing or picking errors of medication and is time-consuming for staff.

Table 2.13 summaries the risk factors in healthcare supply chain operations from previous studies. A common limitation of the above articles is the applied qualitative methods for risk factors identification (Breen, 2008; Maryland, 2012; Enyinda *et al.,* 2014; Kanyoma *et al.,* 2013), and they did not quantify the negative effects and severity of the risk factors. Some researchers conducted studies based on a sample of hospitals from a single state (Enyinda *et al.,* 2014; Kanyoma *et al.,* 2013; Zepeda *et al.,* 2016).

Table 2.13: Summary of HSC risk factors from previous studies

Risk Factors	Authors
Drive competitors out of the market, manufacturer defence tactic diversions of manufacturing capacity, cash-flow threat associated with small pharmaceutical companies and hospitals, demand versus capacity, lack of forecasting-customer side, demand/economics not able to respond to demand, increase in demand due to NICE approval, short-term supply chain planning, prioritisation conflict between patients/profits, regulatory issues such as manufacturing licensing, change of standards, drug recalls, risk of litigation, and influence on market.	Breen (2008)
Counterfeit risk and grey-market activity.	Breen (2008), Kamath *et al.,* (2012), Maryland (2012), Enyinda *et al.,* (2014)
Unexpected increase in demand, fluctuation in customer demands, and demand uncertainty for clinical requirements.	Breen (2008), Elleuch *et al.,* (2014), Zepeda *et al.,* (2016)
Unavailability of raw material, true and commercially induced, and domestic drug shortages.	Breen (2008), Ilie and Popa (2013), Maryland (2012), Aguas *et al.,* (2013), Elleuch *et al.,* (2014)
Unavailability of supplier, location of manufacture/supplier (not domestic based), inferior quality of purchased drugs from supplier, supplier failure, contract problems with suppliers, and contracting treated as a commodity, where big contracts equal big risk.	Breen (2008), Kanyoma *et al.,* (2013), Ilie and Popa (2013), Elleuch *et al.,* (2014), Enyinda *et al.,* (2014)
Time limit of drugs.	Enyinda *et al.,* (2014)
Inventory risk, insufficient inventory at Central Medical Store (CMS), lack of visibility of stock, inadequate buffer stock (JIT/lean), and poor inventory management by pharmacies.	Breen (2008), Kamath *et al.,* (2012), Kanyoma *et al.,* (2013), Lord Carter's report, (2016)
Delay by procurement staff, procurement hubs – introduce more complexity.	Breen (2008), Kanyoma *et al.,* (2013)
Clinician's preference.	Ilie and Popa (2013)
Slow information transmission and single channel, asymmetries of the information, information flow or lack of demand information, too much information, fragmentation of supply chain (no single source, multiple channels, no communication, unilateral decisions), and lack of data standardisation (common codes).	Breen (2008), Ilie and Popa (2013), Aguas *et al.,* (2013)
Fragmentation of drug distribution processes and use of restricted drug distribution systems, transportation (unavailability of fuel, congestion, weather, illness),	Breen (2008), Maryland (2012), Aguas *et al.,*

dispensing/picking error-medication/packaging, storage/cold chain, and capacities of logistics systems.	(2013), Lord Carter's report, (2016)
Lack of incentive mechanism.	Maryland (2012)
Financial risk and lack of funds at the hospital.	Kamath *et al.,* (2012), Kanyoma *et al.,* (2013)
Reimbursement policies not consistent, regulatory risk, rigorous government intervention, and regulation risks (EU).	Breen (2008), Kamath *et al.,* (2012), Kanyoma *et al.,* (2013), Ilie and Popa (2013)
Unexpected disease outbreaks and external influences-disaster recovery.	Breen (2008), Kanyoma *et al.,* (2013)
High purchase price and high product and supplier/brand variety.	Lord Carter's report, (2016)

2.3.3.1.2 Healthcare supply chain risk assessment

Breen (2008) recommended that further examinations could apply the AHP method to rate identified risk factors to assist in more structured decision making. Furthermore, this method has been used by several researchers (Kamath *et al.,* 2012; Enyinda *et al.,* 2014) in healthcare SCRM. Regulation risk has been ranked as the priority risk factor by Kamath *et al.,* (2012). Moreover, Enyinda *et al.,* (2014) investigated infrastructure risks (transportation logistics, electricity, and technology risks), which are important risks. Meanwhile, for sub-risk categories, the most important risk is counterfeits.

The system dynamics model has been applied in various types of organisations, leading to capturing complex dynamics for representing causal relationships and inter-dependence between variables (Sterman, 2002). Wang and Zhang (2010) set the risk rate as the rate of emergency process in completion by utilising the system dynamics model. They revealed that there is a higher risk rate when the patient quantity is random, and the hospital staff is stable, while there is an obvious drop in the risk rate when medical affairs are adjusted in time on the condition of actual demand. Aguas *et al.,* (2013) also developed a system dynamics model for assessing oncological medicine supply risk effect on supply chain operation and performance. They pointed out that the risk mitigation and management strategies focused on policy definition and negotiation rules with market provider and agent coordination, where logistics service operators and suitable information systems for management would

cause the reduction of overall supply chain costs and improve service and quality performance.

Elleuch and Chabchoub (2011) evaluated the FMECA technique to identify and assess the risks in the PSC and proposed a simulation method to analyse the proposed scenarios according to the risk exposure levels. The methodology was illustrated by a real case study in a drugstore.

Limitations exist in the above articles. Kamath *et al.,* (2012) and Enyinda *et al.,* (2014) surveyed samples that are geographically limited to only one country (*i.e.,* India or Nigeria) with a small sample size. Moreover, AHP has a subjective modelling process nature, which is a constraint. That means that the methodology cannot guarantee the decisions as definitely true. The historical data was used to determine the severity index, and the probability of the identified risk factors would not be reliable (Elleuch *et al.,* 2014). The major limitation of the study is that it was conducted at a time when stock outs of drugs were at crisis levels in Malawi's public hospitals (Kanyoma *et al.,* 2013). The data were collected based on subjective opinions, which will cause bias for the results (Breen, 2008). Elleuch *et al.,* (2014) surveyed one hospital for the case study, which is limited to examining the structure of the hospital PSC.

2.3.3.1.3 Healthcare supply chain risk mitigation

Many risk mitigation strategies in the healthcare supply chain have been mentioned in the previous studies. Kamath *et al.,* (2012) examined the four reactive risk mitigation strategies based on the different types of risk by applying the AHP method. In this study, transfer of risk, such as outsourcing insurance, was determined as the best management strategy with respect to regulatory risk and financial risk.

Lord Carter (2016) presented five strategies for managing the unwarranted variations in the NHS supply chain as follows: collaboration, supply chain integration, outsourcing the non-core supply chain activities to a third party, NHS e-procurement strategy, and implementing information system technology. Moreover, some other researchers also indicated that building vertical inter-organisational relationships between an organisation and its suppliers is a key element to manage supply chain risk (*e.g.,* Wiengarten *et al.,* 2014; Zsidisin and Ellram, 2003).

Table 2.14 summaries the risk mitigation strategies in healthcare supply chain operations from previous studies. However, there are limited studies focused on the establishment of horizontal inter-organisational arrangements among organisations with regards to the management of supply chain risks (Chen *et al.,* 2013). To fill this gap, Zepeda *et al.,* (2016) examined the moderating effects of horizontal inter-organisational arrangements on hospital inventory accumulation in the presence of supply chain risks arising from its environmental conditions, namely, the logistics services infrastructure where the hospital is located and the demand uncertainty for clinical requirements that the hospital experiences. The authors suggested that affiliation with a local system safeguards hospitals from supply chain risk under the conditions of a weak logistics service infrastructure. Furthermore, Riley *et al.,* (2016) suggested that interaction and exchange of information between intra-organisational entities would positively affect organisations' warning and recovery capabilities.

Employee training can reduce risks in the healthcare industry. Most studies have paid much attention to it. This is because most supply chain activities are handled by pharmacists who lack skills to provide proper training of personnel and ensure adherence to quality-control policies and procedures for compounding sterile products and repackaging bulk medication supplies in all settings in the healthcare industry (Maryland, 2012). Ellench *et al.,* (2014) examined personnel training and reward systems, which are important mechanisms to reduce human error in handling and storing drugs. Training also can identify risk factors and handle anomalies (Riley *et al.,* 2016).

2.3.3.1.4 Healthcare supply chain risk monitoring

Until now, no studies in the academic literature have focused on risk monitoring in the healthcare SCRM process.

Table 2.14: Summary of HSC risk mitigation strategies

Risk Mitigation Strategies	Authors
Collaboration with the manager of the care units, forecasting, ERP, involvement of doctors and nurses of the care units, communication and information sharing with suppliers, collaboration with FDA to develop guidelines for importing drugs in short supply, and affiliation with local healthcare systems for hospital inventory management.	Breen (2008), Maryland (2012), Lord Carter's report, (2016), Riley *et al.,* (2016), Zepeda *et al.,* (2016)
Employee training, ameliorating working ergonomics, reward system revision, investment in handling materials, motivation,	Maryland (2012), Ellench *et al.,* (2014),

relation with labour union, career management, providing proper training of personnel and ensuring adherence to quality-control policies and procedures for compounding sterile products and repackaging bulk medication supplies in all settings, and educate personnel about how to comply with FDA and USP requirements for sterile compounding and repackaging of bulk supplies.	Riley *et al.,* (2016)
Outsourcing the non-core supply chain activities to a third party.	Kamath *et al.,* (2012), Lord Carter's report, (2016)
NHS e-procurement strategy.	Lord Carter's report, (2016)
Implement information system technology (RFID), traceability and information systems, and EDI.	Lord Carter's report (2016), Kim *et al.,* (2016), Ellench *et al.,* (2014)
Inventory management and improving just-in-time and other inventory management practices.	Maryland (2012), Jurado *et al.,* (2016), Zepeda *et al.,* (2016)
Multiple sourcing strategies and development of contractual arrangements between health systems and multiple suppliers of selected essential products to avoid relying on a sole source.	Maryland (2012), Kanyoma *et al.,* (2013)
Statistical quality control, inspection, and quality control.	Ellench *et al.,* (2014)
Periodic maintenance and statistical process control.	Ellench *et al.,* (2014)
Design PSC systems to support a patient-centred model of healthcare delivery (integrate all drug distribution channels, implement electronic medical record technologies that support data exchange with multiple provider functional profiles, such as pharmacist–pharmacy provider electronic health records), standardise communication (eligibility for receipt of drugs with restricted distribution and file format for reports), develop a national standard for tracking and tracing medications that includes pricing information to deter price gouging, encourage greater manufacturer transparency and communication about the anticipated duration of shortages to allow practitioners to address the shortage, and encourage the FDA to compile and maintain a list of approved foreign sources of drugs in short supply in the United States.	Maryland (2012)

2.3.3.1.5 Integrated HCSCRM process

Most researchers applied SCRM strategies in more than one stage. Most of these studies focused on two SCRM processes, such as risk factors identification and assessment (Aguas *et al.,* 2013) or risk factors identification and mitigation (Maryland, 2012; Kanyoma, *et al.,* 2013;

Kim *et al.,* 2016; Lord Carter, 2016). Additionally, four out of 12 papers dealt with the entire process of SCRM in the healthcare setting. Kamath *et al.,* (2012) conducted a literature review to identify four major risks affecting the PSC, and then the AHP model was proposed for ranking the identified risks. In addition, those solutions, based on risks, were provided in the results of the survey questionnaires and literature study.

Similarly, Enyinda *et al.,* (2014) explored SCRM using a questionnaire survey and AHP based on the qualitative judgements or opinions of the experts. Elleuch *et al.,* (2014) developed a combined approach including FMECA, design of experiment, discrete event simulation, AHP, and the desirability function approach to deal with the SCRM process. Moreover, i-RM was suggested by Kim *et al.,* (2016) as a divide-and-combine approach comprising context identification, risk detection, and response action judgement in semantic ontologies.

2.4 LITERATURE GAPS IDENTIFIED

From the research aspect, the importance of understanding the current research status and finding the research gaps based on the existing knowledge should be mentioned (Boote and Beile, 2005). Although the studies reviewed in this chapter have provided some valuable insight on risks and risk management in the healthcare supply chain, it shows that the research in this area is still in the early stage and is rather fragmented. For example, there has been limited academic research on the effects of external risks on healthcare supply chain disruption. Therefore, identifying the effects of risks on supply chain processes and functions should be considered in this research. During the last ten years, a considerable number of studies have emphasised the importance of process redesign and performance measurement to rationalise supply chain processes to improve the performance of patient risk flows. The existing studies indicated that most of the research focus has been on some specific risk management steps (e.g., risk factors identification or risk mitigation).

However, there is a lack of research that has explicitly developed a thorough and sound risk management framework for evaluating integrated SCRM (e.g., risk factors identification, risk assessment, and risk mitigation) performance in the public healthcare sector, especially concerning physical flows. Moreover, to employ a single method is not appropriate as a risk management technique, as a multiple model would help reduce each models' drawbacks.

Thus, it is imperative to develop a combined risk management model that contains several fuzzy-based MCDA models to deal with the complex supply chain risk-related decisions in an efficient manner. Besides, the majority of extant SCRM research regarding risk assessment only explored risks and provided typologies or taxonomies of those identified risks without concerning interrelationships between each risk. Mason-Jones and Towill (1999) have emphasized the significance of discovering risk interactions because it would support decision makers by understanding and tackling the root causes inherent in each of the risk area, and, equally importantly, how they interact with each other.

Risk factors identification is the first step of SCRM to recognise the cause of risks across the healthcare supply chain. Although some studies can be found that deal with healthcare supply chain risk factors, the attention that is given to systematic identification is limited. A further analysis of risk factors identification is required to capture a more exhaustive variety of risk factors under a broader context. More importantly, no studies have examined the efficiency of the current implemented supply chain risk mitigation strategies in public healthcare organisations, although many risk mitigation strategies could be used to manage the effect of risk factors.

However, due to the limited budget and resources of each public healthcare organisation, they must first pay more attention to the most imminent and significant risk factors. It is therefore necessary to evaluate the relative importance of different implemented risk mitigation strategies under given performance criteria.

2.5 CONCLUSION

The literature on HCSCM, SCRM and HCSCRM have been thoroughly reviewed in this chapter. Definitions of most of the terms used in healthcare supply chains, the developments of conventional SCRM, the status of risk management in the healthcare supply chain, and risk management methodologies implemented have been presented. Based on the analysis conducted in this paper, the healthcare supply chain can be expounded to include the supply of medical and surgical supplies, technology, partnerships, and consolidation within the supply chain community. Afterwards, the term risk management, which has previously been used to mean identification, prioritisation, and assessment of risks, can be used to include

coordination and economical application of resources with the aims of minimising, monitoring, and controlling the probability of unfortunate events. Thirdly, SCRM in the healthcare sector is subjected to a wide range of challenges, hence, procurement department leaders among other personnel who are in charge of whole supply chain activities in the hospital setting should be aware of the vulnerability of HCSC and adopt appropriate risk management methodologies. In general, it is fair to conclude that the analysis carried out in this paper has made a crucial contribution to the field of SCRM in a hospital setting. Finally, literature gaps on healthcare supply chain risk management were identified and summarised as follows:

- There is no research that has explicitly developed a thorough and sound risk management framework for evaluating integrated SCRM (e.g., risk factors identification, risk assessment, and risk mitigation) performance in the public healthcare sector, especially concerning physical flows.
- There is a deficiency in the research relating to external risks stemming from healthcare supply chains.
- Although a number of studies have been found dealing with HCSCRM problems, the systematic way of risk factors identification and classification have not been provided by the existing literature.
- There is a lack of consideration on the interdependencies between different risk factors.
- No studies have examined the efficiency of the currently implemented supply chain risk mitigation strategies in public healthcare organisations.

In order to address the research gaps aforementioned and to bridge the existing literature with healthcare supply chain risk management, this thesis proposes research questions outlined below. More specifically, RQ1 is associated with the first research gaps (risk management conceptual framework) while RQ2 relate to the second and third research gaps (risk factors identification and classification), thereafter, RQ3 and RQ4 dealing with the fourth research gaps (risk assessment) and lastly, RQ 5 and RQ6 are associated with the fifth research gap which highlight risk management strategies identification and evaluation.

- RQ1. What is the most effective HCSCRM framework that can be implemented to deal with the HCSC risks?
- RQ2. What are the main sources of risk factors causing public sector healthcare supply chains to be vulnerable and how to identify and classify those risks?
- RQ3. Which risk factors are relatively more significant to a hospital's supply chain management performance?
- RQ4. How are these risk factors interacting with each other?
- RQ5. How can the hospitals from both UK and China effectively manage their supply chain related risks?
- RQ6. What are the main risk mitigation strategies to be considered?

CHAPTER THREE - RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter aims to explain research methods that can adequately address the research questions in the previous chapter based on the research gaps found in the literature review. As the interests of this research encompass all three phases of the risk management process, namely risk factors identification, risk assessment and risk mitigation, one research method is not able to sufficiently cover the entire topic of risk management. Rather, selection of appropriate research methods for each phase will be more desirable, which eventually leads to serves Chapters five, six and seven which are at the core of this thesis. Meanwhile, this chapter also helps for the selection of the appropriate methodology to validate and further develop the proposed model of this research.

This chapter starts by presenting an overall structure of the research methodology to illustrate the philosophical stance of this research. The next section focuses more on the data collection methods and analysis techniques that will be applied in Chapter five, six and seven respectively. It needs to be mentioned that this research conducts the empirical studies from both the UK and China healthcare industries as well as other healthcare SCM research centers such as LogHealth Center in Thailand. Questionnaire survey and Semi-structured interviews are employed for the empirical study design. In addition, direct observation and official documentation were implemented as data input. Figure 3.1 demonstrates an overview of a methodological framework for the purpose of this thesis upon which the research methodology will be developed.

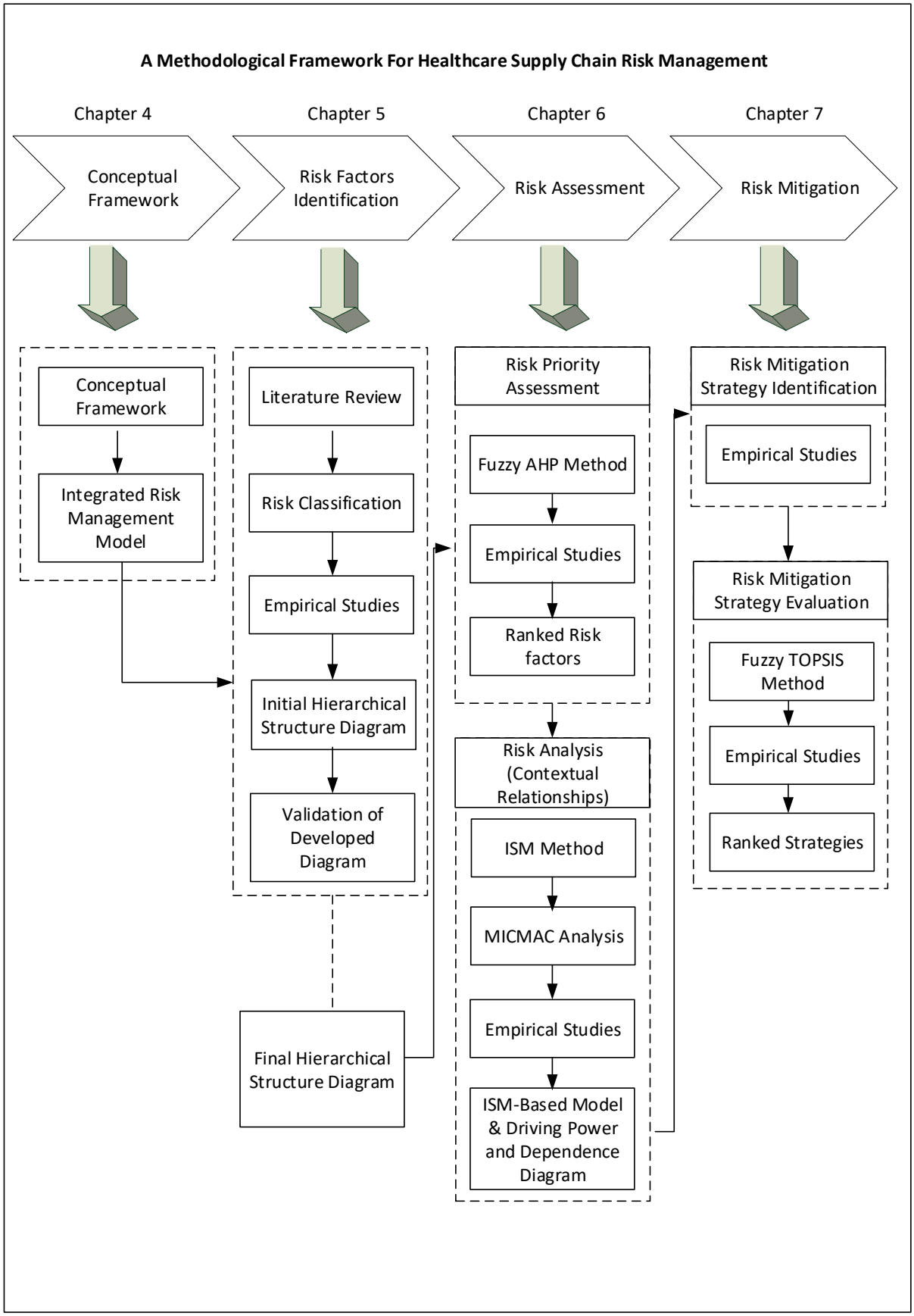


Figure 3-1: Proposed methodology of Healthcare Supply Chain Risk Management

3.2 RESEARCH DESIGN

Research onion can be regarded to as an overview framework, which has been developed by Saunders *et al.*, (2009) as indicated in Figure 3.2, to facilitate the research process of the researchers. The research onion is a multiple layer model, and in this model, each inside layer is more detailed as compared to the outside layer of the model. The research onion essentially starts with the layer which deals with the research philosophies. After this, it considers research approaches, research strategies, choices, time horizons and lastly the research techniques and procedures.

As far as the outermost layer of the research onion is concerned, it deals with the research philosophies, which includes four types of research philosophies, namely positivism, realism, pragmatism and interpretivism. The second layer of the research onion deals with the research approaches, which includes two types of research approaches, namely deductive and inductive. The third layer of the research onion deals with the research strategies. Depending on the nature of the research work, there are various strategies that can be adopted by a researcher, such as an experiment, survey method, ethnography, grounded theory and many more. The fourth layer of the research onion deals with the research choices. Here, the researchers need to decide whether they wish to apply a mono-method, multi-method or a mixed method to the research. The fifth layer of the research onion deals with the time horizons, which classifies the research work into either cross-sectional research or a longitudinal research. The last layer, the innermost layer, deals with techniques and the procedures, which include the data collection and data analysis methods which can be adopted by the researcher to carry out the research work.

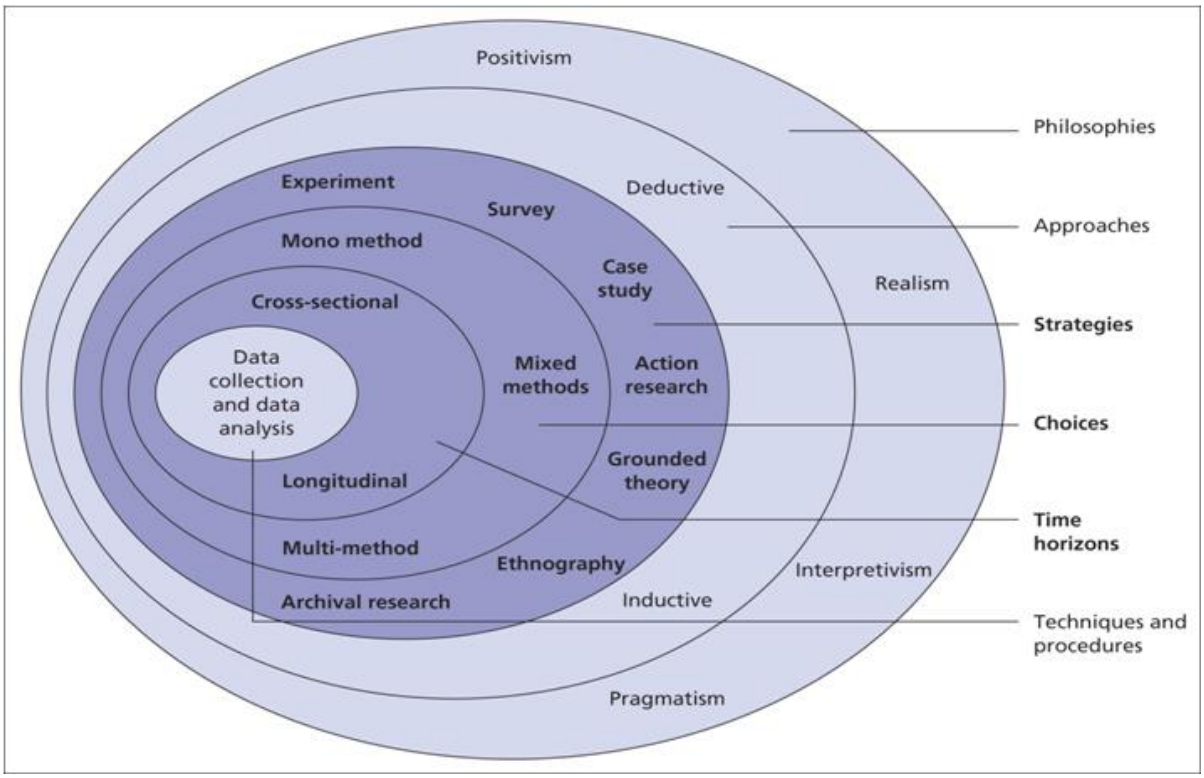


Figure 3-2: Research onion

[Source from Saunders *et al.,* 2009]

3.3 RESEARCH PHILOSOPHY

The first task for any researcher is to examine the research philosophy, which essentially deals with the knowledge development and assessment of the nature of that knowledge as highlighted by Taylor *et al., (*2015). The choice made by any researcher regarding the research philosophy is largely dependent upon the way of the researcher of viewing the world. It is because each researcher views the similar situation in a different manner as expressed by Wilson (2010). For instance, one researcher might be factual and wish to assess the resources required in a manufacturing process. On the other hand, the other researchers might be concerned with the feelings and attitudes of the employees in an organization in the same research set up. Primarily, there are two types of research philosophies, namely the positivist research philosophy, which is also known as scientific as well as the interpretivist research philosophy, which is also regarded as the antipositivism as highlighted by Panneerselvam (2014).

As far as the positivist research philosophy is concerned, the reality is essentially assumed to be stable and the positivist believes that the reality can be observed as well as described from an objective viewpoint and the researcher to have minimal contact with the research participants thus the researcher should be independent and detached. The researcher, in this case, prefers 'working with observable social reality and that the end product of such research can be law-like generalisations similar to those produced by the physical and natural scientists' (Easterby-Smith *et al.,* 2002). The analysis of observations and results are usually quantitative as it follows rigid guidelines when conducting empirical reseach (Creswell, 2003).

In an interpretivist research philosophy, the researcher is essentially critical of the positivist philosophy and is of the view that the social world is a complex system and it is not possible to theorise this social world by certain definite scientific laws (Gray, 2013). According to this philosophy, there is a difference between researching human beings and some objects. Human beings are considered as social actors in this philosophy as indicated by Babbie (2015). The author further elaborated that the interpretivist philosophy is based on two intellectual traditions, namely phenomenology and symbolic interactionism. Here, phenomenology refers to the way of assigning meaning to the external world by humans and social interactionism refers to the process in which humans continuously interpret the surrounding social world. In other words, humans interpret the actions of other human beings during their interaction. Table 3.1 illustrates the difference between these two research philosophies.

Table 3.1: Methodologies used in the Positivist and Interpretivism Philosophies

	Positivism	Interpretivism
Ontology	It considers reality to be real as well as apprehensible.	It assumes that reality can be multiple as well as constructed.
Epistemology	It assumes the findings to be true, *i.e.,* objectivist	It assumes the findings to be created, *i.e.,* subjectivist
Research Methodologies	Experiments and surveys	Hermeneutical or dialectical

3.4 RESEARCH APPROACH

To carry out a research work, the researcher has to make a choice between the two approaches, namely the deductive approach and the inductive approach as mentioned by Brannen (2017).

In a deductive approach, a research work is thought of as a scientific study by the researcher as expressed by Brannen (2017). The author further expressed that this approach deals with the development of a theory, which is rigorously tested by the researcher. Robson (2002) indicates that in order to conduct a deductive research, it is suggested to progress through five sequential stages. In the first stage, the researcher starts with developing hypothesises, which can be referred to as a theory testing process covering the relationship between two or more variables or concepts. In the second stage, the task of the researcher is to express the deduced hypothesis in the operational terms. In the third stage, the operational hypothesis should be tested by the researcher to check whether the theory applies to particular situations. In the fourth stage, specific outcome of the inquiry will be examined by researcher, i.e., the researcher should check whether the outcome confirms the theory or there are any needs for the modification. In the last stage, the theory on the basis of the findings will be modified by researcher. This approach is mainly related to quantitative research techniques.

In contrast, in an inductive approach, the researcher is required to develop a theory on the basis of the analysis performed on the collected empirical data as highlighted by Jebb *et al.,* (2017). It usually begins by observing and investigating a real life phenomenon based on which generalisations are established and theories are constructed. In addition, this approache is usually linked to qualitiative research techniques. The nature of this research implies the need for intensive literature investigations regarding the concepts, theories and possible practices in supply chain risk management, furthermore, collecting appropriate data through the empirical studies to support the developed framework and models. This research will employ a deductive approach where observations and facts will be clustered together and analysed to test the theory. Table 3.2 indicates the difference between the two research approaches.

Table 3.2: Major differences between deductive and inductive research approaches

Deductive Approach	Inductive Approach
It focuses on the scientific principles.	It emphasises on gaining an insight regarding the meanings attached by the human beings to particular events
It deals with the collection of quantitative data.	It deals with the collection of qualitative data.

It moves from theory to data.	It moves from data to theory.
It is highly structured research approach.	It is comparatively more flexible research approach.
Here, it is necessary to come with generalized conclusion.	Here, there is no need to come up with generalized conclusion.

3.5 RESEARCH STRATEGIES AND CHOICES

3.5.1 Exploratory and explanatory study

An exploratory study is generally conducted when there is a little knowledge about the subject matter in the existing literature (Robson and McCartan, 2016). Or if the research subject is something which is highly uncertain, then an exploratory method is required. In addition, this particular type of research strategy can be characterised as the one which possesses a high degree of flexibility. However, Kotzab (2000) indicated that this type of strategy essentially lacks a formal structure. The main aim behind conducting an exploratory research, as expressed by Ghauri *et al.,* (1995) is to identify the boundaries of the environment in which the events, situations, opportunities or any problem which is of utmost interest to the researcher are likely to reside. An exploratory research is also aiming to identify the significant factors or variables which might be found in that environment and are of utmost relevance to the research as mentioned by Naeslund (2002).

On the other hand, an explanatory research, which is sometimes called as analytical study, is conducted by the researcher with the major aim of identifying any causal links, which might be present between the variables or factors that are of relevance to the research problem. Unlike exploratory research, an explanatory research is very structured in nature (Robson and McCartan, 2016). In this thesis, the above two types of research strategies are applied to carry out this research. In this thesis, Chapter five provides a preliminary exploratory analysis to fill the gap in risk factors identification. In order to investigate the risk generation mechanism, the explanatory strategy is implemented to explain what is going on and conceptualise the risk propagation mechanism (Saunders *et al.,* 2007).

3.5.2 Mixed methods approach

Mixed methods approach can be described “as a method which focuses on collecting, analysing, and mixing both quantitative and qualitative data in a single study or series of

studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone" (Creswell and Clark, 2011).

There are multifarious characteristics associated with mixed methods research as expressed by Creswell and Clark (2011). Firstly, in this type of research, the researcher collects and analyses both quantitative and qualitative data. Secondly, it gives an opportunity to the researcher to mix the two types of data in different ways. Thirdly, it essentially gives priority to either one of the types of data, or both the types of data. Lastly, it can be used by the researcher in a single study or multiple phases of a study. This phenomenon is also known as triangulation technique, as no research methodology is being considered universally superior to the other as each has its drawbacks and advantages. "By combining multiple observers, theories, methods, and empirical materials, researchers can hope to overcome the weakness or intrinsic biases and the problems that come from single-method, single-observer and single-theory studies.

Often the purpose of triangulation in specific contexts is to obtain confirmation of findings through the convergence of different perspectives. The point at which the perspectives converge is seen to represent reality." (Liouka, 2007). The researchers expressed their concern by stating that in the contemporary era, scholars and researchers are often interested in utilizing both the qualitative and quantitative methods in order to analyse the same phenomenon. Due to this, there is an observable growth in the practice of utilizing some sort of 'triangulation'. Further, Mangan *et al.,* (2004) described Triangulation' as a process which involves the verification, which certainly increases the validity of any research work via the incorporation of multiple viewpoints as well as research methods. Based on the research paper produced by Yeasmin and Rahman (2012), indicated that the triangulation method could be used by the researchers for two main reasons, *i.e.* for confirmatory and for completeness purposes. With confirmation, Young (2007) refers to the validation of results of the qualitative study by quantitative studies, and with completeness, Yeasmin and Rahman (2012) refer to the increase in the in-depth knowledge as well as understanding of the researcher regarding the phenomenon under investigation because the researcher has essentially utilized the combination of multiple methods and theories to come up with the outcome. Amaratunga *et al.,* (2002) concluded their research by stating that the triangulation

technique is essentially a good technique because it allows the researcher to reap the benefits of both qualitative and quantitative methods.

The choice of data collection method should be in line with the research questions and its aim and the objectives (Saunders *et al.,* 2009). Two types of data collection methods will be used in this thesis. Primary data collective involves collecting new data, whereas secondary data collection concerns the collection of existing data. Therefore, both qualitative and quantitative methods are applied to identify, assess and mitigate SC related risks in the healthcare setting. To determine the risk factors in healthcare SC, literature review and questionnaire surveys are adapted to investigate and categorise unstructured risks. The questionnaire is proposed to verify the comprehensiveness and validation of identified risk factors as well as to examine the appropriateness of the risk classification method. Another questionnaire surveys and semi-structured interview are used for the data collection in risk assessment and mitigation stages. The data collection method applied in this thesis is mainly based on expert judgements. The obtained risk data are used as inputs of the proposed integrated risk management models to understand the priority of risks and evaluation of currently implemented risk mitigation strategies. Full details about research methods and research techniques will be discussed in the following sections.

3.6 METHODOLOGY FOR DATA COLLECTION AND ANALYSIS

This section presents a detailed explanation of the data collection and analysis methods used in the research. For the purpose of systematically identifying and understanding the relevant risk factors, it is necessary to employ an approach involving the use of both qualitative and quantitative methods to obtain and investigate the risks along with justification. The first sub-section describes the data collection method in each risk management phase. More specifically, the first phase of questionnaire survey covering the key concepts of the identified risk factors will be conducted to verify the comprehensiveness of risk factors identification and the initial assessment of addressed risks as well as the validation of the proposed classification method. The second and third phase of the questionnaire survey will be conducted to quantifying the level of identified risks along with their contextual interrelationships. The empirical studies are conducted to extract identified supply chain risk mitigation strategies for further evaluation. Moreover, the last questionnaire survey is

designed to acquire the priority ratings of identified strategies for mitigating supply chain risks. The second sub-section introduces the data analysis methods in each risk management phase. Table 3.3 describes the methodologies for data collection and data analysis, which involves the three main risk management steps, and the related approaches and purposes of these approaches.

Table 3.3: Summaries of the research methods for data collection and analysis

Steps	Approaches	Purposes
Risk factors identification	Literature review	To identify the existing risk factors in healthcare supply chain from the selected articles.
	Questionnaire survey	To investigate the reliability and validation of identified risk factors and risk classification method, and explore if there are more risk factors that are not mentioned in previous studies.
	Email and face to face interviews	To further explore the appropriateness of the developed hierarchy model.
Risk assessment	Fuzzy Analytic Hierarchy Process survey (web-based questionnaire (eSurvey Creator)	To evaluate the risk factors for determining of their priority (weight) of concern.
	Interpretive Structural Modelling survey (telephone, email and face-to-face interview)	To develop contextual relationships to analyze the inter-relationships among healthcare supply chain risk factors.
Risk mitigation strategies identification	Empirical studies (semi-structured interview, direct observation, official documentation)	According to the finding from previous chapter, to explore the current complemented risk mitigation strategies from both UK and China hospital cases. Meanwhile, to validate the identified risk mitigation strategies through documentation review and direct observation during the semi-structured interview,
Risk mitigation strategies evaluation	Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) survey (email questionnaire)	To rank the importance of the identified risk mitigation strategies under difference risk context.

3.6.1 Data collection methods

The data collection will be presented in relation to each step of the risk management process. In order to capture and understand the risk factors, it is necessary to conduct an approach involving the use of both qualitative and quantitative methods to gather and examine the risk source along with justification due to the scarcity of the existing research in this field. In general, the purpose of empirical study is to verify the existing or newly proposed collected evidence about a piece of research on the basis of empirical data. A well-structured methodology, based on experienced should enable organizations to take full advantage of the findings. In this thesis, the purpose of conducting the empirical studies are to refine the understanding of risk factors that lead to major disruption and identify the currently implemented risk mitigation strategies in the hospital sector. Empirical studies were conducted separately for Chapters five, six, and seven respectively. The first sub-section introduces the data collection methods in risk factors identification phase. Questionnaire survey A covering the key definitions of the identified healthcare SC risk factors will be conducted to verify the comprehensiveness of risk factors identification and the importance of addressed risk factors as well as the appropriateness of the risk classification model. The second sub-section discusses the data collection methods in risk assessment phase. Another two questionnaire surveys B and C will be proposed to evaluate the weighted priority and contextual relationships between each risk factor. The third sub-section describes the data collection methods in risk mitigation strategies identification, validation and analysis. Some source of evidence in empirical studies, *i.e., semi-structured interview, site observation, official documentation* are utilized in order to identify the current implemented risk mitigation strategies from both the UK and China hospitals. Then the questionnaire survey D will be conducted to analyse those identified strategies by ranking their priority.

3.6.1.1 Data collection methods in risk factors identification and validation

To conduct the systematic risk factors identification and decomposition, the research continues with the empirical studies including the key definitions of the identified risk sources. Chapter five provides a detailed description of data analysis and taxonomic diagram validation in risk factors identification phase.

Several methods can be used for identifying risk factors such as, historical data collection, interviews, relevant document review and group meetings (Water, 2007). Researchers also used a literature review to identify the risks in the supply chain sector (Barry 2004; Wagner and Bode 2006; Kayis and Karningsih 2012; Ranger *et al.,* 2015; Blos *et al.,* 2016; Rogers *et al.,* 2016). This research first reviewed the relevant literature in order to identify all the risk factors that have been directly addressed in the healthcare supply chain, especially in the hospital drugs/pharmaceutical supply chain. The advantage of literature review is that it saves time since it has already been collected, and it is also less expensive than other methods (Saunders *et al.,* 2009). After this, some experts from both academic and practitioner fields will be invited to take part in the expert panel so as to validate the identified risk factors and explore other potential risks. The experts are selected based on their professional working experience, job position as well as the qualification to the research topic.

Following the rigorous approaches, the questionnaire is developed in line with research questions and the relevant studies to collect the opinions from the experts who are most familiar with conditions to clarify the ambiguity (McCormack and Hill, 1997). Besides, behind doing this, the researcher also aims to investigate the reliability of the proposed risk classification model in the healthcare supply chain. In general, the number of parameters in the construct, the selection of a Likert scale and avoiding negative words are the critical issues, which must be given more attention (Hinkin, 1995). This research adapts a five-point Likert scale so as to investigate the level of agreement with each question from the experts.

Initially, the questionnaire is developed in English language by the researcher, however, it is later translated from English language to the Chinese language by the researcher because the targeted experts are both from China as well as the UK. It is deliberately done by the researcher to make it easy for the experts from China to understand the questionnaire in the Chinese language. In order to verify the appropriateness as well as accuracy of the questionnaire after it is translated to the Chinese language, the researcher has made use of both forward and backward translation methods in order to examine the developed questionnaire. Two forward translators, native speakers of the Chinese and fluent in English. Both translators are come from Wuhan University of Technology in China and conduct translations independently. Any disagreements are resolved via a reconciliation process, resulting in a single provisional forward translation. Using this translation, backward

translation is carried out by a translator (fluent in Chinese and English, and different from the forward-translators) from Liverpool John Moores University to subsequently translate back the Chinese questionnaire into the English language.

The draft of questionnaire A is then pilot tested on the target participant before being field-tested on a larger sample. Face-to-face and telephonic interviews are carried out to assist the questionnaire builder to obtain a clear picture of the meaningful advice. After the questionnaire feedbacks are received, a validity test was required to be conducted so as to test whether the study measured the necessary items and whether the study received the reliable responses. Based on the comments, the questionnaire is properly modified to fit in with the requirements (See Appendix One). By the end, the identified risk factors will be summarized into a hierarchy structure. Before conducting the further larger-scale risk assessment survey (to measure their weight priority and inter-relationships), the developed hierarchy structure will be send to the "validation team" by email and the face-to-face interviews are distributed and conducted with them so as to further explore the appropriateness of the developed hierarchy. Based on the obtained results, the identified risk factors are summarized into a final hierarchy structure, which provides a comprehensive risk database to healthcare SCRM research.

3.6.1.2 Data collection methods in risk assessment stage

Following the questionnaire development procedures described in *section 3.6.1.1*, the questionnaire surveys B and C are constructed to elicit expert opinion on the healthcare SC risk factors regarding their weight priority and inter-relationships. The Chinese/English translation processes are applied on both of these questionnaires, the same as applied in questionnaire survey A. The draft of both the questionnaires will be send to experts with very good knowledge and experience firstly as pilot study and then questionnaire Survey B will send to the experts from both UK and China hospitals, pharmaceutical manufacturer, pharmaceutical companies and supply chain service consultant organizations. According to Saaty (1980), an AHP-based questionnaire survey is acceptable when the consistency ratio (C.R.) is smaller than 0.1. Therefore, if the consistency ratio (C.R.) is over the standard acceptable value (0.1), the received survey will be returned to the experts to modify the answer. After the results obtained from questionnaire B, following the same procedure, the

questionnaire Survey C is developed and conducted via the email, telephonic and face-to-face interview to the experts both from academic and practitioner fields. Full explanations and discussion in respect of those two questionnaire survey procedures are explained in Chapter six. The finalised English and Chinese questionnaires B and C are attached in Appendix Two and Three.

3.6.1.3 Data collection methods in risk mitigation strategies identification and analysis

An empirical approach with surveys, followed by reviewing the official documentation, direct observation and semi-structured interview from both China and the UK hospitals, pharmaceutical companies. The current implemented risk mitigation strategies will firstly be identified, validated, and finally evaluated.

Based on the obtained results from risk assessment phase, this thesis firstly reviews the most relevant official documentations to identify the risk mitigation strategies in the healthcare industry. The following step is conducting the direct observation in the relevant departments hospitals and pharmaceutical company *(e.g. procurement department; material department, pharmacy department etc.)*. According to Yin (2009), the leading strength of conducting direct observation in the case based organization is to ensure the reality in real time and cover the event context. The semi-structured interview will be constructed to identify more risk mitigation strategies. During these formal interviews, the above results will be presented to the experts, and they are supposed to decide whether the identified strategies are relevant or not. In addition, these experts will be asked if they would be willing to accept the invitation of the interview in advance.

In the last phase, depending on the results obtained from above, another questionnaire survey D will be conducted aiming to evaluate the efficiency of the identified risk mitigation strategies with related to each risk factor. Following the same procedure of developing the questionnaire survey above, the Chinese/English translation process will applied on questionnaire D and the forward format is the pilot tested by four academic researchers before being field-tested on a larger sample. The finalised English and Chinese questionnaire D is attached in Appendix Four.

3.6.2 Data analysis methods

The data collected in the previous sections are explained and analysed prior to being used in other stages of the research. According to Yin (2009), some specific methodologies and techniques are required to analyse collected data in order to produce high quality results. In this thesis, Fuzzy AHP and ISM models have been used to analyse the survey results from questionnaire B and C respectively and further fuzzy TOPSIS has been utilized to analyse the survey results from questionnaire D. For the purpose of ensuring the reliability and consistency of the gathered data, a series of tests (*e.g.* statistical test, consistency check and sensitivity analysis) should be conducted prior to carrying out the evaluation of risk factors and mitigation strategic research. The procedure of applying each model and producing a high-quality data analysis will be presented in Chapter six and Chapter seven.

3.7 CONCLUSION

In this chapter, various research methodologies were reviewed based on the "research onion" categorization which serves as an approach constituted by different layers of the research in a strategic manner. Based on the literature study, the appropriate methodologies for this research were identified and outlined. The techniques for the data collection and analysis by conducting the empirical studies have been described in this chapter. There are three main parts for the data collection methods, which are: (1) data collection methods in risk factors identification, validation, (2) data collection methods in risk assessment phase, and (3) data collection methods in risk mitigation strategies identification, validation and evaluation. In the first part, the risk factors are identified through literature review, and then the validation and exploration of the identified risks are done through questionnaire survey with both industrial and academic experts. Next, another two questionnaire surveys and telephone interview are conducted for the assessment of risk factors. In the last part, the implemented risk mitigation strategies are identified and validated by conducting the empirical studies (*e.g.* interview, direct observation and official documentation). In order to evaluate the identified risk mitigation strategies, a mitigation-strategy questionnaire survey is conducted. This enables the researcher to select the most efficient risk mitigation strategies. The techniques for the analysis of data are based on the employment of combined Fuzzy AHP, ISM and Fuzzy TOPSIS for the risk assessment and mitigation strategy evaluation.

CHAPTER FOUR - CONCEPTUAL FRAMEWORK AND INTEGRATED RISK MANAGEMENT MODEL

4.1 INTRODUCTION

The previous literature review indicated that there is lack of knowledge about how to control supply chain related risks in the healthcare industry. The majority of existing studies on healthcare SCRM merely imitated the traditional risk management approaches from manufacturing industry directly without considering the unique characteristicd of the healthcare setting. Specifically, there is a lack of risk management framework in healthcare organizations as a guidance or foundation which would support decision makers in the achievement of efficient risk management. The objective of this chapter is to develop a novel supply chain risk management conceptual framework. Hence, the chapter is structured as follows: firstly, the development of a risk management framework in the context of healthcare setting will be presented. Based on the proposed conceptual framework, the three steps risk management process (*i.e.* risk factors identification, assessment and mitigation) as the main guideline to structure the research process are discussed. Finally, the chapter concludes by developing an integrated risk management model incorporating the reviewed MCDM and qualitative models.

4.2 CONCEPTUAL FRAMEWORK

Risk management has an integral role in the establishment of an effective supply chain that operates in the existence of different turbulences. In any supply chain, a risk management framework depicts an integrated process that takes place across a number of business settings before a turbulent event happens. The importance of a contemporary healthcare supply chain is evident in the improvement of patient care quality through practices of removing unnecessary costs and in the achievement of more robustness as well as resilience. Most healthcare providers and suppliers are committed to automating and streamlining supply chain processes with the aim of improving its efficiency. In fact, the current healthcare

supply chain is extensive and intricate and hence increases the level of potential risks for all the organizations involved.

The proposed risk management conceptual framework is based on the idea of determining different factors that creates a risk-supporting environment as shown in Figure 4.1. It has five unique components that elaborate on the sequence that is supposed to be followed in assessing and managing uncertainties in a healthcare supply chain. They are the component of risk drivers and sources, decision makers, SC strategies, SCRM process and performance outcomes. The feature of the framework is more than simply to aggregate all the elements together but far more interactive and repetitive. The framework has a sequential process that is repetitive in nature and is centered around the risk management process, which is connected in circulation process, indicating that one component is dependent on another component. The literature on SCRM show that a common risk management process is generally organized into three steps: risk identification, risk assessment and risk mitigation (Kleindorfer and Saad, 2005; Hendricks and Singhal, 2005; Bode and Wagner, 2009; Kern *et al.,* 2012). These three key steps are adapted in the framework for managing supply chain risks. Besides, many researchers also emphasiszed the importance of an ongoing risk monitoring and iterative risk management process that is constantly adapted to the requirem ents of a changing environment (Kleindorfer and Saad, 2005; Hendricks and Singhal, 2005; Bode and Wagner, 2009; Kern *et al.,* 2012). Without continuous improvement, even successful risk management processes will become weak and unable to identify and address risks with the risk measures when environmental conditions change and new risks arise. Therefore, risk management activities need to go hand-in-hand with a continuous improvement process in the long run.

For risk management to be successful, there is a need to identify the risk driving factors that have a direct impact on SC performance. Several SC disruptions reported were clearly caused by these driving factors, or at least exacerbated by them. The term driver has been introduced to differentiate those factors likely to have a significant impact on the exposure to undesirable performance and risk outcomes, or possibly providing the opportunity to improve performance, albeit with increased risk (Ritchie and Brindley, 2007).

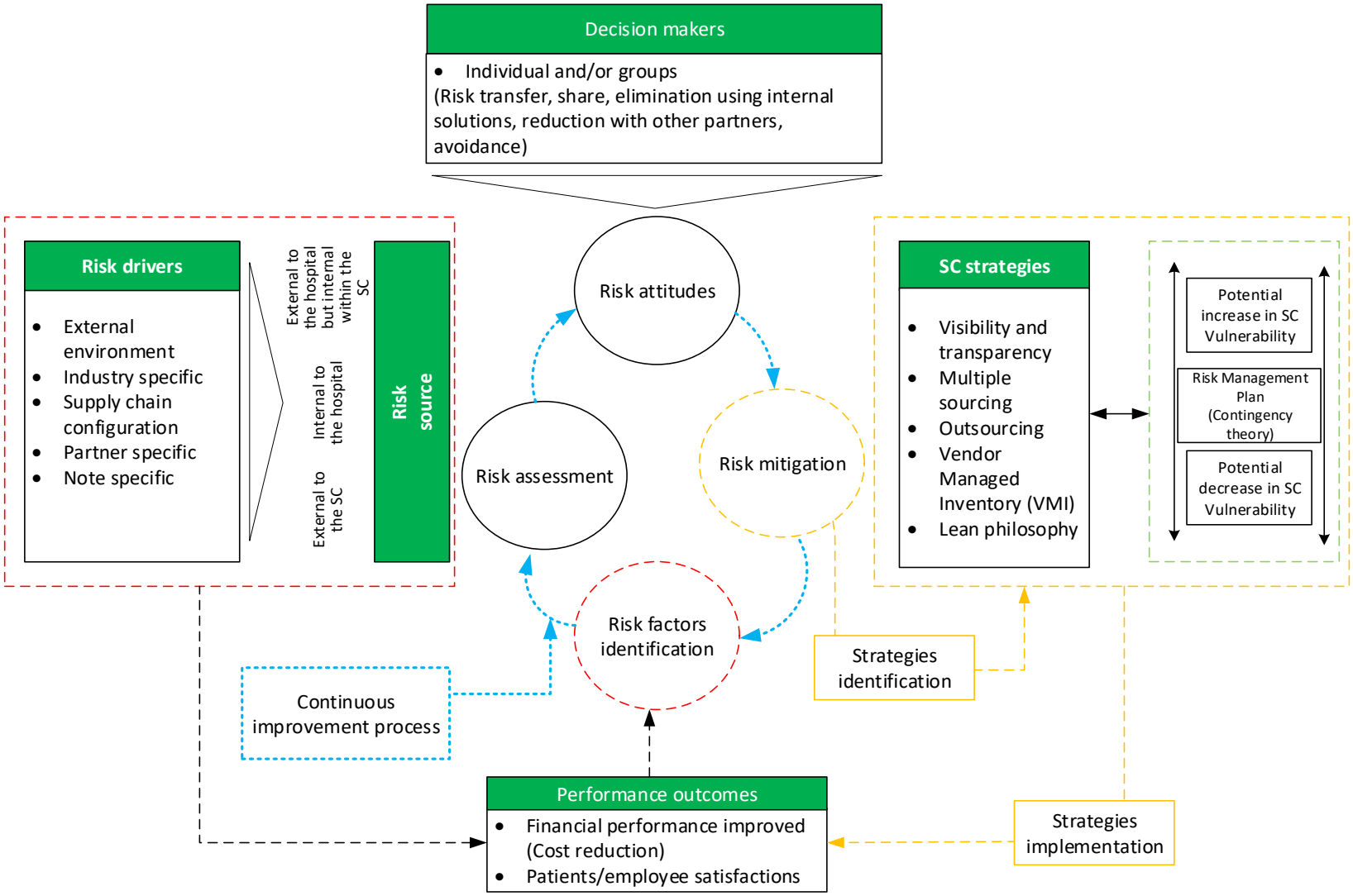


Figure 4-1: Healthcare supply chain risk management conceptual framework by author

To assess supply chain risk, triggering events are modeled as a function of their severity in terms of impact on the supply chain goals and their frequency of occurrence. Different researchers have identified and configured risk drivers from different perspectives, such as the globalisation of supply chains or the trend towards outsourcing, have exacerbated the risk exposure as well as the impact of any supply chain disruption (Christopher and Lee, 2001). Since competitive pressures are often the drivers of risk, Svensson (2002) uses the term "calculated risks" that a company takes in order to improve competitiveness, reduce costs and increase or maintain profitability. The risk drivers in the developed framework are comprised more generically under five categories, linking to the level at which they are likely to have most impact (e.g. *external environment* risks likely to impact every organization, whereas *node specific* will impact only the organization itself). The idea also based on the suggestion of Jüttner *et al.,* (2003), who discovered the potential disruptions faced by organizations in supply chains into three categories: environmental-related (*i.e. external environment and industry specific*), network-related (*i.e. supply chain configuration and partner specific*) and organizational-related (i.e. *note specific*). This is then followed with the phase of determining the available risk sources that are expected to facilitate and support risk management initiatives. Based on different types of decision-making unit, the perception and attitude towards risks might be different. The subjective perception of the significance or risks in divided into five groups: risk transfer (i.e. transfer the risk to another actor in the supply logistics (*e.g. supplier, subcontractor, service, distributor, customer. etc*) so they bear the risk), risk share (i.e. share or divide the risk with another actor in the supply chain networks), elimination using internal solutions (i.e. singlehandedly try to reduce or eliminate this risk using internal solutions), reduction with other partners (e.g. supplier, service, customer, etc), risk avoidance (i.e. do nothing at all and ignore the risk). These attitudes may drive managers' decision-making processes and lead to different solutions. Supply chain risk, as risk in general, may be regarded as a subjective concept that relies on the individual's assessment of potential outcomes, rather than an objective concepts (Heckmann *et al.,* 2015). The decision maker's degree of acceptance with respect to the deterioration of target-values defines their attitude towards supply chain risks. For example, risk taker supply chain managers would behave in a way that can potentially cause harm and financial loss, but also have opportunities to get reward. On the other hand, risk avoidance decision makers would avoid the activities that may lead to exposure to a risk, such as not select suppliers that use unsustaintable

technique and process. In addition to this, the framework also highlights the essence of implementing appropriate SC strategies that should be tied to both risk context and type of decision-making units.

Moreover, the contingency theory is used to describe the importance of situational influences on the risk management initiatives due to different SC networks being unique in certain respects and requiring the tailored strategies. Otherwise, risk management helps to reduce the adverse impact while absorbing many resources and increasing the supply chain vulnerability. This feedback loop acknowledges that attempts to manage risks can sometione have an impact on that risk itself either positively or negatively, or another risk source. For example, Enterprise Resource Planning (ERP) system can be used to improve production planning and reduce control risks. However, highly dependency on such computer-based system may initiate another risks in terms of delayed processes caused by computer/hardware problem. Regarding to the performance outcomes, due to the different perspectives, the focus in the healthcare provider is towards both cost reduction and service quality improvement as well as employee satisfaction. The detailed discussions of each component are given below.

4.2.1 Risk drivers and sources

The component of risk sources and drivers are based on the assumptions that the supply chain is conceptually and practically holistic and supply chain risk resources are triggered by various factors. This framework can be acting as a platform to group them into five sectors: external environmental, industry specific, supply chain configuration, partner specific, and node specific.

External environmental factors are associated with the changes in the natural disasters, unexpected disease, and economic, social as well as political environments, basically on a local, national and global scale and how they affect the performance of healthcare organizations. In China, since the initiation of economic reforms in 1978, the country has undergone profound transformations in its social and economic structures associated with healthcare reform. As a matter of fact, the reform has brought tremendous opportunities and also the huge challenges to the healthcare industry. These challenges are associated with growing inequality in access to healthcare services, ineffective supervision and increased financial burden on hospitals. At the same time, the regulated pharmaceutical supply chain

system in China has always lacked the competitive mechanisms and leads to bureaucratic behaviour, inefficiencies and an imbalanced supply. It is widely acknowledged that the UK National Health System (NHS) is hugely reliant on EU-trained health professional staff who come to work in the UK from 27 other EU countries. Since the UK voted to leave the EU, there are about 10,000 NHS staff who have opted to go back to the EU or other countries. The staff losses will intensify the shortfall problems of the NHS, which is struggling to retain qualified staff.

Some specific risks are also generated within the particular industry (i.e. *Industry specific)* or sector exposing those operating primarily within the sector. Based on the findings of some reports, human life expectancy increased from 67.3 years in 1950 to 77.6 years in 2011 (OECO 2013), it can be expected that the life expectancy will reach 88.5 years by 2050 (Miken Institute, 2013). As people live longer, there is more needs for frequent treatment and quality of healthcare service. Medical tourism is generally referred to as the act of patients travelling away their home country for the purpose of receiving better medical treatment and alternative care. The growth trend has been driven by a great affordability of medical care in other countries, high quality of speciality care, avoidance of long waiting times for certain medical procedures etc. According to Transparency Market Research (2013), the global medical tourism market was estimated to be £10. 6 billion in 2013 and is expected to reach a market worth £33.6 billion by 2020. Moreover, the healthcare reform in the UK includes 'Patient Choice' which aims to provide patients more choices of hospitals for their elective care (Department of Health, 2006a). As a consequence of intensified competition, the healthcare providers have to improve their quality, efficiency and responsiveness. As a result of globalization of the economy, the healthcare supply chain has increased reliance on foreign sources of pharmaceuticals and raw materials with questionable quality. There is evidence that nearly half of the injectable drug shortages were caused by manufacturing quality problems in 2015. More significantly, the increased drug shortages could lead to the emergence of a grey market in which drugs are obtained and aggressively marketed to healthcare providers, usually at inflated prices, or even worse, counterfeiting drugs.

Supply chain configuration, on the other hand, refers to the number of nodes or members within the chain and their relative influence are examples of variables that may influence the risk perceived at any node in the chain. Hospital operations should handle the multifaceted

distribution system consisting of multiple storerooms and warehouses where different pharmaceutical products are stored according to various instructions and regulations. Breen (2008) asserts that the convoluted nature of the pharmaceutical SC is suffering from issues like counterfeit medications, product shortages etc. Similarly, other research has described that in Europe drugs can pass through as many as 20-30 pairs of hands before they can eventually be delivered to patients (Haigh, 2004).

Thus, the total 25 effective pharmaceutical markets in Europe have made the SC network more fragmented, which has resulted in a decline in the transparency of the whole SC (European Federation of Pharmaceutical Industries and Associations (EFPIA), 2005). According to the EFPIA, more than 2,500 medicines have some stage of manufacturer in the UK and 46m patient packs are supplied from the UK to EU countries every month, while another 38m flow in the opposite direction. Therefore, under the no-deal Brexit scenario, it should be considered that medicine supply chain would face 'chaotic disruption' and a rise in prices for UK and some EU hospitals.

Partner specific refers to the key considerations in sustaining an efficiency of relationship between healthcare organization and pharmaceutical supplier and distributor. This can be realized through the introduction of consignment stockholding, retention of skilled labour, service quality and support, financial performance of the pharmaceutical company and training and development especially technical expertise. Moreover, neighbouring hospitals are encouraged to collaborate horizontally to achieve the goal of controlling procurement costs and sharing SCM knowledge (Rego *et al.,* 2014).

Node specific represents relevant considerations for the capabilities of healthcare organizations to respond to the demands of the end user in the supply chain, *i.e.* patients. The reasons for the above are such things as ill-equipped or poorly trained staff, inadequate management control and ineffective communications (Ritchie and Brindley 2007). For example, the Chapel Allerton Orthopaedic Centre (CHOC) in the UK faced the overstock problem due to inefficient inventory management. The centre spent over £3 million per year to improve the inventory management performance (Medwell, 2009). Similarly, in UK NHS, nursing staff have to spend on average 15 per cent of working hours to operate inventory management instead of clinical functions due to the lack of professionals.

It is indicated by Chopra and Sodhi (2004) that the main sources of supply chain risk are delays, capacity, disruptions, receivables, intellectual property, systems, inventory, forecasts, and procurement. Trkman and McCormack (2009) suggested a new theoretical framework in identifying and predicting different supply chain risks as shown in Figure 4.2.

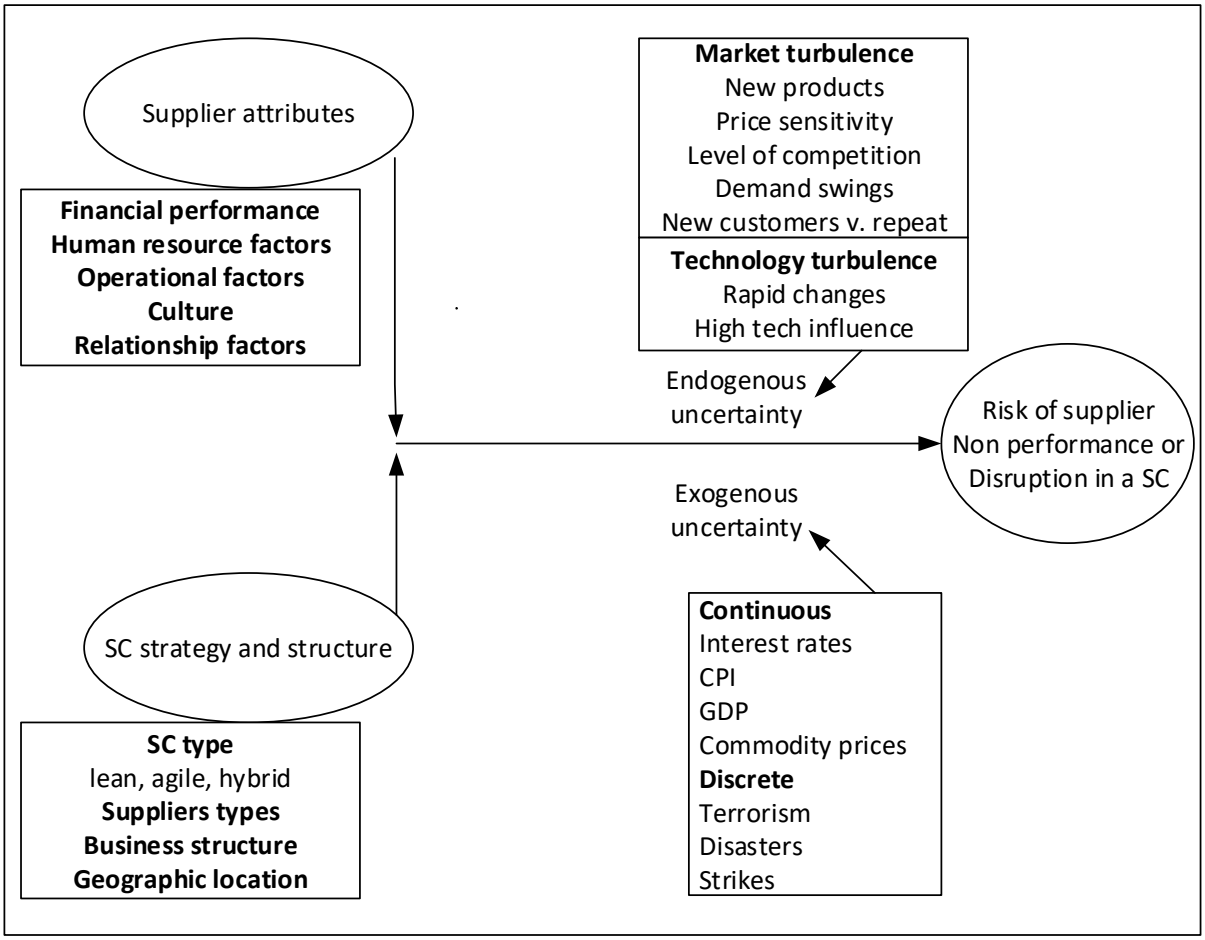


Figure 4-2: Conceptual model

[Source: Trkman and McCormack (2009)]

It is noted that the factors in the specific environment of the supplier, which are endogenous and exogenous uncertainty, transform the nature and functionality of a supply chain. Endogenous uncertainty refers to turbulent situations that are exemplified by recurrent and volatile technological and/or market changes in a given industry that heighten risk and makes it difficult for accurate forecasting. Exogenous uncertainty, on the other hand, refers to environmental disruptions experienced in either human-centred problems (fraud, terrorism, labor strike, delays in logistics) or in the appearance of natural disasters (earthquakes, floods, hurricanes). The proposition of the model is that the relationships between supply chain

attributes, supplier risk of disruption or non-performance in a chain, supplier characteristics, and chain structure and strategy are transformed by environmental, market and technology turbulence. Giannakis and Papadopoulos (2016) also offer a significant contribution in defining a strategic risk management framework that focuses only on sustainability-related risks (Figure 4.3). A supply chain is impacted by environmental risks, financial risks and social risks, which are categorized under two key drivers: endogenous and exogenous.

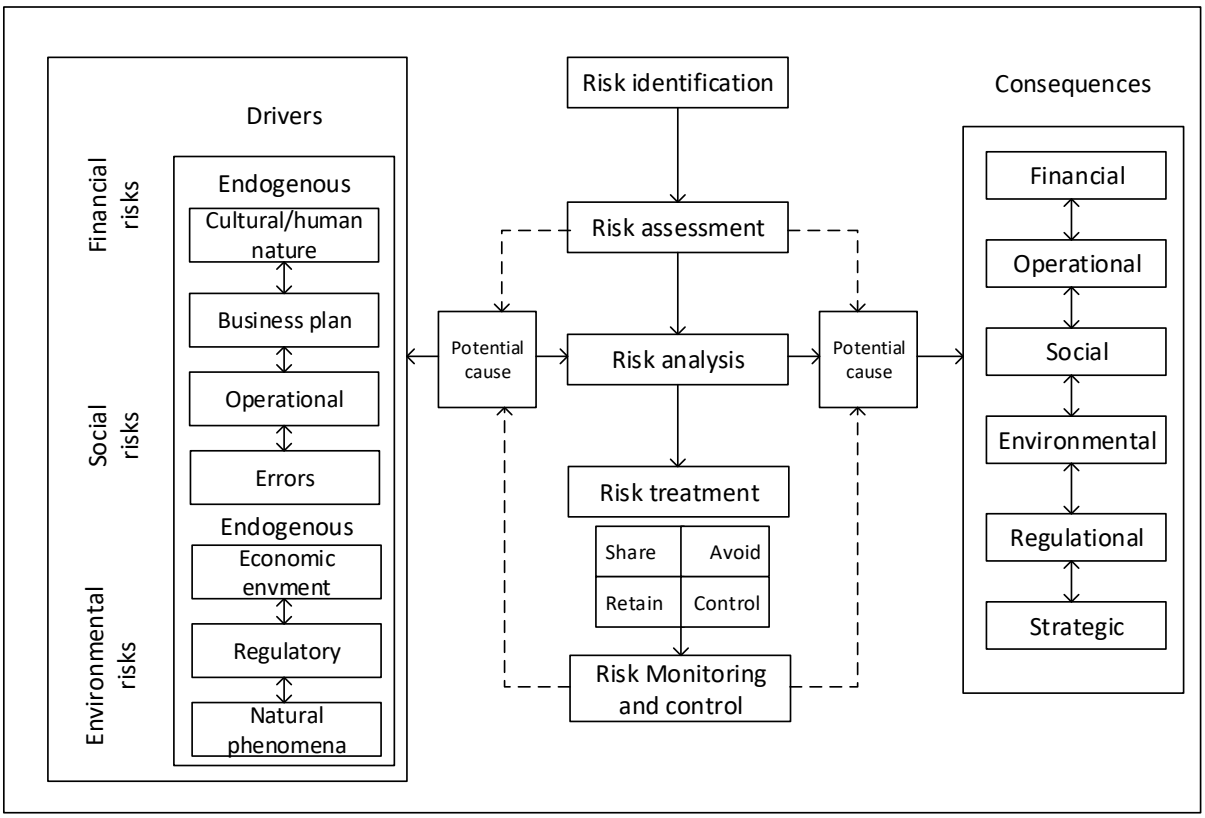


Figure 4-3: A risk management framework for sustainability-related risks

[Source: Giannakis and Papadopoulos (2016)]

Same as discussed by Trkman and McCormack (2009), endogenous and exogenous risks are characterized by disruptive situations that seek to heighten the uncertainty in forecasting and flow of supplies as demanded. It is believed that endogenous environmental risks have a relatively higher interconnectedness between different sustainability-related risks and, hence, are perceived as the most important element of consideration. As a result, there is a need to have integrated sustainability risk management models that assist in the determination and implementation of realistic sustainable initiatives. It is through such proactive projection that the adoption of a sustainability risk-related framework is found to

be useful. The significance of this sustainability risk management framework is that it can be used on various levels of the supply chain. One of the levels can be for the organization that is concerned with integrating sustainability-related risks to its decisions for strategic operations. Another level could be the dyadic connections with some suppliers as a way of improving the selection and assessment process for suppliers. Finally, the framework can be used for the general supply chain strategy, particularly where sustainability-related risks are associated with the decisions on investment and relationship with other networks such as shareholders, customers, and governments. The framework elaborates on an opportunity for creating distinction between typical supply chain risks and sustainability-related supply chain risks. This provides constructive insights concerning the causes and impacts of such risks and the appropriate measures to be taken as risk responses. In this thesis, the proposed risk management framework suggests the categorization of these sources into different areas of focus, including internal to the hospital, external to the hospital but relevant to the supply chain network, and external to the network. Any form of turbulence that is likely to happen in a defined supply chain will definitely have a source, which when determined proper measures can be put in place to ensure that the supply chain is efficient. Chapter five provides a detailed explanation about the risk factors identification and classification.

4.2.2 Decision makers

Individual and/or groups

In terms of the decision-making types, it depends on the whether the external SC partners are participating in the decision making process. In general, the healthcare providers exhibited the combination of individual and group decision-making. Informing policy and operational decisions by identifying supply chain related risks and their likelihood as well as consequences usually involved at least one hospital manager interacting with their corresponding colleagues in the Procurement Department, such as, in order to avoid the shortage of vital drugs would typically involve the Procurement Department and the Material Management Department. In this case, the likelihood and the serious consequence of the shortage in terms of performance measurement (*e.g.* patient's health, service quality, and cost of emergency delivery) are reasonably predictable. If the problem becomes increasingly prominent and escalates into considerations about replacement of the major suppliers and increased stockholding, this might expand the scope of participation based on department

functions and working experience. Hence, as the main unit of pharmaceutical administration, the Hospital Pharmacy Management Committee (HPMC) would be involved in the decision process. The evidence also suggested that in the context of RM strategies and policies in hospital, the decision-making process is rarely the outcomes of a single individual or within a single time period. The process also engaged clinical involvement and the participants including suppliers and the other stakeholders (*e.g*. Finance and Staff training). In terms of risks and performance outcomes, the more strategically the decision is made, the more extensively this engagement took place (Ritchie and Brindley, 2007).

Attitude towards risks

According to Lavastre *et al.,* (2012), attitude towards risk determines the level of success in its management. There are ways that a healthcare organization can adopt in addressing the identified risks in a supply chain. The nature of a given business and individual behaviour and style influences the attitude toward risk. The managerial perception of risks is critical for SCRM has been studied by few researchers (Zsidisinm, 2003b; Sodhi *et al.,* 2012). Some of the generic attitudes that are adopted at this phase include risk transfer, risk share, risk elimination by using internal solutions, risk reduction by other partners, and risk avoidance. The element of attitude towards supply chain risks is associated with organizations' trade-offs or what is considered as a tolerable level of risk. It is also deemed as the attitude of an organization and size of potential benefit with reference to risk taking, and it is such a perspective that determines whether an organization is a risk-taker or a risk-averse, which will have a direct impact on the risk mitigation.

4.2.3 Risk management process

The main tasks of risk management (RM) include the identification of risk sources, assessment of risks and mitigation of risks. Good practice of risk management depends on the preparedness of the whole risk management process, which provides a clear pathway for finding appropriate solutions for the potential turbulences in a supply chain. It should also be understood that the process of risk management is a circular and repetitive process. Therefore, some risk mitigation strategies can turn out to be new risk triggers. As indicated in the framework, the iterative risk management process should adopt the continuous monitoring and improvement process because of the continually changing environment.

When environment conditions change and new risks occur, even efficient risk management processes would become weak and lack capability to identify and reduce risks with the right assessment without continuous improvement. It means the application of the current RM activities needs regular review, measurement and the continuous improvement being made with new inputs at each stages. Learning from previous mistakes will facilitates risk factors identification activities to investigate the root cause of the accidents across the SC. Transparency about an organization's ongoing improvement in the effectiveness of RM can also promote the enormous motivations for staff to raise awareness of crisis and justify financial investment into staff training and other additional resources (Kleindorfer and Saad, 2005).Therefore, the continuous evaluation of an organization's RM processes helps to clarify potential areas for improvement and recognize the contribution of effective measurement and lessons learned from past accidents.

4.2.4 Supply chain risk management strategies

A key assumption established by this conceptual framework is that a number of risks will be reduced while others will be increased when various risk mitigation strategies are used. For example, in a conventional perspective, healthcare providers will increase the level of their stock as a way of mitigating the demand risks. At the same time, an increase in stock level would cause the risk of experiencing costs in terms of losses as the shelf life of some specific drugs is relatively short. The assumption draws upon contingency theory, which emphasized that there is no one-size-fits-all strategy to govern the organization, manage the leadership and decision-making due to different environments providing different antecedents (Fiedler, 1964). The theory argues that implementing the optimal decisions within the organization is contingent on both internal and external factors and the optimal solutions to adopt depend on the characteristic of industry and nature of the organization's environment. That is to say, decision makers should consider that some tailored strategies are more fit than others for given circumstances. The organization's performance is affected by the degree of matching of its organizational resources with the corresponding industry environment (Kim and Pae, 2007). Otherwise, risk management helps to control the impact of turbulence on organizational performance, this brings many benefits, on the other hand, due to some strategies (*e.g.* Lean philosophy) focus on cost reduction could remove all slack from the SC network, increasing vulnerability with unexpected implications for profit. Based on the

contingency theory, it seeks to provide decision makers with guidance to evaluate and implement appropriate mitigation strategies by considering various risk drivers, risk categories, type of decision maker, priority or risk factors as well as the performance outcomes.

4.2.5 Performance outcomes

There are different studies define the meaning of the term performances from the various perspectives. Child (1975) expresses performance on the basis of profitability and efficiency, while Hage and Dewar (1973) define performance in relation to employee satisfaction. Such differences reflect the different purpose and strategic objectives of the organization and the stakeholder composition. It is widely acknowledged that cost reduction and service quality improvement are two main performance objectives for building an efficient healthcare supply chain operation. However, in the meanwhile, most researchers often ignore the serious consequences incurred by the employee dissatisfaction in hospital operations. It can be acknowledge that workforce quality and talent management are not only related to the organizational performance but also cover the entire SC activities (Hohenstein *et al.,* 2014). Thus, existing studies have identified workforce as the key success factor in SCM, even beyond pursuit of quality and profitability (Scott *et al.,* 2015). For example, the UK NHS junior doctors' strikes had significant negative impacts on patient care. There were over 100,000 operations and exceeding 1 million outpatient appointments which were cancelled in 2016. In fact, decision makers should understand what factors both influence the retention of SC professionals and support the effective working environments within the organization, which is crucial for the long-term sustainability and performance of the field.

4.3 DEVELOPMENT OF INTEGRATED RM MODEL IN HCSC

The above novel risk management conceptual framework offers a comprehensive overview of the steps that needs to be followed in addressing various turbulences in a healthcare supply chain. However, due to the time and workload limitations, all the components cannot be covered in this research. Besides, Kleindorfer and Saad (2005) underlined the effective SCRM on the basis of three key tasks: specification of risk sources, risk assessment and risk mitigation. Therefore, based on the guideline of the framework, this research extracts a piece

of structure to develop an integrated risk management model comprising of three main SCRM steps (*i.e.* risk factors identification, assessment and mitigation) as presented in Figure 4.4.

The concept of risks has all the time been associated with the supply chain, and this is based on the fact that it represents a clear picture of what an organization is all about. Both in the upstream of an organization and downstream supply chain, streamlining of operations is an important affair as it minimizes legal, financial, operational, confidentiality and reputational risk. The management of risk sources is a constructive decision-making process that sets a platform of understanding the engineering, social, political and economic factors as they are related to a scenario. In the case of supply chain management, risk management analyses these factors with regard to how they are related to a potential turbulence. This requires a methodology that allows the assessment of such a scenario from all perspectives with the objective of analysing organizational, SC network as well as environmental risks and accordingly, evaluation of the relevant risk management strategies.

Hence, the adoption of an integrated risk management model has also been used in various frameworks and decision models (Samvedi *et al.,* 2013; Elleuch *et al.,* 2014; Nazam *et al.,* 2015). Among these studies. Samvedi *et al.,* (2013) integrated Fuzzy AHP and Fuzzy TOPSIS for quantifying supply chain risks in relation to the probability and severity. Meanwhile, they have the benefit of combining approaches like fuzzy set theory, which by its nature is built to handle subjective assessments. However, there is no systematic approach to identify supply chain risks in this study. By using the combined approach including: (1) Failure model, effects, and criticality analysis (FMEA), (2) Design of experiment (DOE), (3) Discrete event simulation (DSE), (4) Analytic hierarchy process (AHP) and (5) Desirability function approach (DFA) to managing risks in hospital sector. The main focus on this study is centred on determining the most signification supply chain risks mitigation strategy for a supply chain but not to evaluate the contextual relations as hidden influences between the risks which are focused on in this thesis. Using the same set of MCDA methods with Samvedi *et al.,* (2013), Nazam *et al.,* (2015) proposed a decision making model to support ranking and assessing the risks associated with implementation of green supply chain management practices under the fuzzy environment. Nevertheless, this research does not primarily concentrate on estimation of the efficiency of specific risk mitigation strategies but instead on the evaluation of when the GSCM initiatives should be implemented. Moreover, there is also lack of a systematic approach for identifying

the current implemented risk management strategies. Although there is increased attention on SCRM in the literature, only a few studies have focused on the effective risk management methods which support healthcare organizations to make appropriate decisions for a more resilient supply chain.

The integrated risk management model, illustrated in Figure 4.4, focuses on the identification and assessment of supply chain risk factors as well as prioritising implemented risk mitigation strategies through the fuzzy set theory, qualitative and interpretive as well as MCDM methods. Firstly, both literature review and questionnaire survey are employed to systematically identify and classify relevant risks and conduct an initial assessment. It is followed by quantifying the priority weight of identified risks through the use of Analytic Hierarchy Process (AHP) incorporating with fuzzy set theory. Interpretive Structural Modelling (ISM) is then applied to investigate the interrelation among the risks. Lastly, empirical studies are conducted to extract identified current implemented risk mitigation strategies for further evaluation. Thereafter, Fuzzy TOPSIS is employed to capture the priority ratings of identified strategies for managing SC related risks.

4.3.1 Phase 1 - Risk factors identification

Risk factors identification is the first step in the process of risk management and it is an essential stage in the risk management process as the organizations can understand the unfavourable factors in the projects (Norrman and Jansson, 2004). Besides, risk factors identification provide the list of risks that not only impact on the one piece of process but also the whole supply chain network.

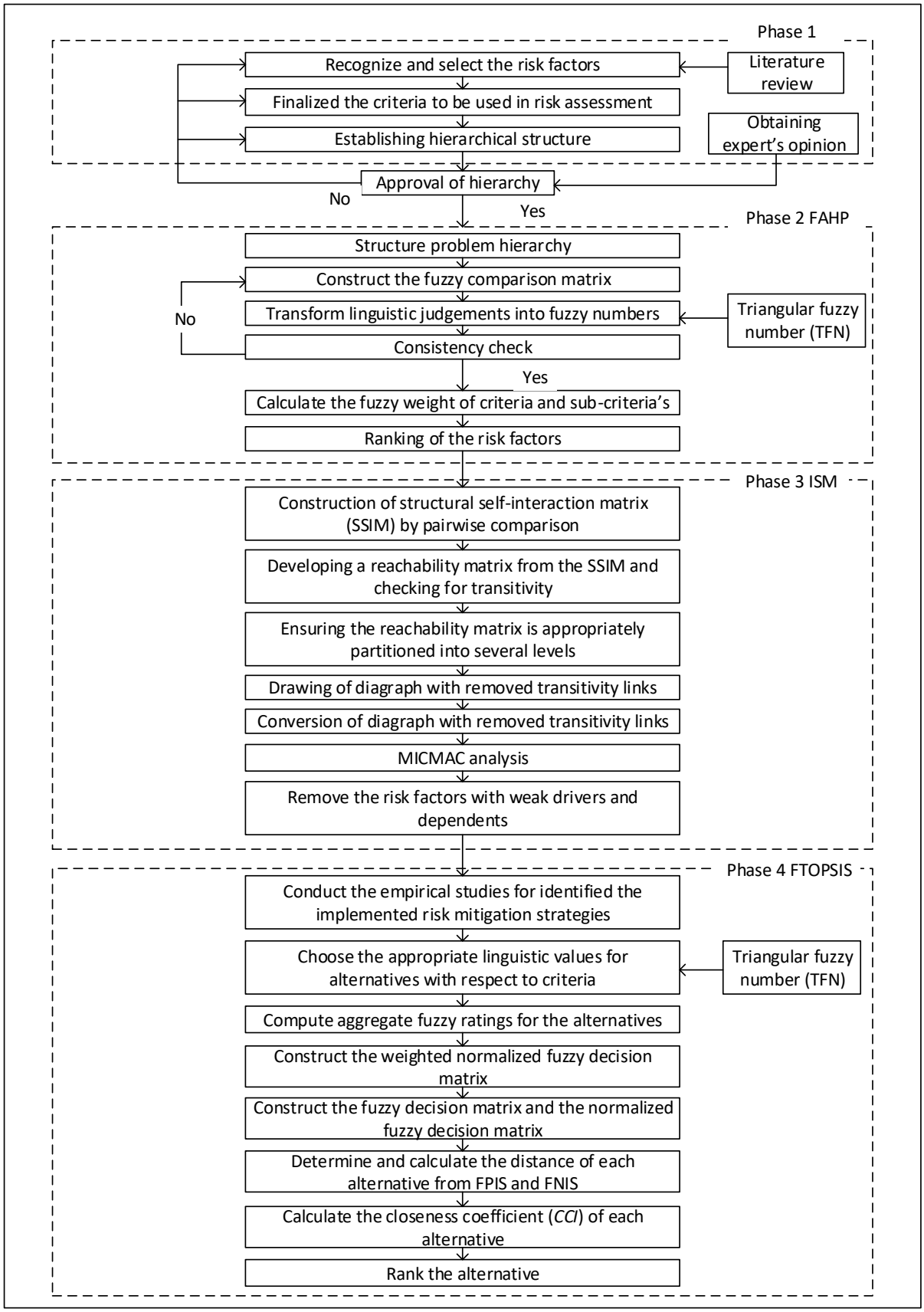


Figure 4-4: Proposed integrated risk management model in healthcare supply chain

Hazard and operability (HAZOP) analysis is a systematic and structured method of examining an intricate operation or process for the purpose of identifying issues that are potential risks. As argued by Venkatasubramanian, Zhao and Viswanathan (2000), HAZOP is based on the idea of breaking the complicated process design into straightforward sections known as 'nodes' for reviewing. As a qualitative method, HAZOP focuses on stimulating the idea of identifying operability issues and potential turbulences in a supply chain. Conducting a semi-structured interview or organizing the focus group through brainstorming session are other appropriate risk factors identification methods that consider the experience of managers in dealing with challenges in supply chains. There are qualitative methods that can be used in inquiring about the nature of risks and the root causes in the supply chain. This is realized by combining a pre-determined set of open-ended questions.

Moreover, literature review and qualitative questionnaire survey are other risk factors identification methods which serves as a base and guide to build upon throughout the risk factors identification research process. In this thesis, it starts with the literature review and then an initial healthcare supply chain risk taxonomic diagram is developed. More specifically, the focus of the risk review needs to be defined in advance and an organized HCSC risk classification schema is mapped for creating a more complete picture of each stakeholder, responsibilities and three different kind of flows (i.e. material, information and cash flow) in the network. It provides an overview by enumerating all possible threats that could produce the adverse consequences for the SC performance. However, it is clear that not all risks are easy to find out. Feedback loops and dependent events chains often pose additional challenges for risk factors identification (Hallikas *et al.,* 2004). Therefore, by conducting the qualitative survey, the obtained risks are analysed to verify the comprehensiveness and validation as well as to confirm the appropriateness of risk classification method. Besides this, an initial assessment is conducted to quantify the important level of identified risks as this thesis only focuses on those risks requiring most attention by experts.

4.3.2 Phase 2 - Risk assessment

Risk assessment is the second step in the risk management process. It provides a quantitative view of the priority of the risks and would help decision makers to understand which risks should be payed more attention as well as which risks are less critical. Risk assessment in a supply chain is an imperative fraction of the SCRM process, and this is based on the idea that

it is an extensive criterion for decision making while under unclear environments. It is always concerned with the probabilities for identifying risk-taking events in the SC system and determining the consequences of these risk events defined in the previous stage. Norrman and Jansson (2004) provide an in-depth analysis of the supply chain risk management model by Ericsson, which proposes the assessment of the impact of risk on profitability. The approach elaborates on the economic damage caused by disruption in a supply chain. It also focuses of the probability of occurrence of a risk. Deleris and Erhun (2011) offer a quantitative model of risk assessment that is a derivative of probabilistic risk analysis (PRA). It is an important method that can be used for various scenarios as it becomes realistic to simulate the impact of risk scenarios on supply chain performance. However, uncertainty issues cannot be presented simply by using the concept of probabilistic or crisp values. The fact that there are a lot of subjective judgements involved in the multiple factor analysis hinders the applicability of many risk assessment methods. Nevertheless, the application of Multiple-Criteria Decision Making (MCDM) methods combined with the fuzzy set theory (FST) in the risk assessment allows the qualitative risk assessment descriptions to be mathematically modelled (Wang *et al.,* 2017). Meanwhile, by applying another interpretive method for developing understanding of the complex relationships among system element aims to analyze the impact of each individual risk on another.

As described above, risk assessment involves multiple factor analysis. Many researchers have conducted studies to assess and measure the supply chain related risks by using multi-criteria decision-making (MCDM) methods from different perspectives. It is a powerful tool widely used for evaluating and ranking problems containing multiple criteria. Moeinzadeh and Hajfathaliha (2009) developed a SC risk assessment approach based on the analytic network process (ANP) and the VIKOR methods to evaluate the risks through ranking the relative importance of the risk categories. Analytic network process (ANP) is a MCDM method, which is capable of handling interdependence and feedback among the evaluation criteria. Feedback can better capture the complex effects of interplay in human society. Each criteria, sub-criteria and alternative are treated equally as nodes in a network. Each node might be compared to another node as long as there is a relation. For example, the ranking of alternatives might not only depend on the weighting of criteria, but also given alternatives can influence the ranking of criteria. However, the method require a specific software to

calculate results and the explanation of concept and process to management extremely challenging. Furthermore, the inconsistency may occur, leading to doubtful or wrong results. Therefore, Wang *et al.,* (2012) applied fuzzy Analytic Hierarchy Process (FAHP) to assess risk of implementing various green initiatives in the fashion industry. Samvedi et al., (2013) applied fuzzy AHP and fuzzy TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) to quantify the risks in a supply chain, and aggregated the values into a comprehensive risk index. Similarly, Nazam *et al.,* (2015) proposed a hybrid model to rank and assess the risks associated with implementation of green supply chain management (GSCM) practices under the fuzzy environment using fuzzy AHP and fuzzy TOPSIS approaches.

Founded by Thomas Saaty in 1971, the Analytic Hierarchy Process (AHP) is an MCDM method to deal with intricate decision making by creating a series of pair-wise comparisons from complex decisions and synthesize the outcome. It is also effective in capturing both objective and subjective elements of decision and, hence, providing a comprehensive analysis of a situation and helps decision makers evaluate whether the problems in each level are of the same order of magnitude. In other words, it provides the decomposition of a complex problem into a systematic hierarchical level. In the conventional AHP model, the pairwise comparison is made using a nine-point scale which converts the human preferences between available criteria and alternatives as equally, moderately, strong, very strong or extremely preferred as shown in Table 4.1.

Table 4.1: Nine-point pairwise comparison scale (Saaty, 2008)

Measure scale	Definition	Description
1	Equal importance	Two factors contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one over another.
5	Essential or strong importance	Experience and judgement strongly favour one over another.
7	Very strong or demonstrated importance	A decision element is favoured very strongly over another. Its dominance demonstrated in practice.
9	Absolutely importance	The evidence favouring one decision element over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values	When compromise is needed.

Reciprocals of above nonzero	If decision element i has one of the above nonzero numbers assigned to it when compared with decision element j, then j has the reciprocal value when compared with i	A reasonable assumption
Rational	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

By incorporating essential techniques of checking evaluation consistency, AHP assists in addressing any form of bias in a decision-making process. Compared with other decision-making approaches, there are three mainly advantageous features of the differentiated AHP: its ability to handle both tangible and intangible attributes; its ability to structure the problems in a hierarchical manner to gain insights into the decision-making process; and its ability to monitor the consistency with which a decision maker makes a judgement (Vargas, 1990; Wedley, 1990). Moreover, Golden *et al.,* (1989) determined the characteristics of AHP as including simplicity, ease of use, flexibility and the ability to deal with ill-structured problems; its principles have been successfully applied on many complex real-life decision-making scenarios. On the other hand, despite the popularity and simplicity of applying AHP, this model is often criticized because it does not adequately address the inherent uncertainties and inaccuracies associated with mapping decision-maker's perception to exact numbers (Chan *et al.,* 2008; Gopalan *et al.,* 2015). In addition, the subjective evaluation is evident with following the capacity of the decision maker, which can be misleading at times. It also over relies on the decision maker and any form on conflict in the decision affects the whole process.

As discussed above, the traditional AHP cannot be directly applied to solving uncertain decision-making problems as it is not able to reflect human cognitive processes. Thus, Bellman and Zadeh (1970) investigated the decision-making method in fuzzy environments, and the fuzzy set theory has been applied by an increasing number of researchers to handle uncertain fuzzy problems. It has proven advantages within vague, imprecise and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions (Chan and Kumar, 2007). There are more than 7,000 journal articles, reports, monographs and books on fuzzy set theory and applications that have been

published since 1965 (Kaufmann and Gupta, 1988). The procedure of fuzzy theory is shown at Figure 4.5.

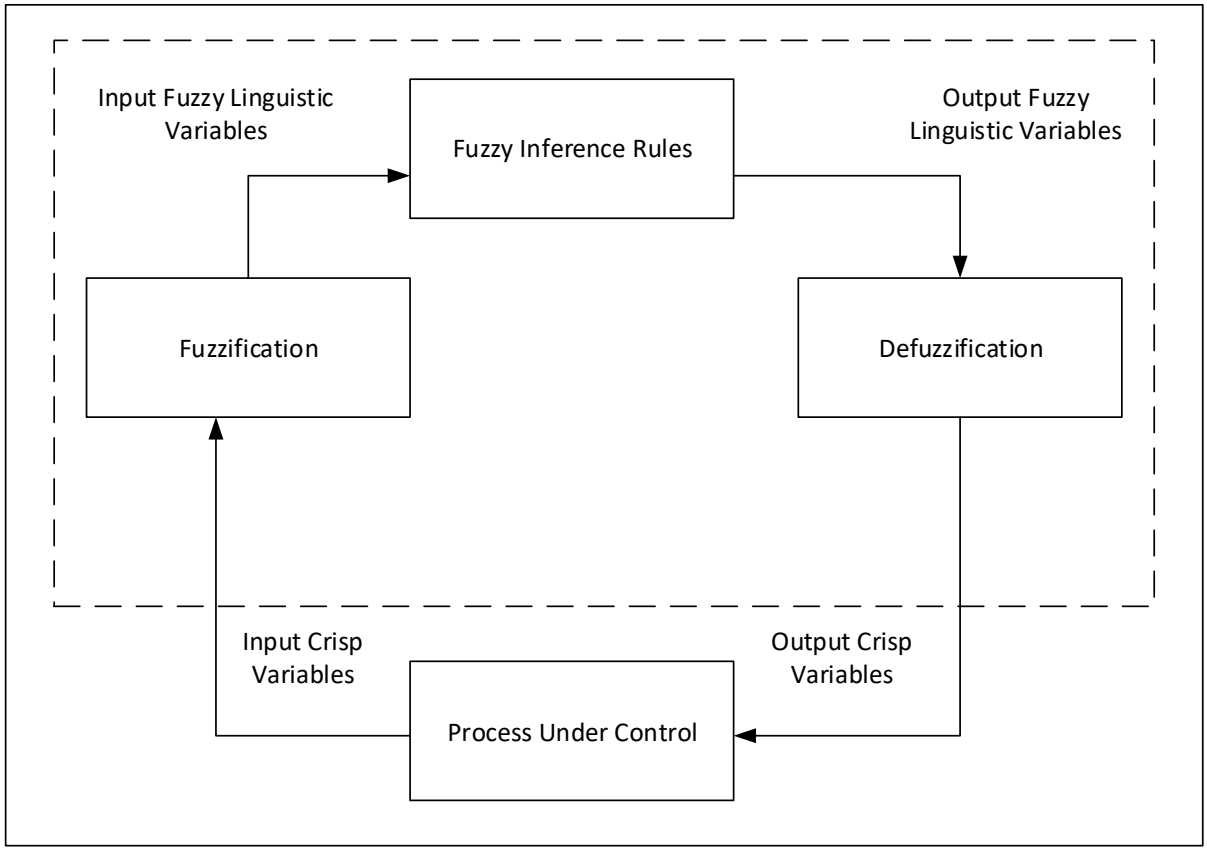


Figure 4-5: A typical Fuzzy Logic control – Fuzzy control system schema

[Source: Köse and Deperlioglu 2015]

The crisp variable is entered into the fuzzy controller and then another crisp variable is output for further evaluation. There are four main components in the fuzzy control system (Köse and Deperlioglu 2015): "(1) the rule-base learns how to best control the system in the form of a series of rules, (2) the reasoning mechanism determines which control rules are currently more relevant at the current time and then decides what the input variables to the plant should be; (3) the fuzzy interface simply modifies the inputs so that it can be interpreted and compared with the rules in the rule-base; and (4) the defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant". Zimmermann (2010) defined fuzzy set theory is an expansion of classical set theory with the capacity of allowing varying assessment of a set element's membership. This is effectively illustrated by the help of membership function, which normally has real unit interval of [0, 1]. A title "~" is placed above a symbol if the symbol represents a fuzzy set. Therefore, fuzzy logic goes beyond

the use of ‘True’ and ‘False’ when expounding on human reasoning by using ‘0’ to indicate ‘False’ and 1 to indicate ‘True’ when describing the reasoning of humans. Conversion scales are used in fuzzy set theory for the purpose of transforming the linguistic concepts into the fuzzy numbers.

The Fuzzy Analytic Hierarchy process (FAHP) method extends the classic AHP method by combining the concepts of fuzzy set theory as the conventional AHP fails to reflect human thinking style. It provides a solution to the drawback of pairwise comparison, which is unable to deal with uncertainty and imprecision related to the mapping of the decision makers’ preference to a crisp number (Deng, 1999). According to Wang and Chin (2011), fuzzy AHP is a practical method that can be used for several criteria decision-making, particularly in fuzzy environments. Van Laarhoven and Pedrycz (1983) initially applied Fuzzy AHP to compare fuzzy ratios described by triangular membership functions. Buckley (1985) conducted a Fuzzy Hierarchy Analysis in which “experts are allowed to replace exact ratio by using fuzzy ratio”. The majority of fuzzy AHP applications focus on the crisp point estimate method, therefore, the basis of this thesis is on Chang’s extent analysis method as it is a widely accepted FAHP method by many researchers (Kahraman *et al.,* 2003; Chan and Kumar, 2007; Chan *et al.,* 2008; Kumar and Singh, 2012; Ganguly and Guin, 2013; Samvedi *et al.,* 2013; Radivojević and gajović 2014; Gopalan *et al.,* 2015; Prakash and Barua, 2016 *etc*.). Chang (1992, 1996) introduced a new extent analysis approach for the synthetic extent values of the pairwise comparison for handling fuzzy AHP. The proposed method with extent analysis is simply and easy to implement to prioritise decision variables as compared with the conventional AHP (Chan and Kumar, 2007). However, the disadvantage of this method is that it lacks the capacity of handling any form of vagueness possible in numbers as only triangular fuzzy numbers are allowed in the application. The computational procedure for calculating the priority weights of the different criteria and sub-criteria using Chang’s extent analysis method can be summarized as follows:

- Construct the fuzzy comparison matrix of criteria and sub-criteria with respect to the goal.
- Determine the fuzzy synthetic extent value with respect to the each criterion with the help of the equations.

- Determine the degree of possibility of the superiority of each fuzzy synthetic extent value with respect to each other.
- Decide the minimum degree of possibility of the superiority of each criterion over another.
- Determine the weight vectors of the criteria with the help of minimum degree of possibility of superiority of each criterion.
- Normalize this weight vectors and determine the final weight of the criteria with respect to the goal.
- Repeat this process to decision weight of all the sub-criteria with respect with their specific criteria.

In this research, the proposed risk management model aims to interpret the fuzzy logic for dominance of one risk factor over the other by determining and confirming of their relative importance. By choosing one method out of all the existing ones should based on its multicriteria task and appropriateness of the data, the structure of the problem, method applicability, acceptance of the decision, etc. Moreover, the method should be easy to understand and apply and match the human thinking. Also, as compared to the ANP, AHP is a linear assessment type of method. It provides an easily understandable and defensible approach to practitioners. It allows practitioners to be involved in the analysis and actually to guide the decision more effectively. This managerial transparency and lack of complexity allow for greater acceptance by both researchers and pracitioners. Therefore, fuzzy AHP is considered to be the most appropriate method for assessing the priority weights of supply chain risks in this research.

The technique, ISM, proposed by Warfield (1974) is qualitative in its approach used in identifying key relations among explicit items that define an issue. The model is described as interpretive since a group discussion is deciding, whether and how the elements are related (Srivastava *et al.,* 2015). It involves a set of elements that are directly and indirectly related, which are structured into an all-inclusive systematic model. Thus, such a model represents the structure of an intricate problem depicted in words as well as graphics.

Figure 4.6 presents the basic logic of the ISM model. The complex problem or the dependencies between each element to be examined are interpreted as a complex system (object system). The modelling converts the object system into a well-defined and

representative system consisting of directed graphs (digraph). Then the object system mapped as digraphs becomes the “basic structural model”. The expansion with content finally leads to an “interpretive structural model” (Szyperski and Eul-Bischoff, 1983). Thus, its basic idea is to use expert’s practical experience and knowledge to decompose a complicated system into several elements and construct a multilevel structural model (Warfield, 1974). The model is developed since the complex variables are structured comprehensively by considering all possible pairwise interaction between each other.

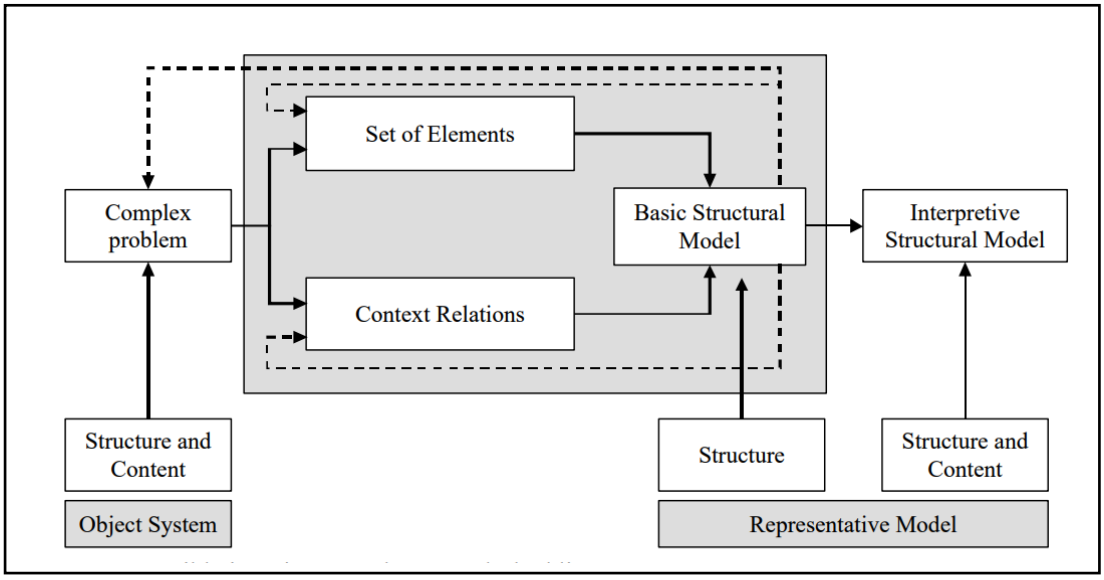


Figure 4-6: ISM-logic

Interpretive Structural Modelling (ISM) has been widely used by multiple authors for supply chain risk management (Faisal *et al.,* 2007; Alawamleh and Popplewell, 2011; Hachicha and Elmsalmi, 2013; Chaudhuri *et al.,* 2016; Prakash *et al.,* 2017), modelling of supply chain risks (Pfohl *et al.,* 2011, Srivastava *et al.,* 2015), risk mitigation (Diabat *et al.,* 2012), the measurement of supply chain resilience by using ISM for evaluating enablers for supply chain resilience and their relationships (Soni *et al.,* 2014) as well as a framework built for designing robust food supply chain (Vlajic *et al.,* 2014). Under the supply chain context, it is not sufficient for merely understanding the significance of each individual risk for the organization as there are various types of risks which may affect each other. The direct and indirect relationships among risk driver reflect the situation more accurately than the individual risk taken into isolation (Chaudhuri *et al.,* 2016). Therefore, the model provides an insightful understanding

by which the decision maker can impose and structure risks and highlight interrelationships between each risk in the SC sector (Mandal and Deshmukh, 1994).

The modelling process of ISM is systematic, efficient, easily applicable, and produces a graphical representation or structured model for the problem. It transforms unclear, poorly articulated models of systems into clear, well-defined-models (Sage, 1977). On the other hand, the disadvantage of this method is that the possibility of having many variables to an issue increases the difficulty of the ISM method. This makes it difficult to be used in situations where there are many variables to a problem (Lim et al., 2017). Another disadvantage is that the model constructed may be strongly influenced by the bias of the subjective judgement by the experts since the relationships between each variable always based on the expert's experience and familiarity with the organization and industry. In addition, in the ISM model, no weights are associated with the variables to take into account their relative importance.

As illustrated in Figure 4.4, ISM is being employed with the following steps:

- Construction of structural self-interaction matrix (SSIM) by pairwise comparison.
- Developing a reachability matrix from the SSIM and checking for transitivity.
- Ensuring that the reachability matrix is appropriately partitioned into several levels
- Drawing of diagraph with removed transitivity links.
- Conversion of digraph into an ISM and checking of conceptual inconsistency.
- Matriced'Impacts Croisés Multiplication Appliquéea'un Classement (MICMAC) analysis

Decision-Mking Trial and Evaluation Laboratory (DEMATEL) can be another approach used to develop relationships between the various elements but requires selection of a threshold value to generate impact diagraph map. DEMATEL and ISM are similar as both use diagraphs. DEMATEL can divide the factors into cause group and effect group. Fazli *et al.,* (2015) applied the approach to determine the interdependency between risks in crude oil supply chain, while Rajesh and Ravi (2015) uses it to find out cause/effect relationships among the enablers of supply chain risk mitigation. In this thesis, the author are not particularly focused on dividing the risk factors into cause and effect groups, but pay more attention on how interaction between each risk factor, ISM is considered to be the most appropriate methodoloy for this thesis.

Lastly, it needs to be mentioned that using quantitative or qualitative risk assessment methods solely is inadequate for prioritising risks (Wang et al., 2017), as the main drawback of employing Fuzzy AHP is that it cannot examine the contextual relations between each variable. By contrast, in the ISM model, no weights are associated with the variables to take into account their relative importance. The model should combine both numerical and graphical results. Thus, in this thesis, both Fuzzy AHP and ISM models are incorporated to complement each other, in order to effectively evaluate and analyze supply chain risks.

4.3.3 Phase 3 - Risk mitigation

There is a need for decision makers to adopt some risk mitigation strategies in order to reduce any adverse impacts. The risk mitigation procedure represents the method of dealing with unexpected hazardous events. The literature in SCRM has provided extensive researches in assisting decision making for analysing and mitigating various types of supply chain risks like Multiple Criteria/attribute Decision Making, Bayesian Theory, System Dynamics (SD), Data Envelopment Analysis and Structural Equation Modelling (SEM), etc. However, there are some drawbacks in each of these method. For example, by employing Bayesian theory, a large amount of data is required in order to generate stable results; Data Envelopment Analysis focuses on measuring organizational performance in respect of the inputs; in order to apply Artificial Neural Networks, Genetic Algorithms, and Simulation-based Methods, high computer language design skills and extensive quantitative data are usually required.

Among the mentioned MCDM methods, TOPSIS is a practical and advantageous technique for ranking and choosing the best alternatives. TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) is based on the suggestion that the selected option should be closer to the positive ideal exposition and far from the negative ideal exposition when addressing complex issues. The most preferred alternatives should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution (Hwang and Yoon 1981). As indicated by Abidin *et al.,* (2016), the method sensibly represent the cogent option with consideration of both the best and the worst-case scenario of the alternatives in a simultaneous way, which is highlighted by a scalar value. The capability for TOPSIS to be effective in dealing with various weight estimation systems makes it to be a scalable method for risk mitigation strategies evaluation. However, the limitation of TOPSIS is in its inability to handle the vagueness and imprecision inherent in the cognitive process of

mapping the perceptions of decision makers which also leads to its combination with fuzzy set theory (Krohling and Campanharo, 2011). Thus, it is affirmed by Sodhi and TV (2012) that Fuzzy TOPSIS is effective in systematic and objective evaluation of multiple criteria's alternatives. The technique can be used in evaluating different alternatives at the same time and against the identified criteria. Just as the TOPSIS method is conducted, an optimal value is arrived at in Fuzzy TOPSIS by identifying and selecting an alternative that is closer to the Fuzzy Positive Ideal Solution (FPIS) and far from the Fuzzy Negative Ideal Solution (FNIS). The FPIS and FNIS are best and worst performance values respectively. Fuzzy TOPSIS has successfully been applied to solve different types of MCDA issues, such as supply chain risk management strategies evaluation and mitigation (Nazam *et al.,* 2015; Chatterjee and Kar 2016; Wang *et al.,* 2017), supply chain risk modelling (Samvedi *et al.,* 2013; Wang and Hao 2016), supplier selection and evaluation (Chen *et al.,* 2006; Sevkli *et al.,* 2008; Zouggari and Benyoucef, 2012), evaluation of the banks' performance (Seçme *et al.,* 2009), location selection for the ITU Faculty of Management (Suder and Kahraman, 2015), logistics provider selection and evaluation (Kannan *et al.,* 2009, Selçuk 2009) and rank the solutions of knowledge management adoption in SC (Patil and kant, 2014).

As presented in Figure 4.4, the following steps of Fuzzy TOPSIS are given:

- Conduct the empirical studies for identified the implemented risk management strategies.
- Choose the appropriate linguistic ratings values for alternatives with respect to criteria.
- Aggregate the weight of criteria to get the aggregated fuzzy weight of criterion.
- Construct the fuzzy decision matrix and the normalized fuzzy decision matrix.
- Construct the weighted normalized fuzzy decision matrix.
- Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) and calculate the distance of each alternative from FPIS and FNSI, respectively.
- Calculate the closeness coefficient of each alternative.
- According to the closeness coefficient, the ranking order of all alternatives can be determined.

4.4 CONCLUSION

This chapter develops a conceptual framework in the healthcare supply chain sector as a research platform. It takes considerations of risk drivers, risk sources, decision makers, risk management process, SC strategies as well as performance outcomes. The proposed framework can be built as a guidance to address the industrial needs for practical decision support methodology. Based on the framework, an integrated healthcare supply chain risk management model is proposed to support effective risk factors identification, assessment as well as sensible decision-making on the adoption of supply chain risk mitigation strategies.

With the increasing emphasis on risk management across different industries, many approaches including both quantitative and quanlitative methods have been suggested in the literature. However, neglecting the call to integrate modern risk management models has a negative impact on the whole procedure as most of the risks behind the failures experienced in the supply chain of healthcare organizations are complex in nature. There are a lot of complex systems and procedures involved in facilitating the supply chain and the application of the suggested risk management framework offers a dynamic approach to dealing with the causes of such turbulences. It enables us to take explicit account of multiple types of risk in the analysis systematically and to compare and prioritise current alternative mitigation strategies based on the experts' professional experience and knowledge both from academic and industrial fields. The proposed model has the capacity of reflecting the internal hierarchical nature of a healthcare organization's extensive systems, and this allows a deeper analysis of complicated systems as they are linked to a supply chain. Integrating these risk management methods allows the facilitation of trade-off analysis, particularly among different subsystems and the general system. Finally, the method adds realism to the overall risk management process by identifying any form of disruptions in a supply chain and determining useful measures that can be numerable for the efficiency of a healthcare organization. The application of the proposed integrated risk management model is followed in the next chapters to identify risk factors, assessment and reduce the associated risks in the healthcare supply chain.

CHAPTER FIVE - HEALTHCARE SUPPLY CHAIN RISK FACTORS IDENTIFICATION

5.1 INTRODUCTION

Identification of the relevant supply chain related risk factors is the vital step for employing efficient risk management in the healthcare industry. Furthermore, there is a substantial number of supply chain risk classification methods that can be found in the current literature. Most researchers identify sources of risks related to the unpredictable environment, organizational operations, and supply chain related networks with the potential to directly affect the outcome of supply chain activities. This chapter describes risk factors identification undertaken to capture and verify risk issues through a questionnaire survey. It also presents a modified comprehensive taxonomy and classification approach to decompose the unstructured risks to strengthen the knowledge base in healthcare SCRM. In further risk assessment research, the classified risks can be evaluated through analysing various risk assessment methods to find out the unacceptable ones. Figure 5.1 illustrates the proposed methodology for risk factors identification.

5.2 HEALTHCARE SUPPLY CHAIN RISK FACTORS IDENTIFICATION AND CLASSIFICATION

The objective of this chapter is to develop a comprehensive supply chain risk factors identification and classification model within the context of the healthcare industry. The procedure for risk factors identification and classification is one of the most significant steps in SCRM process. Risk classification helps firms to identify the causes of possible disruptions of supply activities (Heckmann *et al.,* 2015) and helps risk managers to understand the events and the circumstances from which they arise (Harland *et al.,* 2003; Chopra and Sodhi, 2004). However, many researchers note the lack of a standard classification for SC resulting in a research gap due to the conception of risks (Harland *et al.,* 2003; Jϋttner *et al.,* 2003; Chopra and Sodhi, 2004; Christopher and Peck, 2004; Tang 2006; Wu *et al.,* 2006; Manuj and Mentzer, 2008; Tang and Tomlin, 2008).

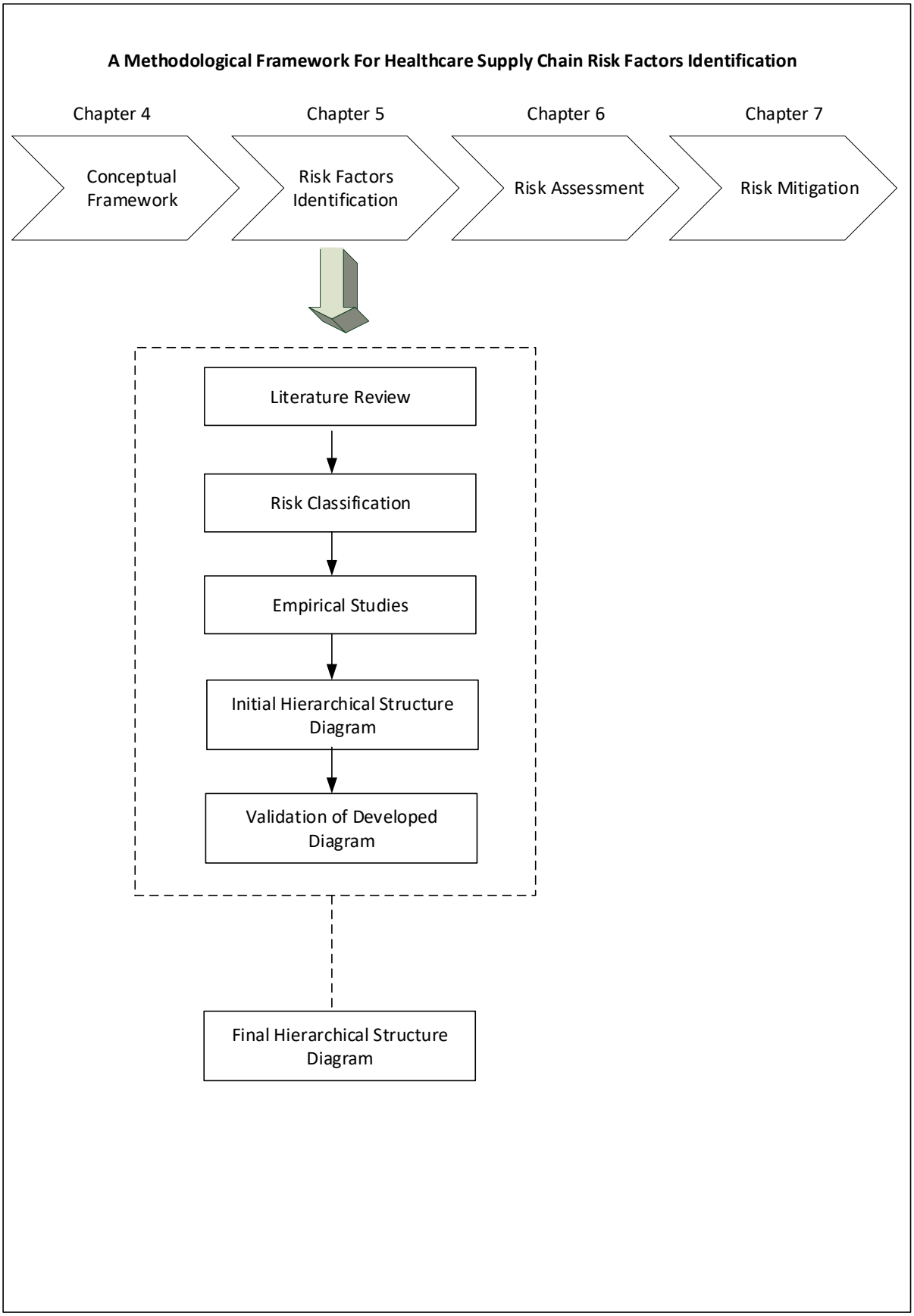


Figure 5-1: Proposed methodology for healthcare SC risk factors identification

The extensive review of the literature in the previous chapter provides an outline for critical insight into the supply chain risks characterised with contemporary firms. The literature review showed that many researchers have identified several different supply chain risk classification methods, sources, or types. However, the literature review also showed the lack of a common methodology or consensus among researchers that can outline a universally accepted supply chain risk classification. The present methods and approaches of classification demonstrate the ever-growing complexity and difficulty of the process. It is evident that researchers have yet to arrive at a universally acceptable supply chain risks classification method. Thus, it is necessary to establish a standard vocabulary that can be used to assess and to identify risk fators between organizations operating within the healthcare supply chain for strategy with the most potential to mitigate risks.

In this thesis, the researcher adopted the risk classification model suggested by Christopher and Peck (2004) to build a new organized classification model in the context of healthcare SC as presented in Figure 5.2.

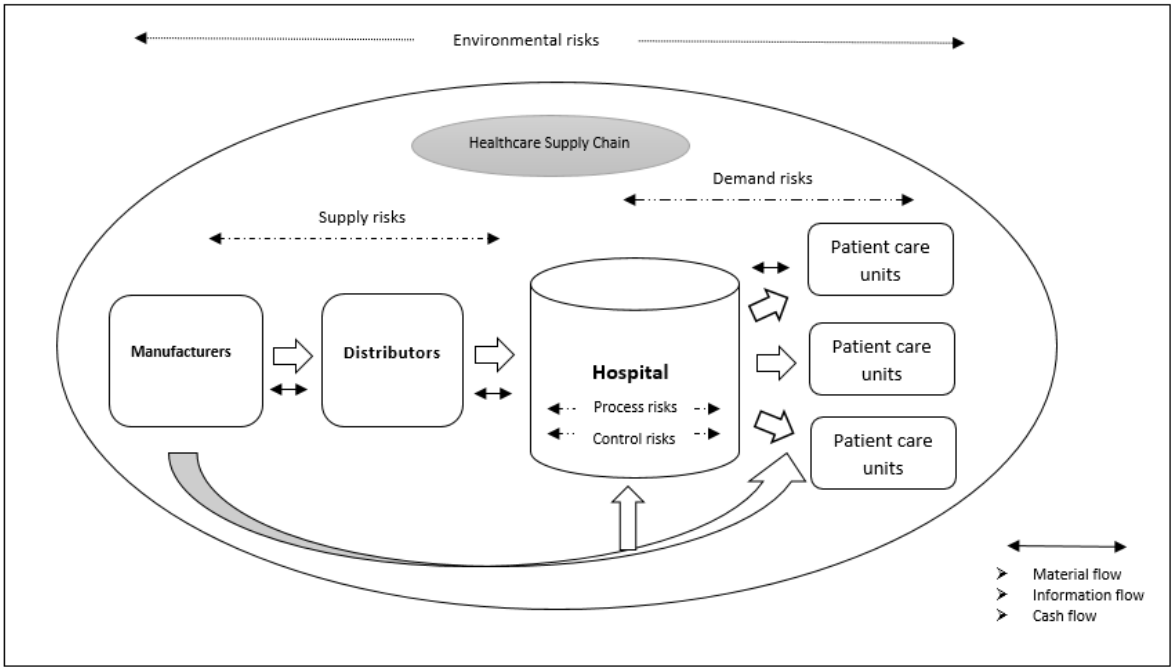


Figure 5-2: Sources of risks in the healthcare supply chain

Based on the uncertainty framework originally proposed by Mason-jones and Towill (1998), Christopher and Peck (2004) suggested a classification model to divide SC risks into three broad categories which can be sub-divided into five main types:

- *Internal to the firm* (*i.e.* arise from the boundaries of the cross-functional departments and range from labour (*e.g.* strikes) or production uncertainties to IT-system uncertainties).
    - *Process risks and control risks*
- *External to the organization yet internal within the supply chain* (*i.e*. arise from interactions between organizations within the supply chain).
    - *Demand risks and supply risks*
- *External to the supply chain network* (*i.e.* any uncertainties arising from the supply chain-environment interaction).
    - *Environmental*

More specifically, integrating the distinct risk perspectives in the healthcare SC strengthens the knowledge base in risk factors identification that comprises the risk portfolio for the material, information and cash flows from original pharmaceutical manufacturer through the healthcare provider to end-user, *i.e.* patients. It enhances the understanding of different sources of risks and the interrelation of risk factors that can disrupt the processes, control, demand, distribution, or supply of healthcare services and products. Using the model, this thesis adopts and presents a new healthcare supply chain risk factors identification and classification method. The new approach divides the five sub-categories of Christopher and Peck's (2004) model into eleven sub-category levels: ***process risks*** are divided into *information risks*, *logistics risks*, and *procurement risks*. ***Control risks*** are divided into strategic risks and labour risks; ***demand risks*** are divided into *capability risks* and *focus risks*; ***supply risks*** are divided into *quality risks* and *supplier risks;* and lastly*,* ***environmental risks*** are divided into *natural risks* and *man-made risks.* Based on the initial literature review in Chapter two, the risk factors have been identified and classified into the Table 5.1 and summarized in Table 5.2. Thereafter, the eleven sub-levels of healthcare supply chain risks are discussed in detail in the section below.

Table 5.1: Classification of healthcare supply chain risk factors identified by researchers

	External to the hospital but internal to the supply chain network		Internal to the hospital		External to the supply chain network
Authors	**Supply risks**	**Demand risks**	**Process risks**	**Control risks**	**Environmental risks**
Breen (2008)	Counterfeiting; Drive competitors out of market; Manufacturer defence tactics diversion of manufacturing capacity; Unavailability of raw material – true and commercially induced; Cash flow threat associated with small pharmaceutical companies and hospitals;	Unexpected increase in demand; Demand versus capacity; Lack of forecasting-customer side; Demand/economics-not able to respond to demand; Increase in demand due to NICE approval; Demand trigged by the nurse, not the patient	Lack of visibility of stock; Inadequate buffer stock-JIT/Lean; Transportation-unavailability of fuel, congestion, weather, illness; Dispensing/picking error-medication/packaging; storage/cold chain; Procurement Hubs-introduce more complexity. Information flow or lack of demand information; Too much information; Fragmentation of SC-no single source, multiple channels, no communication, unilateral decisions;	Short term SC planning; Prioritisation-conflict between patients/profits.	The requirement of environment protection Regulatory issues-manufacturing licensing/change of standards/drug recalls; External influences-disaster recovery; Risk of litigation-influence on market.

			Lack of data standardization (common codes); Contract problems with suppliers; contracting treated as a commodity-big contracts equals big risk;		
Kamath *et al.,* (2012)	Counterfeit risk		Inventory risk		Financial risk; Regulatory risk
Kanyoma *et al.,* (2013)	Unavailability of supplier	Wrong demand forecasting	Insufficient inventory at central medical store (CMS); delay by procurement staff,	poor inventory management by pharmacies;	Withholding of funds by donor partners; lack of funds at the hospital; rigorous government intervention; unexpected disease outbreaks.
Ilie, C., and Popa, V., (2013)	Domestic drug shortages, location of manufacture/supplier(not domestic based)		Clinician's preference; Slowly information transmission and single channel;		Regulation risks (EU);

Maryland (2012)	Grey-market activity, counterfeiting, and diversion of drugs; drugs shortage;		Fragmentation of the drug distribution processes and use of restricted drug distribution systems;	Lack of incentive mechanism;	
Aguas *et al.,* (2013)	Medicine availability in the market;		Capacities of logistics systems; Asymmetries of the information;		
Elleuch *et al.,* (2014)	Poor quality in the purchased drugs from supplier; shortage of drugs (without substitute); Time limit of drugs;	Fluctuation in customer demands;		Lack of personnel; human error.	
Enyinda et al., (2014)	Supplier failure; counterfeiting.		Transportation logistics, electricity; technology	Strikes and lack of key talents.	Geopolitical; public opinion; regulations and laws.
Kim *et al.,* (2016)					Unexpected changes in environmental conditions.
Zepeda *et al.,* (2016)		Demand uncertainty for clinical requirements.	Weak logistics services infrastructure (obsolete equipment in the warehouse, improper distribution facility, route)		

Lord Carter's report (2016)			High purchase price; High product and supplier/brand variety;		

Table 5.2: Summary of the identified healthcare supply chain risk factors

External to the hospital but internal to the supply chain network		Internal to the hospital		External to the supply chain network
Supply risks	**Demand risks**	**Process risks**	**Control risks**	**Environmental risks**
- Counterfeiting, Grey- market activity; **(S1)** - Poor quality in the purchased drugs from suppliers; **(S2)** - Time limit of drugs, drugs perishability; **(S3)** - Shortage of drugs, unavailability of drugs on the market; **(S4)** - Location of manufacture/supplier (not domestic based) **(S5)** - Unavailability of raw material – true and commercially induced. **(S6)** - Cash flow threat associated with small	- Capability versus demand; inability of capacity to meet demand; **(S8)** - Demand trigged by the nurse, not the patient **(S9)** - Demand uncertainty; **(S10)** - Wrong demand forecasting; **(S11)**	- Poor IT system, lack of data standardization; **(S12)** - Asymmetries of the information, unilateral decision; collaboration issues, restriction, not share information between each department; **(S13)** - Dispensing/ picking error-medication/ packaging; **(S14)** - Weak logistics service infrastructure **(S15)** - Fragmentation of the drug distribution process; **(S16)** - Inadequate buffer stock-JIT/Lean **(S17)**	- Focus on short term SC planning than long term; **(S24)** - Prioritization-conflict between patients/profits; **(S25)** - Strikes and lack of key talents; **(S26)** - Lack of incentive mechanism; **(S27)**	- External influences-disaster recovery; **(S28)** - Unexpected disease outbreaks; **(S29)** - Unexpected changes in environmental conditions; **(S30)** - Regulatory issues-manufacturing licensing/change of standards/ drug recalls; **(S31)** - Rigorous government interventions; **(S32)** - Lack of funds from government to the hospital; **(S33)** - The requirement of environment

pharmaceutical companies and hospitals; **(S7)**		- Lack of visibility concerning placement and availability of stock; **(S18)** - Procurement Hub- introduce more complexity, long lead time; **(S19)** - Contract problems with suppliers; contracting treated as a commodity-big contracts equals big risk; **(S20)** - Clinician's preference; **(S21)** - High purchase price; **(S22)** - High product and supplier/brand variety; **(S23)**		protection; **(S34)**

5.2.1 Process risks

The processes refer to the managerial and value-adding activities the firm undertakes (Christopher and Peck, 2004). The success of these activities depends on internally owned or managed assets, such as the infrastructure, that can support the firm's transport and communication, and process risks that arise when they are disrupted (Breen, 2008). The sub-levels of process risks include *information risks, logistics risks,* and *procurement risks. Information risks* arise from poor information technology (IT), asymmetries of information, and high product or supplier/brand variety. *Logistics risks* occur from dispensing or picking error, lack of stock visibility, distribution fragmentation, contract problems with suppliers, and weak logistics service infrastructure. Lastly, *procurement risks* arise from long lead time, high purchase prices, lack of visibility, and inadequate buffer stock as shown in Figure 5.3.

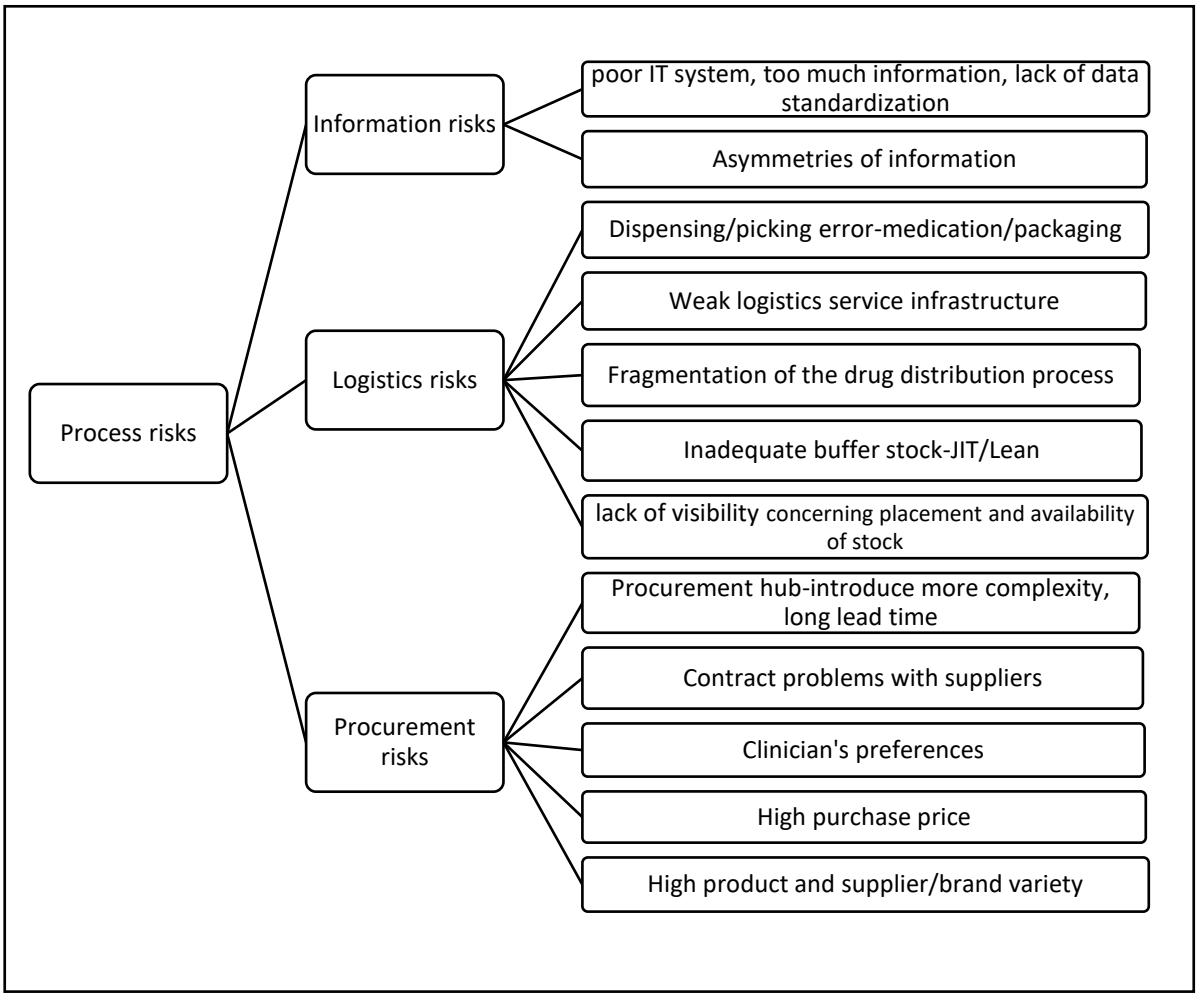


Figure 5-3: A schematic classification of sources of the process risks

Information risks are associated with the potential disruption in the flow of information or failure in communication within the healthcare supply chain network. They may also arise from the probability and impact of cooperation from shared information with suppliers, or an internal cross-functional department. A *poor IT system* is likely to lead to information dissemination causing disruptions in communication or information flow such as poor access to information on demand. Decision based on poor quality information provides ineffective healthcare services which negatively affects the outcome of treatment for patients and provides to the healthcare provider with significant and avoidable cost (Gibbons, 2009). In the United Stated, most health industries have been greatly affected by the inconsistent as well as inaccurate information about drugs hence ending up giving poor service to the patients. In addition, results from a study by Pleasant, (2009) showed that more than $ 11 billion has been wasted because of inadequate processes, use of outdated information and technology, and invoice and order errors. Moreover, Simangunsong *et al.,* (2012) also found other threats that affect information and technology used in the health industry at the organizational level, application or among organizations: technical breakdowns, misuse of information, computer viruses and information accessed by unauthorised individuals, among others.

Further, *lack of data standardisation* likely to contribute to many data silos. The difficulty faced by UK National Health Service (NHS) trusts is that the available data in a large volume whereas quality information is in short supply. In fact, in the NHS database, there are 130 different information descriptions for a single product. Therefore, to promote operational improvement and healthcare supply chain integration, standardisation is of concern. Implementation of supply chain standard data contributes to information synchronisation so that all stakeholders in the industry can speak the same electronic language (Kreysa and Denecker, 2009).

Asymmetries of information associated with unilateral decision-making and poor collaboration between the hospital and suppliers, or between the patient care units and the hospitals, which is a serious risk factors found in SC links. This leads to power relationships, lack of coordination and communication among the supply chain agents, rivalry conditions among the providers in the market, and limited use of communication and information technologies. Even worse, the healthcare industry exists as highly fragmented systems in

which manufacturers, distributors, wholesalers, and providers operate independently from one another. Burns *et al.,* (2002) found that all members in the healthcare SC still lacked coordinated effort, strategic alliance formation, and information to share among the agents of the supply chain. A study by Gibbons (2009) underlined that healthcare is an information intensive environment and the availability of quality information is essential for the delivery of safe and effective healthcare services. Thus, due to lack of inter- or intra-organizational information sharing, the supply chain acts more to push products down the chain instead of pulling them from the customer (Burns *et al.,* 2002).

Lack of visibility concerning placement and availability of stock, for instance, may cause a drug shortage in the warehouses, which can lead to hospitals' inadequate buffer stock. For example, the UK's Chapel Allerton Orthopaedic Centre's (CHOC) inefficient inventory management contributed to an overstock problem. Yet, the centre spend in excess of £3 million on inefficient inventory management (Medwell, 2009). Research shows that in the retail or industrial sector there is less inventory accumulation compared with the health sector because of product-based supply chain cost, which is generally not the main driver of inventory decision-makings among healthcare organizations. In fact, the purpose of inventory is to meet the outcome of the service performance instead of cost saving.

Dispensing or picking error-medication/packaging may arise from packaging through manually operating, sound-alike or look-alike drug names, same appearance from outside covers, similar packages and labelling, unclear or incomplete labelling information, handwritten prescriptions, or high delivering frequency per day. For example, handwritten recommendations for medicine can be dangerous because it can cause different medication errors, such as prescribing, transcribing, pre-dispensing, and dispensing. Moreover, *fragmentation of the drug distribution process* is also likely to cause disruption in hospital services. For example, about 50 per cent of medicine supplies come from a small number of wholesalers, however, the remaining is obtained directly from manufacturers. This means each hospital will receive up to 30 medicine deliveries every day, which is time-consuming for staff (Lord Carter's report, 2016) and more opportunity for errors. Furthermore, Breen (2008) showed that there was no uniform information sharing and decision making among the Pharmaceutical SC, which also led to such problems and affected the efficacy of the complete supply chain.

Weak logistics service infrastructure can be caused from poor service infrastructure, such as poor supplier routes, obsolete equipment in the warehouse, improper drug store environment and transportation facility/route, inefficient cold chain management during transportation that affects the quality and stability of temperature-sensitive products. In the hospital sector, certain categories of goods have a short shelf-life and need to be stored at specific temperatures. Sooksriwong (2009) also carried out a similar study and realised that if there is inefficient cold chain management during the transportation of goods, the quality and stability of products is highly affected. It is vitally important to maintain the freshness of pharmaceutical logistics because the reduced freshness of products, especially medicine, leads directly to serious impacts on human health. In particular, logistics services infrastructure affects the level of integration between an organization and its supply chain partners partly because with access to a well-developed infrastructure can support a range of logistics services and transportation modes enabling suppliers to meets distribution requirements for goods and services (Bookbinder and Tan, 2003). Moreover, several researchers also supported this viewpoint and emphasized that well developed infrastructure can promote organizations' operating efficiency by facilitating shorter and more reliable replenishment lead times as well as accurate delivery of desired supplies (Zsidisin and Ellram, 2003; Shirley and Winston, 2004; Narasimgan and Talluri, 2009). Therefore, Zepeda *et al.,* (2016) further suggested that the better developed a hospital's local logistics services infrastructure, the lower the hospital's inventory costs.

In the UK, a number of NHS trusts have implemented Just-In-Time (JIT) logistics systems given its advantages of reducing inventory costs and involving the supplier the hospital SC operation. According to Wilson *et al.,* (1992), the JIT approach can reduce inventory holding costs in the organization, while maintaining service levels. Nevertheless, the major issues with implementing JIT are demand fluctuation, which is hard to predict in the healthcare industry (Kowalski, 1986), and inadequate buffer stock level in hospital centre stores as JIT is more likely to reduce the inventory level as low as possible.

An uncoordinated procurement hub is also likely to introduce more complexities and long lead times for drug orders until they arrive at the hospital's central store. Procurement lead time is defined as the average duration of time between placing of the order and receipt of material. It may be divided into internal lead time (time required for organizational formalities

to be completed for placing the order) and external lead time (time interval in placement of order and receipt of drugs). Anand *et al.,* (2016) found that average lead time between the preparation of indent and receipt of drugs in the hospital pharmacy is 161 days, while the average internal lead time is 114 days and the average external lead time is 47 days. Only 59% of the drugs were received in time. Kamath *et al.,* (2012) and Kanyoma *et al.,* (2013) identified procurement related process risks that delays by the untrained procurement staff, lack of handling material, and the high product and supplier/brand variety, which can cripple the supply chain network. According to Lord Carter's report (2016), a sample of 22 hospitals covering approximately 16 per cent of NHS spending revealed that in one year they used 30,000 suppliers, 20,000 different product brands, and more than 400,000 manufacturers' product codes with more than 7,000 people being able to place orders. This high product and supplier/brand variety disaggregates and undermines NHS buying power with the inevitable result of variation and higher prices. Furthermore, product variety is the root cause of hospital supply chain wastes, such as high inventories, expiration and obsolescence, and low value orders and delivery changes.

Managing contracts effectively can save hospital substantial money each and every year. One problem that becomes a consistent issue is that hospitals may not remember that their contracts or leases automatically renew if they do not renegotiate or follow the end of lease terms detailed in the written contract. Hospital employee does not always know that they have existing contact in place, and may duplicate services such as a service and maintenance contract on a piece of medical equipment. Furthermore, there is another risk that the vendor could inadvertently fail to comply with all the terms of that contact.

In any case, clinical professionals do not always prioritise efficient resource utilisation and cost-effectiveness due devoting their attention to the treatment effect rather than to corporate performance (Lega *et al.,* 2013). Nevertheless, these demand-side problems often limit the cost-effective procurement of clinical solutions as those clinical professionals lack the awareness of cost containment. Because clinician education is founded on science and clinicians, it responds favourably to scientific, fact-based justification for proposed changes (Freidson, 1988). Moreover, Mckone-Sweet *et al.,* (2005) also found that the primary challenge is to balance costs with physician and other clinician preferences because allowing the clinicians to be involved in product selection would add complexity since most lack any

formal training in supply chain practices. The findings are also in line with Böhme's (2016) research, which was conducted among health organizations through a survey, which indicated that the executives give consultant clinicians a higher status as opposed to the supply professionals, leading to the high level of uncertainty in the hospital sector.

5.2.2 Control risks

The concept of controls as the assumptions, rules, procedures and systems that a firm employs to manage its processes (Christopher and Peck, 2004). Sub-levels of control risks are *strategic risks,* including a *focus on short term SC planning than long term*, *prioritization conflict between patient/profits,* and *labour risks,* including *employee strikes, inadequate talents,* and *poor incentive mechanisms,* as presented in Figure 5.4.

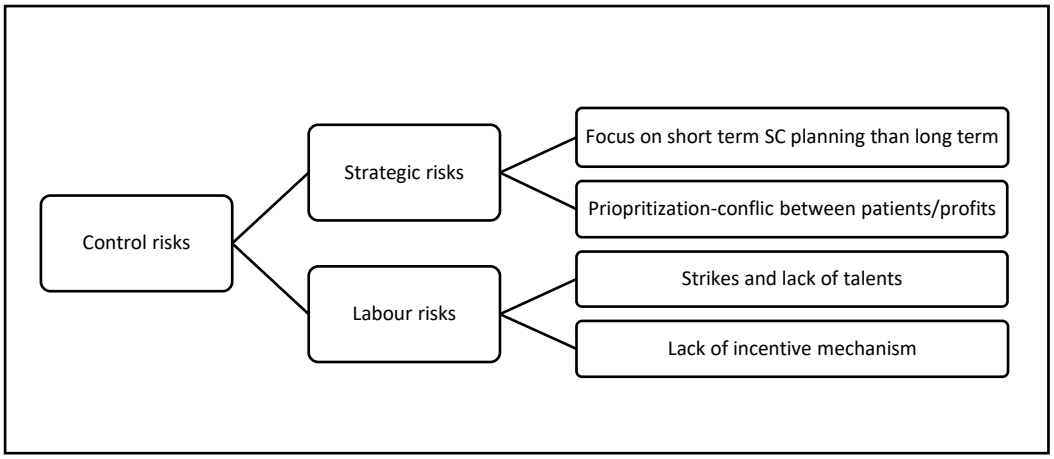


Figure 5-4: A schematic classification of sources of the control risks

Strategic risks are associated with the direction of fundamental decisions concerning an organization's objectives. For example, a possible source of loss that might arise from the pursuit of an unsuccessful business plan, inadequate resource allocation or from a failure to respond well to changes in the business environment. Breen (2008) observed that good planning should focus on product quantities, nature, batch sizes, priorities, and safety stock policies and other control procedures that outline transport and asset management to address both short-term and long-term supply chain risks. *Prioritization conflict between*

patients/profits are likely to arise from poor planning and poor focus on service delivery at the expense of profit making. It is likely to find hospitals making prescriptions and charges on drugs for profit rather than gains at the expense of quality and service delivery. Moreover, healthcare organizations face a variety of stakeholders who place demands and constraints on their managers. Thus, the presence of different stakeholders (*e.g.* taxpayers and recipients of services or industrial groups) requires healthcare organizations to pursue different and sometimes conflicting objectives (Lega *et al.,* 2013). It has frequently been argued that public agents often meet distinctive goals, such as ethics, equity, or accountability, which are non-existent in the private sector (Flynn, 2007).

The range of actions available to healthcare organizations is restricted by political constraints. Political dynamics lead to frequent policy changes and the imposition of short time horizons on healthcare organizations (Lega *et al.,* 2013). Therefore, developing comprehensive long-term SC strategies and innovative projects is more difficult in this context (Zanjirani *et al.,* 2009). *Focus on short term SC planning than long term* may mean hospitals lack the basic infrastructure, such as IT and network designs. Supply chain orientation based on the functional not long term strategic objectives. It goes with short term profit rather than making long-term but necessary investment. Hospitals can thus experience inadequate information sharing and partner relationship management challenges and experience the improper selection of health facilities and poor sourcing of healthcare products. For instance, proper planning may consider single, dual, and multiple sourcing strategies to address issues of supplier reliability and minimise potential supplier-based disruptions in the supply chain network.

Furthermore, *strikes* are associated with poor management or lack of *incentive mechanisms* that can motivate employees to work under challenging conditions or during extra hours. For example, in 2015 and 2016, England's junior doctors took part several times in a general strike, such that up to 100,000 operations were affected and up to one million appointments were cancelled. *Inadequate talent* can cause lack of adequate process capacity, poor inventory management by pharmacies, and labour problems that can create core control breakdowns in operational processes within the hospital and the patient care unit. Inadequately skilled workers, strikes, carelessness, and poor motivation are likely to damage the reputation of the supply chain. Though the risks are regarded as short-term, they can

cause serious disruption to the control of the entire supply chain and should, therefore, be solved with a long-term perspective (Elleuch, 2014). McKone-Sweet's (2005) research suggested that most health organizations with executives who possess high levels of supply chain information or experience always stand a higher chance of high levels of supply chain performance.

5.2.3 Demand risks

Demand risks specify the possibility of unexpected changes arising from market or downstream members (Christopher and Peck, 2004). Existing literature revealed that more attention is given to demand side risks than other sources of supply chain risks (Elleuch, 2014). Two sub-levels of demand risks adopted in this thesis are *capability risks,* which include the *hospital's inability to meet demand, poor flow of demand information;* and f*orecast risks,* which include *wrong demand forecasting* and *demand uncertainty. A schematic presentation of the demand risk sources discussed is* presented in Figure 5.5.

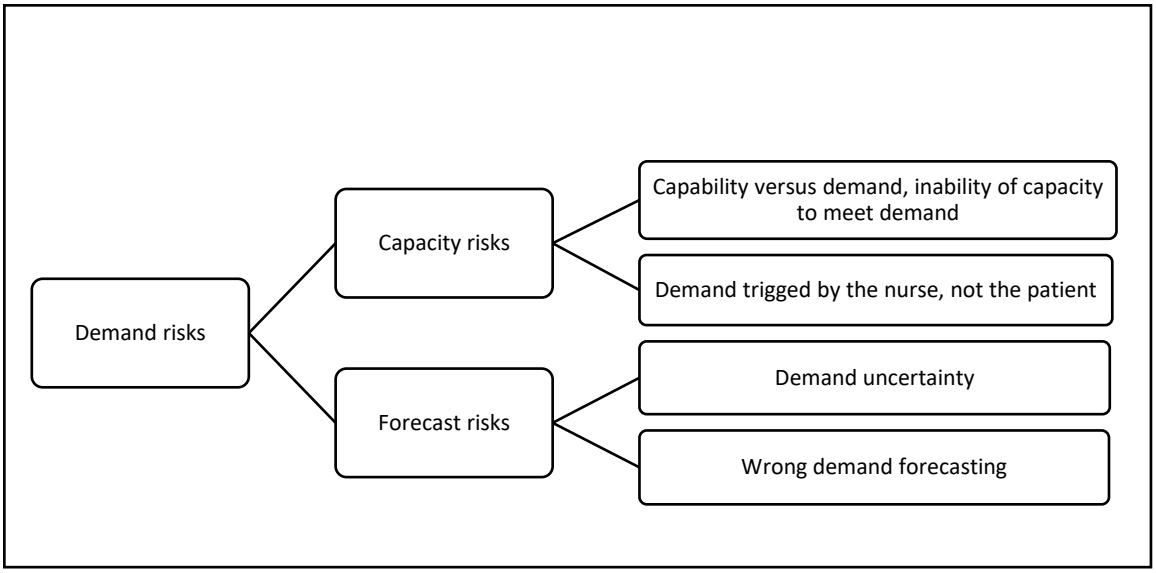


Figure 5-5: A schematic classification of sources of the demand risks

Capacity risks are caused by lack of flexibility towards environmental changes, inefficient production with over- or under-utilization capacity, poor planning, failed schedule, control production, and inventory organization. In the hospital sector, capacity risks may arise from

the lack of capacity or flexibility to meet the needs of the patients or patient care units. Supply chain system capacity is associated with response times and quality regarding drug management and delivery. In other words, these risks are associated with either financial constraints or time/staff constraints. Elmuti *et al.,* (2013) found that the US healthcare industry's major challenge is lack of training for the supply chain professionals. They surveyed 700 healthcare organizations to measure their familiarity with, and utilization of, healthcare SCM initiatives. The results indicated that approximately 62 per cent of respondents reported no existing healthcare SCM programmes. The remaining organizations reported the duration of their SCM programme to be less than one year. The lack of attention to SCM was due to senior managers failing to recognise the importance of efficient SCM therefore the employees also paid less attention to SCM services (McKone-Sweet *et al.,* 2005). Furthermore, regarding demand and flow complexity compared with industry, the disparate care processes and clinicians increasingly difficult to manage and align, resulting in greater risk to patients and inefficient use of system resource. Hence, understanding and quickly adapting to the ever-changing needs of patients as they move through networks of healthcare providers is crucial to the success of the healthcare delivery system (Rust *et al.,* 2013). For example, unlike other consumer products where the customer can either defer their purchase or acquire an alternative can be critical in providing patient care, as there may be no alternative option for treatment. Therefore, urgent orders need to be delivered immediately. Meanwhile, as the nurse-to-patient ratio decreases, nurses are under increasing pressure to spend more time with patients, and errors tend to occur. Friedrich (2017) found that a critical decrease in the number of nurses at a facility can have detrimental effects on patients. Studies show that there are different reasons that led to nursing shortages in the United States, such as the nation continues to age, foreshadowing an ever-growing need for care and nursing schools struggle to expand capacity to meet the need for care, and so forth. Moreover, another risk factor is triggered when clinicians and nurses bypass the official replenishment channels and directly order supplies from manufacturer or distributors. In fact, a 'vicious cycle' is created because the real-time demand is not triggered directly by patients. As one SC manager reported, *"We have the knee replacement parts found in their theatre which are worth a hundred thousand pounds, and the new surgeon won't even touch them and require an alternative one*" (Böhme *et al.,* 2016).

Another theme raised by several researchers is *demand uncertainty* (Lee *et al.,* 1997; Mustaffa and Potter, 2009; Zepeda *et al.,* 2016; Böhme *et al.,* 2016). In the case of the hospital sector, demand uncertainty is observed in the clinical requirements to treat patients at any given time (Gittell, 2002). In other words, demand uncertainty is a construct of demand invisibility, which is not known in advance, *i.e.,* it is stochastic. There may also be uncertainty in the transport delays (Jurado *et al.,* 2016). Moreover, since the provision of hospital services requires both intangible services supported by supplies and supplies supported by intangible services (Berry and Bendapudi, 2007). The hospital's tast environment will impact the ability to accurately predict the supplies necessary to carry out required tasks. For this reason, it is usual a push to get hospitals to prepare for healthcare supplies or intangible services to satisfy uncertain demand within time constraints. Therefore, the higher level of a hospital's demand uncertainty for alternative clinical services, the higher the risk of stock out of needed items because the hospital's task environment makes it increasingly difficulty to reliably forecast the supplies needed to meet patient's demand (Lee *et al.,* 1997; Sodhi and Lee, 2007). As a result, operational failures in hospitals can results from the inability of the related work system to reliably provide supplies when, where, and to whom they are needed (Tucker, 2004).

Therefore, the dynamic changes, fluctuation in demand, and other related risks call for close monitoring of the control process to identify novel hazards to enhance the risk assessment, control, and reduction in hospitals. Kanyoma (2013) found that low visibility of the sourcing and supply chain network is likely to hinder effective supervision and control. Jüttner (2005) also suggested that players within the healthcare supply chain should work as a team to improve transparency of all control activities that relate to medicine flows.

5.2.4. Supply risks

Supply risks may arise from the actual interruption or disruptions within the supply procedures and related operations that a firm adopts to let products or information flow within the supply chain network, commonly upstream from the firm (Christopher and Peck, 2004). In this classification the risk factors are often related to the hospital's external environment but arise from the internal network of the supply chain where services and

products flow. Conducting a critical interpretive synthesis of the literature, two sub-levels of supply risks adopted in this research are *quality risks* which may arise from *counterfeiting, time limit of drugs/perishability, availability of raw materials* and *supplier risks* related risks which may arise from the *location of suppliers in relation to their availability, flexibility, shortage of drugs, availability of raw material-true,* and the expected flow of cash/ cash management treated associated with small companies and hospitals. Figure 5.6 presents a schematic view of the supply risks.

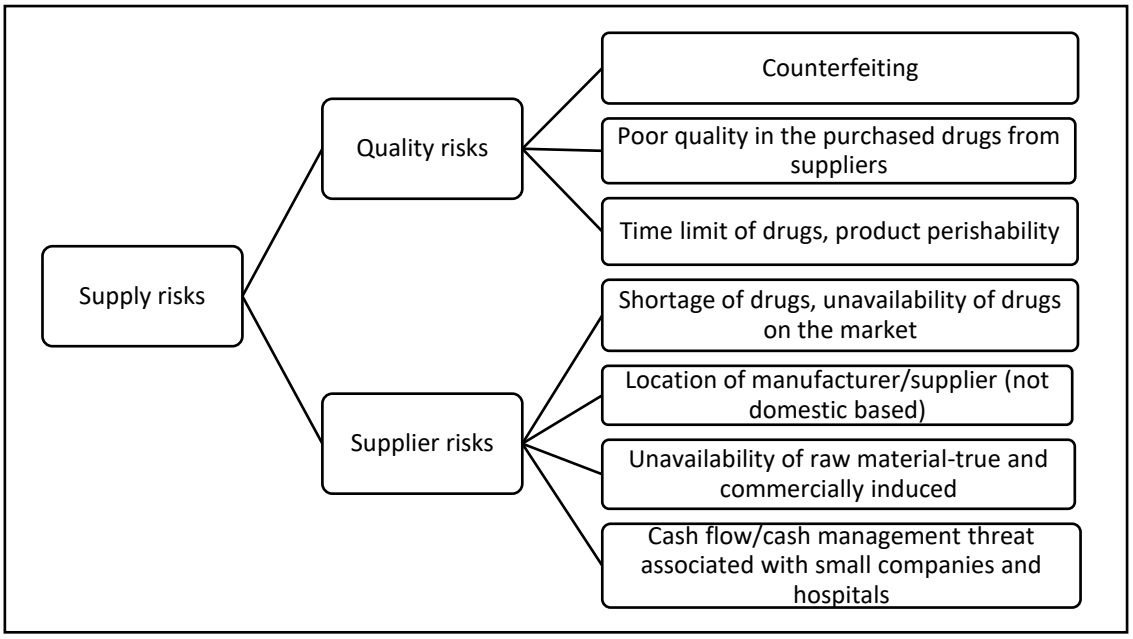


Figure 5-6: A schematic classification of sources of the supply risks

Many healthcare organizations continue increasing rapidly with most of them getting involved in *counterfeiting* (Thun *et al.,* 2011). Counterfeit drugs are defined as drugs sold under a product name without proper authorization, where the identify or the source of the drug is knowingly and intentionally mislabelled to suggests that it is an authentic Food Drug Administration (FDA) approved product (Maryland, 2012). According to Kamath *et al.,* (2012), issues regarding counterfeiting can be managed by incorporating the current anti-counterfeiting technologies such as the hologram, mass encoding systems, bar-codes, and Radio Frequenct iDentification (RFID) systems. The *shortage of drugs* can adversely affect patients' health results and lead to extra spending on healthcare services. Shortages may be the result of limited supply or the poor quality of raw materials needed for manufacturing and regulatory or legislative issues, business or market factors, unanticipated increases in demand, natural disasters, or inventory control practices (Maryland, 2012). Previous studies

show that since 2011, in Malawi public hospitals have faced a serious shortage in drugs, which affected health delivery services leading to the increased patient deaths. In addition, delays in medical surgery, and worsened medical conditions of the patients among other effects (Kanyoma and Khomba, 2013). Moreover, a shortage of medicines forces the search for substitutes thereby causing over costs due to the difference in prices for available medicine on the market (United Nations, 2013). Aguas *et al.,* (2013) found that the main problems in the health systems are related to poor supply and unavailability of essential medicines. In their case from Colombia, about 15.8 per cent of patients had been prescribed medicine and received the wrong medication, while 21.2 per cent did not receive any medicine. Most pharmaceutical manufacturers source raw materials from remote and unstable areas where unanticipated events may occur, for instance civil wars or terrorist activities. The shortage may force manufacturers to use materials of low quality in the production of healthcare products. Thus, *unavailable raw materials* and *poor quality of medicines* are frequently experienced which lead to supply process disruption or even breakdown. For hospital, some raw material obtained from manufacturer, but manufacturer mergers often result in decisions to narrow the focus of product lines, resulting in the discontinuation of a key raw material. Meanwhile, the unique characteristics of the *product perishability* of some specific pharmaceutical items must always be stored under the strict temperature-monitoring environment. Therefore, it is necessary to manage risks caused by the unexpected changes in environmental conditions for delivery items during the distribution process, as such risks can directly or indirectly negatively affect the *quality in purchased drugs from the supplier* (Kim *et al.,* 2016).

Considering issues of *remote location of pharmaceutical manufacturer or supplier*, Colicchia and Strozzi (2012) observed that the current supply chain physical extension includes global sourcing which creates a massive volume of healthcare items bought and supplied worldwide. However, transport costs for hospitals and pharmaceutical distributors are likely to increase because of the high distance to travel to either deliver or collect supplies. In addition, different from the typical consumer products, where the customer can either postpone their purchase or obtain an alternative one, this can be critical in providing patient care as there may be no alternative treatment for the patient. Thus, the immediate response of urgent delivery may be required. For this reason, the stock levels of normal and urgent medicines need to be

monitoring as the daily work, due to the remote location of some pharmaceutical suppliers. Greater domestic manufacturing was considered to reduce the risk of medicine shortages especially in global crisis situations.

The success of supply and control activities depends on the reliability and flexibility of suppliers within the healthcare supply chain. Low supplier flexibility and reliability are likely to force hospitals to incur high sourcing costs, storage problems, acute drug shortages, and poor monitoring of the supply activities (Brown *et al.,* 2014). Thus, a reliable supplier is expected to give quantities and qualities ordered within a given time frame. Moreover, the flexible suppliers makes the supply chain quick able to respond to the changing consumer demands and other complex requirements. Otherwise, hospitals will frequently experience the supply process disruption or even breakdown in the supply market (Colicchia and Strozzi, 2012). Meanwhile, in terms of cash flow, the risks arise from the delayed payment from hospitals to the small pharmaceutical companies. More than a quarter of UK hospital trusts are now routinely delaying payments to their supplier because of cash flow problems. Obviously, the consequences of such activities could be significant challenges faced by several pharmaceutical suppliers as their cash flow would be interrupted, especially for those small-scale companies. In fact, several NHS hospitals confirmed that some suppliers had put their account "on stop" and refused to deliver further supplies due to the late payments. Although both hospitals and suppliers are confronting such issues, though, it appears that this problem will last for a long time due to an increasing number of hospitals struggling to maintain adequate cash levels given recurring income and expenditure deficits.

5.2.5. Environmental risks

Environment risks refer to the unexpected events that may directly influence the focal firm, or impact directly the downstream or upstream flow of goods or services in the supply chain network (Christopher and Peck, 2004). Environmental risks are likely to arise when the events negatively affect the value stream such as the contamination of the healthcare products or damages. Sources of environmental risks are divided into two sub-levels which include *natural risks* and *man-made risks*. Sources of *natural risks* include *natural disaster, unexpected disease outbreaks,* and *unforeseen changes in environmental conditions* such as adverse weather or natural catastrophe (Breen, 2008**)**. *Man-made risks,* on the other hand, may arise from *regulatory issues, rigorous government interventions,* and *inadequate funds from the*

government to support hospitals and the requirement of environment protection (Kamath *et al.,* 2012), as shown in Figure 5.7.

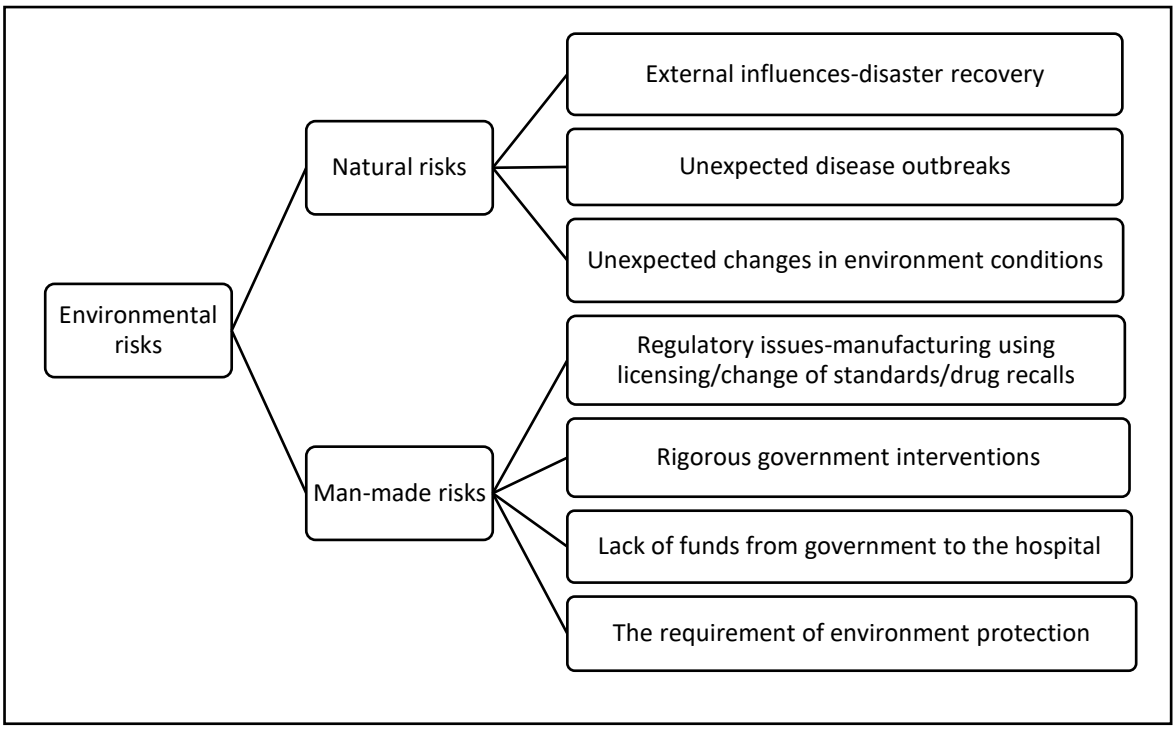


Figure 5-7: A schematic classification of sources of environmental risks

A United Nations report indicates that frequent *natural disasters* and catastrophes, such as earthquakes or hostile weather conditions, are becoming more active and common in various parts of the world. In fact, earthquakes and heat waves, for instance, increase the chances of damaging drugs in transit. Meanwhile, flooding can cause delay in supplies or transportation of healthcare products. More importantly, the delay is highly likely to cause healthcare drugs perish, which can make hospitals experience drug shortages and cause tremendous losses. *Unexpected disease outbreaks* have caused significant losses in the healthcare supply chain as well. The World Health Organization (WHO) reported that a severe outbreak of acute respiratory syndrome that caused over approximately 800 deaths in Southern China between November 2002 and July 2003. The outbreak spread to over 36 countries within weeks (Breen, 2008). The lack of essential drugs and medical staff as well as the government travel ban in the affected area resulted in the shutdown of 75 per cent of the plants and subsequently, significant economic losses (Colicchia and Strozzi, 2012). Therefore, the nature of disasters and disease outbreaks can reveal the cascade of problems that may have been unforeseen

and unplanned but overcome had officials been prepared and trained to deal with the complexities related to emergency management (VanVactor, 2012). *Unexpected changes in environment conditions*, such as the impact of extreme weather events and climate change (*i.e. heatwaves and coldwaves*). The extreme weather may impair functionality of hospitals including medical equipment and shortage of medicines. More concerns is needed on the extent of such problems, especially since mortality risks during heatwaves are particularly high for vulnerable patients. Other issues, particularly transport systems, are likely to be disrupted by snow and ice, creating diffculities of access for patients needing to use health facilities and for domiciliary care staff in reaching their clients in their homes. Ambulance response times also fall during very cold weather.

Government always plays an essential role in healthcare SCRM, not only allocating funds to the healthcare organizations, but also providing industry with informal regulatory guidance and recommendations. In the UK NHS, since 2015, the budget's gaping hole was on social care, which is close to collapse and putting ever-increasing pressure on hospitals through bed-blocking. Furthermore, the Local Government Association estimates a £1.3bn funding gap between what care providers need and what councils pay. Under this circumstance, the UK NHS front-line services simply lack the funding to manage. Besides, the increased demand has led to more people waiting longer to be seen in Accident and Emergency (A&E) over the festival period. *Rigorous government interventions* may adversely affect the total output (quantity and quality) of physicians and other healthcare providers. For example, if government uses its monopsony power to reduce prices of medical services and wages of healthcare employees, shortages of medical services might result. Those shortages would lead to higher mortality rates. Government regulation gives a distinct competitive advantage to companies large enough to maintain secure funding. For example, some drugs benefit from additional government incentives. Orphan drugs receive special consideration from the UK Medicine & Healthcare Products Regulatory Agency in order to encourage pharmaceutical companies to develop treatments for rare diseases. Incentives for the development of orphan drugs include quicker approval time and potential financial assistance for development. Companies are often permitted to charge substantial prices for orphan drugs, making them more profitable than they would be without government intervention. *Regulatory issues* may arise from unpredictable regulations and legislations such as new licensing policies, changes

in the standards of requirements, drug recalls from the manufacturers, inconsistent government interventions, and quota restrictions. Any change in the manufacturing process necessitates a licence variation which often entails a delay (Breen 2008).

In the healthcare supply chain, the increasing attention on policy risk is emphasised on the safe use and disposal of hazardous drugs presents potential challenges to the surrounding environment and general supply chain operations. Improper drug disposals threatens human health as well as the ecological balance leading governments and other environmental conservation agencies to implement formal and informal regulatory policies (Scruggs *et al.,* 2014). The provided investigation estimated that some of these policies expose hospitals to hefty fines and potential financial losses. Therefore, it is advisable for hospitals to avoid loses by ensuring the safe disposal of used or expired drugs.

5.3 RISK FACTORS IDENTIFICATION DATA ANALYSIS AND TAXONOMIC DIAGRAM VALIDATION

The visibility of the supply chain related risks is one of the most challenging aspects of healthcare SCRM, it is therefore essential to comprehensively identify and validate risk factors existing in the healthcare SC. The foundation of effective SCRM requires three critical tasks: specification of sources, risk assessment and risk mitigation (Kleindorfer and Saad, 2005). This research started with identifying the risk factors that have been addressed in the relevant literatures (shown in Chapter two), and then a decomposition method was applied to classify unstructured risk factors into different risk domains. The preliminary structured hierarchical diagram of healthcare supply chain risks is developed as shown in Figures 5.8 to 5.11.

5.3.1 Procedure for questionnaire design and pilot study

The questionnaire was built to explore the feasibility of the developed risk classification taxonomic diagram and to explore if any other remaining risks were yet to be explored. Therefore, the performance of risk factors identification and classification is based on the expertise of the constructed group. The data was obtained and content validity was performed to improve the clarity of the developed questionnaire. Firstly, a draft version of the questionnaire and cover letter was developed. The questionnaire was examined by two

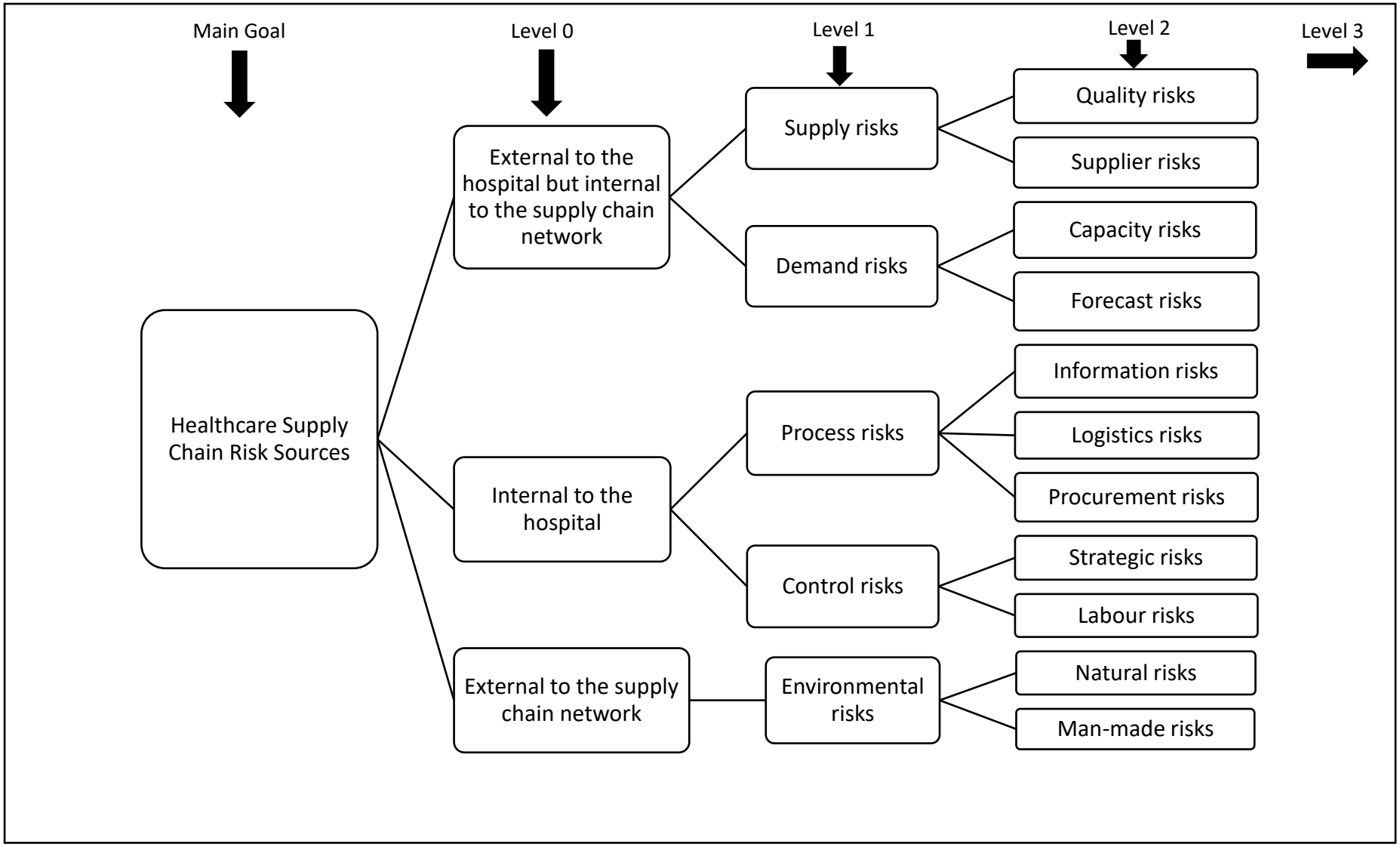


Figure 5-8: The preliminary hierarchical structure of healthcare supply chain risks

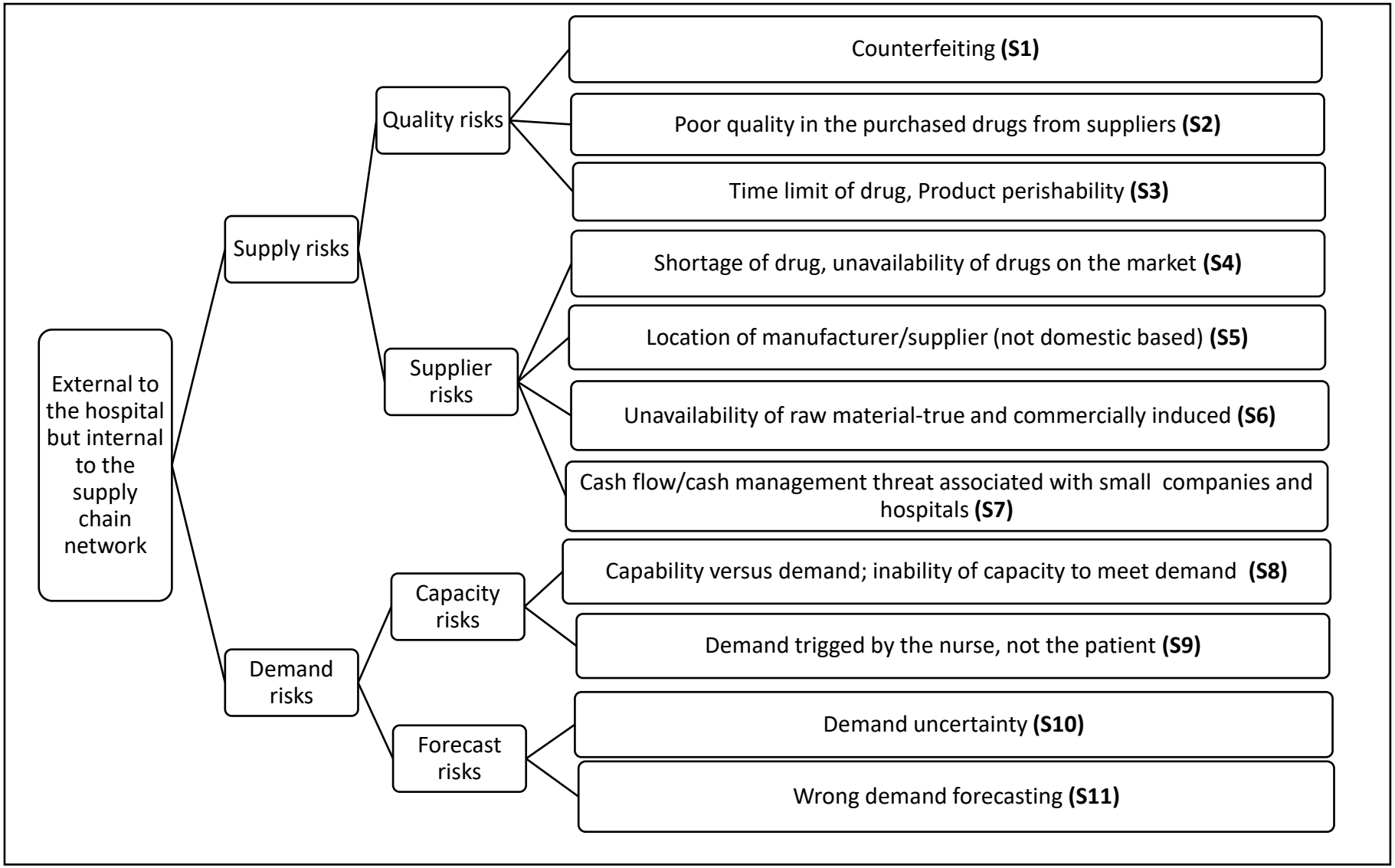


Figure 5-9: The preliminary External to the hospital but internal to the supply chain network risks hierarchical structure for healthcare SC

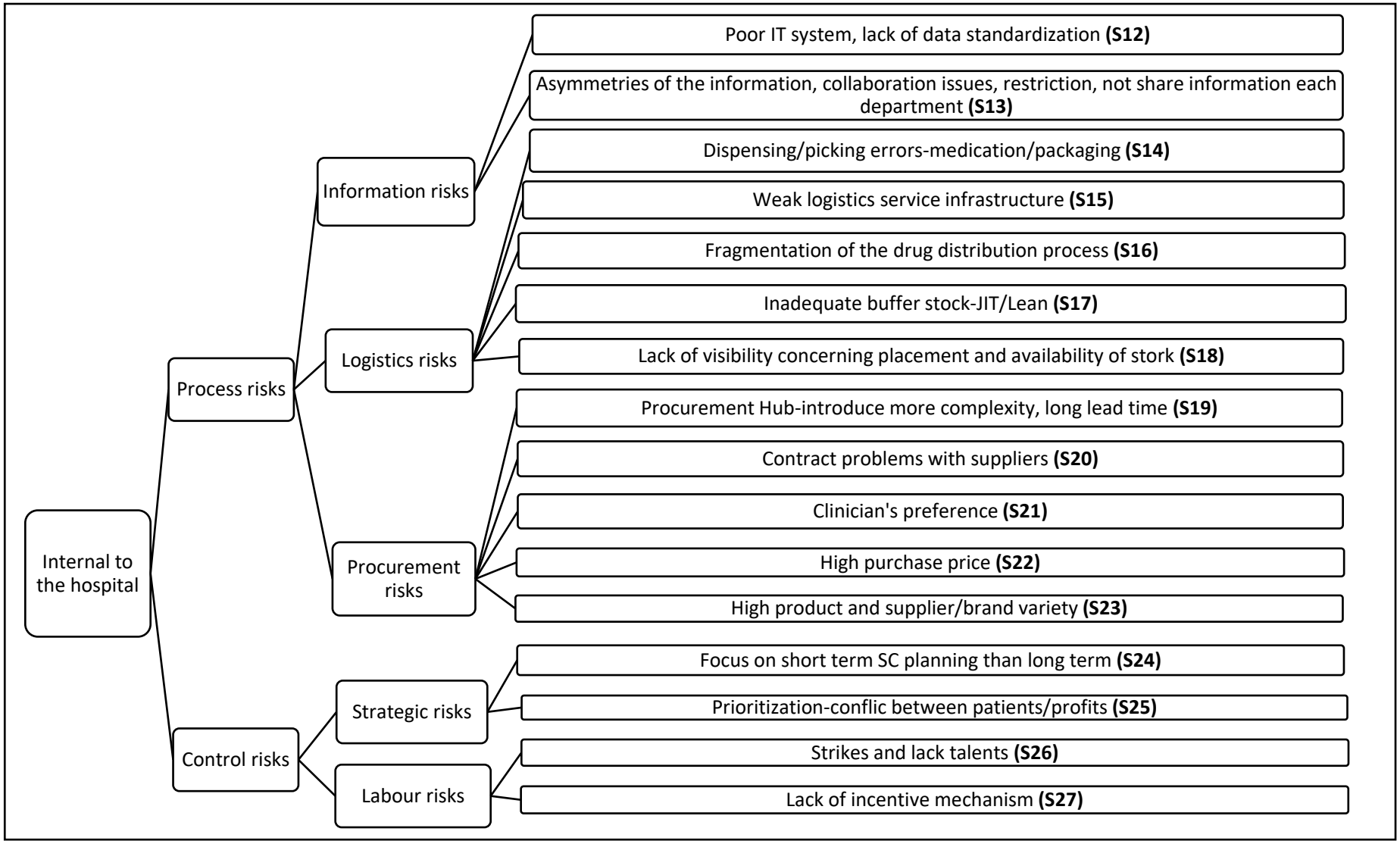


Figure 5-10: The preliminary Internal to the hospital risks hierarchical structure for healthcare SC

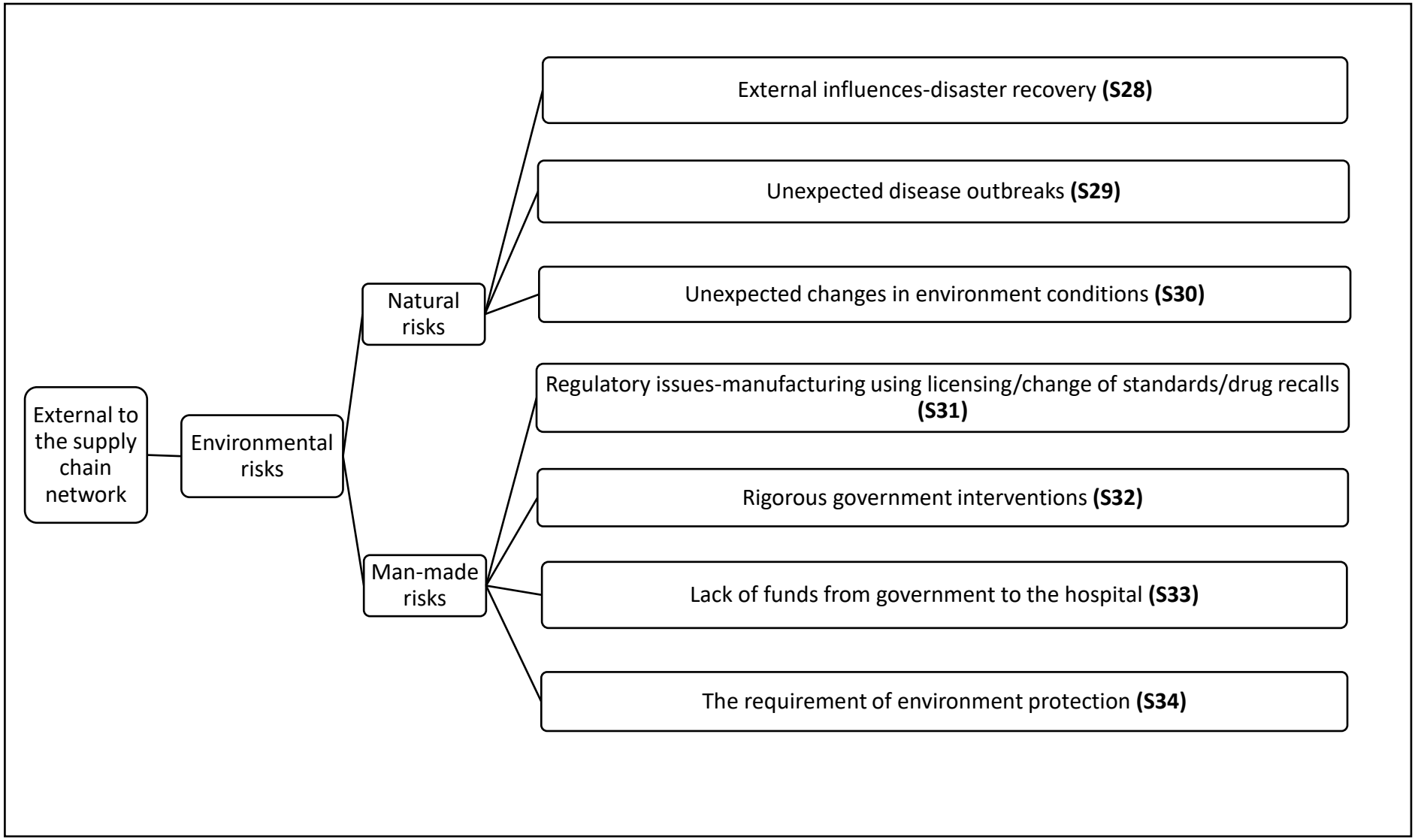


Figure 5-11: The preliminary External to the supply chain network risks hierarchical structure for healthcare SC

academic researchers and two specialists to comment on the appropriateness and clarify of the questions. Based on their feedbacks, the questionnaire was revisited for the pilot study. The pilot study was conducted by exploring different judges to pre-asses the questionnaire's effectiveness, accuracy, and unambiguous communication. All items on the questionnaire were measured on a five-point Likert-type scale with response options ranging from 1 (very unimportant) to 5 (very important). Ethical approval was also obtained to further validate the questionnaire content and participant consent. The questionnaire (see Appendix One) as represented at the end of the pilot study was used for data collection.

5.3.2 Selection of experts for validation

As an exploratory study, a cross-section of experts or decision makers was considered for participation in the survey. The questionnaire survey was conducted with six experts from both the UK and China in academic fields as well as the healthcare industry to address the concerned risk-related events. The sample size was considered acceptable for this study. Satty (2001) stated that just a small sampling size (<10 responses) was necessary if the data collected were gathered from the experts. This is due to that fact that professionals should share consistent belief and thus diminish the need for a huge sample size. Experts working experience and academic qualifications were used as the selection threshold (John *et al.,* 2016). Meanwhile, the group included experts from a wide variety of professionals with expertise from different functional groups, such as supply chain and logistics management, pharmacy science, and risk management, which are grouped for risk factors identification and assessment groups. Hammitt and Zhang (2013) emphasized that a sample size of N experts (i)(where i =1,2,3,…, N) was necessary if the well-calibrated experts are of equal or unequal quality and their judgements are independent, positively or negatively dependent. In order to obtain a balanced view from different professional areas, the invited experts consisted of two heads of procurement (*i.e.* pharmacy department leader in Chinese hospital is the same as the head of procurement in UK NHS) in charge of all the supply chain and logistics activities in the hospital; two academic professors within a background in both pharmacy and supply chain and logistics management; and one senior lecturer and one senior manager who have rich experience and knowledge in risk management. The risk validation and exploration procedure in this thesis includes two major parts: (1) the results of the questionnaire survey and (2) the results of email and face to face interview. Within the results obtained from the

questionnaire survey, this thesis firstly presents the confirmation of the identified risk factors and the developed classification model and the risk factors exploration. In the results of email and face to face interviews, the modified hierarchy model was confirmed.

Different experts have different impacts on the final decisions and results, thus, the evaluation weighting criteria have been developed and allocated to each expert on the basis of their job position, qualification and work experience. According to Cooke *et al.,* (2008), expert weighting criteria refer to the measure of the relevance of data that is considered as a function of professional duty (position in the organization) and work experience in terms of time in years. Table 5.3 presents the details of weighting and relevant description of each expert evaluation criteria used in identifying respondents.

Table 5.3: Experts' Weighting Criteria（expert evaluation）

Weight value	Keyword	Description (either-or)
20%-30%	Highly relevant	The respondents have many years of rich experience in pharmaceutical supply chain management; and they always hold the top position in pharmaceutical logistics activities; In academia, the respondents have a rich knowledge and in-depth studies that make a demonstrate contribution to pharmacy or supply chain risk management.
10%-19%	Fairly relevant	The respondents have at least 10 years work experience in pharmaceutical supply chain management or doing the similar work in other industry. In academia, the respondents have a good knowledge in pharmacy or supply chain risk management. They clearly understand the severity and consequence of supply chain disruption.
1%-9%	Relevant	The respondents have basic work experience in pharmaceutical supply chain management or doing the similar work in other industry. In academia, they have the general understanding of the status of the healthcare industry and the pharmacy supply chain risk aspects.
0	Irrelevant	No experience or knowledge in relation to the research topic.

Based on the experts weighting criteria proposed above, six experts were assigned the weighting on the basis of their individual background and experience as shown in Table 5.4. Expert A has the highest weighting (30 per cent) as he holds a position of head of procurement with a very long professional work experiences in the UK NHS hospitals. While, both experts

B and C have the same weighting (20 per cent) as they are either a specialist in pharmacy sciences or hold a managerial positions in the pharmacy department. The remaining three experts have the lowest weighting (10 per cent) among the experts group because their background is not relevant to the healthcare industry, but they have rich knowledge in supply chain and risk management.

Table 5.4: Research expert weighting respondents' profile

Expert	Weight	Organization type	Job title	Years of experience	Functional SCM/RM/Pharmacy experience
Expert A	30%	hospital	Head of Procurement	>20	Procurement , warehousing and logistics
Expert B	20%	Academic	Professor	>20	Pharmacy and Biomolecular Sciences
Expert C	20%	Hospital	Pharmacy department leader	10	Procurement , warehousing and logistics
Expert D	10%	Academic	Professor	13	Transportation and Logistics management
Expert E	10%	Academic	Senior Lecturer	12	Risk and Operation management; supply chain management
Expert F	10%	Logistics Company	Senior Manager - Operations	9	Supply Chain Risk management

5.3.3 Data analysis and description

The survey equally aimed at establishing the extent to which the identified risk factors are comprehensive. Accordingly, a reliability and validity test was carried out to test whether the study measures the required items and the reliability of the received responses. It should be mentioned that the reliability of the questionnaire survey is closely associated to its validity. A questionnaire survey cannot be valid unless it is reliable. Cronbach's Alpha has become the widely accepted method in different types of research when multiple-item measures of a concept or construct are employed. This is because the method is much easier to use in comparison with other estimates as it only requires one test administration. The reliability of the obtained results was examined through employing Cronbach's Alpha method (Sijtsma, 2009; Cohen and Swerdlik, 2010) by using the following functions and equations:

$$a = \frac{K}{K-1}(1 - \frac{\sum_{i=1}^{K} \sigma_{Y_i}^2}{\sigma_x^2} \quad (5.1)$$

$$a_{standardised} = \frac{\mathrm{K}\bar{\mathrm{Y}}}{1+(\mathrm{K}-1)\bar{\mathrm{Y}}} \quad (5.2)$$

where K is defined as number of the questions in the investigation, σ_x^2 is the variance of the total sample, $\sigma_{Y_i}^2$ is the variance of the current question, and i is the question number. Eq. 5.1 is for the calculation of Cronbach's Alpha, whereas Eq. 5.2 examines the Alpha based on standardised items, where K is defined as the number of the questions in the survey and $\bar{\gamma}$ refers the meaning of the non-redundant correlation coefficients.

The study tested 204 questions in total. The calculated Cronbach's Alpha value was 0.944. The Cronbach's Alpha based on standardised items was found to be 0.952. Alpha coefficient ranges in value between 0 and 1 and can be used to describe the reliability of factors extracted from the questionnaire. The higher the score, the more reliable the generated scale. In practice, a value of 0.8 indicates that the collected data is reliable. The data is also satisfactory if the value falls between 0.7 and 0.8. However, in principal, a value less than 0.7 shows poor internal consistency of the data (Chomeya, 2010). It can be deduced that the survey attains a high level of reliability. Table 5.5 presents the reliability test results of Cronbach's Alpha.

Table 5.5: The reliability test for the questionnaire survey

	Reliability Statistics		
	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of questions
Whole survey	0.944	0.952	204

Tables 5.6 and 5.7 illustrate the Sum, Mean, the Weighted Average and Standard Deviation (S.D.), and the ranking of the identified risk factors on the basis of expert judgements. Standard deviation is the measure of dispersion of a given data. The result analysis shows the standard deviation to range from 0 to 2.74. When the value of a standard deviation is high, it implies that the experts attribute a particular factor of measurement value to spread to a

Table 5.6: Results of the significance of healthcare supply chain risks (Questionnaire Survey)

Identified risk factors		How important is this risk factor to healthcare SC operations?			
		Sum	**Mean**	**Weighted Average**	**S.D.**
Quality risks	Counterfeiting **(S1)**	30	5	5	0
	Poor quality in the purchased drugs from suppliers **(S2)**	28	4.67	4.8	1.15
	Time limit of drug, Product perishability **(S3)**	25	4.17	4.2	0.91
Supplier risks	Shortage of drug, unavailability of drugs on the market **(S4)**	27	4.5	4.6	1.22
	Location of manufacturer/supplier (not domestic based) **(S5)**	22	3.67	3.6	2.31
	Unavailability of raw material-true and commercially induced **(S6)**	22	3.67	3.7	1.15
	Cash flow/cash management threat associated with small companies and hospitals **(S7)**	21	3.5	3.6	2.74
Capacity risks	Capability versus demand; inability of capacity to meet demand **(S8)**	26	4.33	4.3	1.15
	Demand trigged by the nurse, not the patient **(S9)**	25	4.17	4.1	2.2
Forecast risks	Demand uncertainty **(S10)**	22	3.67	3.7	1.7
	Wrong demand forecasting **(S11)**	24	4	4	1.41
Information risks	Poor IT system, lack of data standardization **(S12)**	27	4.5	4.4	1.22
	Asymmetries of the information, collaboration issues, restriction, not share information each department **(S13)**	21	3.5	3.5	1.83
Logistics risks	Dispensing/picking errors-medication/packaging (**S14)**	27	4.5	4.5	1.87
	Weak logistics service infrastructure **(S15)**	27	4.5	4.4	1.22
	Fragmentation of the drug distribution process **(S16)**	23	3.83	3.7	2.2
	Inadequate buffer stock-JIT/Lean **(S17)**	22	3.67	3.5	2.61
	Lack of visibility concerning placement and availability of stock **(S18)**	24	4	4	2
Procurement risks	Procurement Hub-introduce more complexity, long lead time **(S19)**	25	4.17	4.1	0.91
	Contract problems with suppliers **(S20)**	22	3.67	3.6	2.31
	Clinician's preference **(S21)**	25	4.17	4.2	2.61

	High purchase price **(S22)**	27	4.5	4.6	1.22
	High product and supplier/brand variety **(S23)**	25	4.17	4.2	1.68
Strategic risks	Focus on short term SC planning than long term **(S24)**	22	3.67	3.5	1.68
	Prioritization-conflict between patients/profits **(S25)**	21	3.5	3.6	1.87
Labour risks	Strikes and lack talents **(S26)**	23	3.83	3.6	2.61
	Lack of incentive mechanism **(S27)**	22	3.67	3.4	1.83
Natural risks	External influences-disaster recovery **(S28)**	26	4.33	4.2	1.83
	Unexpected disease outbreaks **(S29)**	28	4.67	4.5	1.15
	Unexpected changes in environment conditions **(S30)**	25	4.17	4	1.68
Man-made risks	Regulatory issues-manufacturing using licensing/change of standards/drug recalls **(S31)**	22	3.67	3.4	2.45
	Rigorous government interventions **(S32)**	22	3.67	3.4	2
	Lack of funds from government to the hospital **(S33)**	21	3.5	3.3	2.2
	The requirement of environment protection **(S34)**	22	3.67	3.6	1.83

* S.D.= Standard Deviation

Table 5.7: Ranking of the significance of healthcare supply chain risks (Questionnaire Survey)

Risk Factors	Sum	Rank (Sum)	Mean	Rank (Mean)	Weighted Average	Rank (W.A)	S.D.	Rank (S.D.)
S1	30	30	5	5	5	5	0	0
S2	28	28	4.67	4.67	4.8	4.8	1.15	0.91
S3	25	28	4.17	4.67	4.2	4.6	0.91	0.91
S4	27	27	4.5	4.5	4.6	4.6	1.22	1.15
S5	22	27	**3.67***	4.5	**3.6***	4.5	2.31	1.15
S6	22	27	**3.67***	4.5	**3.7***	4.5	1.15	1.15
S7	21	27	**3.5***	4.5	**3.6***	4.4	2.74	1.15
S8	26	27	4.33	4.5	4.3	4.4	1.15	1.22
S9	25	26	4.17	4.33	4.1	4.3	2.2	1.22
S10	22	26	**3.67***	4.33	**3.7***	4.2	1.7	1.22
S11	24	25	4	4.17	4	4.2	1.41	1.22
S12	27	25	4.5	4.17	4.4	4.2	1.22	1.41
S13	21	25	**3.5***	4.17	**3.5***	4.2	1.83	1.68
S14	27	25	4.5	4.17	4.5	4.1	1.87	1.68
S15	27	25	4.5	4.17	4.4	4.1	1.22	1.68
S16	23	25	**3.83***	4.17	**3.7***	4	2.2	1.7
S17	22	24	**3.67***	4	**3.5***	4	2.61	1.83
S18	24	24	4	4	4	4	2	1.83
S19	25	23	4.17	**3.83***	4.1	**3.7***	0.91	1.83
S20	22	23	**3.67***	**3.83***	**3.6***	**3.7***	2.31	1.83
S21	25	22	4.17	**3.67***	4.2	**3.7***	2.61	1.87
S22	27	22	4.5	**3.67***	4.6	**3.6***	1.22	1.87
S23	25	22	4.17	**3.67***	4.2	**3.6***	1.68	2
S24	22	22	**3.67***	**3.67***	**3.5***	**3.6***	1.68	2
S25	21	22	**3.5***	**3.67***	**3.6***	**3.6***	1.87	2.2
S26	23	22	**3.83***	**3.67***	**3.6***	**3.6***	2.61	2.2

S27	22	22	**3.67***	**3.67***	**3.4***	**3.6***	1.83	2.2
S28	26	22	4.33	**3.67***	4.2	**3.5***	1.83	2.31
S29	28	22	4.67	**3.67***	4.5	**3.5***	1.15	2.31
S30	25	22	4.17	**3.67***	4	**3.5***	1.68	2.45
S31	22	21	**3.67***	**3.5***	**3.4***	**3.4***	2.45	2.61
S32	22	21	**3.67***	**3.5***	**3.4***	**3.4***	2	2.61
S33	21	21	**3.5***	**3.5***	**3.3***	**3.4***	2.2	2.61
S34	22	21	**3.67***	**3.5***	**3.6***	**3.3***	1.83	2.74
* denotes the identified risk factors with both Mean and Weighted Average below 4.								

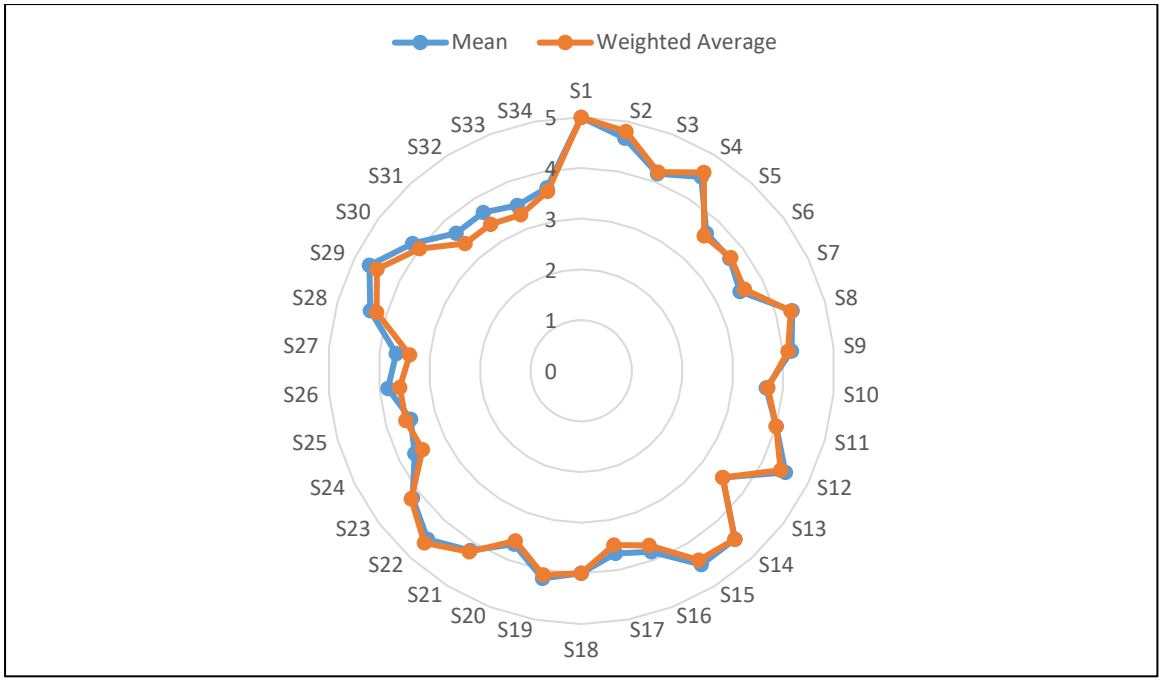


Figure 5-12: Comparison the results based on Mean and Weighted Average

range of many other values. Furthermore, a set of data was chosen based on the expert weighted average as the weighting of each expert has been considered.

Figure 5.12 illustrates the comparison between the data based on Mean and Weight Average for each risk factor. It showed that the results are almost the same as the two lines are close to each other. Therefore, an indication is that the proposed expert weighting criteria is reliable. In the questionnaire survey, the experts were asked to respond to the items by indicating their level of agreement using a five-point Likert scale *(i.e. 1=very unimportant, 2=minor unimportant, 3=moderate, 4=minor important and 5=very important)*. Finally, some risk factors with Weighted Averages below 4 were omitted by the end of the score analysis as they are less important or moderate. Those eliminated risk factors are highlighted in grey as shown in Figures 5.13 to 5.16.

As well, low Weighted Average values indicated that most of the experts expressed similar concerns about a particular factor. In this case, the remaining risk factors were observed to address other factors with low Means. The summary from the table shows the surveyed experts' in relation to the identified categories of supply chain risks to suggest the concerned hazardous events. Moreover, it also justifies the reliability and validity of the research findings on the methods of supply chain risk classification methods in the healthcare industry.

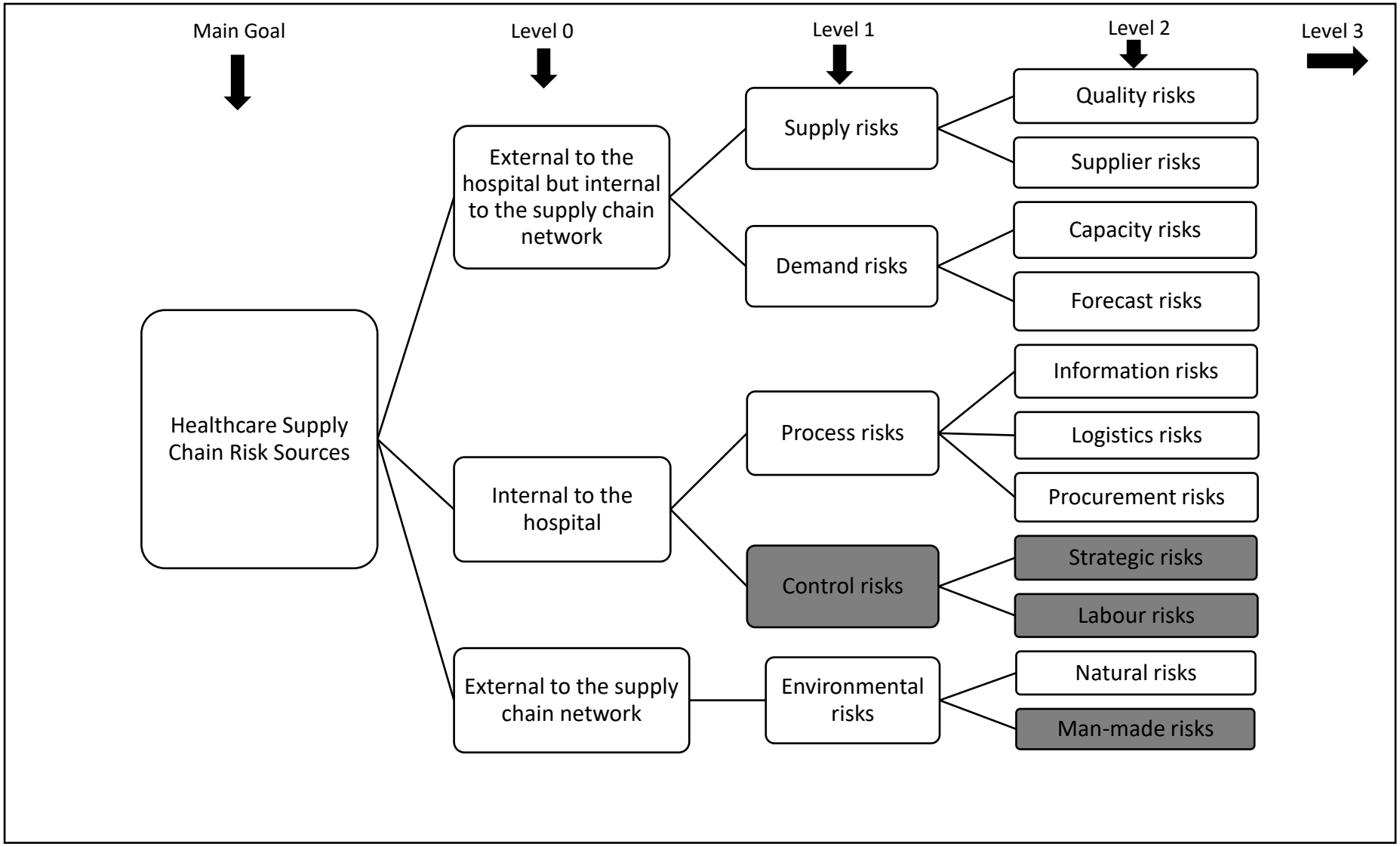


Figure 5-13: The modified hierarchical structure of healthcare supply chain risks

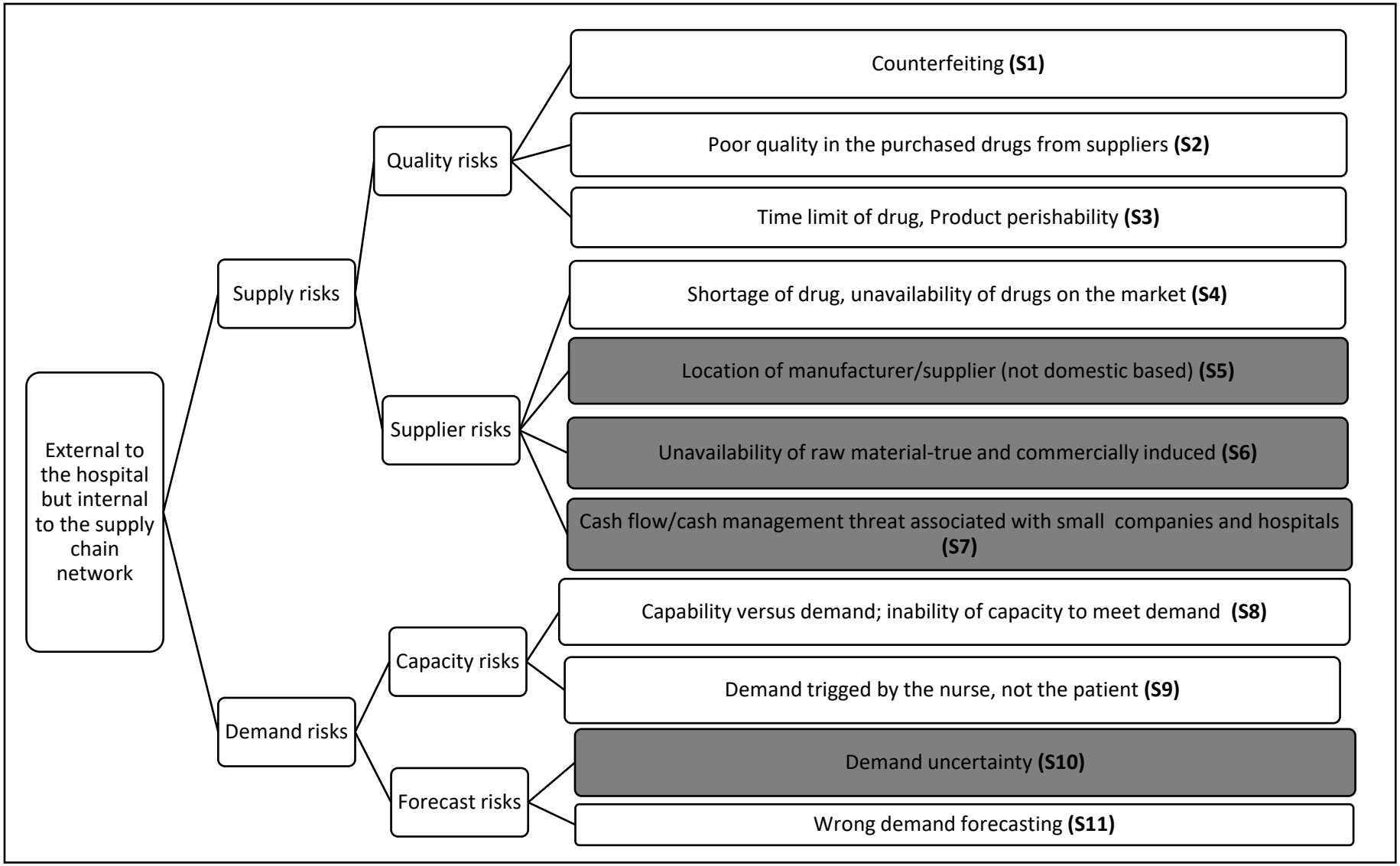


Figure 5-14: The modified External to the hospital but internal to the supply chain network risks hierarchical structure for healthcare SC

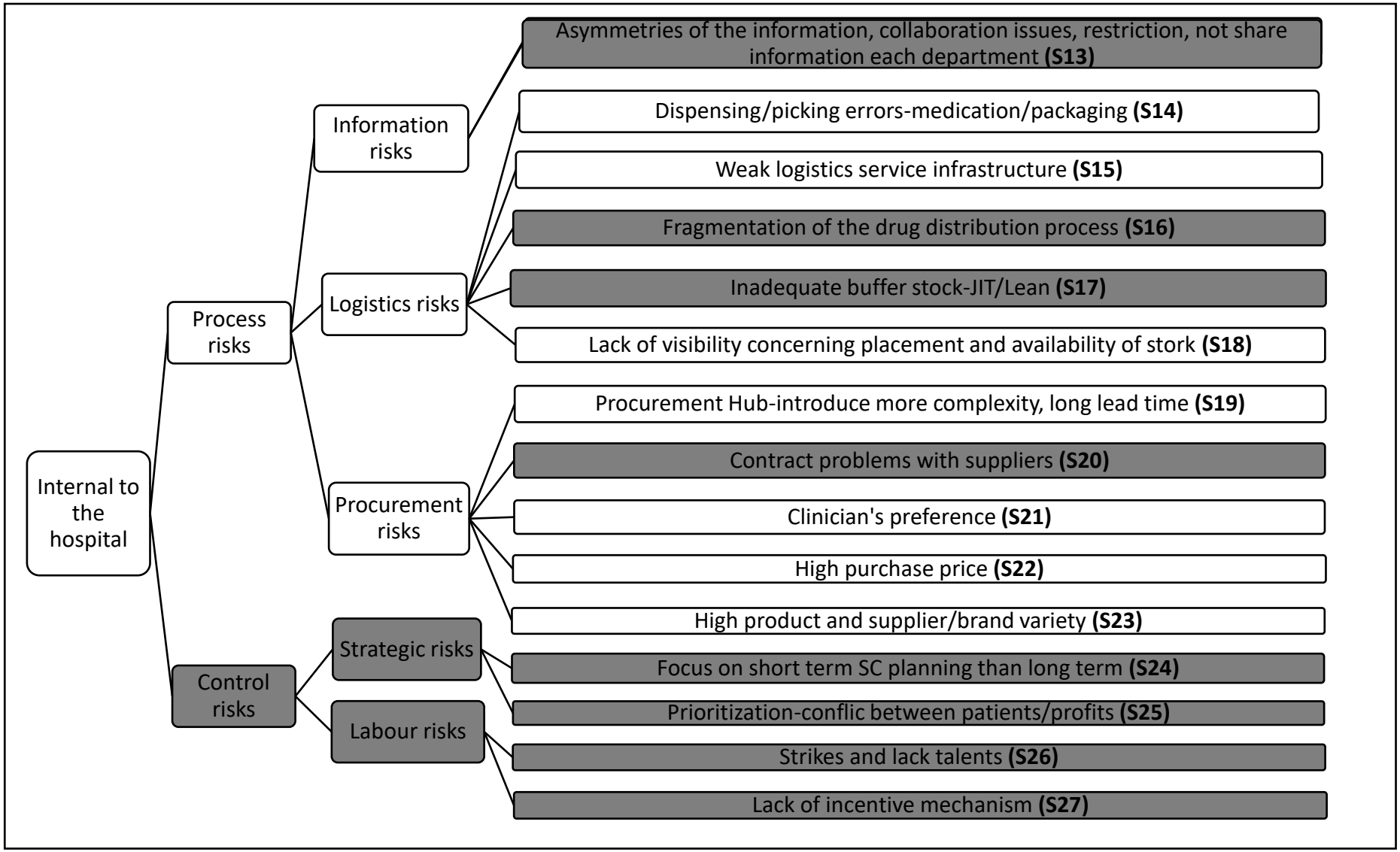


Figure 5-15: The modified Internal to the hospital risks hierarchical structure for healthcare SC

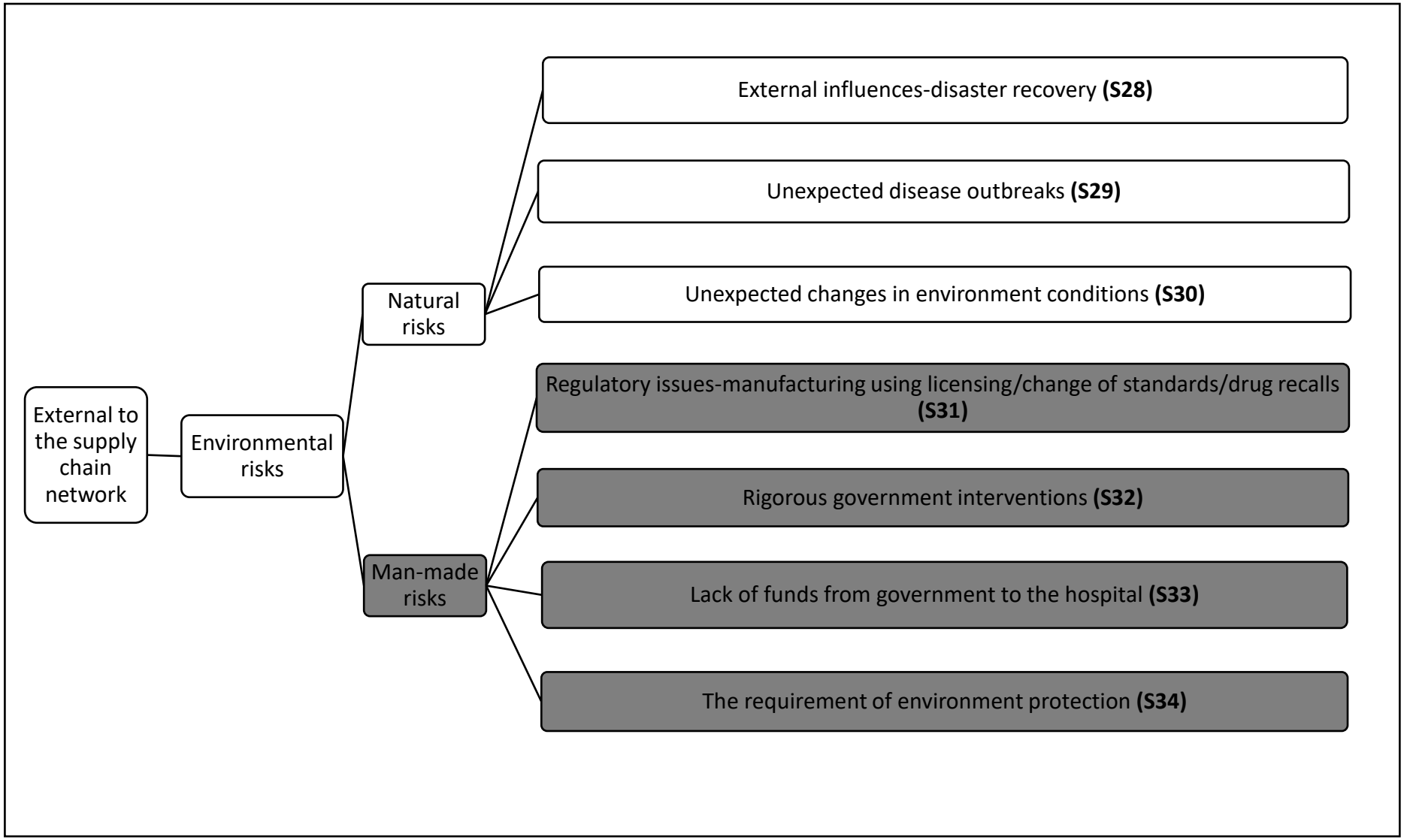


Figure 5-16: The modified External to the supply chain network risks hierarchical structure for healthcare SC

Among the total 34 risk factors, the results analysis according to the statistical means demonstrated that the quality related risks, including *counterfeiting (grey market activity) (5) and poor drug quality from suppliers (4.8), supplier related risks including shortage of drugs in the market (4.6), logistics related risks including dispensing/ picking error-medication/ packaging (4.5), procurement related risks including high purchase price (4.6), and natural disaster related risks, including unexpected disease outbreaks (4.5),* are of high concern to the experts, which could frequently be experienced within the healthcare supply chain networks. The significance for each identified risk factor is ranked to suggest the significant and influential factors to healthcare SC operations. Nevertheless, although the invited experts consisting of the people from different fields and countries, the results also reflect the consensus of their opinion under a different contexts. Thus, a typological model of healthcare SC risk factors was developed through the preceding discussion of risk factors in the healthcare SCs and integrating summarised questionnaire results. The identified healthcare SC risk factors are ranked in each categorisation and outlined in a hierarchical structure, shown in Figure 5.17.

Thereafter, to assure the validity and reliability of the developed hierarchy diagram, emails and face-to-face interviews were subsequently distributed and conducted with the "validation team" (six earlier experts as well as two academics with experience in supply chain and risk management who were not part of the expert panel). Finally, experts agreed and the developed hierarchy diagram was accepted without modification. Additionally, the experts offered informal advice and opinions, such as this research attend more to the 15 key recommendations provided in Lord Carter's report. Moreover, the risks can also be categorised as controllable and uncontrollable risk factors (Behnezhad *et al.,* 2013). In this thesis, more attention is paied to the several controllable risks instead of uncontrollable risks (*e.g.* natural risks). Collaboration and employing information communication technology (ICT) are also highly recommendations given by the experts as the key elements for efficiency risk mitigation strategies.

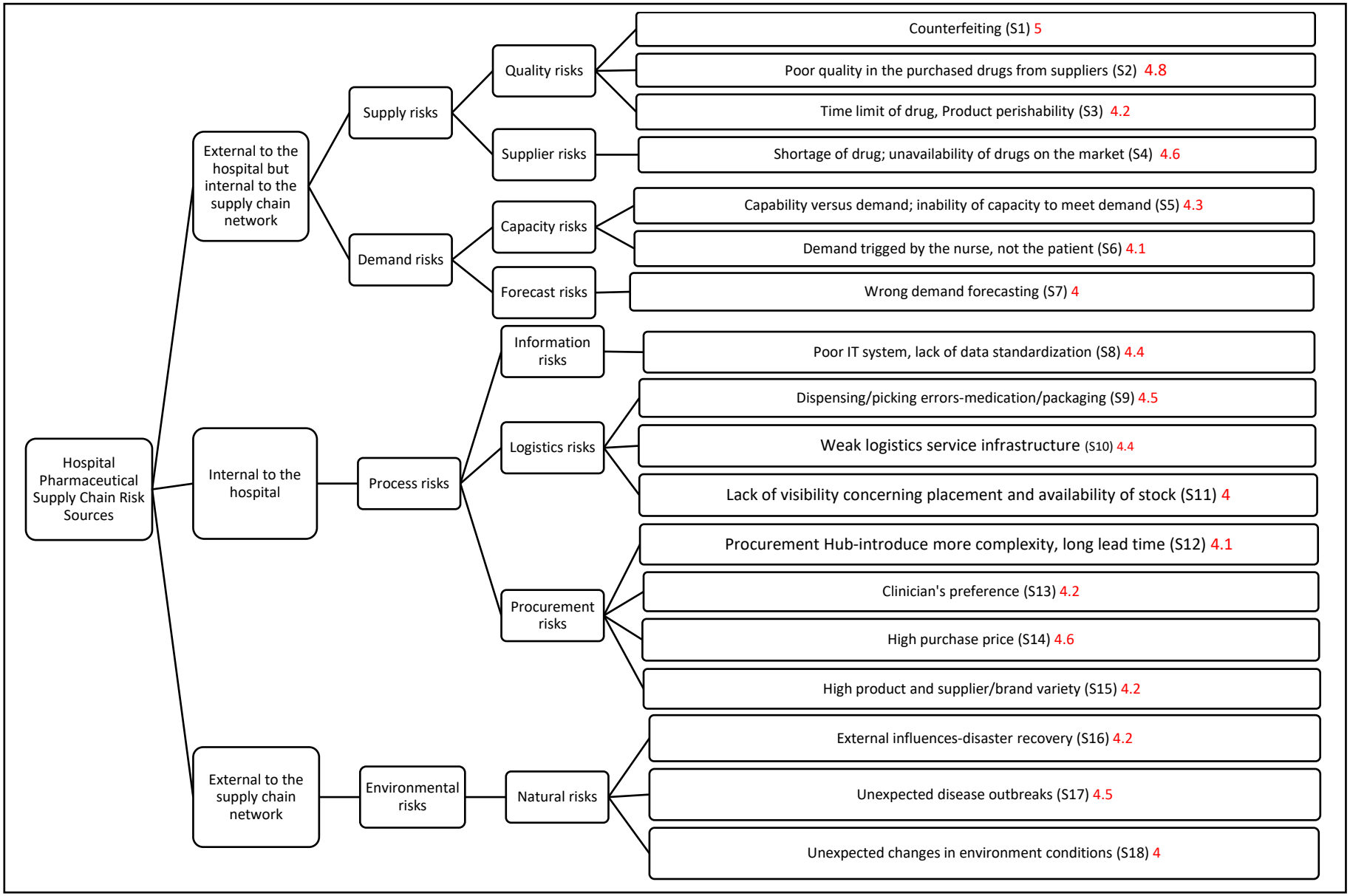


Figure 5-17: Final hierarchical structure of healthcare supply chain risks

5.4 CONCLUSION

This chapter recognises supply chain risk factors identification and classification as the significant process for conducting the efficient risk management. The literature review and the questionnaire survey serves as a base and guide to strengthen the knowledge base for supply chain risk factors identification. In order to identify the risk factors as completely as possible, the literature review investigated the broad risk classification methods addressed in the previous studies and the questionnaire survey and a series of emails as well as face-to-face interviews were established to develop a structural hierarchy risk taxonomic diagram.

In the thesis, a hierarchical risk classification is presented, which consists of five different supply chain risk categories (*i.e.* supply, demand, control, process and environment) based on organizational-related, network-related, and environmental-related. Thereafter, those five categories of risk factors were further divided into eleven different sub-categories risks: quality, supplier, capacity, forecast, information, logistics, procurement, strategic, labour, natural, and man-made risks.

The empirical studies in this chapter were carried out to make an inference about the experts'attitudes and opinions in order to capture the risk factors in a more comprehensive and reliable way. Meanwhile, the importance of the performance of the identified risk factors and developed classification model for the healthcare SC system was addressed. There is a consensus between the inputs from academic and industry experts. It provided a portfolio of risks and suggested the most concerning hazardous events from both academic and industrial perspectives. In the next chapter, the captured risk factors can be assessed by applying both Fuzzy AHP and ISM models to discover the priorities and context relations among them.

CHAPTER SIX – HEALTHCARE SUPPLY CHAIN RISK ASSESSMENT

6.1 INTRODUCTION

This chapter focuses on risk assessment using Fuzzy AHP to prioritise and detect the critical risk factors that can lead to serious consequences for healthcare SC operations. Furthermore, it will analyse those important risk factors using an ISM model to provide a comprehensive outline by considering their interconnectedness. Empirical studies were conducted to collect the primary data on the risk factor weighting and risk factors inter-relationship. It also illustrates the applications of the proposed methods. This will facilitate the decision-making process for choosing appropriate strategies and take preventive/corrective actions in later stages for mitigating risks towards a successful healthcare supply chain management.

6.2 METHODOLOGY FOR RISK ASSESSMENT IN HEALTHCARE SUPPLY CHAIN

Based on the developed integrated risk management model, a generic Fuzzy AHP and ISM based risk assessment model is proposed for determining and assessing the critical levels and interrelationship of identified risk factors. The proposed model is a key part in the RM model and the schematic diagram of the proposed Fuzzy AHP and ISM based risk assessment model is illustrated in Figure 6.1. The proposed Fuzzy AHP and ISM based risk assessment model will be implemented on the healthcare SC sector during risk assessment phases via carrying out the following steps:

Step 1: Developing a generic hierarchical structure based on the identified risk factors (this step has been done in the last chapter).

Step 2: Conducting the Fuzzy AHP based questionnaire survey to obtain the experts' judgement and opinions, the significance of the structured risk factors will be explored. These

judgements will be carried out in the form of the pre-defined linguistics variables which have been explained in Chapter four.

Step 3: The linguistic variables then will be transformed into the Triangular fuzzy numbers (TFNs) for the pair-wise comparisons.

Step 4: The consistency check test will be conducted on the comparison matrix in order to ensure that experts' judgements and pair-wise comparisons were reasonable.

Step 5: By use of the expert's judgements and pair-wise comparisons matrices the local and global weights of the risk factors will be calculated. Moreover, the risk factors will be ranked directly per their numerical priorities in order to show their significance.

Step 6: Those risk factors with high priorities will be selected to develop a structural self-interaction matrix (SSIM) on the basis of pairwise comparison of the risk factors.

Step 7: A questionnaire containing selected risk factors will be administered to the experts with an instruction to compare each and every pair of criteria depicted in SSIM.

Step 8: Construction of reachability matrix from the SSIM and checking for transitivity property.

Step 9: The obtained reachability matrix is partitioned into different levels.

Step 10: Drawing a directed graph by removing the transitivity links and also on the basis of reachability matrix.

Step 11: Conversion of diagraph into ISM model by replacing element nodes with statements. Moreover, the conceptual inconsistency of developed ISM model will be checked.

Step 12: MICMAC analysis will be carried out by investigating the driving and dependence power among each risk factor. Those risk factors with weak driving power and weak dependence will be removed and the remaining risks will be used for the risk mitigation strategies identification and evaluation.

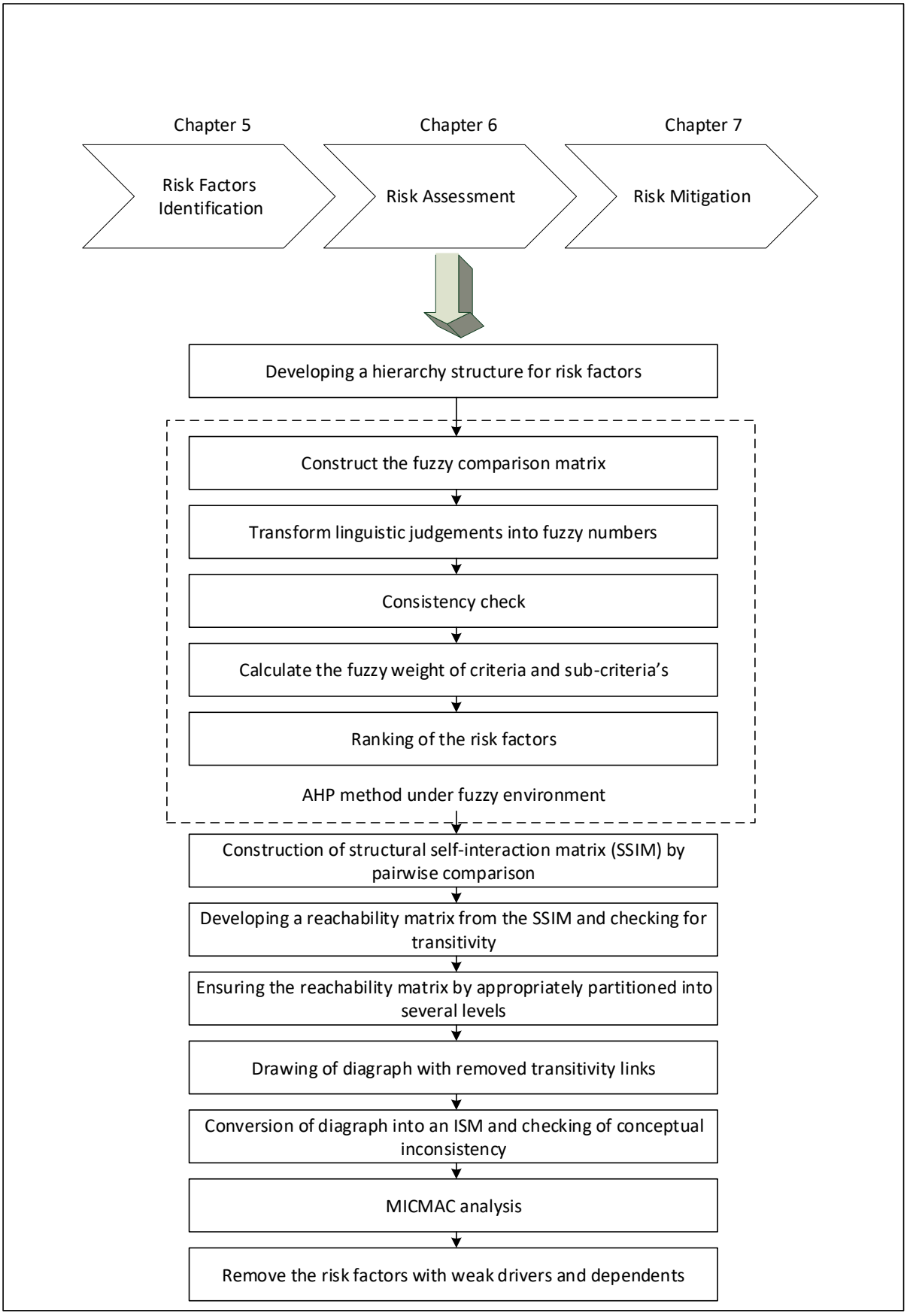


Figure 6-1: Proposed Fuzzy AHP and ISM based risk assessment model for healthcare SC

6.3 RISK ASSESSMENT WITH FUZZY ANALYTIC HIERARCHY PROCESS (FUZZY AHP)

For the purpose of solving various uncertain decision-making problems in the real world, it is necessary to handle the vagueness and uncertainty in the environment. Uncertainties in decision making process include, for example, ill-posed questions, imprecision in computation, ambiguity in data/knowledge representation, and some terms of expressing opinions, such as “neither agree nor disagree” and “nearly equal importance” can often be heard in daily life. It is acknowledged that some methods are widely used for dealing with these uncertainties, including heuristic approaches, possibility theory, probability theory, and fuzzy set theory (FST).

FST was originally proposed by Zadeh (1965) to deal with vagueness in human judgement, which oriented with the rationality of uncertainty due to ambiguity or vagueness. It is defined by a membership function that maps elements to degree of membership within a certain interval between o and 1 (Patil and Kant 2014). The main advantage of FST is to provide a range to express the vague data and to tackle the ambiguities involved in the process of linguistic estimation. In practice, these linguistic terms can be represented by fuzzy numbers. According to Chang’s (1996) definition, the fuzzy number is established when various factors have been considered in formation of a closed interval. This is represented as follows:

1) exists $x_0 \in R$ such that $\mu_M(x_0)$=1.

2) For any $a \in [0, 1]$.

$A_a = [x, \mu_A(x) \geq a]$

Then the fuzzy number will be represented by:

$M \in F(R)$

It is possible to use different fuzzy numbers according to the situation and in practice triangular and trapezoidal fuzzy numbers are the most commonly used (Klir and Yuan, 1995). Trapezoidal fuzzy numbers are specific case of triangular fuzzy numbers. A trapezoidal fuzzy number *A* is a fuzzy number denoted as *A= (a, b, c, d)* which membership function is defined as:

$$\mu_{A(x)} = \begin{cases} 0, & x < a \\ \mu_{l_A}(x) = \frac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \mu_{r_A}(x) = \frac{x-d}{c-d}, & c \le x \le d \\ 0, & otherwise \end{cases} \quad (6.1)$$

where a, b, c, d are real numbers and a<b<c<d. If b=c, it is defined a triangular fuzzy number.In applications it is often suitable to work with Triangular Fuzzy Numbers (TFNs) due to their computation ease, they are useful in supporting illustration and information processing under a fuzzy environment (Ertugrul and Karakasoglu, 2007). Moreover, this research applied Chang's (1996) extent analysis method. In this method an extent is quantified using triangular fuzzy number. This method is preferred over other fuzzy AHP method's because the method is easy, simple and its application similar to conventional AHP.

In this case, F(R) refers to all fuzzy sets established while R represents the set of real numbers. A fuzzy number M on R is defined as a triangular fuzzy number when its membership function, which is $\mu_M(X)$: R → [0, 1], is equivalent to the following function:

$$\mu_{M(x)} = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in \{l, m\}. \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in \{m, u\}. \\ 0, & otherwise \end{cases} \quad (6.2)$$

The membership function of TFN is illustrated in Figure 6.2.

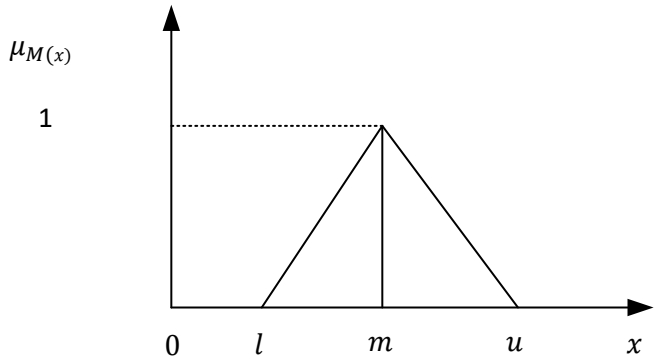


Figure 6-2: Membership function of TFN

In this case, *u* and *l* represent the respective upper and lower measures of the support of M, where m refers to the modal measure, and $l \leq m \leq u$. Therefore, (*l, m, u*) can be used to represent the triangular fuzzy number. In a situation where $l = m = u$, a non-fuzzy number is realized by convention. At the same time, the support of M is a collection of the following elements.

$$\{x \in R | l < x < u\}$$

Consider two triangular fuzzy numbers M_1andM_2,M_1=(l_1, m_1, u_1) and M_2=(l_2, m_2, u_2). The distance measurement d(M_1, M_2) is identical to the Euclidean distance. Then under fuzzy environments their basic operations laws such as addition i.e. +, multiplication i.e. ⊗ and their inverse can be depicted as follows:

$$(l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (6.3)$$

$$(l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (6.4)$$

$$(\lambda,\lambda,\lambda) \otimes (l_1, m_1, u_1) = (\lambda l_1, \lambda m_1, \lambda u_1) \quad \lambda \rangle 0, \lambda \subset R. \quad (6.5)$$

$$(l_1, m_1, u_1)^{-1} \approx (1/u_1, 1/m_1, 1/l_1) \quad (6.6)$$

The Analytic Hierarchy Process (AHP) was initially devised by Saaty (1977, 1980) as a powerful and flexible decision making method for the complex criteria structure in different levels. In principle, it aims to facilitate the decision maker to decompose the complex problems into a series of smaller sub-problems and enable making several pair-wise comparisons, assign priority weights to each element in different levels. It helps to provide a preference list of the best criteria that have the significant influence. However, despite the advantages of applying the AHP method mentioned above, it is believed to have some drawbacks since it is often used in nearly crisp-decision applications. The experts usually feel more confidence to make interval judgements rather than expressing their opinion in the form of single numeric values. Therefore, Fuzzy AHP extends the conventional AHP method by combing it with fuzzy set theory (FST) to solve such problems. Although Fuzzy AHP requires tedious computations, it is

capable of capturing the experts' judgement of ambiguity when complex multi-criteria decision making problems are considered.

It can be observed that many researchers have proposed Fuzzy AHP method in different areas. Van Laarhoven and Pedrycz (1983) initially use it to compare fuzzy ratios described by triangular membership functions. Buckley (1983) further determined fuzzy priorities of comparison ratios whose membership functions are trapezoidal. Both studies extended Saaty's conventional AHP method to deal with the imprecision and subjectivity of the pairwise comparison process using fuzzy numbers. Their fuzzy utilities need to be ranked to prioritise the concerned alternatives. This ranking method can be quite complex and may produce unreliable results. Mikhailov (2004) proposed a fuzzy preference programming method to derive optimal crisp priorities, which are obtained from fuzzy pairwise comparison judgements based on α-cuts decomposition of the fuzzy judgements into a series of interval comparisons. The most widely accepted Fuzzy AHP method is proposed by Chang (1992, 1996) to introduce a new extent analysis approach for the synthetic extent values of the pairwise comparison. The proposed method with extent analysis is simple and easy for implementation to prioritise decision variables as compared with the conventional AHP method.

As suggested by Chang (1996), the fuzzy AHP's pair-wise comparison scale uses triangular fuzzy numbers, which by integrating the extent analysis method, the introduction of the pair-wise comparison's synthetic extent value S_i is achieved. The principle used is the comparison of fuzzy numbers to estimate the weight vectors. The value of fuzzy synthetic extent can be defined by taking each object and carrying out an extent analysis for each goal. Considering that $X = \{x_1, x_2 ...., x_n\}$ is a goal set and $G = \{g_1, g_2 ...., g_n\}$ as an object set, the *m* extent analysis values can be achieved for each object as follows:

$\widetilde{M}_{g_i}^1, \widetilde{M}_{g_i}^2, \ldots, \widetilde{M}_{g_i}^m, i = 1,2, \ldots n.$

Where the triangular fuzzy numbers are represented by the following:

$\widetilde{M}_{g^i}^j. (j = 1,2, \ldots m)$

The sequences of Chang's analysis can be given in the following sections (Chang, 1996):

Firstly: The value of fuzzy synthetic extent with respect to the i th object is defined as:

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{g^i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g^i}^{j} \right]^{-1} \tag{6.7}$$

To obtain $\sum_{j=1}^{m} M_{g^i}^{j}$, perform the fuzzy addition operation of *m* extent analysis value for a particular matrix such that:

$$\sum_{j=1}^{m} \widetilde{M}_{g^i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{6.8}$$

and to obtain $\left[\sum_{j=1}^{n} \sum_{i=1}^{m} \widetilde{M}_{g^i}^{j} \right]^{-1}$, perform the fuzzy addition operation of

$\widetilde{M}_{g^i}^{j}$(j= 1, 2, …, *m*) values such that:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g^i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \tag{6.9}$$

and then compute the inverse of the vector above, such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g^i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{6.10}$$

Calculating the priority vectors of the fuzzy AHP requires the consideration of comparison for fuzzy numbers principle, which involves determining the fuzzy value of the greatest or least

number. This is achieved by evaluating the degree of possibility of $\widetilde{M}_2 = (l_2, m_2, u_2) \geq \widetilde{M}_1 = (l_1, m_1, u_1)$, and it is defined as follows:

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = \sup_{y \geq x}[\min(\mu_{\widetilde{M}_1}(x), \mu_{\widetilde{M}_2}(y))] \tag{6.11}$$

and can be equivalently expressed as follows:

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = hgt(\widetilde{M}_1 \cap \widetilde{M}_2) = \mu\widetilde{M}_2(d) \tag{6.12}$$

$$= \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \quad . \end{cases} \tag{6.13}$$

Figure 6.3 illustrates Eq. 6.12 where *d* is the ordinate of the highest intersection point *D* between $\mu\widetilde{M}_1$ and $\mu\widetilde{M}_2$. To compare $\widetilde{M}_1$ and $\widetilde{M}_2$, it requires both the values of "$V(\widetilde{M}_1 \geq \widetilde{M}_2)$" and "$(\widetilde{M}_2 \geq \widetilde{M}_1)$"

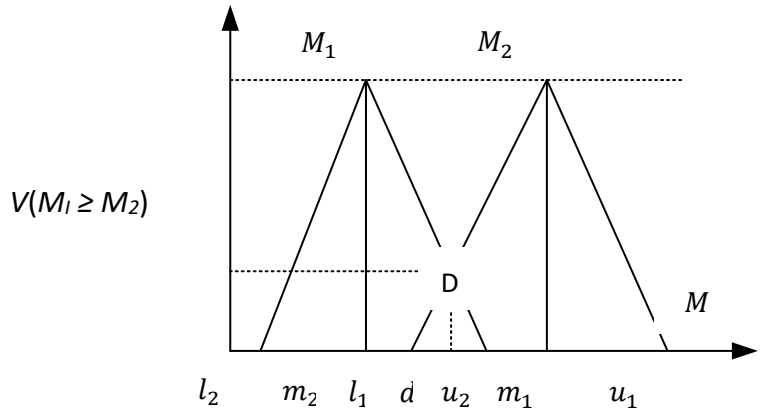


Figure 6-3: The intersection between M_1 and M_2

The degree of possibility for a convex fuzzy number to be greater than *k* convex fuzzy $\widetilde{M}_1(i = 1,2,k)$ numbers can be defined by:

$$V(\widetilde{M} \geq \widetilde{M}_1, \widetilde{M}_2, \dots M_k) = V[(\widetilde{M} \geq \widetilde{M}_1 and\ (\widetilde{M} \geq \widetilde{M}_2) and \dots . and\ (\widetilde{M} \geq \widetilde{M}_k)]$$

$$= min\, V\left(\widetilde{M} \geq \widetilde{M}_i\right), i = 1,2,3, \ldots, k \tag{6.14}$$

Assume that $d(A_i) = minV(S_i \geq S_k)$ for K= 1,2, …, n; k ≠i. then the weight vector is given by

$$W' = (d'(A_{1),}d'(A_2), \ldots., d'(A_n))^T \tag{6.15}$$

Where A_i is ith element and $d'(A_1), \ldots., d'(A_n)$ are priority weights calculated by Eq.6.13 before their normalization.

In the end, via normalization, the normalized weight vectors are:

$$W = (d(A_{1),}d(A_2), \ldots., d(A_n))^T \tag{6.16}$$

where W is a non-fuzzy number.

In this chapter, Chang's extent analysis method is used since this approach is widely acceptable and easier than other Fuzzy AHP approaches. The triangular fuzzy numbers (TFNs) are applied as a pairwise comparison scale for deriving the weights of the criteria (i.e. risks) and sub-criteria (i.e. sub-risks). In practice, experts usually express the opinion using the linguistic variables to appraise the importance of one criterion over another or even to rank the alternatives with respect to various criteria. Table 6.1 illustrates the idea of the Fuzzy Multi-Attribute Criteria Decision-making (FMACD) has intentionally transformed the existing linguistic values to TFNs *i.e.* equal, weak, strong, very strong and absolute strong importance along with their values, and the illustration of membership function of triangular fuzzy numbers used in Fuzzy AHP is presented in Figure 6.4. The purpose of the transformation process is to illustrate the application of the proposed method and benchmark the empirical results using other precise value methods in the later analysis. Moreover Ma *et al.,* (2007) and Karahalios (2009) highlighted the following issues when using linguistic variables:

- Experts need to select linguistic terms for presenting their opinions by their preference. It is not demanded that all experts must use the same linguistic terms.
- It is not required for all linguistic terms to be placed symmetrically and to have total order. Therefore experts and decision makers have more independent right to present their opinions.
- Each linguistic term should be treated as a whole and the only concern is on its determinacy and consistency.

Among the commonly used fuzzy numbers, triangular and trapezoidal fuzzy numbers are likely to be the adoptive ones due to their ease in modelling easy interpretations. Anoop *et al.,* (2006) explain it is known that for engineering applications, to reduce the computational complexity, fuzzy sets with triangular or trapezoidal form are most commonly used. Both triangular and trapezoidal fuzzy numbers are applicable to the present study; however, this study use TFN for Fuzzy AHP application due to its easiness in use. In practical applications, the triangular form of the membership function is used most often for representing fuzzy numbers (Ding and Liang, 2005; Karsak and Tolga, 2001). TFN can adequately represent the mentioned fuzzy linguistic variables, thus it is used for the analysis thereafter. During the calculations whenever it is supposed to carry out a pair-wise comparison between the same criterion e.g. to compare criterion C_1 with C_2, C_2 with C_3 *etc* obviously the result is equal is 1 in which its converted TFN will be (1,1,1).

Table 6.1: Linguistic scales for difficulty and importance

Linguistic judgement	Triangular fuzzy number (l,m,u)	Inverse linguistic judgements	Inverse triangular fuzzy scale
Equal importance (Eq)	(1, 1, 1)	Equal importance (Eq)	(1, 1, 1)
Weak importance (Wk)	(2/3, 1, 3/2)	Weak importance (Wk)	(2/3, 1, 3/2)
Strong importance (St)	(3/2, 2, 5/2)	Strong importance (St)	(2/5, 1/2, 2/3)
Very strong importance (Vs)	(5/2, 3, 7/2)	Very strong importance (Vs)	(2/7, 1/3, 2/5)
Absolute strong importance (As)	(7/2, 4, 9/2)	Absolute strong importance (As)	(2/9, 1/4, 2/7)

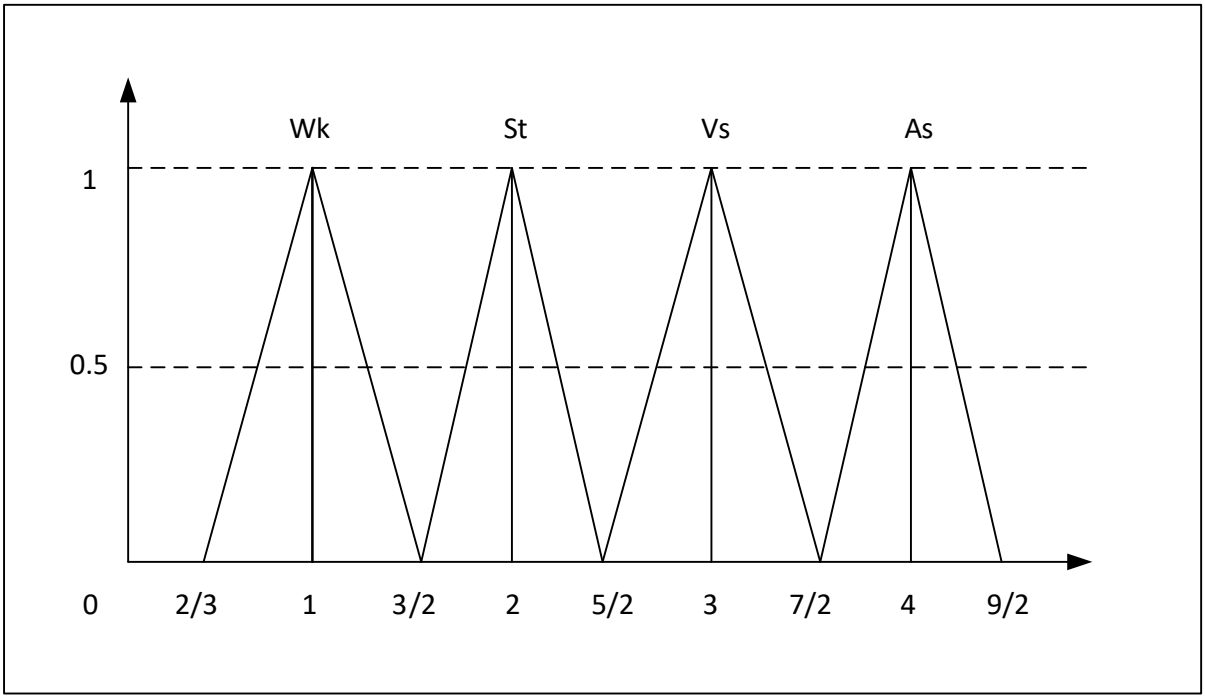


Figure 6-4: The membership functions of the triangular fuzzy numbers

6.4 AN EMPIRICAL STUDY ON THE APPLICABILITY OF THE FUZZY AHP METHOD

To investigate the significance of the identified healthcare supply chain related risks, a Fuzzy AHP method has been developed. This study was executed in four phases: (1) conducting a questionnaire survey, including questionnaire formulation, pilot study, and the selection of experts, (2) data collection, description, and analysis, (3) testing the robustness of the proposed method and (4) the finding discussion.

6.4.1 Conducting the Fuzzy AHP-based questionnaire survey

Prior to actual data collection, content validity was performed to improve the clarification of the questionnaire. A cover letter and questionnaire were drafted and the same forward as well as backward translation process was applied on the questionnaires as was applied earlier. Two drafted versions of the questionnaires with different languages were further examined by two academic researchers and two specialists from Universities in the UK and China for comments. Their feedbacks were useful for the final drafted questionnaire, which was used for a pilot study. The pilot study was conducted by asking different judges to pre-assess the

questionnaires effectiveness, accuracy and unambiguous communication with the experts. Ethical approval was also obtained to further validate the questionnaire contents and participant consent. The final questionnaire is shown in Appendix Two.

In Section A, the personal details of the experts were included in order to verify their organization, position, and length of working year, which can be used for the evaluation of each expert's proficiency. Section B firstly provides the predefined linguistic terms for experts to make decisions in the rest of the questionnaire. The experts are asked to choose a set of pairwise comparisons for demonstrating the extent to which a risk factor is more important than another in each pair. The last part of Section B has ten matrices which need to be duly marked as per experts' judgements.

The target sample is selected from the National Health Service (NHS) Choices which provides the comprehensive health information service including all NHS hospitals in England, to support patients making the best choices. In China, the target sample was selected from a list from the Chinese National Hospital Association. The main factor in selecting experts was their expertise and their contribution to the fields related to the identified risk factors. Experts who specialize in supply chain and logistics related work in hospitals were selected as the respondents. The research also used publicly available directories and LinkedIn to obtain contact details. For the pharmaceutical manufacturer and distributor, the relevant information was provided from some hospitals involved into our empirical studies. Moreover, the NHS Supply Chain has been providing supply chain services to the UK NHS since 2006. As well, the LogHealth Center in Thailand is one of three research institutes that specialize in the healthcare supply chain management. Thus, those consulting organizations are also selected as the respondents in this research. In total 231 UK NHS hospitals, eleven Chinese hospitals, seven pharmaceutical distributors/companies, NHS Supply Chain, and LogHealth Center were selected and each organization was sent several questionnaire surveys to relevant departments, *e.g.* director, pharmacy department, operation department, material department, and procurement department. The target respondents were first asked by email or phone call whether they were willing to take participate in our survey. Then, the link to the online questionnaire via eSurveyCreator or email questionnaire were distributed. In total 431

questionnaires were distributed in 14th Feb 2017 with 72 replies in three months, including 56 valid and 16 invalid questionnaires as the respondents did not answer all the questions of this survey, within a month. The valid return rate is 13 per cent, see Table 6.2.

Table 6.2: Questionnaires return detail

Questionnaire distributed	Questionnaire returned	Invalid replies	Valid replies	Valid reply rate
431	72	16	56	13%

Table 6.3 presents the 56 respondents' profile. Approximately 55 per cent of respondents have already worked within the healthcare industry for more than 16 years. This indicates that most respondents have long professional working experiences in the relevant supply chain and logistics operations and therefore the results of this survey have a high reliability. From the types of organization, most respondents are working in the hospital (76 per cent in total, 30 per cent from Chinese hospitals and 70 per cent from UK NHS), followed by the supply chain consulting agency (11 per cent in total, 5 experts from LogHealth Center and one from the NHS supply chain), and pharmaceutical distributor/companies (13 per cent, all respondents from China). Although in this survey the author has tried to distribute the questionnaire to the pharmaceutical distributor/companies in the UK since the response rates from different departments appeared to be quite different. The unbalanced samples might cause bias in the risk assessment. Nevertheless, the similar structure of the healthcare supply chain in both countries and each respondent from the Chinese pharmaceutical companies holding the position at a manager level may reduce such bias. In addition, the validity test of the survey results is conducted by some respondents from UK NHS could also ensure the reliability of this survey.

In terms of the professional role, the largest type of respondent' role is head of procurement/pharmacy department leader (38 per cent) in charge of all the hospital's supply chain and logistics activities, and the second group is head of supply chain, logistics and warehouse manager (16 per cent). Most respondents hold a position at or above the manager

level and have the power to make decisions within healthcare organizations. From the classification degree China's hospitals, most are 3A grade with at least 500 beds and 25 care departments, and so forth.

Table 6.3: respondents' profile

		Number	%
What is the type of your organization?	Pharmaceutical Manufacturer	0	0
	Pharmaceutical distributor (pharmaceutical company)	7	13%
	Hospital	43	76%
	Other	6	11%
What is your job title?	Head of Procurement/Pharmacy department leader	21	38%
	Purchase/procurement Manager (Non-clinical, clinical)	8	14%
	Head of Supply chain, Logistics, Materials, Warehouse	9	16%
	Head of Contracts, category, IT manager, E-commerce	3	5%
	General manager (pharmaceutical company)	7	12%
	Supply chain consulting institute	6	11%
	Hospital Director	2	4%
For how many years have you worked in the healthcare industry or healthcare supply chain?	1 – 5 years	0	0
	6 – 10 years	9	16%
	11 – 15 years	16	29%
	16 – 19 years	13	23%
	≥20 years	18	32%
Location based	UK	31	55%
	China	20	36%
	Thailand	5	9%

6.4.2 Numerical illustration

The fuzzy AHP phase obtained respondents' judgements about the relative importance of identified risk factors and calculated total weights. The details of the data analysis are described in the following steps.

Step 1, Structure problem hierarchy

The first step is to construct the problem into a hierarchy including a goal, set of criteria and sub-criteria. As Fuzzy AHP method is employed only for the risk assessment in this research, thus the decision alternatives are not carried out in the hierarchy. The hierarchical structure was built from the previous chapter as shown in Figure 6.5.

Step 2. Construct fuzzy pairwise comparison matrices

Table 6.4: Linguistic judgements for Fuzzy AHP

Linguistic judgements	Explanations
Equal importance (Eq)	Two activities contribute equally to the objective
Weak importance (Wk)	Experience and judgement slightly favour one over another
Strong importance (St)	Experience and judgement strongly favour one over another
Very strong importance (Vs)	An activity is favoured very strongly over another
Absolute strong importance (As)	The evidence favouring one activity over another is of the highest possible order of affirmation

In this step, the respondents were asked to compare each risk factor at a given level of the hierarchy on a pair-wise basis. This is to measure their relative importance. It is noteworthy that the input to the risks has to be well-defined to give the experts an exact understanding of all risks that have to be assessed. This research uses the basic linguistic preference as equal importance (Eq), weak importance (Wk), Strong importance (St), Very strong importance (Vs) and Absolute strong importance (As). Instead of using nine-point scales for the judgments as the traditional AHP, the fuzzy AHP uses linguistic preference to take into account the uncertain preference of the decision maker. Moreover, it is easier to use these terms to express the respondents' feelings of judgements like good, bad etc (Kunal *et al.,* 2013). The

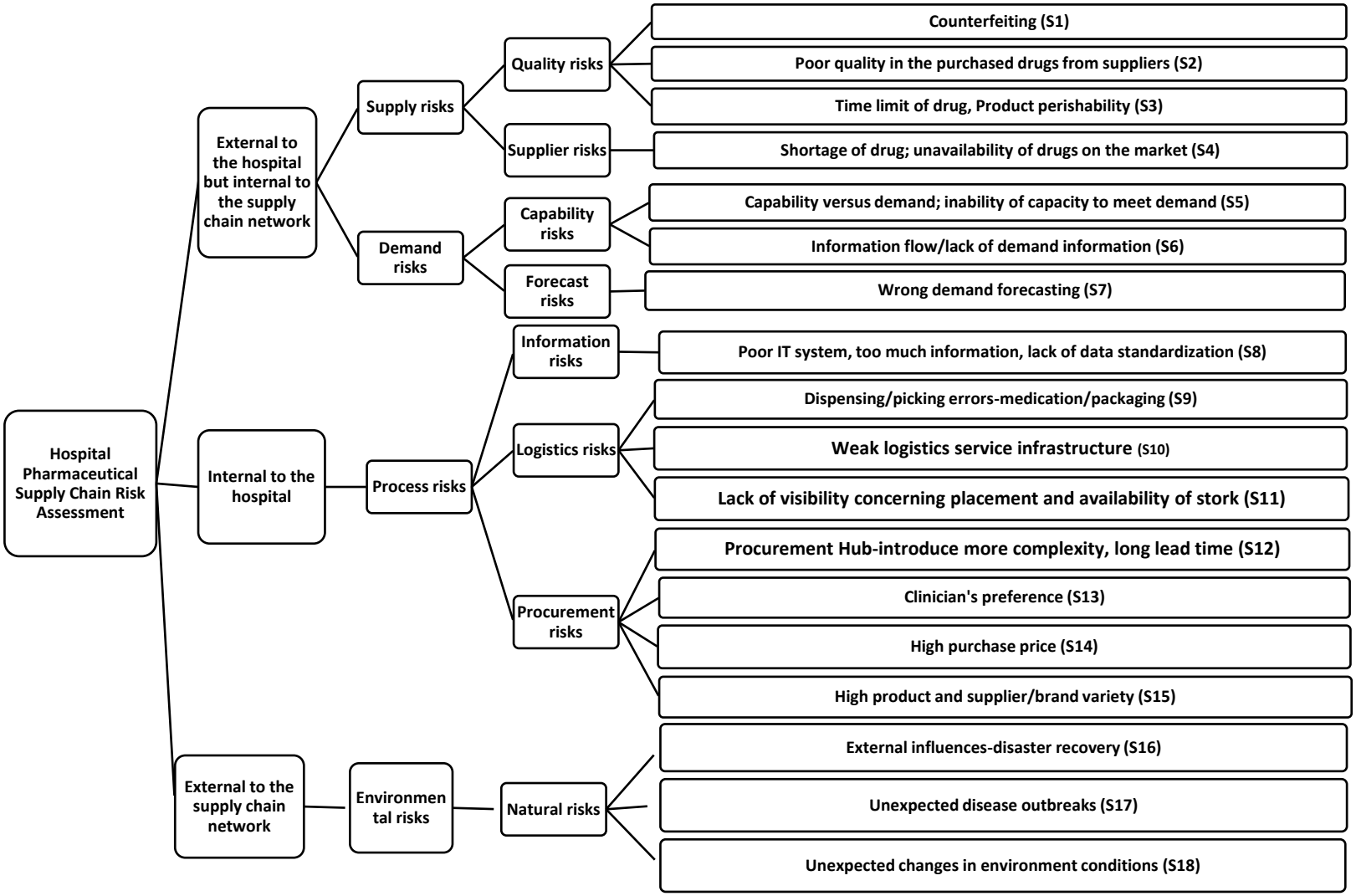


Figure 6-5: Hierarchical structure of healthcare supply chain risks

linguistic judgements and their explanations used for measuring the importance of the risk factors in pair-wise comparisons are shown in Table 6.4.

Step 3. Transform linguistic judgements into fuzzy numbers

In this step, after received the 56 valid questionnaires, the linguistic terms need to transform into triangular fuzzy numbers as shown in Table 6.5. In order to save space, the author only presents the results of the fuzzy AHP for one selected respondent's opinion. The result of the fuzzy pair-wise comparison matrix at criteria layer is shown in Table 6.6. The consistency ratio of the criteria level is 0.033.

Table 6.5: Linguistic scales for difficulty and importance

Linguistic judgement	Triangular fuzzy number (l,m,u)	Inverse linguistic judgements	Inverse triangular fuzzy scale
Equal importance (Eq)	(1, 1, 1)	Equal importance (Eq)	(1, 1, 1)
Weak importance (Wk)	(2/3, 1, 3/2)	Weak less importance (Wk)	(2/3, 1, 3/2)
Strong importance (St)	(3/2, 2, 5/2)	Strong less importance (St)	(2/5, 1/2, 2/3)
Very strong importance (Vs)	(5/2, 3, 7/2)	Very strong less importance (Vs)	(2/7, 1/3, 2/5)
Absolute strong importance (As)	(7/2, 4, 9/2)	Absolute strong less importance (As)	(2/9, 1/4, 2/7)

Table 6.6: The fuzzy pair-wise comparison matrix of three criteria

Linguistic judgement	External to the hospital but internal to the supply chain network	Internal to the hospital	External to the supply chain network
External to the hospital but internal to the supply chain network	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
Internal to the hospital	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
External to the supply chain network	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(1, 1, 1)
C.R. = 0.033			

The AHP method provides a measure of the consistency of pairwise comparisons by introducing the Consistency Index (CI) and Consistency Ratio (CR), which can be calculated by using Eq. 6.17 and Eq. 6.18. The λ_{max} is the maximum average of the values or the maximum eigenvalue of an *n*n* comparison matrix and is calculated by Eq. 6.19. RI is the random index for the matrix size, *n* and depends on the number of items being compared and is shown in Table 6.7 (Saaty, 1994). If CR is valued less than or equal to 0.1 then a consistency is indicated and the pairwise comparisons are reasonable.

It needs to be mentioned that the survey will be sent back to the respondents to revise the choice if the C.R. is larger than 0.1.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{6.17}$$

$$CR = \frac{CI}{RI} \tag{6.18}$$

$$\sum_{i=1}^{n} x_{ij}\, w_i = \lambda_{max} W_j; \quad \text{where } i=1,2, \ldots, n \tag{6.19}$$

Table 6.7: Average random index value

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: based on Saaty (1994)

Before the fuzzy weights for each risk factor was calculated, every preferences made by the individual respondent were aggregated into a group preference for each risk factor. The aggregation of the triangular fuzzy numbers (TFNs) were performed by applying two mathematical models, namely an Arithmetic Mean method and a Geometric Average method. According to the literature, most researchers have highly recommended that the Geometric Average method as more reliable (Kahraman *et al.,* 2003; Ramkumar, 2016), However, in order to obtain more reliable and accurate results in this thesis, both mathematical models have been applied. The result of the fuzzy matrix at the criteria layer

using Arithmetic Mean method is shown in Table 6.8; and the results of the fuzzy matrix at the criteria layer using Geometric Average method is shown in Table 6.9.

Table 6.8: The fuzzy pair-wise comparison matrix of three criteria (Arithmetic Mean method)

	External to the hospital but internal to the supply chain network	Internal to the hospital	External to the supply chain network
External to the hospital but internal to the supply chain network	(1, 1, 1)	(1.23, 1.4, 1.64)	(1.5, 1.85, 2.3)
Internal to the hospital	(0.97, 1.1, 1.26)	(1, 1, 1)	(1.6, 1.9, 2.3)
External to the supply chain network	(0.63, 0.78, 0.99)	(0.65, 0.8, 0.99)	(1, 1, 1)
C.R. = 0.013			

Table 6.9: The fuzzy pair-wise comparison matrix of three criteria (Geometric Average method)

	External to the hospital but internal to the supply chain network	Internal to the hospital	External to the supply chain network
External to the hospital but internal to the supply chain network	(1, 1, 1)	(1, 1.15, 1.3)	(1.25, 1.65, 1.96)
Internal to the hospital	(0.77, 0.87, 0.99)	(1, 1, 1)	(1.26, 1.56, 1.9)
External to the supply chain network	(0.51, 0.63, 0.8)	(0.55, 0.64, 0.79)	(1, 1, 1)
C.R. = 0.001			

Step 4. Calculate fuzzy weights

In this step, the fuzzy weights of the criteria and sub-criteria are calculated, based on the extent analysis method suggested by Chang (1996). It is a widely accepted methodology which has been used by several researchers owing to its simplicity. The extent analysis method was

applied to consider the extent of an object or criteria to be satisfied for the goal. (Kunal *et al.,* 2013)

The numerical analysis of deciding the weight vectors of the criteria with respect to goal is discussed as follows:

The fuzzy comparison matrix of the criteria by Arithmetic Mean method as an example which is shown in Table 6.9. The fuzzy synthetic extent value with respect to each criterion was calculated by using Eq. 6.7.

The different values of fuzzy synthetic extent with respect to the three different criteria were denoted byS_1,S_2, S_3, respectively.

S_1 = (3.73, 4.25, 4.94) $\otimes$ (1/12.48, 1/10.83, 1/9.58) = (0.3, 0.39, 0.52)

S_2= (3.57, 4, 4.56) $\otimes$ (1/12.48, 1/10.83, 1/9.58) = (0.29, 0.37, 0.48)

S_3 = (2.28, 2.58, 2.98) $\otimes$ (1/12.48, 1/10.83, 1/9.58) = (0.18, 0.24, 0.31)

These fuzzy synthesis values were compared with each other by using Eq. 6.13 of the extent analysis as follows:

V($S_1 \geq S_2$)= 1

V($S_1 \geq S_3$)= 1

V($S_2 \geq S_1$)= $\frac{0.3-0.48}{(0.37-0.48)-(0.39-0.3)} = 0.9$

V($S_2 \geq S_3$)= 1

Similarity, V($S_3 \geq S_1$)= $\frac{0.3-0.31}{(0.24-0.31)-(0.39-0.3)}$ = 0.06

V($S_3 \geq S_2$)= $\frac{0.29-0.31}{(0.24-0.31)-(0.37-0.29)}$ = 0.13

Then priority weights were calculated by using Eq. 6.14 of the extent analysis as follows:

d'(C_1)= min V($S_1 \geq S_2, S_3$) = min (1, 1) = 1,

Similarity, d'(C_2)= min V($S_2 \geq S_1, S_3$) = min (0.9, 1) = 0.9

d'(C_3)= min V($S_3 \geq S_1, S_2$) = min (0.06, 0.13) = 0.06

Therefore the weight vector was given as

W'= $(1, 0.9, 0.06)^T$

Finally after normalisation of these value as per Eq. 6.16 of the extent analysis, the weight vector with respect to criteriaC_1, C_2, C_3 is obtained as follows. The complete result is also given in Table 6.10.

W= $(0.51, 0.46, 0.03)^T$

Table 6.10: The fuzzy pair-wise comparison matrix of three criteria (Arithmetic Mean method)

	External to the hospital but internal to the supply chain network	Internal to the hospital	External to the supply chain network	Weight
External to the hospital but internal to the supply chain network	(1, 1, 1)	(1, 1.15, 1.3)	(1.25, 1.65, 1.96)	0.51
Internal to the hospital	(0.77, 0.87, 0.99)	(1, 1, 1)	(1.26, 1.56, 1.9)	0.46
External to the supply chain network	(0.51, 0.63, 0.8)	(0.55, 0.64, 0.79)	(1, 1, 1)	0.03
C.R. = 0.001				

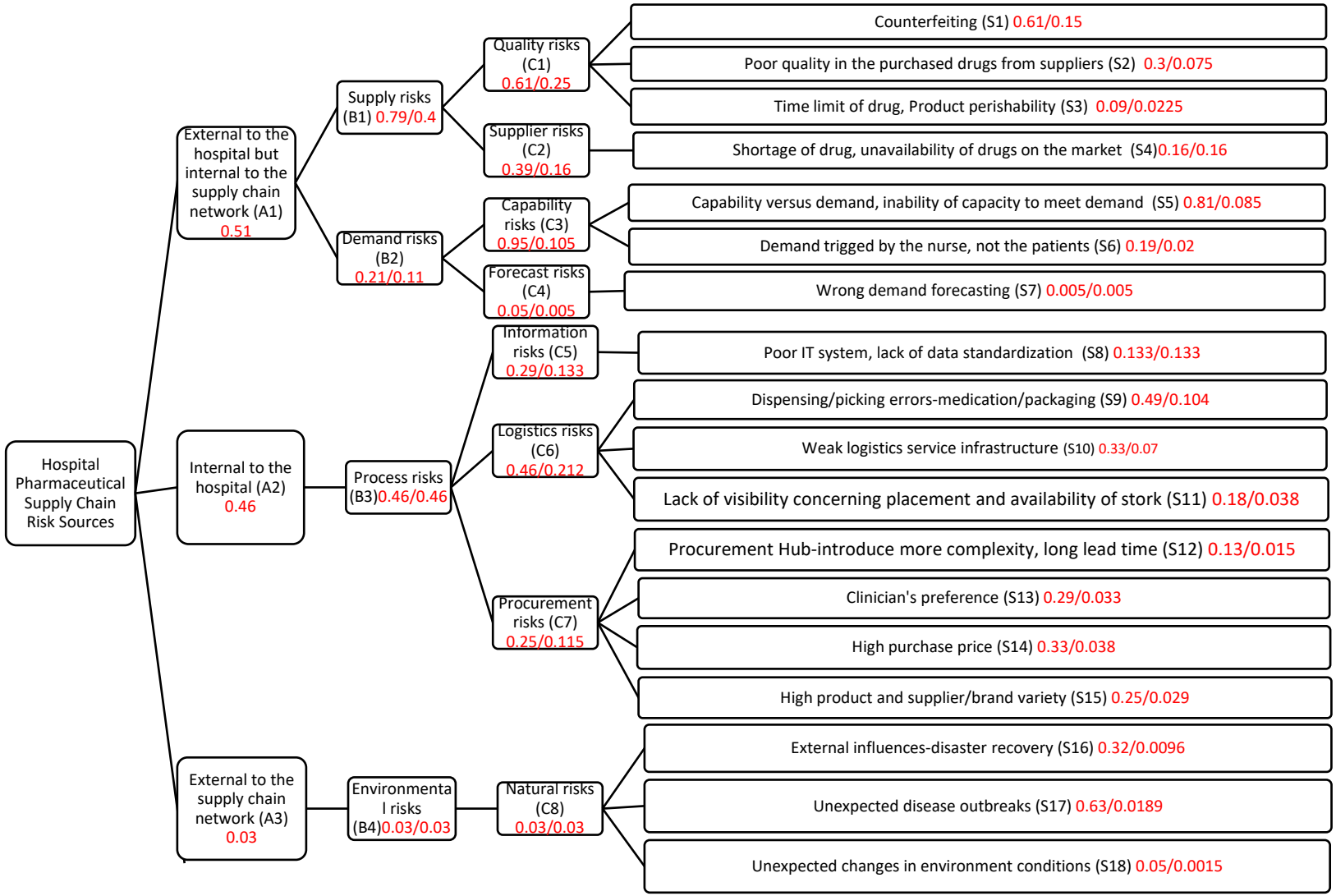


Figure 6-6: Results in relation to Arithmetic Mean Method

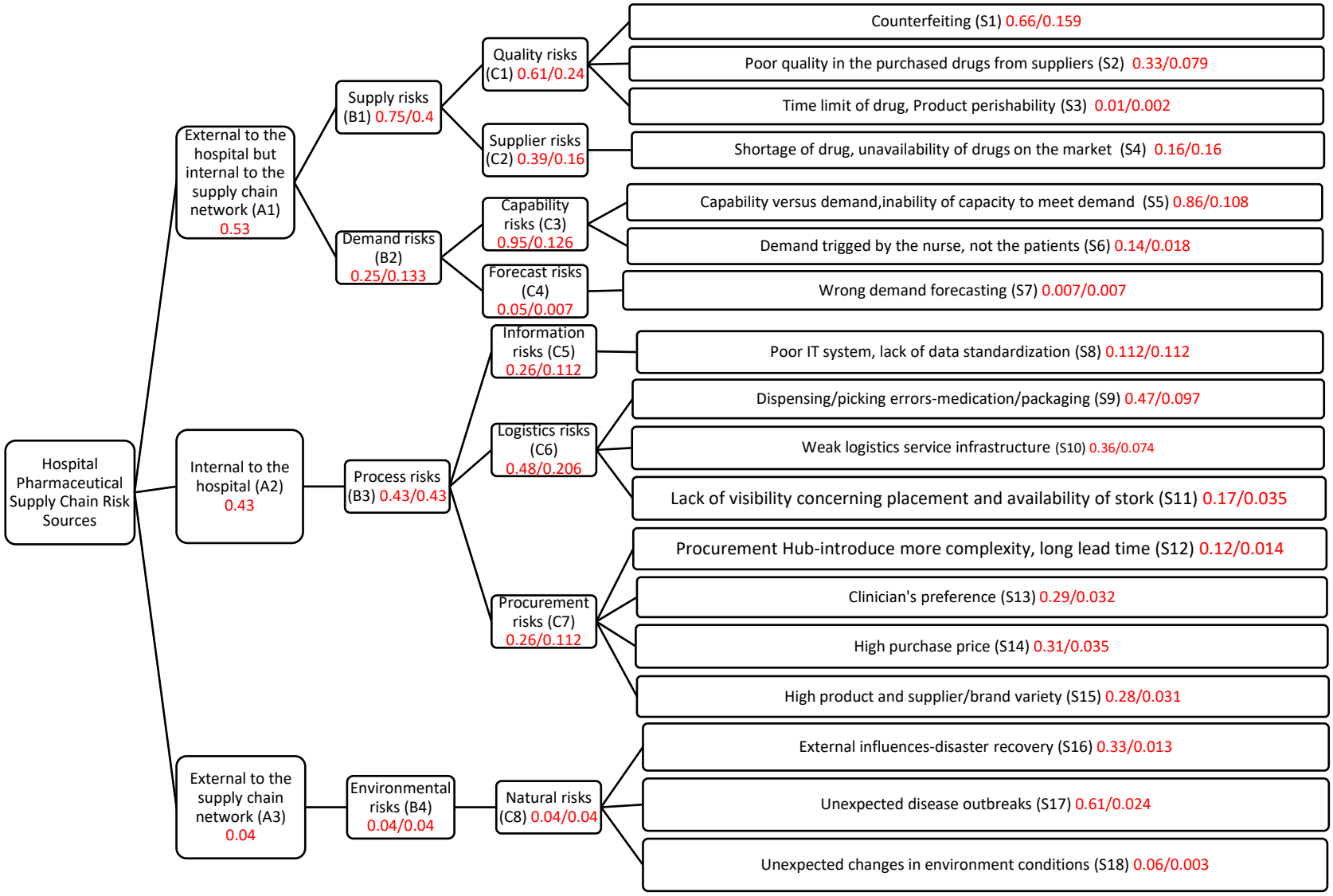


Figure 6-7: Results in relation to Geometric Average Method

Now the different sub-criteria are compared under each criteria separately by following the same procedure as discussed above. It needs to be mentioned that the value of the elements of the matrix must be normalized whenever the value is larger than zero and then the same process will be repeated again to calculate the weight vector of each attribute.

Step 5. Calculate global weights

Once the local weights of criteria and sub-criteria of different levels of the hierarchy were calculated, the final results were aggregated to obtain the final or global weights. The values are shown in both Figures 6.6 and 6.7.

6.4.3 Testing the robustness of the proposed Fuzzy AHP approach

6.4.3.1 Comparing the results of both methods (Geometric and Arithmetic mean)

As described above, both mathematical methods were employed for the aggregation of the survey results in order to ensure the reliability and accuracy of the findings. Figure 6.8 presents the comparison of the results obtained by using both methods. The summary of the results, as shown in Table 6.11, reveals that the higher risk weighting is obtained for "shortage of drug, unavailability of drugs on the market **(S4)",** followed by "counterfeiting **(S1)"** and "poor IT system and lack of data standardization **(S8)"**. As a summary of the results, one can argue that for both methods, a minor deviation is observed in the outcomes, but it does not affect the final ranking. Thus, it can be concluded that the consequences are reliable. By the end, 11 risk factors with the highest priorities were chosen for further evaluation based on the results obtained by using the Geometric Average method.

Table 6.11: Summary of results from Arithmetic Mean and Geometric Average methods

Geometric Average	Rank	Global weights	Arithmetic Mean	Rank	Global weights
Shortage of drug, unavailability of drugs on the market (S4)	1	0.16*	Shortage of drug,, unavailability of drugs on the market **(S4)**	1	0.16
Counterfeiting (S1)	2	0.159*	Counterfeiting **(S1)**	2	0.15
Poor IT system, lack of data standardization (S8)	3	0.112*	Poor IT system, lack of data standardization **(S8)**	3	0.133
Capability versus demand; inability of capacity to meet demand (S5)	4	0.108*	Dispensing/picking errors-medication/packaging **(S9)**	4	0.104
Dispensing/picking errors-medication/packaging (S9)	5	0.097*	Capability versus demand, inability of capacity to meet demand **(S5)**	5	0.085
Poor quality in the purchased drugs from suppliers (S2)	6	0.079*	Poor quality in the purchased drugs from suppliers **(S2)**	6	0.075
Weak logistics service infrastructure (S10)	7	0.074*	Weak logistics service infrastructure **(S10)**	7	0.07
Lack of visibility concerning placement and availability of stork (S11)	8	0.035*	Lack of visibility concerning placement and availability of stork **(S11)**	8	0.038
High purchase price (S14)	9	0.035*	High purchase price **(S14)**	9	0.038
Clinician's preference (S13)	10	0.032*	Clinician's preference **(S13)**	10	0.033
High product and supplier/brand variety (S15)	11	0.031*	High product and supplier/brand variety **(S15)**	11	0.029
Unexpected disease outbreaks (S17)	12	0.024	Time limit of drug, product perishability **(S3)**	12	0.0225
Demand trigged by the nurse, not the patients (S6)	13	0.018	Demand trigged by the nurse, not the patients **(S6)**	13	0.02
Procurement Hub-introduce more complexity, long lead time (S12)	14	0.014	Unexpected disease outbreaks **(S17)**	14	0.0189
External influences-disaster recovery **(S16)**	15	0.013	Procurement Hub-introduce more complexity, long lead time **(S12)**	15	0.015
Wrong demand forecasting **(S7)**	16	0.007	External influences-disaster recovery **(S16)**	16	0.0096
Unexpected changes in environment conditions **(S18)**	17	0.003	Wrong demand forecasting **(S7)**	17	0.005

Time limit of drug, product perishability **(S3)**	18	0.002	Unexpected changes in environment conditions **(S18)**	18	0.0015
"*****" denotes those risk factors are significant and selected for further analyses					

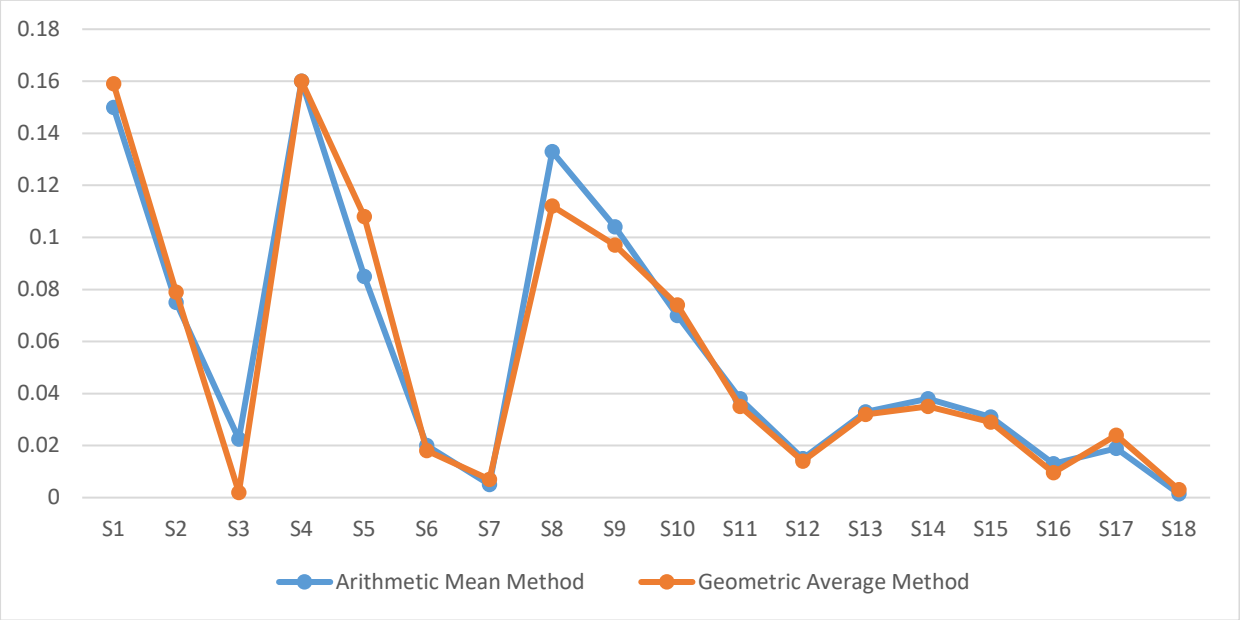


Figure 6-8: Comparison of the results from Arithmetic Mean and Geometric Average methods

6.4.3.2 Reliability test for weights obtained by the pairwise comparison

To implement the Fuzzy AHP method, the pairwise comparison was carried out by covering each variable in the hierarchical structure. The less important risk factors have been omitted from the initial developed structure based on their importance levels in the phase of risk identification. During the phase of risk assessment, only the remaining risks with experts' comments are measured. As depicted in Figures 6.6 and 6.7, there are few risks to stay in isolation not involved in the comparison among the same level, i.e. "S4 shortage of drugs", "S7 wrong demand forecasting", "S8 poor IT system". Therefore, this will give rise to concerns about the larger weight of these individual risks when compared those risks involved in either two or three-time comparison in each level. Therefore, in order to ensure the reliability of our results, a sensitivity analysis was done by gradually changing the weights for some sub-criteria while keeping other weights at the same value, and the impact on the concluding results was examined. Among those risk factors, 18 sub-criteria were selected for the evaluation. Until now, there is no study in the literature that determine the feasibility of individual weighting.

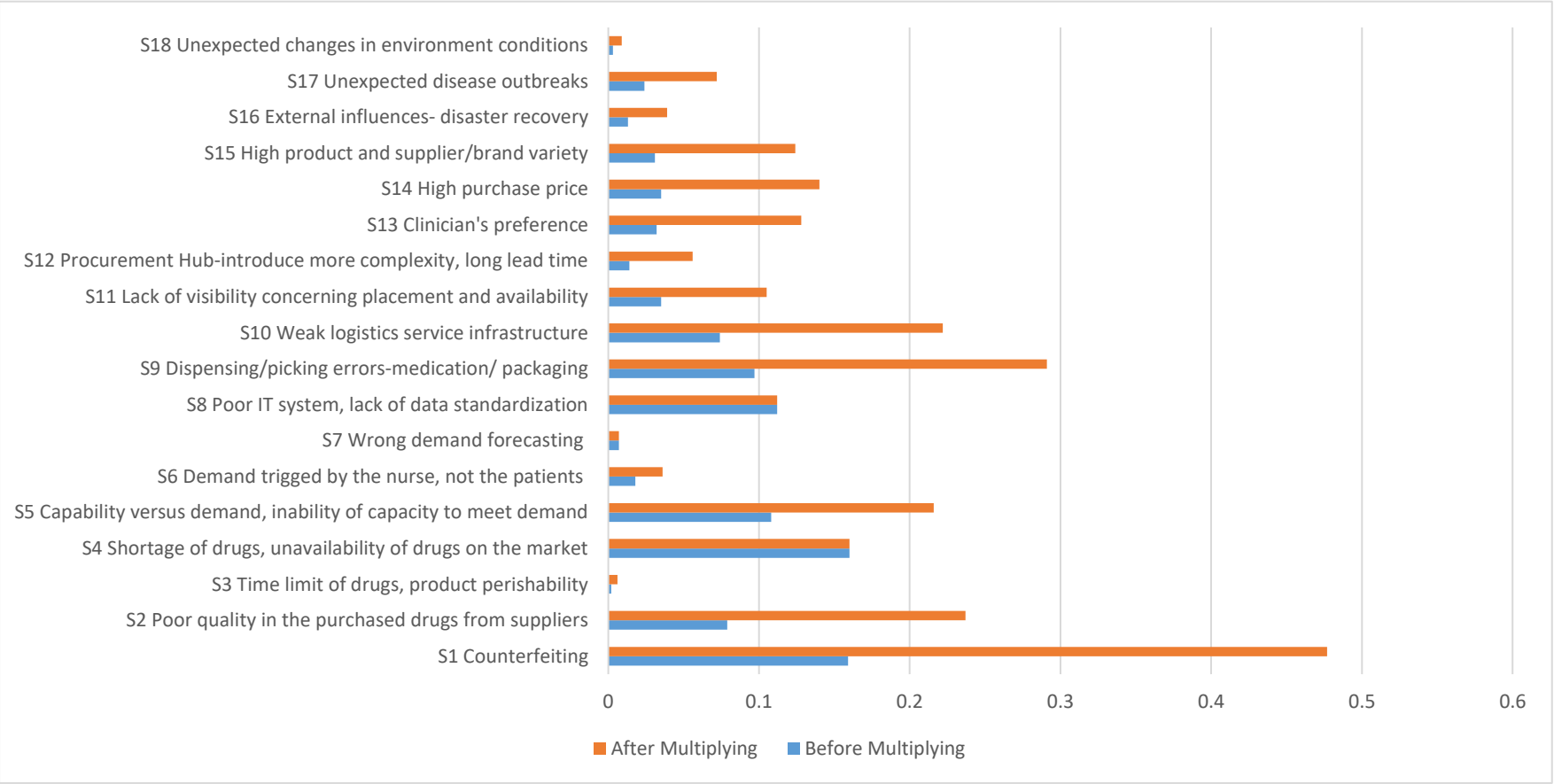


Figure 6-9: Results of the sensitive analysis (multiplication)

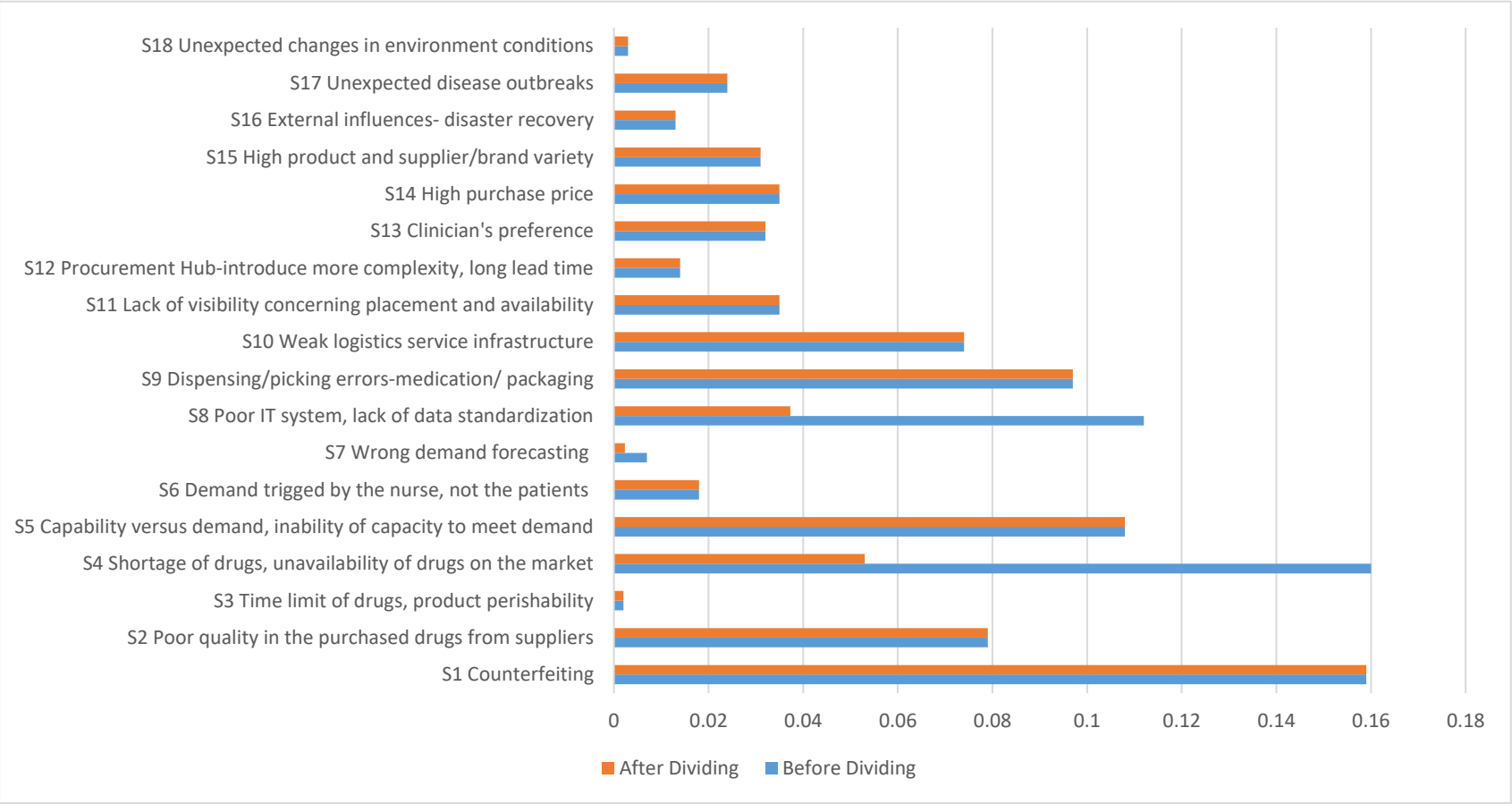


Figure 6-10: Results of the sensitive analysis (division)

Table 6.12: Summary of the sensitivity analysis for weight obtained by pairwise comparison

Risk factors	Before Multiplying (rank)		After Multiplying (rank)		Before Dividing (rank)		After Dividing (rank)	
S1 Counterfeiting*	0.159	**S4***	0.477	**S1***	0.159	**S4***	0.159	**S1***
S2 Poor quality in the purchased drugs from suppliers*	0.079	**S1***	0.237	**S9***	0.079	**S1***	0.079	**S5***
S3 Time limit of drugs, product perishability	0.002	**S8***	0.006	**S2***	0.002	**S8***	0.002	**S9***
S4 Shortage of drugs, unavailability of drugs on the market*	0.16	**S5***	0.16	**S10***	0.16	**S5***	0.053	**S2***
S5 Capability versus demand, inability of capacity to meet demand*	0.108	**S9***	0.216	**S5***	0.108	**S9***	0.108	**S10***
S6 Demand trigged by the nurse, not the patients	0.018	**S2***	0.036	**S4***	0.018	**S2***	0.018	**S4***
S7 Wrong demand forecasting	0.007	**S10***	0.007	**S14***	0.007	**S10***	0.0023	**S8***
S8 poor IT system, lack of data standardization*	0.112	**S11***	0.112	**S13***	0.112	**S11***	0.0373	**S11***
S9 Dispensing/picking errors-medication/packaging*	0.097	**S14***	0.291	**S15***	0.097	**S14***	0.097	**S14***
S10 Weak logistics service infrastructure*	0.074	**S13***	0.222	**S8***	0.074	**S13***	0.074	**S13***
S11 Lack of visibility concerning placement and availability stock*	0.035	**S15***	0.105	**S11***	0.035	**S15***	0.035	**S15***
S12 Procurement Hub-introduce more complexity, long lead time	0.014	**S17**	0.056	**S17**	0.014	**S17**	0.014	**S17**
S13 Clinician's preference*	0.032	**S6**	0.128	**S12**	0.032	**S6**	0.032	**S6**
S14 High purchase price*	0.035	**S12**	0.14	**S16**	0.035	**S12**	0.035	**S12**
S15 High product and supplier/brand variety*	0.031	**S16**	0.124	**S6**	0.031	**S16**	0.031	**S16**
S16 External influences-disaster recovery	0.013	**S7**	0.039	**S18**	0.013	**S7**	0.013	**S18**
S17 Unexpected disease outbreaks	0.024	**S18**	0.072	**S7**	0.024	**S18**	0.024	**S7**
S18 Unexpected changes in environment conditions	0.003	**S3**	0.009	**S3**	0.003	**S3**	0.003	**S3**
"*****" denotes those risk factors are significant and selected for further analyses								

Thus, this research could be a preliminary study to deal with the pairwise comparison under such a context.

The first step is to multiply each set of data which covers at least two risk factors by the same number of risk factors in the pairwise comparison group. For example, the quality risks consist of three various types of risk factors, which are "S1 counterfeiting", "S2 poor quality in the purchase drugs", and "S3 time limit of drugs". Therefore, each risk factor will be multiplied by three to get a new weighted number (See Figure 6.9). Along the same line, those individual risk factors will be divided by three, which is the amount of most sets of data (See Figure 6.10). The summary of the results are in a list in Table 6.12, where the top 11 risk factors are retained as the same results before either multiplying or dividing calculation. Based on their high priority among all the risk factors, the results of pairwise comparison are not affected. As a result, it can be concluded that the proposed model is robust since the best result is impervious to the changes in weighting either by multiplying or dividing.

6.4.4 Findings from Fuzzy AHP method

It was found that healthcare supply chain related risk sources can be categorized into three risks "**external to the hospital but internal to the supply chain network (A1)",** weighted 0.53; **"internal to the hospital (A2)",** weighted 0.43; and **"external to the supply chain network (A3)",** weighted 0.04. The results showed that factors "external to hospital but within supply chain" have the greatest effects in the healthcare supply chain. It is easy to understand that almost every organization faces challenges in the dynamic environment either from the unexpected demand or unstable supplier relationships and performance. These results corroborate the findings of Ho *et al.,* (2015), who reviewed categorization of sources of supply chain risks and concluded that external factors to firms contribute to risks in the supply chain. The results also showed that "**risks external to the hospital but internal to the supply chain network, A1"**, are "**supply risks (B1)"** weighted as 0.75 and "**demand risks (B2**)" weighted as 0.25. The weights result in an overall global weight of $0.75 \times 0.53 = 0.3975$, approximated as 0.4 for supply risk and $0.25 \times 0.53 = 0.1325$, approximated as 0.133 for demand risks. It

indicated that supply risks are about triple the weight of demand risks. This is because supplier performance and relationship management is very sensitive to the healthcare industry.

6.4.4.1 Supply risks

The results further show that those two components of supply risks are weighted as: "**quality risks (C1)"** weighted as 0.61 of 0.4 giving overall global weight of 0.24; and "**supplier risks (C2)"** weighted as 0.39 of 0.4 giving overall global weight of 0.16. Therefore, it is noted that quality risks have a higher weight than supplier risks. These results corroborate the findings by Tse and Tan (2011) who found that quality risks is an inherent part of the supply chain risks. In other words, it tends to encompass some or all of the risk elements in a multi-tier supply chains, such as disruption risks and operational risks. Therefore, it must be considered for successful management of multi-tier supply chains, especially in the healthcare setting as they are a major cause of health problems or even deaths.

Furthermore, supplier risk is associated with "**shortage of drug, unavailability of drugs on the market (S4)"** weighted as 0.16, which is most important risk factors among 18 sub-criteria. As discussed in the previous chapter, such shortages/stock outs can have serious consequences on patients' health since they can result in total failure of healthcare delivery systems (White and Modhzain, 2009). This finding is also in line with research by Aguas *et al.,* (2013) and Kanyoma *et al.,* (2013), who investigated the shortage of drugs caused by inadequate drugs in the healthcare industry, the health service delivery has perfomed poorly, resulted in delays in medical surgery, and led to more worsed medical conditions of patients. It was also found that the major causes of shortage, such as unexpected diease outbreaks, wrong demand forecasting, and lack of funds at the hospital. For example, supply of drugs should be linked to some specific environment, such as seasonality where during a certain season, more individuals are diagnosed with a certain disease, which means the demand for some particular drugs are substantially increased. Thus, special circumstances require that healthcare organizations be both efficient (in the care of products with predictable demand) and responsive (in the case of transplants, pharmaceutical and surgical supplies with an unpredictable demand) (Matopoulos and Michailidou 2013).

Thereafter, results show that of the three quality risk factors studied, "**counterfeiting (S1)"** accounted for 66 per cent of 0.24 giving overall weight for the risk factor as 0.159, "**poor quality in the purchased drugs from suppliers (S2)"** accounted for 33 per cent of 0.24 giving weight of 0.079 while "**time limit of drug and product perishability (S3)"** accounted for 1 per cent of 0.24 giving weight of 0.002. It is therefore noted that of the three studied **quality risk factors**, counterfeiting has the highest risk index followed by poor drug quality and time limit of drugs. The results also support some existing findings, *e.g.,* findings from Kamath *et al.,* (2012), Enyinda *et al.,* (2014), Jaberidoost *et al.,* (2015), and Lawrence and Kopcha (2017), that determined that counterfeiting also has serious risk consequences among other risk factors, especially when hospitals depend on third parties for medical commodities that can cause a breakdown in the healthcare SC, which can disrupt core health services. The research suggested managing the risks by incorporating the lastest anti-counterfeiting technologies such as hologram, mass encoding systems, bar-codes, and RFID system (Kamath *et al.,* 2012). Since the supply of counterfeit drugs is a major threat as revealed by our data, which is consistent with Mackey *et al.'s,* (2015) findings show that over 51.3 per cent of drugs in supply chains are counterfeit. Thus, hospital management must set up a strict quality control and quality assurance department for curbing the supply of counterfieit drugs. However, in terms of the time limit for drugs and product perishability, it plays a less important role in healthcare SC with the smallest weight among 18 risk factors. This result reveals that although the concern should be given to the risks associated with the inefficient cold chain management during transportation and storage, healthcare providers still need to pay more attention to managing the other higher priority risks.

6.4.4.2 Demand risks

The results show that "**demand risks (B2)"** accounted for 25 per cent of the weight of risks "**external to the hospital but internal to the supply chain network"**, which is $25 \text{ per cent} \times 0.53 = 0.133$. "**Demand risks"** are categorized into two types: "**capability risks (C3)",** which were weighted at 0.95 of 0.133 giving global weight of 0.126; and "**forecast risks (C4)"** weighted at 0.05 of 0.133, which gave global weight of 0.007. Under "**forecast risks (C4)"**, "**wrong demand forecasting (S7)"** was given weight of 0.007. "Capability risks" were

categorized into "**capability versus demand, inability of capacity to meet demand (S5)"** which was weighted at 0.86 of 0.126 giving a global weight of 0.108 and **"demand trigged by the nurse, not the patients (S6)"** weighted at 0.14 of 0.126 giving a global weight of 0.018. Compared with the sub-criteria "**capability versus demand (S5)"**, the weights of **(S6)** and **(S7)** are less notable. This may be explained by the fact that it is imperative to improve clinician and pharmacist education in relation to the relevant knowledge of supply chain management (Maryland 2012; Elleuch *et al.,* 2014). Moreover, more effort has been made in developing a closer cooperative relationship between the hospital and its major suppliers or among hospitals in the same region. Such a movement increases operational capacity with less capital investment to deal with the uncertain demands.

6.4.4.3 Process risks

"**Process risks (B3)**" are classified under risks "**internal to the hospital (A2)**" and weighted as 0.43. Results of Fuzzy AHP shows that the three risk factors under "process risks" were weighted as: "**information risks (C5)**" given weight of 0.26 of 0.43 giving 0.112 with "**poor IT system, lack of data standardization (S8)"** under it given similar weight of 0.112; "**logistics risks (C6)**" given weight of 0.48 of 0.43 giving 0.206; and "**procurement risks (C7)**" given weight of 0.26 of 0.43 giving 0.112. Categories of risks under "logistics risks" were weighted with "**dispensing/picking errors-medication/packaging (S9)"** at 0.47 of 0.206 which resulted in weight of 0.097, "**weak logistics service infrastructure (S10)"** at 0.36 of 0.206 which resulted in weight of 0.074 and "**lack of visibility concerning placement and availability of stock (S11)"** at 0.17 which resulted in weight of 0.035. "Procurement risks" sub-categories were "**procurement hub-introduce more complexity, long lead time (S12)"** weighted as 0.12 of 0.26 giving 0.014, "**clinician's preference (S13)"** weighted as 0.29 of 0.26 giving 0.032, "**high purchase price (S14)"** weighted as 0.31 of 0.26 giving 0.035 and "**high product and supplier/brand variety (S15)"** weighted as 0.28 giving 0.031.

Among those risk factors under the criterion "process risks", "**Poor IT system, lack of data standardization (S8)** is the most important risks, followed by S9, S10, S11, S14, S13 and S15. These results confirm findings by several studies (Jaberidoost, *et al.,* 2013; Bŏhme et al., 2016; Graudins, et al., 2016) that have suggested the necesssity of investing in the development of

a modern information system because of independent and loosely-coupled information systems that contain incomplete information and cannot be trusted. Moreover, the results also corroborate Kritchanchai's (2012) results that implementation of standard data in the SC network would facilitate information synchronisation so that all stakeholders in the industry can speak the same electronic language. Meanwhile, it needs to be mentioned that "**high purchase price (S14)"** and "**high product and supplier/brand variety (S15)"** are matters of important concern in Lord Carter's report (2016). It suggested the implementation of a *new purchasing price index* and eProcurement strategy as well as developing procurement partnerships between UK NHS trusts to manage those risks.

6.4.4.4 Environmental risks

"**Environmental risks (B4)**", weighted as 0.04, are part of the "**risks external to the hospital supply chain network (A3)**". Under "environmental risks" there were "natural risks (C8)" weighted 0.04. Natural risks were further categorized as: "**external influences-disaster recovery (S16)**" weighted as 0.33 of 0.04 giving 0.013; "**unexpected disease outbreaks (S17)**" weighted as 0.61 of 0.04 giving 0.024; and "**unexpected changes in environment conditions (S18)**" weighted as 0.06 of 0.04 giving 0.003. Among the 18 risk factors, the weight of these three risks are significantly lower than the others. These three risks are often beyond the control of hospitals, which means that it is difficult to reduce their impact through likelihood reduction. To reduce these risks, these supply chains should be designed to accommodate readiness of unplanned events, to be ready to offer efficient and quick response in case of an emergency. They should also be able to recover to the original state of the health facility after the disruption event and make the state even better than it was before (Ponomarov and Holcomb 2009).

6.4.4.5 Summary of Fuzzy AHP results

Results of fuzzy AHP process were summarized in Table 6.11. The 18 risk factors were ranked according to their weights from highest to lowest. "**Shortage of drug, unavailability of drugs on the market (S4)"** with global weight of 0.160 has the highest risk compared with other risk items, followed by "**counterfeiting (S1)"** with global weight of 0.159**; "poor IT system, lack of**

data standardization (S8)" with global weight of 0.112; "**capability versus demand; inability of capacity to meet demand (S5)"** with global weight of 0.108; and "**dispensing/picking errors-medication/packaging (S9)"** with global weight of 0.097, "**poor quality in the purchased drugs from suppliers (S2)"** with global weight of 0.079; "**weak logistics service infrastructure (S10)"** with global weight of 0.074; "**lack of visibility concerning placement and availability of stock (S11)"** with global weight of 0.035; "**high purchase price** with global weight of 0.035; **clinician's preference (S13)"** with global weight of 0.032 and "**high product and supplier/brand variety (S15)"** with global weight 0.031. Each of these factor has a significant impact on supply chain operational performance, the uncertainty associated with these factors will make the supply chain more complex to manage and therefore more attention must be paid to them and acknowledgment of their work. It is not surprising to see "**shortage of drug, unavailability of drugs on the market (S4)"** at the top of the risk ranking because unlike other consumer products where the customer can either defer their purchase or acquire an alternative, shortage of drugs can adversely affect patient outcomes and increase health care costs. Therefore, this risk factors need to be analysed and eliminated precisely during the future works.

By using the developed risk-based model, risk managers can obtain a broad view of the risk factors in healthcare supply chain. The proposed risk-based model is suitable for comprehensive risk assessments. It can be developed by different users in the healthcare industry. The developed risk-based model can be simply established at various hierarchical levels according to the needs of users and existing data. Additional, it can aggregate various groups of risk factors along with a consistent order to generate useful risk-based information for decision makers. It can be simply applied on the other risk factors not mentioned in this study (such as patient pathway related risks, *etc*). In next step, the ISM model is applied to supports risk managers in identifying and understanding interdependencies among those selected 11 supply chain risks.

6.5 RISK ASSESSMENT WITH INTERPRETIVE STRUCTURAL MODELLING (ISM)

Interpretive Structural Modelling (hereinafter, "ISM") is a qualitative and interpretive method that supports the decision-making process to identify the structure of complex relations of

elements by analysing two elements pair-wisely (Pfohl *et al.,* 2011). The structural mapping of the ISM model provides decision makers with the solutions to complex issues by highlighting the interconnections of elements in a graphical manner. It is seen as an interactive learning process by considering different direct and indirect relations among each risk factor so that complex interconnections of risks can be portrayed within a model. In fact, knowledge of individual risks alone may not be enough for an organization planning to understand the relationship between the various risks. In this respect, ISM can provide insightful understanding of those relations to describe the situation more accurately than the individual risks taken in isolation (Chaudhuri *et al.,* 2016). In SCRM studies, ISM has been applied by several researchers focusing on various problems (Pfohl *et al.,* 2011; Srivastara *et al.,* 2015; Chaudhuri *et al.,* 2016; Prakash *et al.,* 2017).

ISM generates an understanding of a complex system by considering the hierarchy and relationships among the system's elements (Sage, 1977). ISM is being considered interpretive because of the decision from the experts' judgement on how and whether the elements are related is the basic idea in the ISM process. It is also described as structured because it eventually decomposes a complicated system into several elements and constructs a multilevel structural model (Srivastara *et al.,* 2015). Thus, the model is appropriate for use in capturing experts' practical experience and knowledge for modelling and to portray a structure in a carefully designed pattern. In this research, the ISM model is applied to determine the interdependencies among the selected risk factors from the last phase and obtain a hierarchy to synthesize the knowledge about these risks. It will facilitate the decision makers in easily understanding the dependence and driving power of those significant risks in their SC network while formulating the appropriate risk mitigation strategies.

There are several steps that are involved in ISM modelling, which include the following:

Step 1. Recognizing elements that are relevant to the problem through group or survey problem solving approach. Starting point is the identification of the relevant elements to the problem. This can be done by primary research techniques including: questionnaire survey, interview, focus group *etc*, or secondary research including: desk research *etc*.

Step 2. Creating an appropriate relationship between the identified elements. In this stage, the contextual relation must be explicitly illustrated among the elements. Relations may be of various types such as comparative, influence, neutral or temporal relations (Austin and Burns, 1985; Warfield, 1994).

Step 3. Creating a structural self-interaction matrix (SSIM) for all the elements. It is through such a matrix that the pair-wise relationship accorded for the system's elements is established. In this stage, the experts are required to make the decision upon which one element leads to another one. Keeping in mind the contextual relationship for each element, the existence of a relation between any two sub-elements ($i \; and \; j$) and the associated direction of the relation is questioned. Four symbols are used to denote the direction of the relationship between the elements $i \; and \; j$:

V – for the relation from $i \; to \; j$ but not in both directions;

A – for the relation from $j \; to \; i$ but not in both directions;

X – for both direction relations from $i \; to \; j$ and $j \; to \; i$; and

O – if the relation between the elements does not appear to be valid.

Step 4. Creating a reachability matrix in accordance with the created SSIM and checking for transitivity. The SSIM is transformed into a binary matrix, called the initial reachability matrix by substituting 1 or 0 for the original symbols, *V, A, X* and *O*. The rules for the substitution are the following:

(1) If the (i, j) entry in the SSIM is *V*, then the (i, j) entry in the reachability matrix becomes 1 and the (j , i) entry becomes O.

(2) If the (i, j) entry in the SSIM is *A*, then the (i, j) entry in the reachability matrix becomes O and the (j , i) entry becomes 1.

(3) If the (i, j) entry in the SSIM is *X*, then both the (i, j) and (j , i) entries of the reachability matrix become 1.

(4) If the (i, j) entry in the SSIM is *O*, then both the (i, j) and (j , i) entries of the reachability matrix become O.

Following these rules, the initial reachability matrix for the elements is built. Then the final reachability matrix is developed by incorporating the transitivity which is a basic assumption in ISM. It stated that if element A is related to B and B is related to C, it may be inferred that A is related to C. If element (i, j) of the initial reachability matrix is zero, which means there is neither any direct nor indirect relationship from element i to element j. The initial reachability matrix may not have this characteristic because when there is no direct but an indirect relationship from element i to j, entry (i, j) is also zero. Indirect relationships can be found by raising the initial reachability matrix (with diagonal entries set to 1) to successive powers until no new entries are obtained (Malone, 1975).

Step 5. Ensuring that the reachability matrix is appropriately partitioned into several levels. In this stage, two different sets (reachability and antecedent sets) can be obtained from the final reachability matrix by level partitioning. The purpose of this step is to facilitate the construction of the diagraph from the reachability matrix (Prohl *et al.,* 2011). The reachability set R (S_i) consists of the element itself and other elements which are reachable from S_i, whereas the antecedent set A (S_i) consists of the element itself and other elements that may impact it. Thereafter, an intersection of the reachability set and antecedent set (R(S_i) ∩ A(S_i)). The element for which the reachability and the intersection sets are the same occupies the top-level position in the ISM hierarchy. The top-level element in the hierarchy has no relation to any other elements above its own level. Once top-level elements are identified, they are discarded from the other elements. The same process is then repeated until the levels of all elements are achieved.

Step 6. Drawing of diagraph with removed transitivity links. An initial diagraph including transitivity links is found from the conical form of the reachability matrix. Then, by partitioning the reachability matrix by rearranging the elements according to their level, the appropriate conical matrix is achieved. That means all the elements having the same level are pooled. For the sake of simplicity, sketching the final digraph in relation to the affiliations identified in the reachability matrix and ensuring that transitive links are removed. If there is a relationship between risk i and j, this is shown by an arrow which points from i to j.

Step 7. Conversion of diagraph into an ISM and checking of conceptual inconsistency. Translating the resultant digraph into an ISM-based model. This can be done by putting statements in places of element nodes. Finally, the ISM model is reviewed to check conceptual inconsistency.

MICMAC analysis. MICMAC stands for Matriced'Impacts Croisės-Multiplication Appliquėe a'un Classement, which means "cross-impact matrix multiplication applied to classification". The object of the MICMAC analysis is to assess the driving power and dependence of each element (Mandal and Deshmukh, 1994; Saxena and Sushil, 1990). All elements have been classified into four categories based on their dependence and driving power:

(1) Autonomous elements, which have weak driver power and weak dependence.
(2) Dependent elements, which have weak driver power and strong dependence.
(3) Linkage elements, which have both strong driving and dependence power.
(4) Independent elements, which have strong driving power but poor dependence power.

6.6 AN EMPIRICAL STUDY ON THE APPLICABILITY OF THE ISM MODEL

A survey was conducted to facilitate a general understanding and knowledge of the contextual interrelations among the selected risk factors. This study was conducted in three phases: (1) Conducting the questionnaire survey, (2) application of the proposed ISM model and (3) discussion of the results. Each of the phases will be discussed below.

6.6.1 Conducting the ISM-based questionnaire survey

Similarly, prior to actual data collection and, to eliminate content ambiguity in the questions, a pilot study was conducted to validate the developed questionnaire. Frist, a draft version of the questionnaire was developed and the same forward as well as backward translation process were applied on these questionnaire as was applied earlier. The questionnaire was examined by the same people who participated in a previous pilot study of an AHP-based questionnaire for experts to comment on the appropriateness of the question and whether any were unclear. Based on their feedback, the questionnaire was revised for the pilot study.

Ethical approval was also obtained to further validate questionnaire contents and participant consent. The final questionnaire is shown in Appendix Three.

The participating experts who would decide pairwise relationships of risks were selected from the previous AHP survey because they are experts in the healthcare supply chain and risk management and familiar with the research topic. Hence, these experts were contacted again through either email or telephone to briefly explain the purpose of the survey and their involvement and the reasons for their interest. Additionally, in the context of this research, this would have amounted to filling up another 55 times pairwise comparison which was considered a highly labour-intensive task through a survey. Eleven participants who responded to the survey confirmed their willingness to participate in the study as they were interested in the topic of research, since most of them faced similar problems with the supply chain in their organizations. Thereafter, one of these contracts suggested involvement of another manager from his own hospital leading the inventory management department and he was allowed to join also the expert panel. Thus, a panel of twelve experts was secured to participate in this survey. The experts, represented multiple roles within the healthcare industry like procurement, warehousing and logistics, and demand planning, SC consulting, and they possessed the requisite experience to participate in the research. The experts' profiles are presented in Table 6.13. The presence of each expert with a different background, reduced the individual researcher bias (Oppermann, 2000). In addition, unlike the Fuzzy AHP survey conducted, considering the highly labour-intensive task in the ISM survey, thus the interview proved to be more reliable than an assessment based on paper-based questionnaires only. Hence, the questionnaire were sent to them first and their inputs were solicited through in different ways (*i.e.* telephonic interview, email and face-to-face interview) between 10th June and 3th Aug 2017.

Table 6.13: respondents' profile

No	Participant	Position	Method	Location Operating Base

1	Chinese Hospital 1	Stock Manager	Telephone	China
2	Chinese Hospital 1	Pharmacy department leader	Telephone	China
3	Chinese Hospital 2	Pharmacy department leader	Telephone	China
4	Chinese Hospital 3	Pharmacy department leader	Telephone	China
5	Chinese Hospital 4	Pharmacy department leader	Telephone	China
6	Chinese Hospital 5	Pharmacy department leader	Telephone	China
7	Chinese Hospital 5	Stock Manager	Telephone	China
8	Pharmaceutical Company	General Manager	Telephone	China
9	LogHealth Center	Researcher/Consulting	Telephone	Thailand
10	University	Researcher/Consulting	Face-to-Face interview	UK
11	NHS Trust 1	Head of Procurement	Face-to-Face interview	UK
12	NHS Trust 2	Purchase and Supply Manager	Face-to-Face interview	UK

It is recommended that the researcher share the study objectives and classify the meaning of each risk factor with the experts. This step provides an exact understanding of all risks to ensure that their responses concentrated on the direct relationships between each pairwise comparison. In the subsequent stage, the replies were combined, analysed and a convergence in various relationships identified by the research. Finally, the results were discussed with the experts and a final matrix was arrived at reflecting the experts' consensus (Srivastava *et al.,* 2015).

6.6.2 Interpretive structural modelling (ISM) and MICMAC analysis

Each step of employing the ISM model has been discussed above. The details of the practical application are as follows:

Step 1. Construction of structural self-interaction matrix (SSIM) by pairwise comparison.

During this stage, the twelve experts decided upon the pairwise relationship between the selected 11 risk factors from the previous section. Thus. four symbols were used to denote the direction of the relationship between the element *I* and *j* (*i.e*. V, measure *I* will influence measure *j*; A measure *j* will be influence by measure *I*; X, measure *I* and *j* will help influence each other; O, measure *I* and *j* are unrelated). For the sake of the simplicity, in the survey,

four symbols were replaced by four Arabic numerals as 1=V, 2=A, 0=O, 3=X. Thereafter, based on these contextual relationships, the SSIM developed for all the 11 relevant risk factors are shown in Table 6.14.

Step 2. Developing a reachability matrix from the SSIM and checking for transitivity.

During this stage, following the rules for the substitution (*i.e*. the entry V, A, X and O of the SSIM are converted into 1 and 0), the initial reachability matrix for the variables was developed as shown in Table 6.15. Next, the final reachability matrix was then obtained by incorporating the transitivities rules as if element A is related B and B is related to C, it may be inferred that A is related to C. This is shown in Table 6.16. Moreover, in this table, the driving power and dependence of each risk are also presented. The driving power of a particular risk factor is the total number of risk factors (including the risk factor itself) that it impacts. For example, "counterfeiting **(S1)**" impacts eight other risks and so has a driving power of 8. On the other hand, the dependence is the total number of risk factors that may impact a particular risk factor, such as "weak logistics service infrastructure **(S3)**" is impacted by 10 other risk factors and so has a dependence power of 10. Based on these driving power and dependence, those risk factors have later been classified in MICMAC analysis.

Step 3. Ensuring that the reachability matrix is appropriately partitioned into several levels

In this stage, a hierarchical ordering will be extracted from the reachability matrix by level partitioning. It aims to facilitate the construction of the digraph from the reachability matrix. Thus, the reachability and antecedent set for each variable are obtained from the final reachability matrix (Warfield, 1974). As indicated above, the "reachability set" for a particular variable consists of the variable itself and the other variables which it may help achieve. The "antecedent set" consists of the variable itself and other variable which may help in achieving it. (Srivastava *et al.*, 2015).

Table 6.14: Structural self-interaction matrix (SSIM) of risk factors in healthcare supply chain

Risk factors	S11	S10	S9	S8	S7	S6	S5	S4	S3	S2	S1
S1 Counterfeiting	3	0	2	0	2	0	1	1	0	0	
S2 Capability versus demand, inability of capability to meet demand	0	0	0	0	3	1	0	3	0		
S3 Weak logistics service infrastructure	2	0	0	0	3	3	0	0			
S4 Shortage of drug, unavailability of drugs on the market	0	0	3	2	2	0	0				
S5 Poor quality in the purchased drugs from suppliers	2	0	0	0	0	2					
S6 Dispensing/picking errors medication/packaging	2	0	0	0	0						
S7 Poor IT system; lack of data standardization	0	0	0	3							
S8 Lack of visibility concerning placement and availability of stock	3	0	0								
S9 High purchase price	3	2									
S10 Clinician's preference	1										
S11 High product and supplier/brand variety											

Notes: V, measure *I* will influence measure *j*; A measure *j* will be influence by measure *I*; X, measure *I* and *j* will help influence each other; O, measure *I* and *j* are unrelated (1=V, 2=A, 0=O, 3=X)

Table 6.15: Initial Reachability Matrix

Risk factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	0	0	0	1	1	0	0	0	0	0	1
S2	0	0	0	1	0	1	1	0	0	0	0
S3	0	0	0	0	0	1	1	0	0	0	0
S4	0	1	0	0	0	0	0	0	1	0	0
S5	0	0	0	0	0	0	0	0	0	0	0
S6	0	0	1	0	1	0	0	0	0	0	0
S7	1	1	1	1	0	0	0	1	0	0	0
S8	0	0	0	1	0	0	1	0	0	0	1
S9	1	0	0	1	0	0	0	0	0	0	1
S10	0	0	0	0	0	0	0	0	1	0	1
S11	1	0	1	0	1	1	0	1	1	0	0

Table 6.16: Final Reachability Matrix

Risk factors	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Driving power
S1	1	1*	0	1	1	1*	0	1*	1*	0	1	8
S2	1*	1	1*	1	1*	1	1	1*	1*	0	0	9
S3	1*	1*	1	1*	1*	1	1	1*	0	0	0	8
S4	1*	1	0	1	0	1*	1*	0	1	0	1*	7
S5	0	0	0	0	1	0	0	0	0	0	0	1
S6	0	0	1	0	1	1	1*	0	0	0	0	4
S7	1	1	1	1	1*	1*	1	1	1*	0	1*	10
S8	1*	1*	1*	1	1*	1*	1	1	1*	0	1	10
S9	1	1*	0	1	1*	1*	0	1*	1	0	1	8
S10	1*	1*	0	1*	1*	1*	0	1*	1	1	1	9
S11	1	0	1	1*	1	1	1*	1	1	0	1	9
Dependence	9	8	6	9	10	10	7	8	8	1	7	

Note: 1* entries are indicated as transitivity

More precisely, reachability set of the risk is the set of elements of a final reachability matrix which contain 1 in row of that particular risk. Coversely, antecedent set of the risk is the set of elements which contain 1 in column of that particular risk (Pfohl *et al.,* 2011). Based on the reachability set and antecedent set, the intersection sets have been derived for all elements. Intersection sets are the common elements of both reachability set and the antecedent set. The case where the elements of both reachability and intersection sets are the same, which is the indicator of top-level element in the ISM hierarchy. For example, "poor quality in the purchased drugs from suppliers (**S5**)" have been identified as top-level elements as shown in Table 6.17 (Iteration 1). The top-level variables have no relation to any other variable above their own level. Once the top-level element is identified, it is discarded from the other remaining variables. Then, the same process is repeated till the levels of all elements are achieved. The subsequent iterations identified other levels aiding in building the diagraph and ultimately the final ISM model. The stepwise level partitions of all 11 risk factors have been completed in six iterations are presented from Tables 6.17 to 6.22. The summary of all partition levels has been represented in Table 6.23.

Table 6.17: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements ***Iteration 1***	Reachability set	Antecedent set	Intersection	Level
S1	1,2,4,5,6,8,9,11	1,2,3,4,7,8,9,10,11	1,2,4,8,9,11	
S2	1,2,3,4,5,6,7,8,9	1,2,3,4,7,8,9,10	1,2,3,4,7,8,9	
S3	1,2,3,4,5,6,7,8	2,3,6,7,8,11	2,3,6,7,8	
S4	1,2,4,6,7,9,11	1,2,3,4,7,8,9,10,11	1,2,4,7,9,11	
S5	5	1,2,3,5,6,7,8,9,10,11	5	I
S6	3,5,6,7	1,2,3,4,6,7,8,9,10,11	3,6,7	
S7	1,2,3,4,5,6,7,8,9,11	2,3,4,6,7,8,11	2,3,4,6,7,8,11	
S8	1,2,3,4,5,6,7,8,9,11	1,2,3,7,8,9,10,11	1,2,3,7,8,9,11	

S9	1,2,4,5,6,8,9,11	1,2,4,7,8,9,10,11	1,2,4,8,9,11	
S10	1,2,4,5,6,8,9,10,11	10	10	
S11	1,3,4,5,6,7,8,9,11	1,4,7,8,9,10,11	1,4,7,8,9,11	

Table 6.18: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements ***Iteration 2***	Reachability set	Antecedent set	Intersection	Level
S1	1,2,4,6,8,9,11	1,2,3,4,7,8,9,10,11	1,2,4,8,9,11	
S2	1,2,3,4,6,7,8,9	1,2,3,4,7,8,9,10	1,2,3,4,7,8,9	
S3	1,2,3,4,6,7,8	2,3,6,7,8,11	2,3,6,7,8	
S4	1,2,4,6,7,9,11	1,2,3,4,7,8,9,10,11	1,2,4,7,9,11	
S6	3,6,7	1,2,3,4,6,7,8,9,10,11	3,6,7	II
S7	1,2,3,4,6,7,8,9,11	2,3,4,6,7,8,11	2,3,4,6,7,8,11	
S8	1,2,3,4,6,7,8,9,11	1,2,3,7,8,9,10,11	1,2,3,7,8,9,11	
S9	1,2,4,6,8,9,11	1,2,4,7,8,9,10,11	1,2,4,8,9,11	
S10	1,2,4,6,8,9,10,11	10	10	
S11	1,3,4,6,7,8,9,11	1,4,7,8,9,10,11	1,4,7,8,9,11	

Table 6.19: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements ***Iteration 3***	Reachability set	Antecedent set	Intersection	Level
S1	1,2,4,8,9,11	1,2,3,4,7,8,9,10,11	1,2,4,8,9,11	III

S2	1,2,3,4,7,8,9	1,2,3,4,7,8,9,10	1,2,3,4,7,8,9	III
S3	1,2,3,4,7,8	2,3,7,8,11	2,3,7,8	
S4	1,2,4,7,9,11	1,2,3,4,7,8,9,10,11	1,2,4,7,9,11	III
S7	1,2,3,4,7,8,9,11	2,3,4,7,8,11	2,3,4,7,8,11	
S8	1,2,3,4,7,8,9,11	1,2,3,7,8,9,10,11	1,2,3,7,8,9,11	
S9	1,2,4,8,9,11	1,2,4,7,8,9,10,11	1,2,4,8,9,11	III
S10	1,2,4,8,9,10,11	10	10	
S11	1,3,4,7,8,9,11	1,4,7,8,9,10,11	1,4,7,8,9,11	

Table 6.20: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements ***Iteration 4***	Reachability set	Antecedent set	Intersection	Level
S3	3,7,8	3,7,8,11	3,7,8	IV
S7	3,7,8,11	3,7,8,11	3,7,8,11	IV
S8	3,7,8,11	3,7,810,11	3,7,8,11	IV
S10	8,10,11	10	10	
S11	3,7,8,11	7,8,10,11	7,8,11	

Table 6.21: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements ***Iteration 5***	Reachability set	Antecedent set	Intersection	Level
S10	10,11	10	10	

S11	11	10,11	11	V

Table 6.22: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements ***Iteration 6***	Reachability set	Antecedent set	Intersection	Level
S10	10	10	10	VI

Table 6.23: Iterations of the partition of reachability matrix to arrive at ISM diagram

Elements	Reachability set	Antecedent set	Intersection	Level
S1	1,2,4,5,6,8,9,11	1,2,3,4,7,8,9,10,11	1,2,4,8,9,11	III
S2	1,2,3,4,5,6,7,8,9	1,2,3,4,7,8,9,10	1,2,3,4,7,8,9	III
S3	1,2,3,4,5,6,7,8	2,3,6,7,8,11	2,3,6,7,8	IV
S4	1,2,4,6,7,9,11	1,2,3,4,7,8,9,10,11	1,2,4,7,9,11	III
S5	5	1,2,3,5,6,7,8,9,10,11	5	I
S6	3,5,6,7	1,2,3,4,6,7,8,9,10,11	3,6,7	II
S7	1,2,3,4,5,6,7,8,9,11	2,3,4,6,7,8,11	2,3,4,6,7,8,11	IV
S8	1,2,3,4,5,6,7,8,9,11	1,2,3,7,8,9,10,11	1,2,3,7,8,9,11	IV
S9	1,2,4,5,6,8,9,11	1,2,4,7,8,9,10,11	1,2,4,8,9,11	III
S10	1,2,4,5,6,8,9,10,11	10	10	VI
S11	1,3,4,5,6,7,8,9,11	1,4,7,8,9,10,11	1,4,7,8,9,11	V

Step 4. Drawing of diagraph with removed transitivity links.

An initial digraph including transitivity links was obtained from the conical form of the reachability matrix. The conical matrix is achieved from the partitioned reachability matrix by rearranging the elements according to their level, which means all the elements having the same level are pooled. For the sake of simplicity, transitivity links are removed to obtain the final digraph. If there is a relationship between risk i and j , this is shown by an arrow which points from i to j.

Step 5. Conversion of digraph into an ISM and checking of conceptual inconsistency.

The resultant digraph is converted into an ISM-based model by replacing element nodes with statements. Finally, the ISM model is reviewed by research in order to check for incompatibilities, if any, the result will be sent back to the experts for revision. The final ISM diagram indicated the contextual relations between each risk factor is shown in Figure 6.10.

Step 6. Matriced'Impacts Croisés Multiplication Appliquéea'un Classement (MICMAC) analysis

MICMAC is an indirect classification method to critically analyse the scope of each variables (Pfohl *et al.,* 2011). MICMAC analysis is part of a structural analysis that aims to identify the most important variables of a system from a matrix that establishes the relations among them (Villacorta *et al.,* 2012). It is carried out to classify each risk factor in accordance with their driving power and dependence power, as shown in Figure 6.11. Thus, in MICMAC analysis, the dependence power and driving power of each risk factor was analysed. Cluster I consists of autonomous risk factors with weak driving power and weak dependence and do not have much influence on the system. Therefore, it does not need much managerial focus from risk mitigation perspective. A close look at Figure 6.11 reveals that there is no risk in this cluster. Cluster II includes independent risk factors, which have strong driving power but weak dependence and are at the lower level of the model. Only one risk factor is identified in this cluster, "clinician's preference (S10)", which requires attention from the management in the event of change since it is beyond control. Cluster III comprises linkage risk factors which have both strong driving and dependence power. Figure 6.11 shows that most of the risk factors come under the linkage cluster namely, "shortage of drugs, unavailability of drugs on the market **(S4)**", "counterfeiting **(S1)**", "poor IT system, lack of data standardization **(S7)**", "capability versus demand; inability of capacity to meet demand **(S2)**", "weak logistics service

infrastructure **(S3)**", "lack of visibility concerning placement and availability of stock **(S8)**", "high purchase price **(S9)**" and "high product and supplier/brand variety **(S11)**". These factors form the middle level of the ISM hierarchy model. Though the lower level risk factor induces or affect these risks, these also have significant driving power to influence some other risks, which are at the top of the model (Prohl *et al.,* 2011). More importantly, these risk factors are unstable because if any change occurs to these risks that will have an effect on other risks (Samantra *et al.,* 2016). Thus, these risks need continuous managerial focus and attention.

Cluster IV includes the dependent risk factors with weak driving power and strong dependence. As expected, "poor quality in the purchased drugs from suppliers **(S5)**" and "dispensing/picking errors-medication/ packaging **(S6)**" are grouped into this cluster. In fact, these are consequences and are at the top of the ISM hierarchy. The lower level risks also have a significant resulting power for other risks at the top level of the model. It is good to note that the risk factors are always unstable because if there are any changes, one risk factor will lead to more consequences for other risks. Therefore, more attention should be given to these risks so that management identifies and understands the dependence of these risks on the lower levels and these will help to achieve the SCRM goals as well as the objectives.

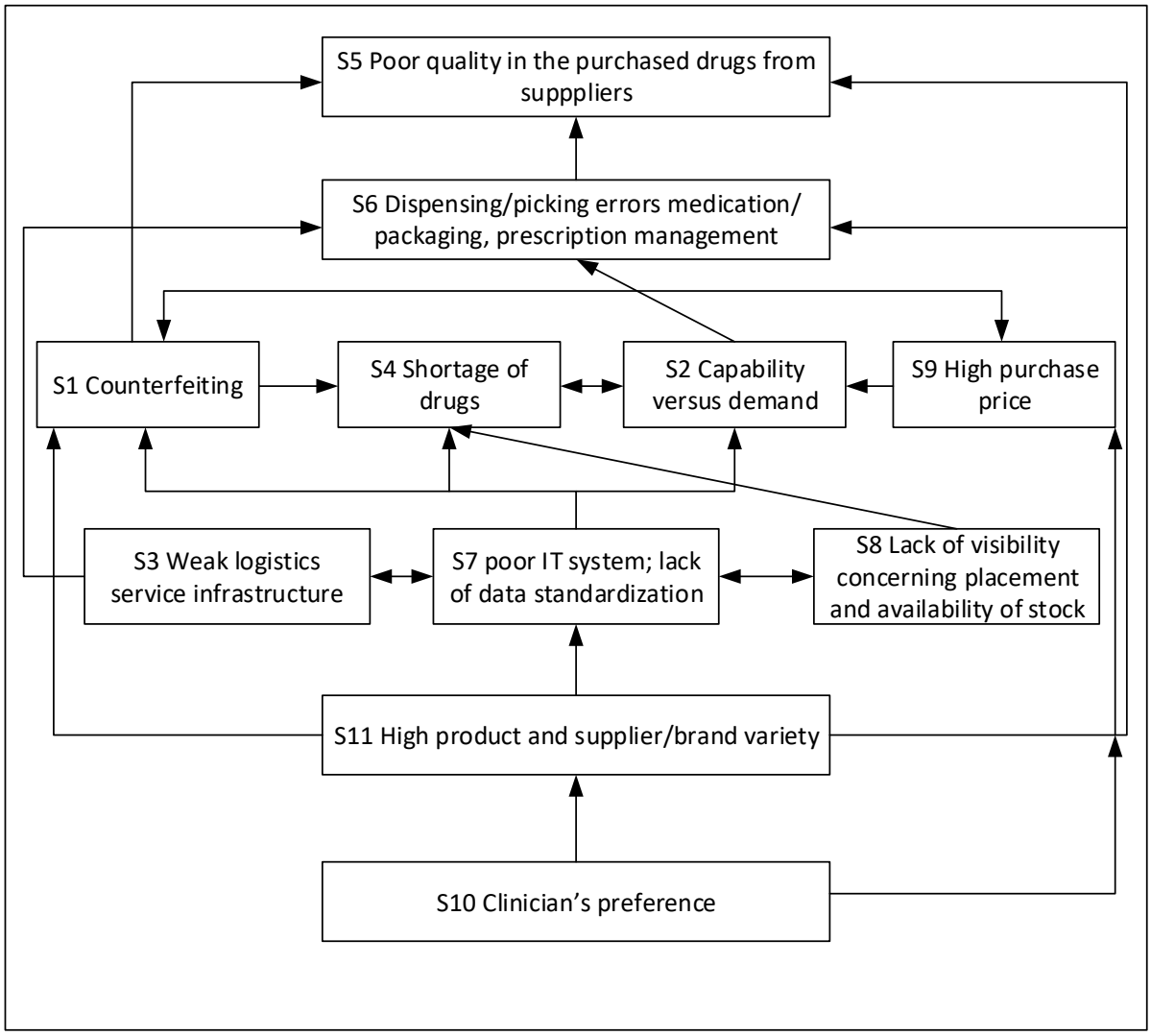


Figure 6-11: ISM-based hierarchy model

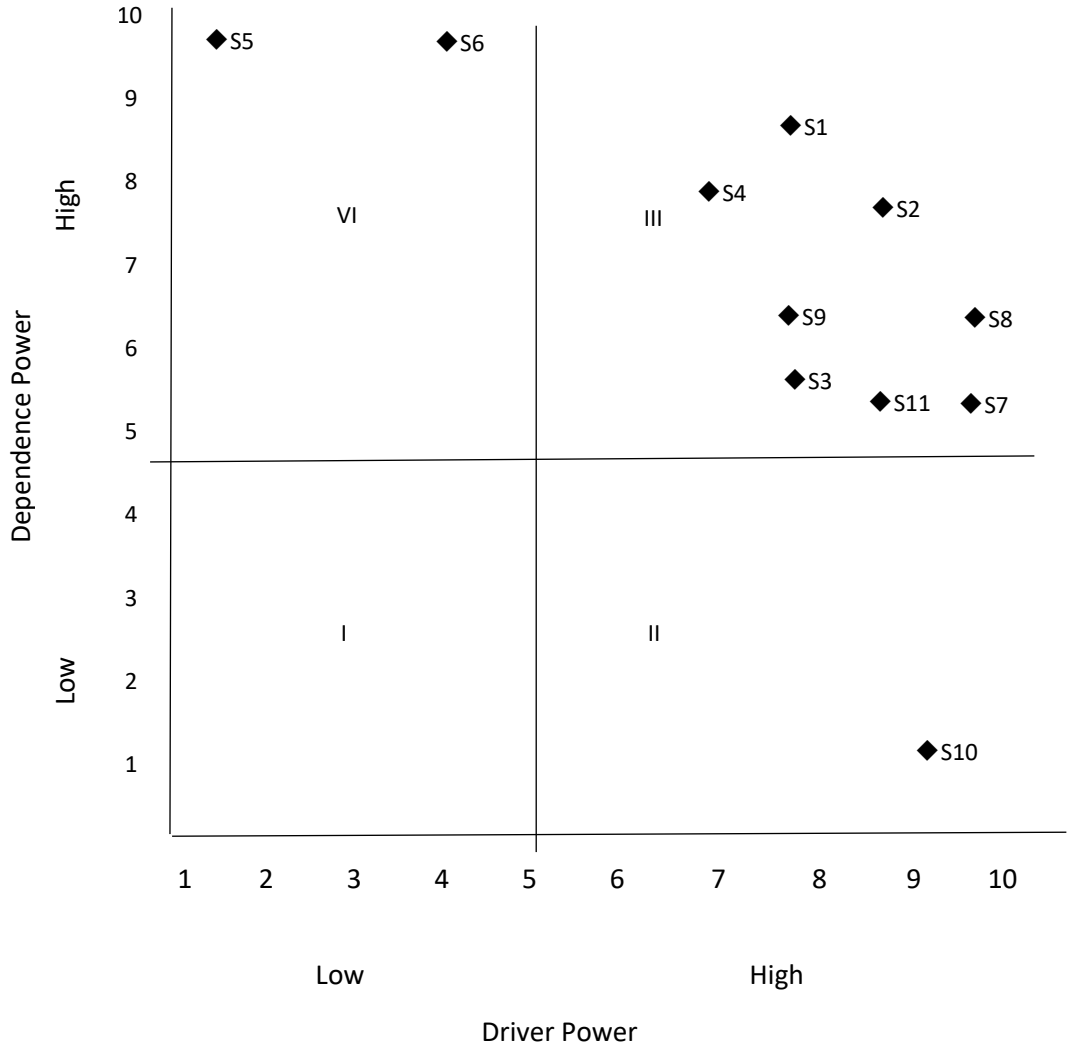


Figure 6-12: Driving power and dependence diagram

6.6.3 Finding from ISM model

Risks are all about choice and how decisions are made (Khan and Burnes, 2007), thus, in this chapter, an attempt has been made to apply the ISM model in the healthcare industry in order to uncover interdependencies of supply chain related risks. Experts stated that management always lacks awareness regarding how the risks relate to each other and how they can affect one another. Thus, improvement initiatives to address the risk factors are not implemented due to either lack of strategic focus or do not obtain the management buy-in. (Srivastava *et al.,* 2015). Therefore, the contextual relationships between pairs of elements were examined for the selected 11 risk factors based on the results of Fuzzy AHP method. The structural self-interaction matrix (SSIM) was developed to indicate pair-wise relationships between each risk

factor as shown in Table 6.13. This matrix was converted to initial reachability matrix (RM) and its transitivity was checked in conformity with recommendations in literature (Upadhye, *et al.,* 2014). Thereafter, the final reachability matrix represented in Table 6.23 was used to create the ISM based model, as shown in Figures 6.10. Moreover, MICMAC analysis has been carried out for the 11 risk factors and classified into four clusters (autonomous, dependent, linkage, independent) based on their driving power and dependence power, as shown in Figure 6.11. The results provide an understanding of the identified risk factors in different levels of the ISM model. In order to facilitate prioritization of the risks for the decision-making process, the developed hierarchical ISM model contains all types of risks starting from the highest to the lowest in different levels. Accordingly, this mapping of inter-relationships is a useful method for supply chain risk managers to evaluate supply chain risks and learn about the impact chains of these risks (Pfohl *et al.,* 2011). Thus, understanding the impact of risks at each level is indeed important as it will help managers to construct and implement successful risk management strategies towards achieving the efficacy of the healthcare supply chain management (Samantra *et al.,* 2016).

It can be observed that "**poor quality in the purchased drugs from suppliers (S5)"** has the lowest driving power (1) and highest dependence (10), thus it is placed in the top level as shown in the ISM based model. In such a case, it could be riskier than the others that can produce major impacts in the healthcare SC because all other risks which are being placed just below the top level, strongly influence to it. Therefore, hospital managers should pay special attention to control them to reduce risks to patient's health.

One of the experts who is in a leadership role in procurement commented

"*When the drugs are received at the drugstore site, all the supplies have to pass strict inspection before they are delivered to the internal drugstore as part of the resupply. If a drug has a quality problem, it is returned to the supplier. It should be noted that both suppliers and hospital pharmacists have to ensure appropriate temperature conditions in their storage areas, and make necessary investments in real-time serial communication of the temperature monitoring system. In addition, it is required that the pharmacy department are working under supervision of the pharmacy administration committee which comprises some clinician, pharmacist and other department leaders. The pharmacy department through collaboration with the pharmacy administration committee will then put in place policies aimed at ensuring*

that drug selection, their distribution as well as subsequent clinical usage to meet the minimum set of standards. It sets up where the pharmacy department directly manages all the pharmaceutical supplies, then the pharmacy administration committee should be put in place to ensure that the roles of drugs procurement are not solely left in the hands of a single individual."

Furthermore, quality associated risks should be emphasized in different approaches, such as getting a suitable logistic provider and designing an appropriate alliance with them to help in managing unplanned risks. Another participating manager in a pharmaceutical company, concurred with this result. He commented "*To ensure appropriate flow and good quality of drugs in the pharmaceutical company should consistent adherence to the guidelines of the supply chain management professionals. What this implies is that all activities pertaining to the sourcing, procurement, logistics as well as conversions are properly planned and managed. In general, we had selected the lowest cost third party logistics service provider. Subsequently, we ran into problems due to pilferage and contamination issues, improper temperature control, and so forth. In essence, the management team should aim at optimizing supply through elimination of the established bottlenecks, ensuring there is a close connection with the logistics service providers as well as to be willing to pay them appropriately through well-designed contracts that will maintain the interests for both parties. More importantly, the supplier should ensure that the quality of drugs meets the safety standards set by the European Medicines Agency (EMA) and Medicines and Healthcare products Regulatory Agency (MHRA), Good Manufacturing Practice (GMP).*" In contrast, lower level risks (*e.g.* **"clinician's preference (S10)"**) have the high driving power (9) with lowest dependence power (1) and strongly influence the middle-level factors such as "**high purchase price (9)"** and "**high product and supplier/brand variety (11)"** (see Figure 6.8). This had indeed been a source of concern for many procurement leaders as the clinician's preference is characterized by a lack of awareness of cost containment. More importantly, doctors were taking money from pharmaceutical companies, which influences their judgement about a medicine. According to a new database published by Association of the British Pharmaceutical Industry (ABPI) in 2016, the practices of NHS staff who take up to £100,000 in advisory fees per year from pharmaceutical companies have been exposed by various Telegraph investigations. In

this case, it raises concerns regarding the possibility of conflicts of interest between the individual commercial and hospital work.

Those middle-level risks seem to influence the risks at the same level or above in the ISM diagraph such as: "**counterfeiting (S1)"** influence "shortage of drug, unavailability of drugs on the market **(S4)**" and "poor quality in the purchased drugs from suppliers **(S5)**". Literature confirms that counterfeiting leads to risks of shortage or unavailability of quality drugs as evidenced by the findings of Koczwara and Dressman (2017) and Patel (2017). In addition, "**high purchase price (S9)"** in turn directly results in "counterfeiting **(S1)**". It means that high pharmaceutical prices have a high likelihood of pushing suppliers to counterfeiting to keep business despite the perceived risks and other implications (Patel, 2017).

One of the pharmacy department leaders in a hospital commented: "*Though the management of counterfet drugs is not easy, most hospitals have tried to set up the* Drug *and Therapeutics* Committee *(*DTC) *in the facility which aims to ensure effective management of a list of approved medicines, reviewing the drugs in place as well as reporting any adverse effects of the supplied drugs. In this committee, each member should have diverse backgrounds from pharmacy, nursing, hospital adminstrations as well as quality assurance department. In the selection of the suppliers, the pharmaceutical manufactures or companies should to be considered are those with Good Manufacturing Practices (GMP), Good Distribution Practice (GDP) as well as Good Supplying Practice (GSP) certificates administered by the MHRA and EMA or China Food and Drug Administration (CFDA).*"

In addition, the DTC should also design a mechanism to ensure that there is effective monitoring of medicine use in the hospital. The committee should also advise on the selection of formulary drugs appropriate for treatment of diseases diagnosed at the facility for lowering the risk of stocking generic duplicate drugs that have lower demand. Although the primary consideration should be cost effectiveness, there is also a need for management to consider some very crucial aspects of the selected drug, such as its toxicity, pharmacokinetics, bioequivalence, therapeutic equivalence, and most importantly its efficacy. Moreover, "counterfeiting risks **(S1)**" was also found to be influenced by "**Poor IT system; lack of data standardization (S7)"** where it could not be easy to verify genuine from counterfeits (Jiang *et al.,* 2016). Experts and practitioners believe that a poor IT system and lack of standardization of data can lead to poor anti-counterfeiting performance and these are likely to gain more

importance in the future. Moreover, it can also be observed that **"shortage of drug, unavailability of drugs on the market (S4)"** was found to be influenced by a "poor IT system, lack of data standardization **(S7)**" and "lack of visibility concerning placement as well as availability of stock **(S8)**". This finding corroborates the findings in literature that precise demand forecasting, timeliness and adequacy of order, reorder patterns and inventory management are affected by a reliable IT system (Bam *et al.,* 2017; Iqbal *et al.,* 2017; Qrunfleh and Tarafdar, 2014). It may be worth mentioning that "**poor IT system, lack of data standardization (S7)"** and **"lack of visibility concerning placement and availability of stock (S8)"** have been identified as risks with both high driving and dependence power.

One of the pharmacy department leaders during the telephone interview stated: "*For the reason of the importance of information system management and integration as a vital element to drive towards added value in healthcare supply chain management. Most managers must concentrate on various types of information related risks, such as: inadequate or absence of information management platforms, manual processes, inadequate or lack of standardized product identification, lack of product traceability and integrated system with suppliers, limited information systems which cover logistics activities.*" The comments are consistent with the findings from the literature review. Kitsiou *et al.,* (2007) presents different kinds of technological approaches that can be implemented in the healthcare SC, including Electronic data interchange (EDI), XML, Health level seven (HL7), Common object request broker architecture (CORBA), Distributed healthcare environment (DHE), Web services and RFID. Thus, it clearly shows that the facilitation of an efficient information technology system would increase the visibility of product information and demand predictability, establish integrated process methods to support decision making and balance costs and demands. In terms of lack of visibility concerning placement and availability of stock, one of the purchase and supply managers in the NHS hospital also stated.

"*There are various challenges that are faced by our organization, such as lack of space for storage, the procedures needed the involvement of clinicians, wastage of products and lack of traceability as well as product visibility. We are highly concerned with inventory management because the fluctuated level of stock, product identification was difficult, and storage was spread across the hospital. Thus, these problems prompted us to adopt an innovative inventory management system, which beyond our early expectations, both financially and*

from a service viewpoint. The cost-savings in the theatre was £1.78 million and the consignment stock savings was £350,000. We also realised that the wastages had been reduced and there was a £885,000 stock reduction, and the hospitals have realised a space savings of £31,000. In addition, discovering 13 types of barcode made us to adopt the GSI standards and that helped us to come up with a database that was accurate and up-to-date information, and that was fed in the management systems of our inventory This type of technology has enabled our hospital to really move forward with our aim to achieve supply chain excellence."

"Capability versus demand, inability of capability to meet demand (S2)" and "**weak logistic service infrastructure (S3)"** have been identified as the risks with high driver and dependence power as well. These two risk factors have a direct influence on "**dispensing/picking errors medication/packaging (S6)"**. The findings agree with that of Liu *et al.'s* (2017) findings that the lack of skilled staff and handling material could lead to the human error in handing or storing of drugs. One re-occurring issue was the larger number of patient transports made by nursing staff, despite it being the transportation departments' responsibility (Granlund and Wiktorsson, 2013). The transportation department was perceived as lacking the capacity to handle all transports and often late with deliveries, thus the nurses were forced to carry out transportation which is time wastage and the products are likely to be spoilt hence increasing chances of errors. Meanwhile, automatic transport systems are introduced as a founding principle for current hospital logistics, such as automated guided vehicles (AGVs) that handle the major part of all deliveries of food, linen, waste, and goods, while pneumatic dispatch systems are used for samples, blood, and medicine shipments. According to Granlund and Wiktorsson (2013), healthcare internal logistics strives for a high degree of automation, *e.g.* IT systems for ordering supplies, tracing equipment and staff. Equipment for picking and packing medicine for patients are supposed to be integrated with the pneumatic dispatch system. As a result, the ISM model provides the conceptualization of healthcare SC risks and to understand mutual influence between 11 risk factors that have been identified. Therefore, lower level factors are mainly responsible for increasing the degree of risk extent as they have a strong influence on the higher or equal level factors. In this regard, it is recommended that interdependency among various risk factors plays an important role in assessing the risk effects on healthcare SCM (Samantra *et al.,* 2016).

6.7 CONCLUSION

This chapter presents the implementation of the combined Fuzzy AHP and ISM model to analyse and evaluate the risks in the healthcare SC. The application of the combined models indicated its feasibility as a tool of analysis as well as a decision-support tool that facilitates understanding of the problem. The problem of the study was to determine the exposure level and the relationship of the risks of the supply chain to healthcare products delivery. The fuzzy approach adopted in the chapter is significant especially under circumstances where the uncertainties exist when making decisions. The pairwise analysis of each risk is based on the experts' knowledge from both academic and practitioner fields, that is, contributions from those who understand the issues. Therefore, the developed models from this study will increase awareness among stakeholders and the decision makers to better understand the priority weighting, the relationship and the effects of different supply chain risks and consequences. Therefore, this implies decisions about risk mitigation strategies.

In terms of the findings, the Fuzzy AHP method was used to determine the weights of the criteria and sub-criteria, which are more accurate than the direct weights received from the decision makers. It can be noted that eleven sub-criteria risk factors with high priority weighting were selected. Subsequently, they were used as inputs for the ISM model for evaluating their inter-relationships and providing a concept of identification and classification of those risk factors in four different clusters based on their driving power and dependence power. In this regard, it is recommended that interdependency among various risk factors play an important role in assessing the risk effects on healthcare SCM (Samantra *et al.,* 2016). Lower level factors are mainly responsible for increasing the degree of risk extent as they are influencing strongly to the higher or equal level factors. The ISM model provides the conceptualization of healthcare SC risks and the insightful understanding of mutual influence between 11 risk factors. As a result, the key finding is that no risks are categorized as the autonomous risk, which are weak drivers and weak dependents and with little influence on the system. All the 11 risk factors should be considered when determining the relevant risk mitigation strategies in the next chapter.

CHAPTER SEVEN – IDENTIFICATION AND EVALUATION OF RISK MITIGATION STRATEGIES

7.1 INTRODUCTION

This chapter focuses on the last stage of the risk management process, *i.e.* identification, validation and evaluation of current implemented risk mitigation strategies. The current implemented risk mitigation strategies are identified through conducting empirical studies from both China and UK healthcare industries (*i.e.* official documentation review, direct-observation and semi-structured interview). The validation of the identified risk mitigation strategies and the exploration of new risk mitigation strategies are conducted via the semi-structured interviews. The overview of each identified risk mitigation strategy is presented. The identified strategies are prioritized over the previously identified risk factors using a Fuzzy TOPSIS method.

7.2 METHODOLOGY FOR RISK MITIGATION STRATEGY IDENTIFICATION AND EVALUATION

Based on the developed integrated RM model, a generic risk mitigation model is proposed for determining and evaluating the implemented risk mitigation strategies. It is a key part in the proposed RM model for healthcare organizations. The schematic diagram of the generic risk mitigation model is illustrated in Figure 7.1.

The proposed risk mitigation model will be implemented for healthcare organizations through the following steps:

Step 1: Exploiting the current implemented risk mitigation strategies on the basis of the identified significant risk factors though empirical studies.

Step 2: Develop a questionnaire to evaluate the identified risk mitigation strategies to the case organizations and distributed to the participating experts to contribute their judgements. Next, the Fuzzy TOPSIS method is applied to rank the significance of these strategies.

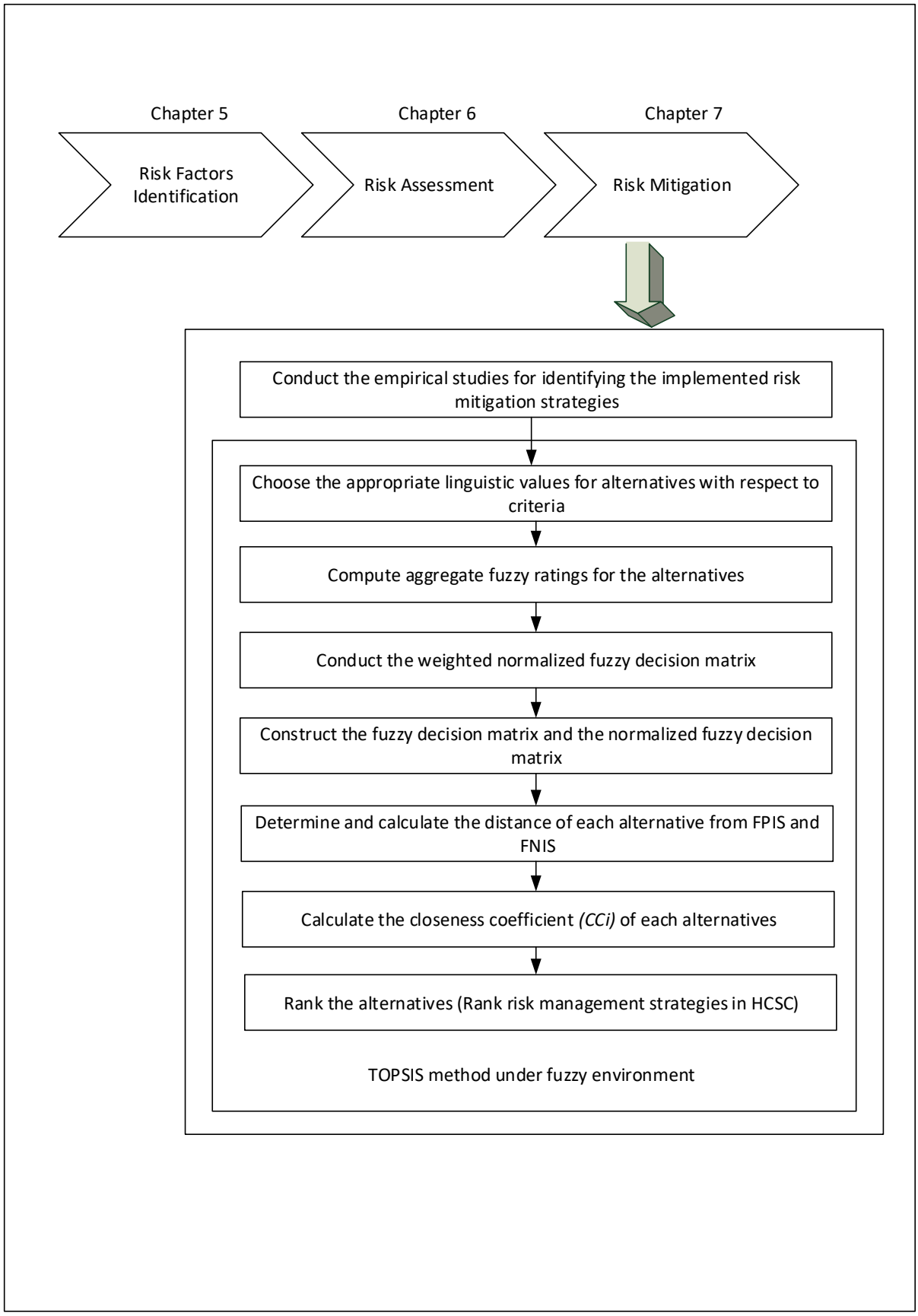


Figure 7-1: A generic risk mitigation model for healthcare supply chain

7.3 IDENTIFICATION OF RISK MITIGATION STRATEGIES FROM EMPIRICAL STUDIES

Various risk mitigation strategies exist in both the general and healthcare supply chain setting. However, the existing literature is rather limited and fragmented. This thesis therefore focuses on the current risk mitigation strategies in both UK and China healthcare organizations. It provides the latest information that can reflect the current situation in both countries' healthcare industry. Especially, instead of identifying the risk mitigation strategies through a literature review, this research explored the currently implemented strategies which turned out to be more reasonable in actual situations. Although it is good to have choices of strategies for supply chain risk mitigation, how to tailor them with their various features and benefits is still a big challenge for many healthcare organizations. In this thesis, the healthcare provider (*i.e.* hospitals) is taken as a focal organization in the context of the supply chain. Based on the identified risk factors in previous chapters, a number of risk mitigation strategies are identified and their efficiency will be evaluated through the developed method.

An empirical studies approach is employed to explore the healthcare supply chain operations in the hospital context. It provides description of what is transpiring by using in-depth interviews, direct observations, and documentation review, which are referenced as both qualitative and quantitative studies (Christensen et al. 2011; Creswell and Creswell 2017; Taylor *et al.,* 2015; Yanow and Schwartz-Shea 2015). The purpose of empirical studies is to verify current existing or newly proposed collected evidence about research on the basis of empirical data. Long (2014) reported that an empirical study is based on 'field' experiences or direct observation, enabling researchers to conduct investigations on modern phenomenon in depth and in its natural context where there is no clear evidence between phenomenon and context. According to Yin (2013), the research design is used to judge the quality of empirical studies that consist of reliability and construct validity, internal validity, and external validity. In this chapter, construct validity is achieved when multiple sources of evidence were employed for data collection. More specifically, semi-structured interviews were used as the primary data collection approach, while site observation and official documentation review were also gathered for triangulation purposes.

Empirical studies were conducted in both UK and China healthcare industries to extract the appropriate number of mitigation strategies for further evaluation. The studies were conducted in three phases: (1) review of official documentation and other published

materials, (2) direction observation, and (3) conducting semi-structured interviews. Each of the phase is discussed below.

7.3.1 Description of the procedure of conducting the empirical studies

The research followed the particular steps to ensure that all sources were used in the study. To begin with, some relevant documentation was reviewed critically, such as *NHS England Risk Management Policy and Process Guide*; *Lord Carter's report*; *NHS Supply Chain Case studies*; *NHS eProcurement Strategy*; *Eight UPS Pain in the Chain Survey*; and *McKinsey and Company reports and other Department of Health and Social Care official documents*. Especially, some official documentation was provided by the participating organizations in the survey. Documentary research has the advantage of ensuring that the researcher gaints access to information which would otherwise be challenging to acquire using other means like people who may be difficult to track down or may be unwilling to engage in an official study. In most cases, documentation review is an effective mechanism to track change over a long period of time. It is also less expensive, especially when documents may be accessed easily. After documentations review, some mitigation strategies are identified. For example, Lord Carter's report has given the discussion on the savings which could be supplied from good e-procurement practices. The strong emphasis is placed on the employee issues as well as informatization of hospital supply chain network. Among these recommendations, some key lessons have been retrieved in relation to our research:

- **Collaboration** *(i.e. local, regional, national)*
  "By collaborating with suppliers and leveraging the NHS's purchasing power on a national scale (aggregating national demand and releasing funds) the Future Operating Model …"
- **Outsourcing the supply chain activities to the third party.** *(capitalise on economies of scale in the provision of non-core services to reduce back-office costs).*
- **NHS eProcurement strategy** *(electronic invoicing by suppliers direct into the Oracle system; GS1 Product bar coding technology; modernizing the complete purchase-to-pay process.*
- **Information technology and system** *(RFID etc.)*
  "*Integrated IT platforms that allow each function within the operating model to work seamlessly..(NHS Procurement Transformation Programme Future Operating Model*

(FOM)). (Lord Carter's report, 2016)

The in-depth observation presented here was conducted in the UK and China. The author visited three hospitals as well as one pharmaceutical company: H_A (children's hospital), H_B (public hospital) and H_C (university hospital), which differ in terms of patient group, size of hospital, and location. H_A is one of the largest childrens' hospitals (309 beds) in the United Kingdom and Europe. It currently employs about 2,400 staff and treats over 270,000 children from across the UK each year. The other two hospitals H_B and H_C are state-owned hospitals in China and third-grade class-A hospital (2,100 beds and 11,000 beds, respectively). H_C is located in one provincial capital city while H_B is located in a third-tier city, and H_B currently employs about 2,447 staff and treats over 1,060,000 outpatients and 60,000 inpatients per year, while, H_C currently employs about 11,859 staff and treats over 5,700,000 outpatients and 410,000 inpatients every year. During the site visits, the author received a tour of the different sites for observation, which was especially helpful in gathering data pertaining to operational aspects. Importantly, carrying out direct observations has a major benefit of ensuring that the author can actually observe what is done or said by the intended participants with interviews (Yin, 2015). Human beings, by their very nature, would not normally be willing to tell strangers their thoughts during interviews or to write their honest opinions on questionnaires. Therefore, observations enable the researcher to access the meaning and context of what people say and do. Nonetheless, a direct observation also has its weaknesses that can be overcome by other data collection methods.

In the last stage, the semi-structured interviews were conducted in the healthcare industry of the two countries by inviting nine experts from seven Chinese hospitals and three experts from one UK hospital and another two general managers from different pharmaceutical companies to take part in the survey as shown in Table 7.1. Most respondents were involved our previous surveys and a regular contact was maintained from the point of contacting until the research project's completion. Interviews were held face-to-face or telephonically with participants from different hierarchical levels of each healthcare organization. It was important to examine if information from participants were consistent throughout the different organizational levels of the cases. Therefore, involving various hierarchical levels as well as different types of organization interviews aided in determining the integrity and

validity of data within cases. In addition to this, as discussed in the previous chapter, organizations were selected on the basis of their experience with supply chain disruptions and represent a leading organization in the healthcare industry (*e.g.* the selected Chinese hospitals are all the third-grade class-A hospitals). Positions held by the interviewees included pharmacy department leader, stock manager, former director of hospital, material department manager, and general manager in a pharmaceutical company. Most interviewees were helpful in gaining access to additional documentation.

Table 7.1: Respondents' profile

Participant	Position	Method
Chinese Hospital A	Pharmacy department leader	Telephone interview (40 min)
Chinese Hospital A	Stock Manager	Face-to-Face interview (30 min)
Chinese Hospital B	Pharmacy department leader	Face-to-Face interview (30 min)
Chinese Hospital B	Pharmacy department senior manager	Face-to-Face interview (30 min)
Chinese Hospital C	Pharmacy department leader	Face-to-Face interview (30 min)
Chinese Hospital D	Pharmacy department leader	Face-to-Face interview (30 min)
Chinese Hospital E	Pharmacy department leader	Face-to-Face interview (50 min)
Chinese Hospital F	Former director	Telephone interview (30 min)
Chinese Hospital G	Pharmacy department leader	Face-to-Face interview (40 min)
UK Hospital A	Head of Procurement	Face-to-Face interview (30 min)
UK Hospital A	Material department Manager	Face-to-Face interview (30 min)
UK Hospital A	Pharmacy department Manager	Face-to-Face interview (40 min)
Chinese Pharmaceutical Company A	General Manager	Face-to-Face interview (40 min)
Chinese Pharmaceutical Company B	Vice-general Manager	Telephone interview (40 min)

The interviewees were asked to validate the identified strategies from the previous steps to determine if they thought the strategies were inappropriate. More so, by providing their opinions about whether some strategies had been addressed. A semi-structured interview in research as a technique has a number of advantages (Creswell and Creswell 2017). It is reliable and efficient to generate a huge amount of details. Therefore, based on the selected 11 sub-criteria risk factors for the cases and interviewees, questions were designed for one hour interviews time. This ensured enough time to get sufficient data to answer research questions, whilst the amount of time was deemed acceptable for any research participant to invest in the research. During the interview, as some confidential topic would be of concern to the interviewees (*e.g.* especially in China), the interviewees might be uncomfortable with being recorded. Hence, the author had honed a pen-and-paper note taking method to record the information due to the interviewees' refusal to allow audio-recorders. Furthermore, the notes would be given to the interviewee to make sure the essence of their comments were transcribed.

The interviews were spread over three months and included four site visits by the author. Each time, the author visited a placement based on the interviewees' locations. Sites visited by the author included hospital's pharmacy department, material management department, centre store, and dispensary and a distribution centre as well as a warehouse in the pharmaceutical company. Three of four visited sites were located in China, whilst the fourth site was located in the United Kingdom. Consequently, integrating the three sources, documentation, direct observation, and interviews ensured research with reduced bias. In the end, nine risk mitigation strategies were identified and discussed below.

7.3.2 Overview of identified implemented mitigation strategies in hospital setting

As presented in Figure 7.2, the identified risk mitigation strategies are summarized and more details will be discussed below.

7.3.2.1 *Strategy 1: Building efficient distribution management*

- *Poor quality in the purchased drugs from suppliers (S2)*
- *Weak logistics service infrastructure (S7)*

The main goal of distribution management is to ensure that pharmaceutical supplies are smooth and maintained to the hospitals where they are required and ensuring that resources are effectively utilized (Jaberidoost *et al.,* 2013). Costs of distribution, such as transportation, are an important issue for running a supply system of a public health supply system. In countries covering large geographical areas like China, the cost of transportation might surpass the distributed medicines' value (Syahrir and Vanany 2015). Therefore, minimizing these costs may imply that more money would be present for clinical care and for the purchase of medicine. A distribution system is considered good only when it is cost-effective and provides quality service.

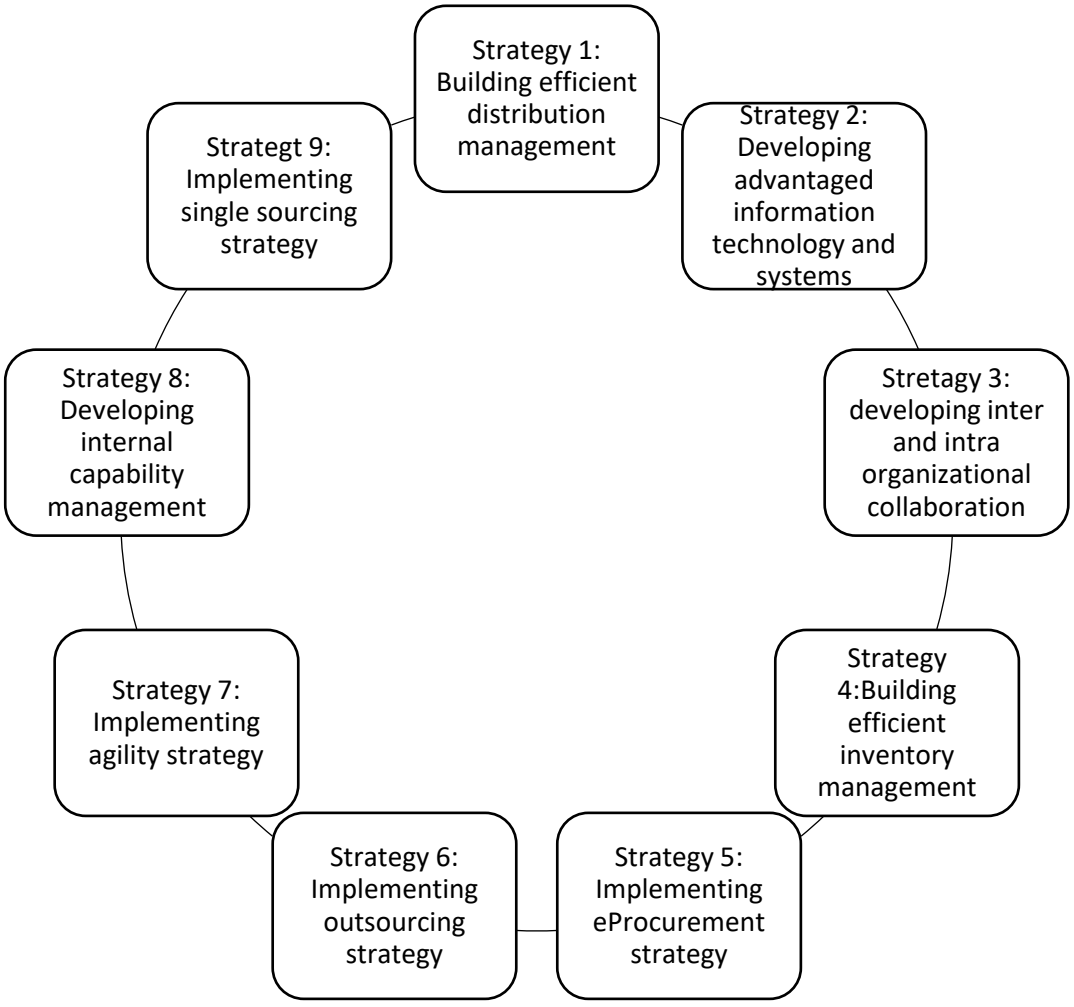


Figure 7-2: Summary of the identified risk mitigation strategies

The distribution cycle starts with the dispatch of pharmaceuticals by suppliers or manufacturers and ends with the reporting of information regarding medicine consumption

to the facility's procurement department (Jaberidoost *et al.,* 2013). The main activities involved in pharmaceutical logistics management are varied. Cold chain management, for example, is one of the most important HCSCM tasks and generally defined as a temperature-controlled supply chain that warrants and extends the shelf life of goods like pharmaceutical drugs, seafood, fresh agricultural products, and frozen food. According to Purssell (2015) and Ogboghodo *et al.,* (2017), understanding cold chain management is important to supply chain management since it manages temperature to minimizes the challenges of risks affecting efficacy and safety of medicines, especially high cost vaccines, stored in large quantities and temperature labile (*i.e.* safety and efficacy may be compromised by excessive heat or freezing). In particular, it is a sequence of activities involved in distribution to steadily maintain this temperature to safeguard drugs from manufacturing to consumption points. The unique characteristics of the product perishability of some specific pharmaceutical items must always be stored under the strict temperature-monitoring environment. Therefore, it is necessary to manage risks caused by the unexpected changes in environmental conditions for delivery items during the distribution process, as such risks can directly or indirectly negatively affect the *quality in purchased drugs from the supplier*. Meanwhile, when logistics services infrastructure is poor, it also lead to the poor supplier routes, obsolete equipment in the warehouse, improper drug store environment and transportation facility/route, inefficient cold chain management during transportation. According to a report produced by the UPS Company (2015),

"There are many organizations which have succeeded in addressing the issue of product damage as well as spoilage last year. The main reasons for success cited are partnering with higher-quality carriers, using faster shipping service levels, and using temperature-monitoring devices."

One general manager in a pharmaceutical company stated that:

"Transparency has to be critical. Applying real time monitoring and recording devices would help us identify where to find the product and evaluate the condition in which the product is found. It can also tell where it can be stored. For example, for the various types of sensors, there are sensors and tags which have been installed on the transportation facilities such as a delivery item, worker, or container. These tags are used when distributing items from one place to another. They are used in the identification of the entities according to the unique

identifiers given to the tags. A sensor is defined as a device that measures environmental conditions according to the environmental features like Thermocouples, Resistance Temperature Detectors (RTD) and Vaccine Vial monitoring (VVM). We use VVM whereby the RTD is found on the Vial label which when exposed to the high temperature it becomes dark. " (Pharmaceutical Company A)

On the other hand, in the hospital setting, refrigerated medicines must be stored at 2-8^{o}C. Most non-refrigerated medicines must be stored at less than 25^{o}C. However, some medicines can be stored at up to 30^{o}C. Sensitivity to changes in temperature varies depending on the medicine. One stock manager mentioned:

"We have to ensure that all medicines are stored within the manufacturers recommended temperature range. Otherwise, it could invalidate the expiry date and cause manufacturers to disclaim responsibility for any apparent failure of the medicine as the safety and efficacy of such medicines can be significantly compromised or unknown." (Chinese Hospital A)

Another pharmacy department leader used vaccine management for example and said:
"In our hospital, all the employees who carry out any activity involving medicine such as transportation, storage as well as administration should be given proper training. This training will help them to ensure that all the medicine or vaccines are in their right status. The pharmacist is the one supposed to be dealing with cold chain management of all the vaccines which are stored in the hospital stores. The nurse manager is responsible for the medicines that are removed from the store and they store them in the clinic refrigerators as they wait for administration to the patient. Once the medicine is transferred from the stores to the ward, they should also be monitored and kept under cool conditions using the battery-operated thermometer. The persons who transfers the medicines should ensure that they are packed well and the temperatures are monitored from the time they are being transferred to the time they reach the ward. The person who receives the vaccine should record their receipt and that the cold chain was maintained during transfer on the Health Vaccine Refrigerator Temperature Chart. The vaccines must be unpacked and stored immediately in the ward/clinic refrigerator. After that the nurse administering the vaccine is responsible for maintaining the cold chain from the time it has been removed from the refrigerator to administration. Especially, during these process, when the refrigerator temperature readings fall outside the

range 2^{o}C to 8^{o}C this must be reported to the service/ward manager for risk assessment and appropriate action." (Chinese Hospital E)

The other activities are receipt and inspection. Kanyoma *et al.,* (2013) noted that central stores staff must accurately inspect all shipments as soon as they are received from local suppliers or the port. The shipments must be kept separate from other stock until the inspection is completed, which should focus on missing and damaged items. The inspection should also pay attention to compliance with agreement conditions relating to labeling, packaging, presentation, quantity, drug type, and other special requirements. It is essential to inspect every shipment promptly and accurately in order to ensure that suppliers fulfill the contracts, where receipts and distribution (R&D) are responsible for matching receipts to orders and arranging the internal delivery schedule. A pharmacy department leader mentioned:

"When expecting a delivery of a refrigerated medicine, the designated accountable person must ensure that whoever accepts the delivery is aware of the need to maintain the cold chain and check the order for leakage, damage and discrepancies. All deliveries of refrigerated medicines must be unpacked immediately on arrival and placed in a pharmacy refrigerator. Items must remain in the manufacturer's original packaging to protect them from light. If there is any concern that the cold chain has been broken prior to delivery, the staff cannot accept the delivery and report the reason for non-acceptance to the distributor." (Chinese Hospital C)

7.3.2.2 Strategy 2: Developing advanced information technology and system

- *Counterfeiting (S1)*
- *Poor IT system, lack of data standardization (S5)*
- *Dispensing/picking errors-medication/packaging (S6)*
- *Lack of visibility concerning placement and availability of stock (S8)*

The issues regarding counterfeiting can be managed by incorporating the current anti-counterfeiting technologies such as the hologram, mass encoding systems, bar-codes etc. With regard to mitigating risks in the supply chain, the empirical studies revealed a number of IT-related techniques currently used. These include data standardization, information

sharing, drugs traceability, integrated IT platform, RFID, and EDI (Coustasse *et al.,* 2013). According to Lord Carter's report,

"All hospital trusts should have the key digital information systems in place where it is fully integrated and utilized e-catalogue and inventory systems for procurement, RFID systems. For *example, there is one hospital which has adopted the same technology like that of the well-known United Kingdom's largest retailers-real time Amazon-style which deals with purchase-to-pay platform. It has an in built catalogue and product information solution which it uses to monitor the processes of the supply chain management. The procurement platform enables the trust to ensure safe delivery and leads to a reduction cost of a £3 millions annual costs. It enables the company to develop transparency, visibility as well as step-change in the interoperability in the health organizations." (Lord Carter's report, 2016)*

In the UK, the Department of Health (DH) has announced a guideline called "Coding for success", which is related to the implementation of an automatic identify and data capture programme (DH, 2010). To address patient safety issues, the National Health System Connecting for Health (NHS CFH) entered into the agreement with GS1 UK to issue the adoption of the GS1 coding standard. In addition to coding, it also encourages manufacturers to implement GTINs while driving the NHS to implement effective supply chain technologies (GS1, 2010). According to Wu *et al.,* (2013), GS1 is the world's leading supply chain organization. The GS1 system is composed of four key standards: barcodes (used to automatically identify things), eCom, global data synchronization standards (GDSS), which allow business partners to have consistent item data in their systems at the same time) and EPC global (which uses RFID technology to immediately track an item). GS1 coding standards are, therefore, integral in the supply chain as they standardize data and require all players to implement the same data standard and system so that they can speak the same electronic language to achieve end to end traceability. Furthermore, GS1 also allows for product traceability through Automatic Identification and Data Capture (AIDC) systems, including barcodes and RFID. The RFID also continuously monitors and provides reports concerning temperature, humidity, and voltage (Coustasse *et al.,* 2013). Through this technology, after the medicines are unpacked from the box or pallet, they also can be tracked or traced. As such, increasing the visibility of stock as well as decreasing the dispensing or picking error-

medication can be interpreted as a reduction in the degree of exposure to supply chain risk. One head of procurement mentioned:

"We have discovered that most medicine products on the shelf did not have a unique identifier. We found thirteen various types of barcode. In addition, there were many codes from the manufacturers, distributors, suppliers' manufacturers leading to a lack of clarity and poor data. Hence, it requires us to adopt GS1 standards and ensure the managers are focused." (UK hospital A)

The key challenges for the efficient inventory management process include a lack of stock control and visibility along with a shortage of management information. A material department manager stated:

"We have worked with Ingenica Solutions to implement a GS1 standards-based inventory management system (GS1 Global Trade Item Numbers (GTINS)) in the hospital's operating theatres. It enables us to manage the processes, secure efficiency savings as well as release valuable clinical time back to patients. Scanning the barcode once the items are received, moved and used in the hospital which help us to capture data electronically as well as exchanged without manual intervention." (UK Hospital A)

Another pharmacy department manager also mentioned:

"Since the GS1 was implemented, everything from patient ID bracelets and bandages, to A4 paper and medical implants, is now trackable." (UK Hospital A)

Moreover, counting items in the pharmacy inventory and using auto-ID technology, *e.g.* RFID (cycle-count policy) to provide inventory visibility and items traceability is now possible. During the empirical study, the author found that several hospitals are applying RFID-enabled real-time inventory management systems. A head of procurement mentioned:

"We had already equipped each cabinet with RFID tags which have records of all the transactions and the information like what was removed, who removed it and for which patient the product is intended. When the hospital has been implemented with the Hospital Information System (HIS), real-time data captured by RFID reader is able to feed the medical document for the patient in the documentation system, modify expiration data as well as eliminating the need to maintain excess inventory." (UK Hospital A)

Last, RFID has been gaining increasing attention for reducing counterfeiting and enabling monitoring of drug quality in supply chains from improved traceability. During the visit observation in the case hospitals, the application of the RFID-enabled traceability system could be learned:

*"Once receiving a product in the centre store, after undergoing careful inspection, the staff scan the manufacturer's barcode on the package to obtain the relevant information (*e.g. *product, serial number and expiry data). The obtained information is then moved to the middleware in real time to save specific information such as requesting department/specialty, the internal product number and product description, the specific storage location where the product needs to be put away. Thereafter, the RFID printer prints a transferrable self-adhesive label which consists of the RFID transponder that is unique as well as any other related information such as the storage location. The RFID label is thereafter affixed to the packaging of the product. Once the product is delivered to the user department, clinical staff use the RFID board to swipe the product, the information will update to the application database, which confirms the delivery time and location as well as the status of product as ready for use. Then the product is stored in a specific storage location. Once the product is selected and dispensed to the doctor, and the product has been used for a certain procedure the automatic transfer of the captured information will trigger the replenishment process to the inventory management system that the hospital HIS has." (UK Hospital A)*

Whenever the product is used for a specific procedure, the replenishment process will be automatically triggered to transfer the captured information to the inventory management application hosted on the hospital's HIS system. Therefore, the end-to-end traceability of medical products in the healthcare SC becomes an important strategy to avoid or reduce the impact from supply and IT related risk factors.

7.3.2.3 Strategy 3: Developing inter and intra organizational collaborations

- *Shortage of drug, unavailability of drugs on the market (S3)*
- *Capability versus demand, inability of capacity to meet demand (S4)*
- *High purchase price (S10)*

Supply chain collaboration is often defined as two or more chain members working together to create a competitive advantage through sharing information, making joint decisions, and

sharing benefits which result from greater profitability of satisfying end customer needs than acting alone (Simatupang and Sridharan, 2005). Studies on service-dominant logic (SDL), for example by Schmenner *et al.,* (2009), significantly show how customer and supplier are no longer external to the system. Instead, they play the important roles in the process of value creation in the central company in the supply chain via the application and sharing of one another's competencies. Similarly, exchanges involve numerous suppliers because of the reliance on a wide range but specialised sources and forms of information and material supplies in the hospital supply chain. And, these exchanges may suggest collaboration because in the healthcare supply chain where independent partners are connected in co-creating values.

The findings, likewise, revealed that collaboration is a great way to mitigate supply chain risks. According to Lord Carter's report:

"Most evidence was done by close working relationships among Trusts at national, regional, and local levels and collaboration with pharmacy wholesalers and manufacturers. This collaboration resulted to the consolidation of medicines supply chain, which led to full utilization of e-ordering, invoicing, aggregating and rationalizing deliveries to be used in the wards. Combining drugs stock-holding and modernizing the supply chain to combine and rationalize distributions to decrease stock-holding days from 20 to 15, deliveries to less than 5 per day. It also makes certain that about 90 per cent of invoices and orders are electronically processed and delivered" (Lord Carter's report, 2016)

In order to realize these supply chain benefits through collaboration, substantial consolidation has been occurring through the formation of hospital systems that entail common ownership of two or more hospitals. In the UK, a Multi Trust Aggregation (MTA) was adopted by most hospital trusts to integrate the requirements across many affiliated hospitals. The procurement activities are aligned to enable each member to take advantage of volume economies and gain better negotiating leverage with suppliers. As such, group buying helps mitigate supply chain-related risks because it confers product variety, price stability, and produces availability for members irrespective of their size and location, which they may otherwise not achieve if they purchased individually (Zepeda *et al.,* 2016). For this reason, the Group Purchasing Organization (GPO) has received increasing attention from both academic and industrial fields (Burns and Lee 2008; Rego *et al.,* 2014; Zepeda *et al.,* 2016;

Yang *et al.,* 2017). According to the Healthcare Supply Chain Association (HSCA), a GPO is "an entity which assist the clinicians at hospitals, nursing homes, and home health agencies to obtain savings and efficiencies by combining purchasing volume as well as using that power to negotiate discounts with their vendors, distributor or manufacturers." GPOs do not purchase products for their own facility but instead support their members in their contract development and management and negotiate contracts with respective vendors. In addition to discounts, many GPOs also offer supply chain optimization consulting services and provide healthcare facilities valuable insights. One former hospital director stated:

"In China, hospitals are increasing relying on their GPO partners for a broad range of services beyond cost-saving, although cost-saving and delivering the quality products are the main elements to the GPOs' core mission. Moreover, many GPOs are expanding their services to meet evolving hospital and provider needs, such as market research, innovative technology integration, electronic product tracking and supply chain experts to share best practices." (Chinese Hospital F)

Meanwhile, "risk sharing" and "reduced inventory costs" are additional benefits from collaboration between hospitals, especially at the local system. It allows the affiliated hospitals to avoid a drug shortage by filling orders from other affiliated hospitals' central stock with inventory on hand. More importantly, this means the inventory is not always physically consolidated at a single location. Instead, the hospitals can physically or virtually access the inventory used by affiliated hospitals allowing the inventories to be shared among demand locations reducing the use of the inventory rate and related costs while achieving required service levels. One pharmacy department leader mentioned:

"Since 2007, we signed the contract with other three hospitals in the same regional area to provide the supply chain consolidation and reduced stock holding. It allows us to obtain needed stock from another hospital, especially when the urgent need for supplies arises. With this back-up arrangement, it enables us to reduce our safety stock and thus avoid the massive waste." (Chinese Hospital B)

It is noteworthy that most healthcare organizations are under pressure to make savings each year. One important reason is a lack of cross-functional department involvement in the procurement process. A pharmacy department leader mentioned:

"We have a large number of stakeholders working on product specifications, it meant difficulty reaching consensus and often led to purchasing several different versions of the same product. Hence, we set up the Pharmacy Administration Committee, which is composed of one vice president of hospital, pharmacy department leader, material department manager, several clinicians and a head nurse. Those members were given responsibility for making decisions on the how and where products could be purchased more efficiently." (Chinese Hospital C)

Working closely with other departments aids in the collaboration across internal boundaries and provides of a structure which enables swift communication. This is also in line with findings from Lord Carter's report (2016):

"…improving employee management capacity, building greater engagement and creates an engaged and inclusive environment for all colleagues by significantly improving leadership capability from "Ward to board."" (Lord Carter's report, 2016)

7.3.2.4 Strategy 4: Building efficient inventory management

- *Capability versus demand, inability of capacity to meet demand (S4)*
- *Poor IT system, lack of data standardization (S5)*
- *Lack of visibility concerning placement and availability of stock (S8)*

Excess inventories may add costs, drugs expiration and result in huge hits to the hospital's bottom line. Since the early 1990s, healthcare organizations began to adopt the idea of Just in Time (JIT) supply chains to decrease the rate of inventory holding costs and reduce employing more labour for managing the inventory management. The implementation of JIT management has a positive impact on the healthcare supply chain processes. In this case, the main objective is to ensure that they remove all stock in the central store. It means that suppliers deliver products to each point-of-use location in the hospitals without intermediate buffer inventories. The different collaborative arrangements between hospitals and pharmaceutical suppliers, such as "ward box", where hospitals place orders of the products required in a specific ward directly and the suppliers deliver to each ward without taking the detour to the central store. However, it is difficult to accurately forecast the demand due to considerable variability and unpredictability. The healthcare providers must transform their relationships with their key suppliers from an adversary to a long-term business partner to improve the supply efficiency and lower the inventory costs. Meanwhile, the healthcare

providers should be working with their suppliers to determine the capability of current logistics systems in order to identify and categorise all types of products and their predicted utilization. Moreover, material managers have to be actively involved since they have an integral role in assisting health facilities to implement more and better standards. Among the key activities that were revealed from the empirical study, a head of procurement said:

"Our new hospital was built in June 2015, since that, our Central Stores have now *been replaced by the Receipts and Distribution facility, that does not have to have so many stock. The amount of stocks held by the General Stores Department is now decreased due to the Just-in-Time approach, as well as ensuring that most of the purchases are done through the NHS Supply Chain (NHS SC) route. The NHS SC supplies to the hospital three times per week now so there is no need have so much stocks on site because the stock is readily available in the nearby warehouse which can be delivered in the shortest time possible. In addition to the above, the ward/department level took the responsibility to create the shopping lists on Oracle e-ordering system for their own requirements. Therefore, each ward/department can manage and control their own budgets and stock levels more closely as they are more accurately predict activity. Because of this, our stockholding costs reduced by 58 per cent to £86,000. There are two people who have been allocated in the General Stores who are supposed to leave under the Mutually Agreed Severance Scheme (MASS) and they save about £40,000. This has realised a reduction in the workload in General Stores because of the few items that are handled locally. In addition to those, ongoing savings of £80,000 in the health care organization hospital based on more exact estimation of activity affecting the purchases." (UK Hospital A)*

Another inventory management strategy, apart from the aforementioned, is adopting inventory management systems. In some cases, a lack of visibility of stock level had let to inefficient processes. For this reason, hospitals only know what is spent and not what is held, consumed, and wasted and use IT as an enabler to initiate a change in the stock management and replenishment process. $Atticus^{TM}$ is the first GS1 compliant inventory management solution, which helped UK NHS hospitals reduce wastage and historical inefficiencies by facilitating greater transparency, better stock and data management. A pharmacy department manager stated:

"Using the system enabled us to significantly improve the control functions of our corporate stores service and has achieved significant savings and visibility. Today consumption of stock is recorded at point of use at the same time ordering is based on exact consumption, allowing a reduction in stock holding. As a result, it has created more space due to being cleared of stock, and more has been reassigned for clinical usage. This has reduced the labour force of the people who deal with stock management saving more than 7,000 hours clinical time which has been initially reallocated to frontline care." (UK Hospital A)

7.3.2.5 Strategy 5: Implementing eProcurement strategy

- *Counterfeiting (S1)*
- *Poor IT system, lack of data standardization (S5)*
- *Dispensing/picking errors-medication/packaging (S6)*
- *Lack of visibility concerning placement and availability of stock (S8)*
- *High purchase price (S10)*
- *High product and supplier/brand variety (S11)*

To increase supply chain efficiency and ensure patient safety, Kritchanchai *et al.,* (2016) suggested that standardized healthcare infrastructures are the important means of managing healthcare supply chain and logistics to increase visibility and security. In their study, the infrastructure was composed of five main areas including: Standardized Product and Location Identification; Electronic product catalogues; eProcurement enabled by Electronic Data Interchange (EDI); Automatic Identification and Data Capture (AIDC) systems, *e.g.* barcodes and RFID; and traceability systems. The findings are also in line with the elements of eProcurement Strategy, such as E-catalogue management, location identification, and GS1 Global Data Synchronisation Network. To address the problem of supply chain capability, Lord Carter's interim report (2016) also suggested that all NHS trusts should work in collaboration both with national procurement strategies and to explore common systems adoption, such as enhancing current purchase to pay systems and adopting GS1 and PEPPOL standards which are all included in the eProcurement strategy.

eProcurement Strategy can be defined as *"the act of using technology application in automating procurement information exchange in the whole supply chain system."* The UK Department of Health (DH) announced its aim to implement global standards throughout the

healthcare sector and support machine-machine processing of transactions with little or no human intervention. More specially, the commonly used standards reported by various hospitals and their suppliers are GS1 coding and Pan European Public Procurement On-Line (PEPPOL). GS1 is meant for data synchronisation, location coding, and product coding (Bartsch *et al.,* 2012; Lichtner *et al.,* 2016). It can be seen that using master data across the whole healthcare supply chain network is essential to achieving effective management of long, complex SCs, *e.g.* procurement activities. In brief, master data is the definitive and accurate version of the information held about an item. However, the main issue for using master data is the same item coded and described differently by healthcare providers and suppliers. To address this issue, adopting GS1 standards provides an opportunity for the healthcare providers to benchmark and analyse medicine expenditure from their systems with other providers, sharing the purchasing requirements when tendering. Moreover, the adoption of these standards will enable interoperability between healthcare provider and supplier systems. Figure 7.3 displays how GS1 master data are maintained between the suppliers and healthcare provider catalogue solution.

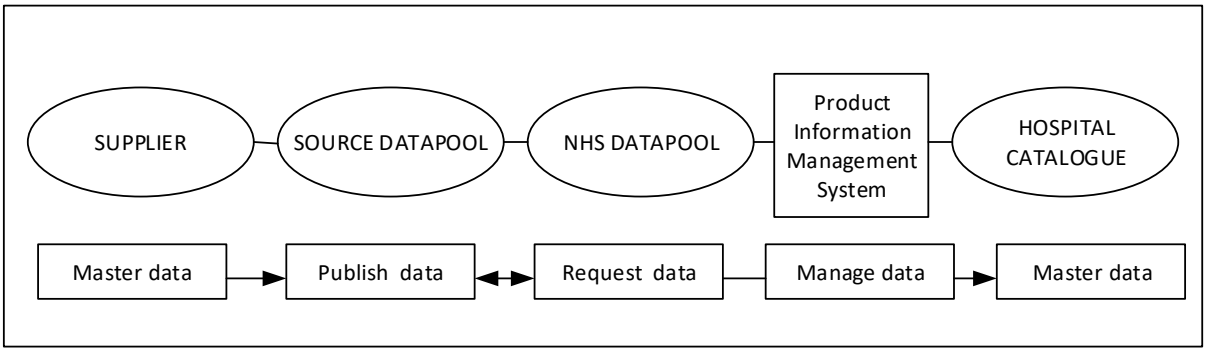


Figure 7-3: GS1 Global Data Synchronization Network in NHS system

(source from NHS E-procurement Strategy)

At the beginning, suppliers need to place the information in the GS1 specialised data pool Then, DH develops a GS1 certified NHS data pool, which takes the supplier master product data from any GS1 certified source datapool and makes it the data repository for master data according to products purchased by the healthcare provider. Next, the national Product Information Management (PIM) system was established by DH to integrate the NHS datapool with local healthcare provider catalogue solutions. Each provider uses the PIM to request and

manage master product data from the datapool, then request master product data from the source datapool selected by a supplier. Also, the GS1 Global Data Synchronisation Network was applied to ensure the master data to be synchronized in near real time, thereby ensuring that healthcare provider catalogues always contain accurate master data.

Master item data synchronized from a GS1 accredited datapool to the healthcare provider catalogue system which is then retrieved in the management of logistics activities in the SC by employing Automatic Identification Data Capture (AIDC) devices to scan barcodes. As discussed above, those capture devices and systems can track and trace items through a lot numbers and serial numbers, manage expiry dates, provide the interface with patient records to support traceability. Pharmaceutical manufacturers should record the unique random serial numbers according to every products in a database by matching it with the barcode printed on the product packaging. So that the product can be scanned at the point of dispensing and checked against the database. A system of pharmaceutical verification to prevent counterfeiting is determined by user.

Furthermore, in the UK NHS, the purchase order transactions are processed using the GHX Pharmacy Messaging Service platform, which integrates both the buying order system and the selling order processing system. To achieve automated machine-to-machine purchase order and invoice transactions performed among providers and suppliers, both are supposed to operate in a common messaging standard. Thus, PEPPOL (Pan European Public Procurement On Line) is recommended as a messaging standard to be adopted by both provider and suppliers. PEPPOL provides a set of messaging standards to exchange key documents (i.e. invoice messaging, advice note, and purchase order) between selling and buying organizations electronically with no manual intervention via PEPPOL 'access points'. Figure 7.4 presents the architecture for the provision of a messaging platform for the NHS provider and its suppliers using PEPPOL messaging standards.

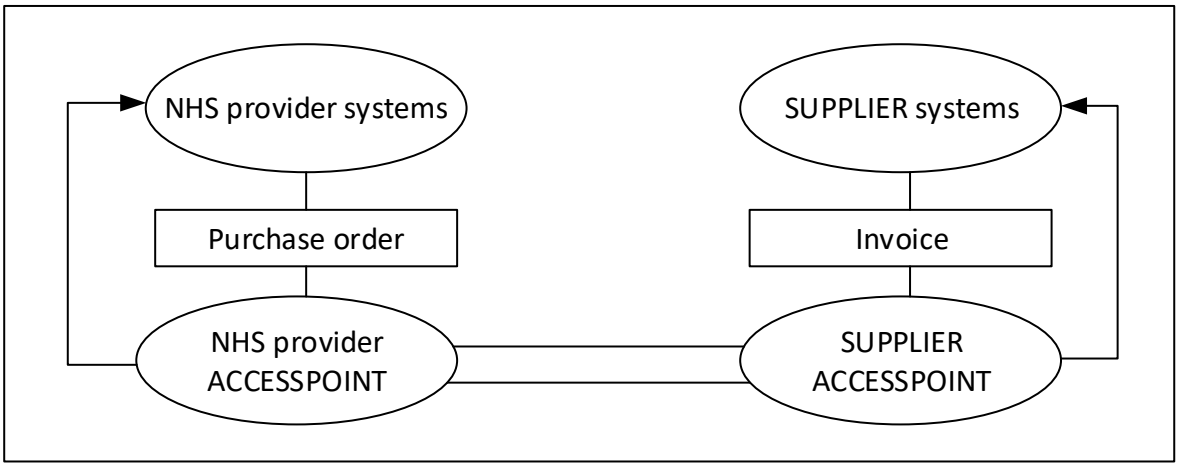


Figure 7-4: the architecture of PEPPOL messaging platform

(source from NHS E-procurement Strategy)

The NHS provider access point is integrated to the NHS provider purchase order processing system. The access point receives the purchase orders from the NHS provider and converts them to the PEPPOL messaging standard. The PEPPOL-compliant purchase order message is exchanged with the supplier access point, which in turn is incorporated into the supplier sales order processing system. As a result, a purchase order from an NHS provider is transmitted and loaded directly into the supplier's sales order processing system without manual intervention. Lastly, this process works in reverse to accommodate the exchange of invoice data between supplier accounts receivable systems and NHS provider accounts payable systems.

7.3.2.6 Strategy 6: Implementing outsourcing strategy

- *Weak logistics service infrastructure (S7)*

Outsourcing the non-core supply chain activities is one risk mitigation strategy. Several studies showed that outsourcing the supply chain related activities to the third party logistics service providers (3rd LSPs) would helps in creating the significant efficiency advantages for both parties because of economies of scale and scope, focus on core competencies, and fixed cost reduction (Azzi *et al.*, 2013; Lannone *et al.,* 2014; Volland *et al.,* 2017). Supply chain activities can be contracted to the 3rd LSPs with specialisation and more experience in logistics than the internal organisation's logistics department. According to Guimarães and de Carvalho (2012), the most important aspect of outsourcing to the 3rd LSPs is building

relationships and integration of IT information are all accomplished, as logistics companies would endeavour to ensure that their clients' (in this case healthcare facilities) requirements are quickly and accurately delivered. Waters and Rinsler (2014) argued that the trend of outsourcing has increased over the last few years in healthcare sector, and extended from meals preparation and washing to division management in the supply chain.

Today, patients are increasingly demanding and informed and they request healthcare more frequently and earlier (Christopher, 2016). Subsequently, healthcare departments require additional focus on their core business more than in previous years. Outsourcing some key elements within the hospital supply chain like pharmaceuticals may result in more efficient inventory management leading to cost savings directly. Hospitals can put more investments into clinical trials and researches linked to their main business in order to meet patients' different and numerous demands with the saved capital. The number of 3rd LSPs offering healthcare inventory management services together with their expertise levels has significantly increased over the last few years. Through their professional experiences, the providers have successfully reduced inventory costs in the healthcare sector. Thus, in the literature on healthcare outsourcing reviewed, the most cited outsourcing drivers include: cost reduction, risk mitigation, and rapid change without compromising internal resources (Roberts, 2001; Volland *et al.,* 2017).

According to the empirical studies, some hospitals outsourced their two-echelon distribution network, from central store to each "point-of-use" department for non-critical medical items (*i.e.* latex gloves, plastic/disposable sheets) does not compromise on the quality of care. In addition, Lord Carter's report (2016) also recommended that:

"…buying and supply services do not need to be handled by hospital staff. It is recommended that those hospitals which have not outsourced their outpatient dispensing services (i.e. community pharmacy providers) should look for a way through outsourcing to improve their productivity and efficiency. This can be done through adopting alternative supply route and make sure that that more than 80 per cent of hospitals' pharmacist resource is utilized for direct medicines optimization activities, medications governance and safety concerns while at the same time revising the provision of all local organizational services, which could be delivered collaboratively with another trust or through a 3rd party provider." (Lord Carter's report, 2016)

In the meantime, during the interview, a pharmacy department manager stated that:

"We wanted to free up time for clinicians so that they are able to focus on their main responsibilities. Achieving this would let us to invest in additional services. We outsourced stock replenishment and maintenance to a logistics provider since last year. It means our resources are more appropriately focused on collaborative arrangements; the clinical element of the service are now out of direct stock procurement and stock control. " (Chinese Hospital D)

7.3.2.7 Strategy 7: Implementing agility strategy

- *Shortage of drug, unavailability of drugs on the market (S3)*
- *Capability versus demand, inability of capacity to meet demand (S4)*

The healthcare industry systems are often characterized as particularly complex systems operating in a changing environment, interacting with a wide variety of heterogeneous actors, interests and factors, often with disparate demands (Tolf *et al.,* 2015). Thus, agility requires both reactive and proactive strategies to enable healthcare organizations to thrive in high-frequency changing, turbulent, and unpredictable environments. According to Ebel *et al., (*2013), agility not only implies quick responses to emergency circumstances, but also implies the ability to remove change as an ad hoc disturbance and make it an essential condition of organizational behaviour. Although most studies argued that the agility strategy is effective in reengineering the patient pathway (Aronsson *et al.,* 2011; Vries and Huijsman 2011; Guven-Uslu *et al.,* 2014), some maintained that it ensures productivity objectives and SC integration. The enabler for an agile organization was explored by Tolf *et al.,* (2015), who focused on the interaction between each party in the SC network and its surrounding context. Breen *et al.,* (2008) emphasized that it is impractical for one organization to have everything it takes to fully meet customer demands. Thus, an agile organization should use the competencies and strengths of network partners.

The different stakeholders within the supply chain, regulators and government must be dedicated to working together to ensure that patients can continue to receive medicines on time and conveniently (*e.g.* under normal circumstances, the medicines should be received from pharmacies within 24 hours). Therefore, the pharmacies' and doctors' dispensaries must have contingency arrangements are in place to source items where understocked from the

supplier. In this case, reasonable steps should be taken to have reciprocal arrangements with neighbouring pharmacies to meet urgent demands and the use of manufacturers' contingency order arrangements.

The cases hospitals highlight the importance of out of hours, urgent and emergency deliveries for major incidents or medical emergencies. NHS Supply Chain, an organization run by the DHL supply chain on behalf of the NHS Business Services Authority, provided a dedicated supply chain service and products to each NHS trust in England. In the event of unexpected emergencies by providing 24 hours emergency service to deliver the order within five hours. For some products not stocked within their distribution centre network, such as Blue Diamond (*e.g.* non-stock items but can be consolidated and sent out with NHS Supply Chain delivery) or eDirect product (*e.g.* delivered separately, direct from manufacturer), they will endeavour to obtain stock for delivery within the shortest time (*i.e.* less than 24 hours). During the interview, a head of procurement stated:

"Most of the time, when we have an urgent requirement for our intensive care unit. We make a call to NHS Supply Chain and to our delight, the delivery arrives one hour later. This is absolutely an exceptionally quick service by anyone's standards. Because of this, we can avoid many serious consequences." (UK Hospital A)

7.3.2.8 Strategy 8: Developing internal capability management

- *Clinician's preference (S9)*

Capability management is a set of activities to facilitate learning and knowledge sharing within the organization (Dow *et al.,* 2013). It identifies the organization's capabilities needed to meet its strategic objectives while ensuring continual alignment of staff talent management, career progression, and employee development to the dynamic business needs. More specifically, Ferlie *et al.,* (2015) argued that capability management includes succession management for all employees and leaders at lower levels, talent pool management, talent reviews, competency maintenance, and modelling, career development and planning, and skills transferability. In the supply chain context, managers use training to learn about different supply chain risk sources and how to employ appropriate SCRM tactics (Riley *et al.,* 2016).

In any case, clinician education is founded on science and clinicians therefore tend to respond favourably to scientific, fact-based justifications for proposed changes. Thus clinical professionals often pay more attention to patient management rather than to organizational performance. The issue should be solved by providing clinicians with empirical evidence that supply chain redesign will streamline processes, improve outcomes, and reduce expenses without lowering levels of clinical effectiveness. Even though the healthcare SCM has attracted increasing attention by several researchers in recent years, the overall tendency in the healthcare sector is to slowly embrace new SCM practice (McKone-Sweet et al., 2005). It reveals that lack of supply chain education and awareness are a common phenomenon to most healthcare providers. According to the empirical studies, most healthcare providers paid attention to staff training as they continually put investment into activities related to training and development. One pharmacy department manager mentioned that:

"We hold regular staff training sessions to train the relevant staff to avoid or at least reduce the failures caused by human errors. Our aims to ensure that about 75 percent of staffs who responsible for material/purchasing management roles could get membership of the Chartered Institute of Purchasing and Supply Qualifications." (UK Hospital A)

Moreover, NHS Procurement and Commercial Standards were launched by Department of Health (DH) in 2012; they provide a clear vision of continual improvement and advisory panel of NHS Procurement professionals. In particular, people and skills are the key elements to be mentioned in the report. For example:

*"All new staff undertaking procurement supply chain operations should, however, have a training plan in place; this should be tailored to the amount of time expected to be spent on them. The procurement team should have a relevant mix of skills to enable strategic and transactional working as needed. Procurement staff can demonstrate a commitment to continuous professional development (CPD), such as having relevant professional qualification (*e.g. *CIPS & IACCM) and evidence of CPD. Good mix of "on the job" training and classroom training provided to the Procurement teams." (NHS Procurement and Commercial Standards, 2016)*

7.3.2.9 Strategy 9: Implementing single sourcing strategy

- High purchase price (S10)
- High product and supplier/brand variety (S11)

Sourcing decisions have become among the most commonly used strategies not only in the healthcare sector, but also in other industries. According to Yu *et al.,* (2009), three sourcing approaches were identified as follows:

- Single sourcing, in which a buyer chooses a single main supplier even though other comparable suppliers do exist.
- Dual sourcing, in which a buyer employs two suppliers, one of which may dominate the other in terms of business share, price and reliability.
- Multiple sourcing, in which a buyer is involved in a business with various suppliers and plays one supplier against the other via the bidding process to enjoy the best purchase conditions.

Yu *et al.,* (2009) suggested that a single sourcing strategy represents the narrowest form of supply base and strives for a strategic collaboration between a buyer and a supplier and also improve shared profits, can be used to proactively manage supply risks. Moreover, single sourcing can significantly minimize the supervisory and administrative roles of contracting many firms to perform the same work. In agreement, Tomlin (2006) observed that by adopting Just-in-Time (JIT) management, healthcare providers will constantly source from a single supplier for the given products to establish close relationships with mutual interdependence and a close strategic relationship, cooperative action, short lead times. Therefore, it is sometimes seen as the best option to reduce logistics costs, as placing all purchasing orders with one single supplier. However, Hou *et al.,* (2010) opposed such a strategy, arguing that buyers should have more than one supplier to avoid putting all the eggs in one basket there by increasing the supply risk. Kanyoma *et al.,* (2013) further argued that mutual dependency is the one major limitation related to single sourcing. The relevance of single sourcing is further emphasized by Burke *et al.,* (2007), whereby single sourcing is an ideal solution only when supplier capacities are enough to handle product demand and when the buying organization does not obtain variation in benefits.

This high product and supplier/brand variety disaggregates and undermines hospital's buying

power with the inevitable result of variation and higher prices. Furthermore, product variety is the root cause of hospital supply chain wastes, such as high inventories, expiration and obsolescence, and low value orders and delivery changes. According to the empirical studies, two observed hospital cases using a single sourcing system, rely on a government instituted supplier namely the "Sinopharm Group", which is the biggest Chinese pharmaceutical company. The company manages factories, Research and Developmeng (R&D) laboratories, traditional Chinese medicine plantations, and marketing and distribution networks that cover all 31 provinces in China. One pharmacy department leader stated:

"We have emphasized the importance of collaboration with Sinopharm Group since 2005. As for the single sourcing strategy, which improved our bargaining power and reduced costs as well as decreased effort to track supplier performance. In particular, they can deliver the urgent order very quickly from their nearby distribution center or from other hospitals which are under the same contract with them. (Chinese Hospital A)"

A general manager from a pharmaceutical company stated:

"To be honest, as a pharmaceutical supplier, it is far better for us to be approved as a sole partner of hospitals. If they do, we can upgrade our quality of logistics services as well as price discount, and these efforts eventually lead to win-win scenario. As the rich experience in operating logistics activities, we are in discussion with our partner hospitals about whether they could outsource their second tier pharmacy to us. That would free up time for pharmacists so they could focus on their main responsibilities." (Pharmaceutical Company B)

7.4 EVALUATION OF RISK MITIGATION STRATEGIES

Technique for order Preference by Similarly to Ideal Solution (TOPSIS) is one of the most practical and useful methods for solving multi-criteria decision-making (MCDM) problem (Hwang and Yoon, 1981). The basic idea of the method is to rank and select possible alternatives, which have the longest distance from the negative-ideal solution (i.e. the solution that maximizes the cost criteria and minimizes the benefits criteria) and the shortest distance from the positive-ideal solution (i.e. the solution that maximizes the benefit criteria and minimizes the cost criteria). Despite the benefits of the TOPSIS method, namely that it supports managers for selecting the most suitable alternatives, it has certain drawbacks. One

major drawback is its inability to handle vagueness and imprecision inherent in the process of mapping the perceptions of decision-makers. Fuzzy TOPSIS has been successfully used to solve such problems. In this research, the focus is on the fuzzy TOPSIS by combined TOPSIS with fuzzy set theory. The fuzzy TOPSIS method is suitable for solving the group decision-making problem under the fuzzy environment (Vinodh *et al.,* 2014). More features of fuzzy TOPSIS are detailed in the following sections. There are several fuzzy TOPSIS methods proposed by various researchers. Chen (2000) has used the extensions of the TOPSIS for group decision-making under a fuzzy environment. As per the theory of the TOPSIS, the author has defined a closeness coefficient to conclude the ranking order of all alternatives by calculating the distances to both the fuzzy positive-ideal solution and fuzzy negative-ideal solution at the same time. Nazam *et al.,* (2015) fomulated the fuzzy AHP-TOPSIS framework to calculate the weight of each risk criterion and rank the risks associated with implementation of green supply chain management practices under the fuzzy environment. The proposed models helps the researchers and practitioners to understand the importance of conducting appropriate risk assessment when implementing green supply chain initiatives. The

incorporation of fuzzy risk assessment, fuzzy Delphi and fuzzy TOPSIS as an integrated methodology has been proved by Wang *et al.,* (2017) to be a systematic and practical decision-making tool supporting a very effective supply chain risk communication and risk mitigation strategy evaluation.

In this research, a Fuzzy AHP method has been used for determining the priority weights of the risk factors (*i.e.* criteria and sub-criteria). Fuzzy TOPSIS can be utilized for selecting the most appropriate risk mitigation strategies (*i.e.* alternatives). Using the Fuzzy AHP in Chapter six, the relative weights of the risk factors in the healthcare supply chain systems were calculated.

Using the mentioned fuzzy approach, the chosen fuzzy TOPSIS process is then addressed as follows (Chen, 2000).

Step 1: Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic rating values for alternatives with respect to criteria. It can be assumed that there are *m* possible alternatives called *A*= $\{A_1, A_2, A_3 \dots A_m\}$ which are to be analysed in relation to the criteria, *C*= $\{C_1, C_2, C_3 \dots C_n\}$ The criteria weights are denoted by w_j $(j =$

$1, 2, \ldots n)$. The performance ratings of each expert D_k $(K = 1, 2, \ldots K)$ for each alternative A_i $(i = 1, 2, \ldots m)$ with respect to criteria C_j $(j = 1,2, \ldots n)$ are denoted by $\tilde{R}_k$ = $\tilde{x}_{ijk}(i = 1,2, \ldots m; j = 1,2, \ldots n; k = 1,2 \ldots K)$ membership function $\mu\tilde{R}k(x)$. In this thesis, it is suggested that the experts use the linguistic variables (Shown as Tables 7.2 and 7.3) to evaluate the importance of the criteria and the ratings of alternatives with respect to various criteria, and the illustration of membership function for linguistic expressions is presented in Figure 7.5.

Table 7.2: Linguistic variables for the importance weight of each criterion and sub-criteria

Linguistic judgement	Triangular fuzzy number *(l, m, u)*
Equal importance (Eq)	(1, 1, 1)
Weak importance (Wk)	(2/3, 1, 3/2)
Strong importance (St)	(3/2, 2, 5/2)
Very strong importance (Vs)	(5/2, 3, 7/2)
Absolute strong importance (As)	(7/2, 4, 9/2)

Table 7.3: Linguistic variables for the alternatives rating

Very poor (VP)	(1, 1, 3)
Poor (P)	(1, 3, 5)
Medium (M)	(3, 5, 7)
Good (G)	(5, 7, 9)
Very good (VG)	(7, 9, 11)

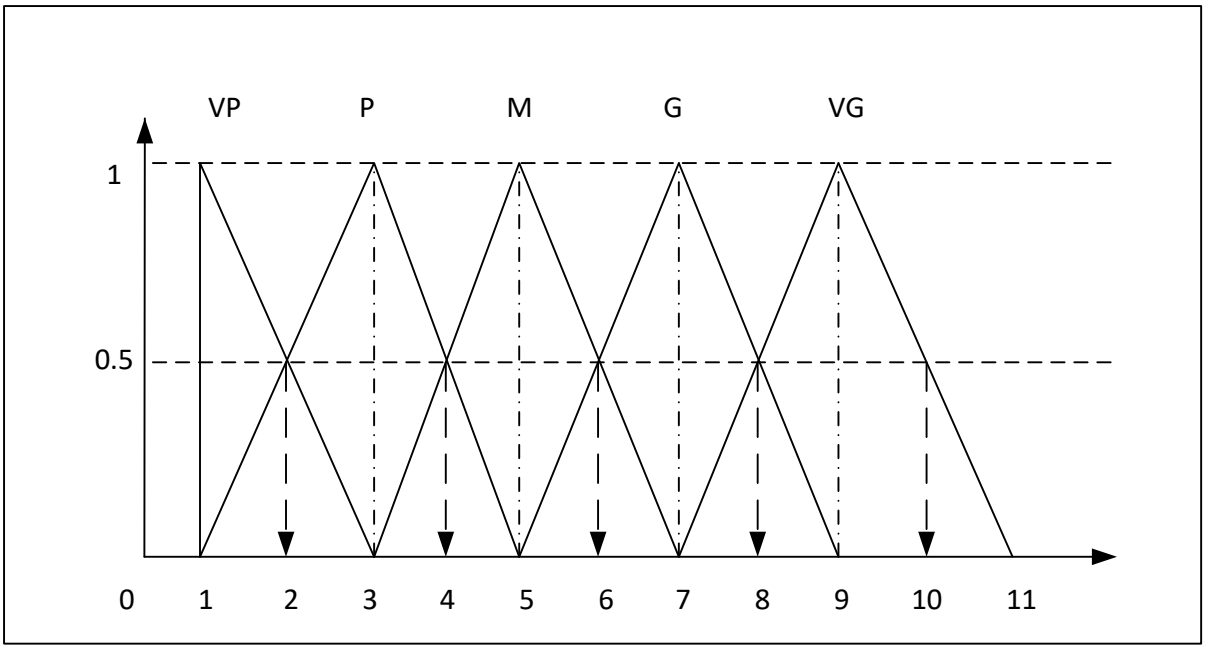


Figure 7-5: Fuzzy membership function for linguistic expressions

Step 2: Aggregate the weight of criteria to get the aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_j and pool the experts' opinions to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterionC_j. If the fuzzy ratings of all experts are described as TFN $\tilde{R}_k = (ak, bk, ck), k = 1,2, \dots K$ then the aggregated fuzzy rating is given by $\tilde{R} = (a, b, c)\ k = 1,2, . . K$ where

$$a = \min_k \{a_k\}, b = \frac{1}{k}\sum_{k=1}^{K} b_{k_i}, c = \max_k \{c_k\} \tag{7.1}$$

Assume that the fuzzy rating of the *k*th expert is $\tilde{x}_{ijk} = \left(a_{ijk}, b_{ijk}, c_{ijk}\right), i = 1,2, \dots \mathrm{m}, j = 1,2, \dots \mathrm{n}$ then the aggregated fuzzy ratings $\tilde{x}_{ij}$ of alternatives with respect to each criterion are given by $\tilde{x}_{ij}(a_{ij}, b_{ij}, c_{ij})$, where

$$a_{ij} = \min_k \{a_{ijk}\}, b = \frac{1}{k}\sum_{k=1}^{K} b_{ijk}, c = \max_k \{c_{ijk}\} \tag{7.2}$$

Step 3: Construct the fuzzy decision matrix and the normalized fuzzy decision matrix. The fuzzy decision matrix for the alternatives ($\widetilde{D}$) is constructed as follows:

$$\begin{array}{c} \\ A_1 \\ A_i \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \dots & C_j & \dots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \dots & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \dots & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \dots & \dots & \tilde{x}_{mn} \end{bmatrix} \end{array} = \tilde{D} \tag{7.3}$$

$$\tilde{w} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_j, \dots, \tilde{w}_n] \tag{7.4}$$

where $\tilde{x}_{ij}, i = 1,2, \dots., m; j = 1,2, \dots., n$ and $\tilde{w}_j, j = 1,2, \dots, n$ are linguistic TFNs, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (a_{j1}, b_{j2}, c_{j3})$. Note that $\tilde{x}_{ij}$ is the performance rating of the ith alternative, A_i, with respect to the jth criterion, $\tilde{w}_j$represents the weight of the jth criterion, C_j. The normalised fuzzy decision matrix denoted by $\tilde{R}$ is shown in Eq. 7.5:

$$\tilde{R} = [\tilde{r}_{ij}] m \times n \tag{7.5}$$

where *B* and *C* are the set of benefit criteria and cost criteria, respectively, and

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), j \in B;$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), j \in c;$$

$$c_j^* = \max_i c_{ij} \quad if \ \ j \in B;$$

$$a_j^- = \min_i a_{ij} \quad if \ j \in C. \tag{7.6}$$

Step 4; Construct the weighted normalized fuzzy decision matrix. The weighted normalized matrix ṽ for criteria is computed by multiplying the weights (w_j) of evaluation criteria with the normalized fuzzy decision matrix $\tilde{r}_{ij}$.

$$\tilde{v} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \cdots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \cdots & \tilde{v}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \tilde{v}_{n2} & \cdots & \tilde{v}_{mn} \end{bmatrix} = \begin{bmatrix} \widetilde{w}_1\tilde{r}_{11} & \widetilde{w}_2\tilde{r}_{12} & \cdots & \widetilde{w}_n\tilde{r}_{1n} \\ \widetilde{w}_1\tilde{r}_{21} & \widetilde{w}_2\tilde{r}_{22} & \cdots & \widetilde{w}_n\tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{w}_1\tilde{r}_{m1} & \widetilde{w}_2\tilde{r}_{m2} & \cdots & \widetilde{w}_n\tilde{r}_{mn} \end{bmatrix} \quad (7.7)$$

Step 5: Determine the fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

The FPIS and FNIS of the alternatives is computed as follows:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) = \left\{ \left(max_i \tilde{v}_{ij} \middle| i = 1, \dots, m \right) j = 1,2, \dots, n \right\} \quad (7.8)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), \left\{ \left(min_i \tilde{v}_{ij} \middle| i = 1, \dots, m \right) j = 1,2, \dots, n \right\} \quad (7.9)$$

Maximun and minimum operations do not give TFN but it is likely to state the approximated values of minimum and maximum as TFNs (Kwang, 2005). It is known that the elements $\tilde{v}_{ij} \forall_{ij}$ are normalised positive TFNs and their ranges belong to the closed interval [0, 1]. Thus, it can define the fuzzy positive ideal solution and the negative ideal solution as $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)\ j = 1,2, \dots n$ (Patil and Kant, 2014).

Step 6: Calculate the distance of each alternative from FPIS and FNIS, respectively. The distance of each alternative from A^* and A^- can be currently calculated as

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), i = 1,2, \dots, m. \quad (7.10)$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), i = 1,2, \dots., m. \quad (7.11)$$

where *d* (. , .) is the distance measurement between two fuzzy numbers.

Step 7: Calculate the closeness coefficient of each alternative.

The closeness coefficient CC_i represents the distances to the fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) simultaneously. The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*}, j = 1,2, \ldots., m. \quad (7.12)$$

Step 8: According to the closeness coefficient, the ranking order of all alternatives can be determined.

7.5 AN EMPIRICAL STUDY ON THE APPLICABILITY OF THE FUZZY TOPSIS METHOD

In order to complete the predefined integrated risk management (RM) model, the identified risk factors must be mitigated to complete the RM model. To investigate the priorities of the identified mitigation strategies over the previous risk factors, the Fuzzy TOPSIS method was developed. A survey was conducted to facilitate an insightful understanding and knowledge of the significance of the implemented risk mitigation strategies and formulate appropriate risk management solutions. This study was conducted in three phases: (1) conducting the survey, (2) application of the proposed Fuzzy TOPSIS method, and (3) sensitivity analysis. Each of the phases will be discussed in this section.

7.5.1 Conducting the Fuzzy TOPSIS-based questionnaire survey

The questionnaire survey was conducted over five weeks from 17th Oct to 21st Nov 2017, with the respondents selected based on their involvement within the healthcare supply chain management, disruption experience, and understanding of risk management related to this research's objectives. However, in order to increase the valid response rate, the respondents were contacted in advance to determine if they would agree to participate into our survey. As explained in Chapter three, the selected respondents consisted of experts from both academic and practitioner fields in order to balance their professional areas.

At the beginning, a pilot study was conducted to address the content ambiguity and other bias in the questions. The draft version of the questionnaire was examined by four academic researchers from both UK and China Universities to comment on the appropriateness and clarify of the questions. Moreover, the ethical approval was also obtained to further validate questionnaire contents and participant consent. The revised questionnaire as represented at the end of the pilot study was sent out to those twenty experts for data collection. The questionnaire was web-based using eSurvey Creator, and thus a link was emailed to the experts. In addition, the cover letter was offered to respondents prior to the main question page (see Appendix Five).

Table 7.4 demonstrates the profile of the respondents who participated the questionnaire survey. The respondents were expected to have expertise in risk mitigation design, strategy, and operations, thus this survey limited participants to department leader, logistics or supply chain executives and risk management professionals. All experts from healthcare organizations are at the manager level or higher. The survey yielded a 90 per cent valid response rate as two experts did not answer all the questions of this survey, within five weeks. Figure 7.6 shows that most of the participant experts come from hospital sectors by 60 per cent, 10 per cent were general manager in pharmaceutical companies and the remaining 30 per cent experts from university or consultative institutes.

Table 7.4: The profile of survey respondents

No	Participant	Position	Method	Location Operating Base
1	Hospital	Stock Manager	Email	China
2	Hospital	Pharmacy department leader	Email	China
3	Hospital	Pharmacy department leader	Email	China
4	Hospital	Pharmacy department leader	Email	China
5	Hospital	Pharmacy department leader	Email	China
6	Hospital	Pharmacy department leader	Email	China
7	Hospital	Former Director	Email	China
8	Hospital	Director	Email	China
9	Hospital	Stock Manager	Email	China
10	Pharmaceutical Company	General Manager	Email	China
11	LogHealth Center	Researcher/Consulting	Email	UK
12	LogHealth Center	Professor	Email	UK
13	University	Researcher/Consulting	Email	UK

14	University	Professor	Email	China
15	University	Senior Lecturer	Email	UK
16	University	Researcher/Consulting	Email	UK
17	NHS Trust	Head of Procurement	Email	UK
18	NHS Trust	Pharmacy Purchasing Manager	Email	UK
19	NHS Trust	E-Procurement and Inventory Systems Team Manager	Email	UK
20	Pharmaceutical Company	General Manager	Email	China

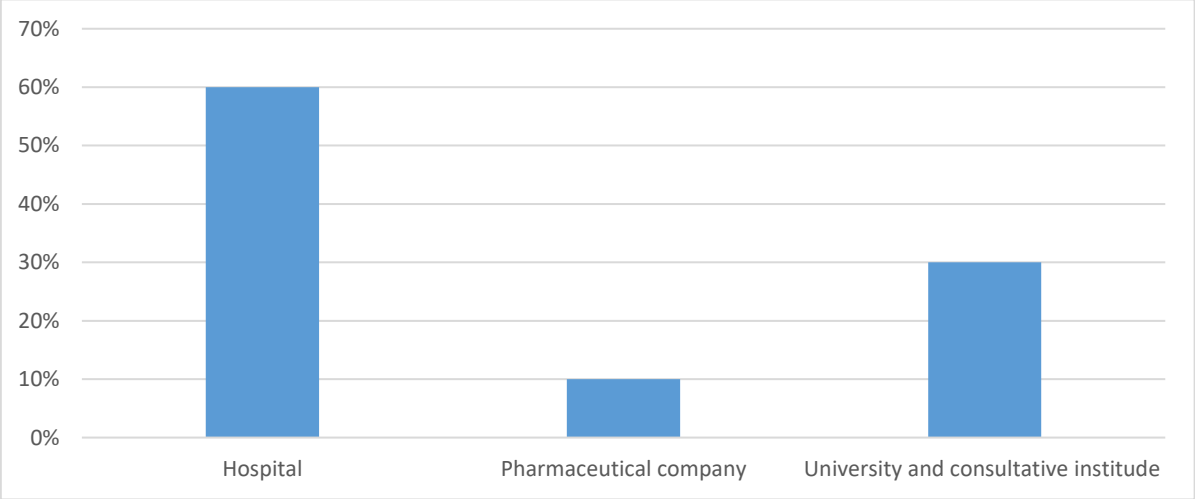


Figure 7-6: Distribution of respondents

7.5.2 Evaluation of identified risk mitigation strategies

In Chapter six all of the relative weights for risk factors (*i.e.* criteria and sub-criteria) in the healthcare supply chain were calculated. In this chapter, nine mitigation strategies (*i.e.* alternatives) which were identified previously in Section 7.3 will be applied on healthcare supply chain operations using the Fuzzy TOPSIS method. The hierarchical structure of this decision problem is shown in Figure 7.7. This process is carried out to rank the alternatives as per their priorities for risk mitigation purpose as per the following steps.

Step 1: Choose the appropriate linguistic ratings values for alternatives with respect to criteria.

The participant experts were consulted to construct a fuzzy evaluation matrix using a linguistic scale for subjective judgments presented in Table 7.5. This research uses the basic linguistic preference as very poor (VP), poor (P), medium (M), good (G) and very good (VG). As discussed above, the concept of linguistic variables is suitable for dealing with real-world decision-

making problems, which are usually complex, partially defined and related to uncertainty (Chatterjee and Kar, 2016). Hence, the linguistic judgements are used to measure the performance of the identified risk mitigation strategies when managing each risk factor. Due to space limitations, the linguistic evaluation matrix and fuzzy evaluation matrix of three experts under sub-criteria counterfeiting risks (S1) are given here only in Tables 7.6 and 7.7. Then, the linguistic terms were converted into assigned TFNs to construct the fuzzy evaluation matrix as shown in Table 7.7.

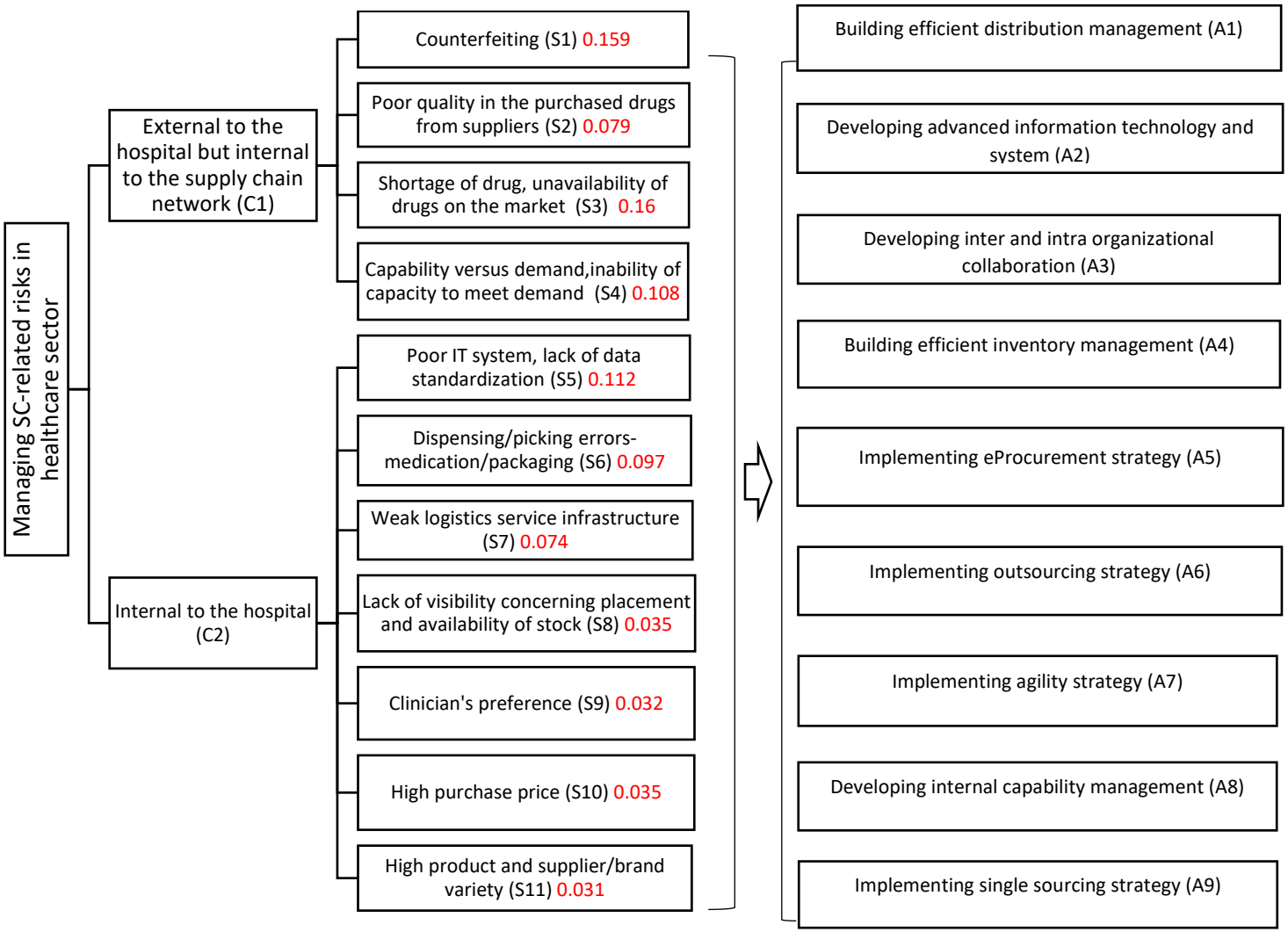


Figure 7-7: Decision hierarchy for the performance of implemented risk mitigation strategies

Table 7.5: Linguistic variables for the ratings

Very poor (VP)	(1, 1, 3)
Poor (P)	(1, 3, 5)
Medium (M)	(3, 5, 7)
Good (G)	(5, 7, 9)
Very good (VG)	(7, 9, 11)

Table 7.6: The ratings of alternatives by three experts under sub-criteria counterfeiting risks (S1)

Sub-criteria	Alternative	Participant Experts		
		E1	E2	E3
counterfeiting risks (S1)	Logistic management (A1)	G	VP	P
	Information Technology System (A2)	G	VG	G
	Collaboration (A3)	VG	VG	G
	Inventory management (A4)	VG	P	P
	e-Procurement strategy (A5)	G	G	G
	Outsourcing (A6)	VP	M	G
	Agility (A7)	P	VG	P
	Capability management (A8)	M	VP	M
	Single sourcing (A9)	P	G	G

Table 7.7: Fuzzy evaluation matrix for the implementation of risk mitigation strategies

Sub-criteria	Alternative	Participant Experts		
		E1	E2	E3
counterfeiting risks (S1)	Logistic management (A1)	(1, 3, 5)	(1, 1, 3)	(1, 3, 5)
	Information Technology System (A2)	(5, 7, 9)	(7, 9, 11)	(5, 7, 9)
	Collaboration (A3)	(7, 9, 11)	(7, 9, 11)	(5, 7, 9)
	Inventory management (A4)	(7, 9, 11)	(1, 3, 5)	(1, 3, 5)
	e-Procurement strategy (A5)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)

	Outsourcing (A6)	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)
	Agility (A7)	(1, 3, 5)	(7, 9, 11)	(1, 3, 5)
	Capability management (A8)	(3, 5, 7)	(1, 1, 3)	(3, 5, 7)
	Single sourcing (A9)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)

Step 2: Aggregate the weight of criteria to get the aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_j and pool the experts' opinions to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterionC_j. In this step, aggregating fuzzy weights of the alternatives are computed using Eq. (7.1) discussed in section 7.4 and presented in Table 7.8.

Step 3: Construct the fuzzy decision matrix and the normalized fuzzy decision matrix. In this research, all the criteria are the risks in the healthcare supply chain, as per the goal mitigation of these risks is required. Hence, all the risks are termed as cost criteria and normalization performed by Eq. (7.6) and for further detail (see Table 7.9).

Step 4; Construct the weighted normalized fuzzy decision matrix. This step is to obtain a fuzzy weighted evaluation matrix. Using the sub-criteria weight calculated by Fuzzy AHP (see Chapter six), the weighted evaluation matrix is established using the Eq. (7.7) which is shown in Table 7.10.

Step 5: Determine the fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

Step 6: Calculate the distance of each alternative from FPIS and FNIS, respectively. In this study, all the sub-criteria risks are the cost criteria. Hence, fuzzy positive-ideal solution (FPIS,A^*) and fuzzy negative-ideal solution (FNIS, A^-) as $\tilde{v}^*$= (0,0,0) and $\tilde{v}^-$=(1,1,1) for all these sub-criteria. Then compute the distance d_v of each alternative form FPIS (A^*) and FNIS (A^-) using the Eq. (7.10) and Eq. (7.1). For example, the distance $d_v(A_1, A^*)$ and $d_v(A_1, A^-)$ for alternative A_1 and sub-criteria C_1 from (FPIS, A^*) and (FNIS, A^-), are calculated as follows.

Table 7.8: Aggregate fuzzy decision matrix for the implementation of risk mitigation strategies

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	(1, 5, 11)	(1, 6.7, 11)	(1, 7.1, 11)	(1, 7.2, 11)	(1, 5.9, 11)	(3, 8.1, 11)	(1, 4.6, 9)	(1, 7.1, 11)	(1, 4.7, 9)	(1, 4.8, 9)	(1, 5.1, 11)
A2	(3, 7.4, 11)	(3, 7.5, 11)	(1, 7.5, 11)	(3, 7.9, 11)	(1, 7.5, 11)	(1, 6.8, 11)	(5, 8.8, 11)	(1, 8.2, 11)	(1, 6.1, 11)	(1, 6.6, 11)	(1, 7, 11)
A3	(1, 7.5, 11)	(1, 8, 11)	(1, 5.3, 11)	(3, 6.3, 11)	(1, 5.5, 11)	(1, 6.4, 11)	(1, 4.8, 11)	(1, 3.9, 9)	(1, 8.2, 11)	(1, 7.7, 11)	(1, 7.7, 11)
A4	(1, 5.9, 11)	(1, 7.1, 11)	(1, 7.1, 11)	(1, 7.3, 11)	(1, 5.4, 11)	(1, 7.7, 11)	(1, 4.4, 9)	(5, 8.7, 11)	(1, 5.6, 9)	(1, 5.4, 11)	(1, 5, 11)
A5	(1, 7.3, 11)	(3, 6.6, 11)	(1, 5.6, 11)	(3, 6.4, 11)	(1, 5.9, 11)	(1, 5.1, 9)	(1, 6.7, 11)	(1, 5.6, 11)	(1, 5.7, 11)	(1, 6.5, 11)	(3, 6.8, 11)
A6	(1, 2.1, 9)	(1, 2.5, 9)	(1, 2.1, 9)	(1, 2.4, 9)	(1, 2.8, 11)	(1, 2.5, 9)	(1, 2.1, 9)	(1, 2.4, 11)	(1, 2.8, 9)	(1, 2.4, 9)	(1, 2.3, 9)
A7	(1, 3.7, 7)	(1, 5.7, 11)	(1, 4.3, 11)	(1, 5.5, 11)	(1, 4.5, 11)	(1, 4.3, 7)	(1, 2.3, 11)	(1, 2.5, 9)	(1, 2.8, 11)	(1, 3.4, 11)	(1, 3.1, 7)
A8	(1, 4.2, 9)	(1, 5.8, 11)	(1, 5.1, 11)	(1, 4.5, 9)	(1, 3.6, 9)	(1, 4.4, 11)	(1, 3.6, 7)	(1, 4.2, 9)	(1, 4.1, 11)	(1, 5.6, 11)	(1, 4.3, 9)
A9	(1, 4.2, 11)	(1, 3.6, 11)	(1, 1.9, 9)	(1, 2.6, 11)	(1, 2.3, 11)	(1, 2.1, 9)	(1, 1.9, 9)	(1, 2.1, 9)	(1, 2.7, 11)	(1, 2.3, 9)	(1, 2.7, 11)

Table 7.9: Normalized fuzzy decision matrix for the implementation of risk mitigation strategies

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
A1	(0.09, 0.2, 1)	(0.09, 0.15, 1)	(0.09, 0.14, 1)	(0.09, 0.14, 1)	(0.09, 0.17, 1)	(0.09, 0.12, 0.33)
A2	(0.09, 0.14, 0.33)	(0.09, 0.13, 1)	(0.09, 0.13, 1)	(0.09, 0.13, 0.33)	(0.09, 0.13, 1)	(0.09, 0.15, 1)
A3	(0.09, 0.13, 1)	(0.09, 0.13, 1)	(0.09, 0.19, 1)	(0.09, 0.16, 0.33)	(0.09, 0.18, 1)	(0.09, 0.16, 1)
A4	(0.09, 0.17, 1)	(0.09, 0.14, 1)	(0.09, 0.14, 1)	(0.09, 0.14, 1)	(0.09, 0.19, 1)	(0.09, 0.13, 1)
A5	((0.09, 0.14, 1)	(0.09, 0.15, 0.33)	(0.09, 0.18, 1)	(0.09, 0.16, 0.33)	(0.09, 0.17, 1)	(0.11, 0.2, 1)
A6	(0.11, 0.48, 1)	(0.11, 0.4, 1)	(0.11, 0.48, 1)	(0.11, 0.42, 1)	(0.09, 0.36, 1)	(0.11, 0.4, 1)
A7	(0.14, 0.27, 1)	(0.09, 0.18, 1)	(0.09, 0.23, 1)	(0.09, 0.18, 1)	(0.09, 0.22, 1)	(0.14, 0.23, 1)
A8	(0.11, 0.24, 1)	(0.09, 0.17, 1)	(0.09, 0.2, 1)	(0.11, 0.22, 1)	(0.11, 0.28, 1)	(0.09, 0.23, 1)
A9	(0.09, 0.24, 1)	(0.09, 0.28, 1)	(0.11, 0.53, 1)	(0.09, 0.38, 1)	(0.09, 0.43, 1)	(0.11, 0.48, 1)
	C7	**C8**	**C9**	**C10**	**C11**	
A1	(0.11, 0.22, 1)	(0.09, 0.14, 1)	(0.11, 0.21, 1)	(0.11, 0.21, 1)	(0.09, 0.2, 1)	
A2	(0.09, 0.11, 0.2)	(0.09, 0.12, 1)	(0.09, 0.16, 1)	(0.09, 0.15, 1)	(0.09, 0.14, 1)	
A3	(0.09, 0.21, 1)	(0.11, 0.26, 1)	(0.09, 0.12, 1)	(0.09, 0.13, 1)	(0.09, 0.13, 1)	
A4	(0.11, 0.23, 1)	(0.09, 0.11, 0.2)	(0.11, 0.18, 1)	(0.09, 0.19, 1)	(0.09, 0.2, 1)	
A5	(0.09, 0.15, 1)	(0.09, 0.18, 1)	(0.09, 0.18, 1)	(0.09, 0.15, 1)	(0.09, 0.15, 0.33)	
A6	(0.11, 0.48, 1)	(0.09, 0.42, 1)	(0.11, 0.36, 1)	(0.11, 0.42, 1)	(0.11, 0.43, 1)	

A7	(0.09, 0.43, 1)	(0.11, 0.4, 1)	(0.09, 0.36, 1)	(0.09, 0.29, 1)	(0.14, 0.32, 1)
A8	(0.14, 0.28, 1)	(0.11, 0.24, 1)	(0.09, 0.24, 1)	(0.09, 0.18, 1)	(0.11, 0.23, 1)
A9	(0.11, 0.53, 1)	(0.11, 0.48, 1)	(0.09, 0.37, 1)	(0.11, 0.43, 1)	(0.09, 0.37, 1)

Table 7.10: Weighted normalized fuzzy decision matrix for the implementation of risk mitigation strategies

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
A1	(0.014, 0.032, 0.159)	（0.01, 0.016, 0.108)	(0.009, 0.014, 0.097)	(0.014, 0.022, 0.16)	(0.007, 0.013, 0.079)	(0.007, 0.009, 0.024)
A2	(0.014, 0.022, 0.052)	(0.01, 0.014, 0.108)	(0.009, 0.013, 0.097)	(0.014, 0.021, 0.053)	(0.007, 0.01, 0.079)	(0.007, 0.011, 0.074)
A3	(0.014, 0.021, 0.159)	(0.01, 0.14, 0.108)	(0.009, 0.018, 0.097)	(0.014, 0.026, 0.053)	(0.007, 0.014, 0.079)	(0.007, 0.012, 0.074)
A4	(0.014, 0.027, 0.159)	(0.01, 0.015, 0.108)	(0.009, 0.014, 0.097)	(0.014, 0.022, 0.16)	(0.007, 0.015, 0.079)	(0.007, 0.01, 0.074)
A5	(0.014, 0.022, 0.159)	(0.01, 0.016, 0.036)	(0.009, 0.017, 0.097)	(0.014, 0.026, 0.053)	(0.007, 0.013, 0.079)	(0.008, 0.015, 0.074)
A6	(0.017, 0.076, 0.159)	(0.012, 0.043, 0.108)	(0.011, 0.047, 0.097)	(0.018, 0.067, 0.16)	((0.007, 0.028, 0.079)	(0.008, 0.03, 0.074)
A7	(0.022, 0.043, 0.159)	(0.01, 0.019, 0.108)	(0.009, 0.022, 0.097)	(0.014, 0.029, 0.16)	(0.007, 0.017, 0.079)	(0.01, 0.017, 0.074)
A8	(0.017, 0.038, 0.159)	(0.01, 0.018, 0.108)	(0.009, 0.019, 0.097)	(0.018, 0.035, 0.16)	(0.009. 0.022, 0.079)	(0.007, 0.017, 0.074)
A9	(0.014, 0.038, 0.159)	(0.01, 0.03, 0.108)	(0.011, 0.051, 0.097)	(0.014, 0.061, 0.16)	(0.007, 0.034, 0.079)	(0.008, 0.036, 0.074)
Weight	**0.159**	**0.108**	**0.097**	**0.16**	**0.079**	**0.074**
	C7	**C8**	**C9**	**C10**	**C11**	
A1	(0.012, 0.025, 0.112)	(0.003, 0.005, 0.035)	(0.004, 0.007, 0.035)	(0.004, 0.007, 0.032）	(0.003, 0.006, 0.031)	
A2	(0.01, 0.012, 0.022)	(0.003, 0.004, 0.035)	(0.003, 0.006, 0.035)	（0.003, 0.005, 0.032)	(0.003, 0.004, 0.031)	
A3	(0.01, 0.024, 0.112)	(0.004, 0.009, 0.035)	(0.003, 0.004, 0.035)	(0.003, 0.004, 0.032)	(0.003, 0.004, 0.031)	
A4	(0.012, 0.026, 0.112)	(0.003, 0.004, 0.007)	(0.004, 0.006, 0.035)	(0.003, 0.006, 0.032)	(0.003, 0.006, 0.031)	
A5	(0.01, 0.017, 0.112)	(0.003, 0.006, 0.035)	(0.003, 0.006, 0.035)	(0.003, 0.005, 0.032)	(0.003, 0.005, 0.01)	
A6	(0.012, 0.054, 0.112)	(0.003, 0.015, 0.035)	(0.004, 0.013, 0.035)	(0.004, 0.013, 0.032)	(0.003, 0.01, 0.031)	
A7	(0.01, 0.048, 0.112)	(0.004, 0.014, 0.035)	(0.003, 0.013, 0.035)	(0.003, 0.009, 0.032)	(0.004, 0.01, 0.031)	
A8	(0.016, 0.031, 0.112)	(0.004, 0.008, 0.035)	(0.003, 0.008, 0.035)	(0.003, 0.006, 0.032)	(0.003, 0.007, 0.031)	
A9	(0.012, 0.059, 0.112)	(0.004, 0.017, 0.035)	(0.003, 0.013, 0.035)	(0.004, 0.014, 0.032	(0.003, 0.011, 0.031)	
Weight	**0.112**	**0.035**	**0.035**	**0.032**	**0.031**	

$$d(A_1, A^*) = \sqrt{\frac{(0-0.014)^2+(0-0.032)^2+(0-0.159)^2}{3}}$$

$d(A_1, A^*)$= 0.0939876

$$d(A_1, A^-) = \sqrt{\frac{(1-0.014)^2+(1-0.032)^2+(1-0.159)^2}{3}}$$

$d(A_1, A^-)$ = 0.933899

Similarly, calculations are done for other sub-criteria for solutions of alternative A_1 and the cumulative distances of d_i^+ and d_i^- as d_i^+ = 0.514646 and d_i^- = 10.63685 are computed.

Step 7: Calculate the closeness coefficient of each alternative.

Step 8: According to the closeness coefficient, the ranking order of all alternatives can be determined.

By using Eq. (7.12), the closeness coefficient (CC_i) of alternative A_1 is computed as follows:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} = \frac{10.63685}{10.63685+0.514646} = 0.95385$$

The same procedure can be adopted to compute the distances and (CC_i) values of the remaining alternatives. The final results are summarized in Table 7.11. Based on the (CC_i) values, alternatives were ranked in descending order. The strategy A2 “developing advanced information technology and system” is regarded as the best strategy for managing supply chain related risks. The strategt A5 “implementing eProcurement strategy” within alternative

ranked second and the strategy A1 “building efficient distribution management” ranked third. Therefore, those strategies are determined as the priority strategies for the case organizations to further implement in order to mitigate their supply chain risks.

Table 7.11: Fuzzy TOPSIS results and final ranking for the implementation of risk mitigation strategies

Alternatives	d_i^+	d_i^-	(CC_i)	Rank
A1 Distribution management	0.514646	10.63685	0.95385	3
A2 Information technology and system	0.370368	10.72934	0.966633	①
A3 Collaboration	0.522004	10.61581	0.953132	4
A4 Inventory management	0.526529	10.63193	0.952814	5
A5 eProcurement strategy	0.431122	10.68783	0.961226	②
A6 Outsourcing	0.582634	10.53498	0.947594	9
A7 Agility	0.554765	10.58862	0.950216	7
A8 Capability management	0.549148	10.59833	0.950738	6
A9 Single sourcing	0.577029	10.54913	0.948138	8

7.5.3 Sensitivity analysis

A sensitivity analysis is proposed to investigate the influence of different sub-criteria weights on selection of risk mitigation strategies. It generates different scenarios that may change the ranking of alternatives and be needed to reach a consensus. If the ranking order be changed by increasing or decreasing the importance of the sub-criteria, the results are expressed to be sensible otherwise it is robust. In this research, sensitivity analysis is implemented to see how sensitive the alternatives change with the importance of the sub-criteria. More specifically, the author has exchanged each sub-criterion’s weights with another sub-criterion’s weights, and hence ten combinations of the eleven sub-criterion’s weights were analysed, with each combination stated as a condition. For each condition, the relative closeness to the ideal solution C_j^* was computed. This type of sensitivity analysis has been

applied by several researchers (Önüt and Soner 2007; Gumus 2009; Perçin 2009 and Bianchini 2018). The results of sensitivity analysis are summarized in Table 7.12 and the graphical representation of these results is shown in Figure 7.7.

The first condition in Table 7.12 shows the original ranking (A2, A5, A1, A3, A4, A8, A7, A9 and A6, respectively), where the strategy A2 obtained 0.967. From Table 7.12 and Figure 7.8, it is possible to observe that the strategies A2 and A5 take turns leading the top in every conditions since they have the higher priorities of relative closeness C_j^* in each combination. In other words, strategy A2 will be selected if conditions 1,3,5,8 and 9 are met. Otherwise, strategy A5 will be selected in conditions 2,4,6,7 and 10. The result gives great effort to facilitate the implementation of both strategies for managing the risks under different contexts. Meanwhile, no significant sensitivity for the remaining alternatives in changing between different conditions can be observed, especially for strategies A6, A7, A8 and A9, which always have the lower C_j^* value in each combination. Therefore, since the weights of sub-criterion are based on experts' assessments, managers could adjust the strategic deployment according to their own conditions.

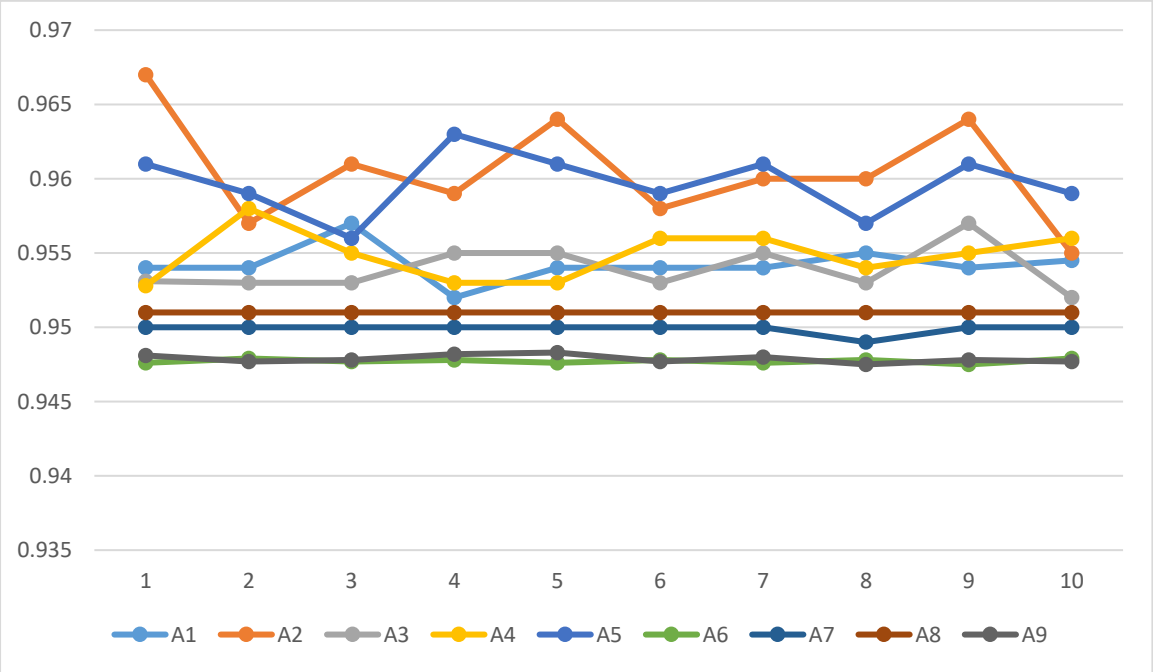


Figure 7-8: Sensitivity analysis: computation of the relative closeness to the ideal solution for each evaluated combination

Table 7.12: Results of the sensitivity analysis

Weights of criteria													C_j^*								
Conditions	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}		A1	A2	A3	A4	A5	A6	A7	A8	A9
1	0.159	0.108	0.097	0.16	0.079	0.074	0.112	0.035	0.035	0.032	0.031	C_j^*	0.954	0.967	0.9531	0.9528	0.961	0.9476	0.95	0.951	0.9481
												Ranking	3	1	4	5	2	9	7	6	8
2	0.031	0.032	0.035	0.035	0.112	0.074	0.079	0.16	0.097	0.108	0.159	C_j^*	0.954	0.957	0.953	0.958	0.959	0.9479	0.95	0.951	0.9477
												Ranking	4	3	5	2	1	8	7	6	9
3	0.112	0.035	0.035	0.032	0.031	0.159	0.108	0.097	0.16	0.079	0.074	C_j^*	0.957	0.961	0.953	0.955	0.956	0.9477	0.95	0.951	0.9478
												Ranking	2	1	5	4	3	9	7	6	8
4	0.079	0.16	0.097	0.108	0.159	0.031	0.032	0.035	0.035	0.112	0.074	C_j^*	0.952	0.959	0.955	0.953	0.963	0.9478	0.95	0.951	0.9482
												Ranking	5	2	3	4	1	9	7	6	8
5	0.16	0.159	0.112	0.108	0.097	0.079	0.074	0.035	0.035	0.032	0.031	C_j^*	0.954	0.964	0.955	0.953	0.961	0.9476	0.95	0.951	0.9483
												Ranking	4	1	3	5	2	9	7	6	8
6	0.031	0.032	0.035	0.035	0.074	0.079	0.097	0.108	0.112	0.159	0.16	C_j^*	0.954	0.958	0.953	0.956	0.959	0.9478	0.95	0.951	0.9477
												Ranking	4	2	5	3	1	8	7	6	9
7	0.108	0.159	0.16	0.097	0.074	0.079	0.035	0.112	0.032	0.031	0.035	C_j^*	0.954	0.96	0.955	0.956	0.961	0.9476	0.95	0.951	0.948
												Ranking	5	2	4	3	1	9	7	6	8
8	0.032	0.031	0.035	0.035	0.074	0.112	0.16	0.079	0.159	0.108	0.097	C_j^*	0.955	0.96	0.953	0.954	0.957	0.9478	0.949	0.951	0.9475
												Ranking	3	1	5	4	2	8	7	6	9
9	0.112	0.108	0.16	0.159	0.035	0.074	0.079	0.097	0.031	0.032	0.035	C_j^*	0.954	0.964	0.957	0.955	0.961	0.9475	0.95	0.951	0.9478
												Ranking	5	1	3	4	2	9	7	6	8
10	0.032	0.035	0.074	0.031	0.079	0.097	0.035	0.108	0.112	0.159	0.16	C_j^*	0.9545	0.955	0.952	0.956	0.959	0.9479	0.95	0.951	0.9477
												Ranking	4	3	5	2	1	8	7	6	9

7.6 DISCUSSION AND MANAGERIAL IMPLICATIONS

Choosing the appropriate risk mitigation strategies is deemed to be an important step in mitigating supply chain related risks. Although the hospital managers did not realized that they had similar approaches to ensure the supply chain operates more efficiency. Instead of identifying the relevant mitigation strategies based on the literature review, in this research, the current implemented management strategies were identified as the risk management solutions through empirical studies. Thereafter, the Fuzzy TOPSIS method was employed to rank the importance levels of those mitigation strategies in relation to 11 risk factors. The mechanism of the Fuzzy TOPSIS model was to analyse twenty experts' subjective judgements. It is an appropriate tool to help MADM under a fuzzy environment where the available data is subjective and vague. Moreover, these strategies also consider all potential risks and the effectiveness of individual strategies in mitigating these risks. It provides a practical decision support tool for taking explicit account of multiple types of risk in aiding decision-making, and compares and ranks alternative strategies in indicator basis individually. To change any management practices or implement any new strategies would require significant additional resources and time before they can commit to investing in the new practices. Theoretically speaking, the costs for implementing these strategies can be viewed as "insurance premiums" that will safeguard the supply chains from major disruptions. However, it is difficult to quantify the return on these insurance premiums, especially in the absence of reliable data (probability that a disruption would occur, potential loss due to a disruption, etc.). More importantly, the healthcare industry is currently under increasing pressure to reduce costs while maintaining the quality of care. The decision of adopting appropriate mitigation strategies requires a trade-off between cost saving and the benefits of implementing such strategies. Therefore, the alternatives with the highest ranking should be given the priority in formulating the strategic plan, *i.e.* strategy A2, "developing advanced information technology and system" and strategy A5, "implementing eProcurement strategy." More importantly, the findings are also in line with the recommendations provided by Lord Carter in their interim report to England NHS trusts.

Furthermore, through our interview with the hospital managers, the major challenge of implementing those strategies is to have supply chain risk management become a part of the job responsibility across different departments with all functions involved collaborating and communicating effectively. The use of the tool as a cross-functional risk mitigating and monitoring process should be considered as a long-term objective. And as such, the involvement of top managers from different areas is essential in establishing a thorough consideration of critical issues and interdepencies in determining a complete supply chain risk management process. In addition to this, Van Vuuren (2000) stated that the success of a strategy is related to the congruency between organizations' strategies and culture. Risk management culture is embedding formally risk management within the decision-making processes at every level of the compant operating within the culture of the organization. It is emphasized that risk management culture can impact on manager's ability to process risk and disruption information, rationalize and exercise discretion in their vulnerability mitigation decision-making processes. The risk management culture within an organization is important to transform vulnerability awareness into mitigation actions. Therefore, hospital managers should give importance to risk management culture, which can become a tool to provide the legal path for risk decisions in a supply chain operation.

More especially, the strategy A2, "developing advanced information technology and systems" provides enabler for managing the healthcare supply chain to increase visibility, traceability and security. As mentioned earlier, advances in interoperability standards and other technology tools, the advanced information technology and system helps in facilitating the aggregation as well as ensuring a timely exchange of useful data among the stakeholders in the supply chain. This, in turn, could provide a rich pool of data to support regulation and oversight of the medicine delivery system from the initial to the end. Instead, paper-based systems are still be common at most hospitals, which are all but "drowning" in paperwork. Therefore, it requires an effort to develop an infrastructure capable of connecting, integrating and supporting various information systems as well as applications at health facilities nationwide. In spite of the demonstrated benefits, financial constraints in many hospitals means creasting different systems for different settings is not feasible. The challenge will be

generating a flexible system, duplicable for various circumstances without investing extra resources. Further, the benefits of developing new information technology and systems are not immediately visible, but the costs are. For instance, the cost of an RFID tag can range from £950 to £1,150 per reader. As the fully functioning RFID system requires tags, readers, infrastructure, middleware, and printers and can cost a hospital millions of pounds. However, a significant resistance to adoptation of technology and changes in work processes and reluctance in the division of labour among health care specialists is actually existing. There is a significant impact in implementing technologies and tools that can only be realized if management can persuade the supporting staff to change their work practices and organization.

Furthermore, strategy A5, "implementing eProcurement strategy" is one of the most effective ways to facilitate the order and demand information among each member in the chain. As such, it is critical for hospital managers to ensure that they share the integrated system with supplier under the same standard (*i.e.* global GS1 coding and PEPPOL messaging), which as a consequence, will be more collaborative than conducting the traditional approach for the procurement procedure. Employing e-procurement process means that the healthcare provider must simplify the existing procurement procedure and shorten the administration lead time. Beyond the benefit that comes from the efficient operation process and enhanced collaboration among trading partners, the strategy also drives patient safety benefits. Automatic Identification and Data Capture like barcodes based on the GS1 standards, can now be accessed and read at any point in the supply chain process. This enables them to quickly locate the safety alert regarding the product. Besides the benefits, there is a significant up-front cost and the continuing costs of implementing this practice are particularly burdensome for small-size hospitals or individual healthcare providers. The relevant costs include the cost of hardware, software and technical support and also the costs of intensive staff training. Hence, this is a considerable limitation to currently implementing the strategy at the national level.

The least important is strategy A6, "outsourcing the non-core supply chain activities to the 3rd party logistics service provider." The healthcare organizations benefit more through

outsourcing expanding activities beyond core and clinical activities and build an environment which is more cooperative with their suppliers. However, some healthcare organizations do not achieve the expected benefits from the outsourcing strategy because outsourcing activities are incredibly complicated and lack a formal outsourcing decision making process, such as medium and long-term cost-benefit analyses, reluctance to embrace any changes. Moreover, it also requires a decision on which activities should remain within the hospital or be outsourced, whether all or part of the supply chain activities should be outsourced, and also how to manage relationships with suppliers rather than internal functions and processes. Another major issue that concerned by hospitals managers is losing good long-term employees if they outsource some functions. Hence, mistakes in identifying core and noncore activities can lead hospitals to outsource their competitive advantages, which are difficult to rebuild. Therefore, this may explain why this strategy became the least important one among the nine identified strategies.

7.7 CONCLUSION

This chapter presented the last step in the supply chain risk management process, *i.e.* risk mitigation strategies identification and evaluation. In this research, all strategies were retrieved from real-life by employing empirical studies from both China and UK healthcare industries. This research empirically identified nine risk mitigation strategies, including: strategy A1, “building efficient distribution management”; strategy A2, “Developing advanced information technology and system”; strategy A3, “developing inter and intra organizational collaboration”; strategy A4, “building efficient inventory management”; strategy A5, “implementing eProcurement strategy”; strategy A6, “implementing outsourcing strategy”; strategy A7, “implementing agility strategy”; strategy A8, “developing internal capability management” and strategy A9, “implementing single sourcing strategy”. After the identification, a risk mitigation-strategy questionnaire survey was used to rank the importance of these strategies. To address risk management issues, both quantitative and qualitative methods have been adopted by both researchers and practitioners. However, risk management is a complex subject involving vagueness and uncertainty in the decision-making

process. Therefore, a Fuzzy TOPSIS model was implemented to provide a practical decision support tool for evaluating risk mitigation strategies. The application of the fuzzy methodology is also useful in situations where uncertainties exist in the decision-making process. The nine strategies are ranked according to their overall priorities *i.e.* A2, A5, A1, A3, A4, A8, A7, A9, and A6. This is generally consistant with the recommendation provided by Lord Carter's interim report. Strategy A2, "developing advanced information technology and system" and strategy A5, "implementing eProcurement Strategy" have the highest relative closeness indices and should therefore be recommended as the top strategies for the healthcare organizations to implement.

CHAPTER EIGHT - CONCLUSION

8.1 INTRODUCTION

This concluding chapter presents a brief overview of the research and introduces future directions for developing the work. Initially, the chapter returns to the defined research objectives and research questions to delineate the research's important findings. This is followed by description of the contribution to established knowledge and its practical implications. The chapter then explores limitations and future research direction arising from this research.

8.2 RESEARCH FINDINGS

Based on the literature review in Chapter two, several research gaps were identified. The primary research gap was the lack of the comprehensive framework proposed to evaluate SCRM (*e.g.,* risk factors identification, risk assessment, and risk mitigation) performance in the public healthcare sector. The second research gap was the limited attention given to systematic risk factors identification in healthcare SC. The third research gap was related to the need for systematic and holistic risk assessment as existing studies have tended to provide independent risk concepts without concerning interconnection and interconnectedness of risk factors. The fourth research gap identified was the lack of studies examining the performance of the currently implemented supply chain risk mitigation strategies under different risk contexts in public healthcare organisations.

To address these gaps, research questions for this study were developed. To answer the questions, a multi-methodology approach involving the questionnaire survey, documentation review, direct observation and semi-structured interviews were adopted. RQ1 was concerned with the proposed novel conceptual framework which presents a platform to support managers in making significant strategic decisions on SCRM. Moreover, when the SCRM

process comprise of risk factors identification, risk assessment and risk mitigation are considered, RQ2, RQ3, and RQ4 were concerned with identification and assessment of healthcare SC risks, whereas RQ5 and RQ6 focused on risk mitigation. A summary of the research outputs specific to each question is given as follows:

RQ1. What is the most effective HCSCRM framework that can be implemented to deal with the HCSC risks?

A novel conceptual framework was developed to support managers in proactively controlling the risks by considering risk drivers and sources, decision-making, SC strategies, performance outcomes, and the risk management process. The focus is towards the proposed framework, recognizing that the key components provide a more robust portrayal of the factors that affect the nature of risk management responses under different situations. It has a sequential process that is repetitive in nature and articulated in a circular process, indicating that one component is dependent on another component. For risk management to be successful, the risk drivers to establish the potential nature of the risks must be identified. This is then followed by the phase of determining the available risk resources expected to facilitate and support risk management initiatives. Based on different attitudes of risk appropriate for the case, a healthcare organization can implement various risk management initiatives for the desired change to be realized. In terms of the performance outcomes, due to the difference perspectives, the focus in the healthcare provider is towards both cost reduction and service quality improvement as well as the employee satisfaction. The proposed conceptual framework can be acting as a risk management platform to address the industrial needs for practical decision support methodology, and to facilitate the integration of innovative approaches such as Fuzzy AHP, ISM and Fuzzy TOPSIS into the healthcare supply chain risk management process.

RQ2. What are the main sources of risk factors causing public sector healthcare supply chains to be vulnerable and how to identify and classify those risks?

It is important for healthcare organizations to be aware of the specification of sources of risks due to the invisibility of risks existing in the supply chain network. Identification of risk factors

is the first step of the supply chain risk management process. In this thesis, the author identifies a comprehensive list of risk factors in the healthcare supply chain system initially through a literature review. It is particularly noteworthy that healthcare supply chain systems have risk factors in common with conventional supply chain risks, but also unique risk factors that can be differentiated from the traditional supply chain risks. In particular, the "counterfeiting risks"; "time limit of drugs, product perishability"; "demand trigged by the nurse, not the patient"; "fragmentation of drug distribution process"; "clinician's preference"; "lack of funds from government to the hospital" and "regulatory issues-manufacturing using licensing/change of standards/drugs recalls" appeared to generate unique threats to healthcare supply chain systems. In addition, various entities involved in the healthcare supply chain network can generate fresh risk areas in inter-organizational and intra-organizational relationships. Thereafter, a total of 34 risk factors were found to reside in the healthcare supply chain operations and classified into three main categories including: "external to the hospital but internal to the supply chain network" (*i.e.* supply, demand risks), "internal to the hospital" (*i.e.* process and control risks) and "external to the supply chain network" (*i.e*. environmental risks). Furthermore, a new classification model applied in this thesis divided the risks into eleven sub-categories: quality, supplier, capacity, forecast, information, logistics, procurement, strategic, labour, natural and man-made risks. Based on the addressed risk factors, a questionnaire survey was conducted to ensure the feasibility of the developed risk classification method and to determine the important levels of identified risk factors. An interesting insight is that "counterfeiting risks", "poor quality in the purchased drugs from suppliers", "shortage of drugs" and "high purchase price" attract more attention than other risk factors from the participant experts' viewpoint. In order to broadly outline the sources of healthcare supply chain risks, a hierarchical structure model was developed. To assure the validity and reliability of the developed hierarchy diagram, a series of emails and face-to-face interviews were subsequently sent out and conducted with the "validation team" (six earlier experts as well as two academic researchers with experience in supply chain and risk management who were not part of the expert panel). Finally, agreement among the experts was received, and the hierarchy diagram was accepted.

RQ3. Which risk factors are relatively more significant to a hospital's supply chain management performance?

In risk assessment research, Fuzzy AHP was used to determine the priority weight among the identified risk factors. It needs to be mentioned that risk assessment is inherently uncertain and imprecision, therefore, any analysis that ignores this uncertainty and imprecision may cause information to be seriously misleading and thus cause major mistakes. In this thesis, Fuzzy AHP was developed along the lines of fuzzy set theory to manage the uncertainty associated with the mapping of experts' judgements. 56 valid replies were received from selected respondents from China, the UK, and Thailand. The respondents are working in both academic and industrial fields. The results indicate that risks associated in "external to the hospital but internal to the supply chain network" (0.53) and "internal to the hospital" (0.43) are much greater than that of "external to the supply chain network" (0.04). Under the criteria "external to the hospital but internal to the supply chain network", "supply risks" (0.75) is the top risk in the same level. It is particularly noteworthy that "shortage of drugs" (0.16), "counterfeiting" (0.159), "poor IT system" (0.112), "capability versus demand" (0.108), "dispensing/picking errors" (0.097), "poor quality in the purchased drugs from suppliers" (0.079), "weak logistics service infrastructure" (0.074), "lack of visibility concerning placement and availability of stock" (0.035), "high purchase price" (0.035), "clinicians' preference" (0.032) and "high product and supplier/brand variety" (0.031) are the key risk factors for hospital's supply chain performance.

RQ4. How are these risk factors interacting with each other?

This thesis sought interactions between each risk by employing an ISM model. A total of 12 industrial and academic experts were invited to identify the relationships between risk elements, analysed with the ISM technique. The results provide an understanding of identified risk factors in different levels of ISM hierarchy model and the cluster in MICMAC diagram. The developed hierarchical ISM model comprises 11 risk factors. Among the 11 risk factors, "poor quality in the purchased drugs from suppliers" and "dispensing/picking errors" were placed on the top level. These are the risks that can produce a major impact on

healthcare SC systems. Furthermore, lower level risks like “clinician’s preference” and “high produce and supplier/brand variety” have strong influence to the middle-level risks like “counterfeiting”, “shortage of drugs”, “capability versus demand”, “high purchase price”, “weak logistics service infrastructure”, “poor IT system”, and “lack of visibility concerning placement and availability of stock”. Also, the aforementioned middle-level risks again seen to influence the top-level in the ISM model. Top-level factors are more risky than the others and can cause serious consequences for supply chain systems. Nevertheless, lower level factors are mainly responsible for increasing the degree of risk exposure as they have strong influence to the top-level factors. In this regard, it is worth noting that interdependency among various risk factors plays an important role in the assessment of risk impact on the healthcare supply chain performance.

MICMAC analysis was carried out by classifying the 11 risk factors into four clusters comprising autonomous, dependent, linkage, and independent, based on their driving power and dependence power. The risk factors are namely, “poor quality in the purchased drugs from suppliers” and “dispensing/picking errors” are dependent factors. The impact of these risks depends on the remaining risks of the healthcare supply chain and seriously affects the supply chain system. Similarly, the risk factor “clinician’s preference” has been found independent with strong driving power: it plays a key role in influencing others and finally intensifies to the strength of its impact on the healthcare supply chain system. The remaining risk factors are clustered as linkage risks with both strong driving and dependence power. Those should be assigned as high priority and the manager should understand the dependence of these risks on lower level risks, in achieving the risk management objectives. Autonomous risks are weak driving power and dependence power and lack influence on the supply chain system. In this research, no risk factor in this cluster. As a result, this cluster analysis provides valuable insight into the extant body knowledge to the researchers to understand and assess the intensity of risk factors as well as to manage these risks by implementing an effective risk management strategy.

RQ5. How can the hospitals from both UK and China effectively manage their supply chain related risks?

This research employed empirical studies from the UK and China healthcare organizations to identify their currently implemented supply chain risk management strategies. The empirical study is based on 'field' experiences or direct observations, and it allows the researcher to investigate a contemporary phenomenon in depth and within its real-life context when the boundaries between phenomenon and context may not be clearly evident. In this thesis, a large amount of official documents and other published materials were reviewed critically. Thereafter, multiple departments in three hospitals and one pharmaceutical company were visited to ensure the collected data was accurate and reliable in nature. By combining direct observation with various other methods, the research results can give a complete picture of the performance situation. The author conducted semi-structured interviews with 14 experts from seven Chinese hospitals, one UK hospital, and two different pharmaceutical companies. The interviews were spread over three months and included four site visits by the author. As a result, healthcare organizations involved in healthcare supply chain operations have implemented nine basic strategies: (1) "strategy A1: building efficient distribution management", (2) "strategy A2: developing advanced information technology and system", (3) "strategy A3: developing inter and intra organizational collaboration", (4) "strategy A4:building efficient inventory management", (5) "strategy A5: implementing eProcurement Strategy", (6) "strategy A6: implementing outsourcing strategy", (7) "strategy A7: implementing agility Strategy", (8) "strategy A8: developing internal capability management" and (9) "strategy A9: implementing single sourcing strategy".

RQ6. What are the main risk mitigation strategies to be considered?

In this thesis, Fuzzy TOPSIS was used to rank risk mitigation strategies. The model incorporates the fuzzy set theory and conventional TOPSIS methods to capture the vagueness of uncertainty in the evaluation of alternative risk mitigation strategies. Twenty experts from both academia and industry were invited to participate the survey. The analysis results indicate that the "strategy A2, developing advanced information technology and system" had the highest ranking among the alternative mitigation strategies, closely followed by "strategy A5, implementing eProcurement strategy". On the contrary, "strategy A6, implementing outsourcing strategy" fell behind other strategies due to the outsourcing activities being

incredibly complicated and lacked formal outsourcing decision-making processes, such as medium and long-term cost-benefit analyses, and reluctance to embrace any changes.

8.3 RESEARCH CONTRIBUTION TO KNOWLEDGE

The significance of this thesis is to complement the existing literature by proposing a comprehensive framework that provided abundant insights into how risks in the healthcare supply chain systems can be understood and how organizations involved in the healthcare industry can effectively manage these risks. Specifically, this research is the first study to provide an integrated SCRM model by using both qualitative and quantitative techniques for risk factors identification, assessment, and mitigation in the healthcare supply chain setting. Although there are studies on this topic, their research scope was limited to a specific mode or a certain phase of supply chain risk management, thus their studies lacked a holistic view of risk management (Breen, 2008; Enyinda *et al.,* 2014). The novelty of the proposed model lies in the fact that it incorporates the Fuzzy AHP, ISM model and Fuzzy TOPSIS as an integrated methodology, which has been proposed enabling the specific decision maker's preferences to be considered in making the strategic decision on a healthcare SCRM. Moreover, the model also considers the uncertainties caused by unknown data. Therefore, the application of fuzzy logic theory can help organizations to solve the problem of handling uncertainty in decision-making in a timely manner. Additionally, compared with most of the SCRM literature using secondary data for simulation, this research makes practical contributions by conducting empirical studies in both the UK and China healthcare industries to support a resource effective and time-efficient decision-making tool for managers. It provides the latest information that can reflect the current situation in both countries' healthcare industry. Especially, instead of identifying the risk mitigation strategies through a literature review, this research explored the currently implemented mitigation strategies which turned out to be more reasonable in actual situations. Therefore, healthcare organizations can evaluate the current status of their risk management efforts with the risk mitigation strategies and practices suggested in this research. Nine strategies were introduced with practical examples from case hospitals, which provide practical ideas as to how the organizations can manage

risks. Furthermore, the profile of healthcare supply chain risks will enable managers to anticipate and proactively deal with potential risks. Although the risks discussed in this thesis are not completely exhaustive, the work is still meaningful because those are explored by literature, Lord Carter's report and experts from different fields involved in a healthcare supply chain and risk management. To the end, although the case discussed in this research is healthcare provider, i.*e.* hospital, the results could be generalised to similar industry or other service-based environments.

8.4 RESEARCH LIMITATION

The limitations of this research are discussed below.

- Firstly, in this study, the risk factors have been retrieved mainly from eleven research literatures and one official interim reports due to the limited research focused on healthcare supply chain risk management to date. Meanwhile, data collection was limited between the years 2003 and 2017 by systematic identification, screening, and synthesis of quality data sources. It provides a way to focus the development of research in the past 14 years but also limited the study's time frame. It would be more comprehensive if the omitted literature could be reviewed.
- Secondly, the confidential nature of the healthcare industry when conducting the empirical studies highlights the difficulty of gathering primary and secondary data. In addition, the sample selection is limited to specific professional roles. Most participants involved in this research either have abundant knowledge in academia or rich practical experience in the field and hold a position at or above the manager level in practitioner fields. Therefore, a further limitation of the research is reflected in the size of the sample.
- Thirdly, the proposed integrated model is highly dependent on the respondents' knowledge, experience, and attitude that might lead to the subjective bias. For instance, respondents and their attitudes or perceptions might be affected by the surrounding environment in which they participated in the survey. The unexpected

factors, such as personal issues, or other external factors might have impacts on their attitudes. Furthermore, another factor that needs to be considered is the length of the interview. In this study, the interview questions were designed to limit interviews to one hour (interviewing time), but some participants might have thought that there were too many questions and these feelings would have negatively affected their attitudes toward the questions.

- Fourthly, this study does not address all the identified 34 risk factors in detail due to the time constraints and the size of the questionnaire survey, which mostly required pair-wise comparison between each factor.

8.5 RECOMMENDATION AND FUTURE RESEARCH

A number of research areas need to be investigated for further study. It is advocated that the following areas should be addressed going forward:

- Further research is expected for the generalisability of the developed conceptual framework and integrated risk management model into other industry sectors and being applied into different tiers of the supply chain network. The application of the same research process to other areas will broaden knowledge into supply chain risk management.

- The cross-validation of the proposed risk management model can be possible by widening the geographical scope of the research. This thesis investigated risk management for hospitals in the UK and China. Both countries are selected for sampling because of their advanced healthcare systems, the larger and costly market and the enormous healthcare demands. Therefore, it is noteworthy that a comparative analysis between countries with different social and economic systems and different healthcare and hospital systems will provide fresh insights into the development of risk management initiatives.

- Supply chain risk management has been defined as “the management of supply chain related risks including both internal and external risks through a coordinated approach among each SC member to managing supply chain vulnerability as a whole” (Christopher *et al.,* 2002). In the healthcare supply chain setting, hospitals are closely linked to other channel stakeholders, such as pharmaceutical manufacturer, supplier, distributor, GPO, insurance company, government, and third-party logistics provider. It requires a coordinated effort from all key members involved in order to mitigate risks and build a resilient healthcare supply chain. Another further research direction is to incorporate the views of other SC members into the decision-making process.

- As mentioned in Chapter five, many types of risk factors exist in the healthcare supply chain, such as strategic risks, labour risks and man-made risks are omitted as they are less significant; nonetheless, they should be of concern. Therefore, it would be more comprehensive to consider all kinds of risks in the structural model so that more complete results could be obtained.

- As any strategic implementation requires substantial investments, the decision to adopt appropriate risk management mitigation strategies requires a trade-off between the benefits and costs involved. Further research can cover cost and benefit analysis to support significant strategic decisions on SCRM.

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APPENDIX ONE

Questionnaire used in Survey A for the purpose of Chapter five

Research on Risk Management for Healthcare Supply Chain in Hospital

Dear Sir/Madam,

My name is Lei Wang, who is currently the PhD candidate at the Liverpool Logistics Offshore and Marine Research Institute (LOOM) in Liverpool John Moores University. My research topic is “Research on risk management for healthcare supply chain in hospital”. The research aims to propose a novel risk management methodology to identify, evaluate and mitigate the risk factors in hospital supply chain.

I should be very pleased if you can take part in this study in view of your professional knowledge in risk management, supply chain management or in hospital. It is necessary to pre-test the reliability and validity of the identified risk factors in the research and your assistance would be greatly appreciated in making this a meaningful questionnaire. The information gathered is this survey will be treated in the strictest confidence. The researcher will make every effort to prevent anyone who is not on the research team from knowing that you provided this information, or what the information is. If you have any questions about this study, please feel free to contract me either email L.Wang@2015.ljmu.ac.uk or by phone. You also can contact my supervisor, Dr Jun Ren, at (44)1512312236, or by email j.ren@ljmu.ac.uk

Yours faithfully,

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Section A: Respondent Profile

1. What is the type of your organization?

Pharmaceutical Manufacturer	Pharmaceutical distributor (pharmaceutical company)	Hospital (Procurement department; Material management department etc.)	Other
☐	☐	☐	☐

2. What is your job title?

_____

3. For how many years have you worked in the healthcare industry or healthcare supply chain?

☐1-5 years ☐6-10 years ☐11-15 years ☐16-19 years ☐≥20 years

4. Would you like to provide additional information and participate in the next survey if necessary?

☐Yes ☐No

Section B:

Based on the research, the purpose categorizing the risks in hospital supply chain into three main categories: 1) external to the hospital but internal to the supply chain network; 2) internal to the hospital; 3） external to the supply chain network. (See the figure below for a schematic of where these risks are focused) The following questions are related to the rank and modify the identified risk factors in the hospital supply chain.

For the identified risk factors in the hospital supply chain, the important levels can be marked based on the corresponding numbers:

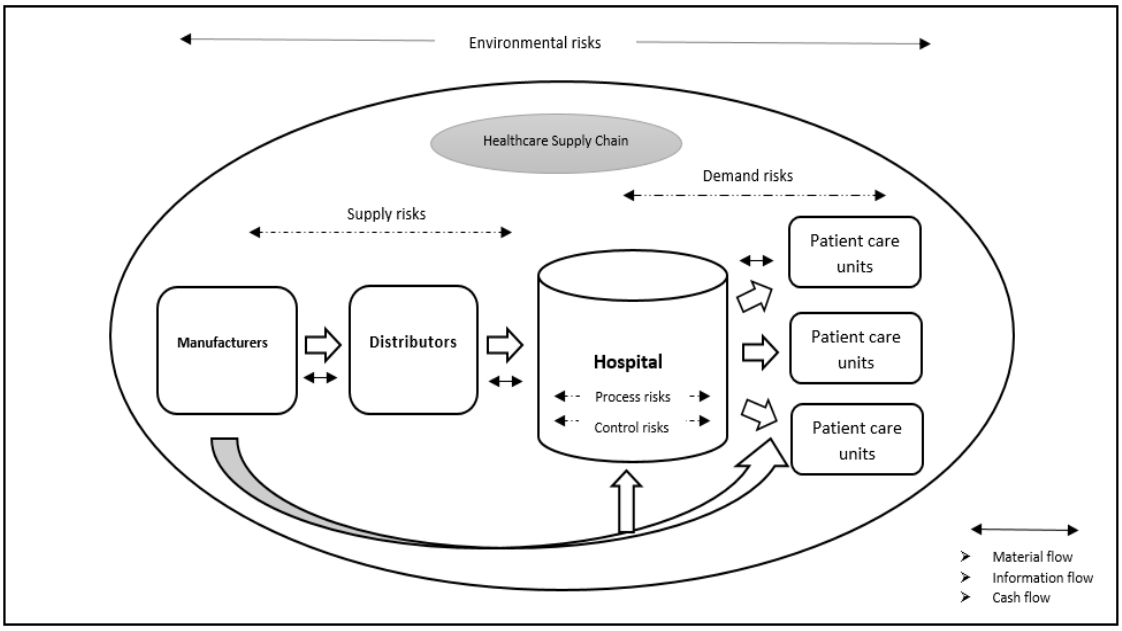
1=Very Unimportant;

2=Minor Unimportant;

3=Moderate;

4= Minor Important;

5=Very Important



<u>*External to the hospital but internal to the supply chain network*</u> *(i.e. arise from interactions between organizations within the supply chain)*

- *Supply risks (i.e. adversely affects inward flow of any type of resource to enable operations to take place or the transpiration of significant and/or disappointing failures with inbound goods and service)*
  - *Quality risks*
  - *Supplier risks*

Identified Risk Factors (Quality risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Quality risks	S1 Counterfeiting	☐1 ☐ 2☐ 3 ☐4☐ 5
	S2 Poor quality in the purchased drugs from suppliers	☐1 ☐ 2☐ 3 ☐4☐ 5
	S3 Time limit of drug, product perishability	☐1 ☐ 2☐ 3 ☐4☐ 5

Identified Risk Factors (Supplier risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Supplier risks	S4 Shortage of drugs, unavailability of drugs on the market	☐1 ☐ 2☐ 3 ☐4☐ 5
	S5 Location of manufacturer/supplier *(not the domestic based); (e.g. sourcing from the global, long lead time, high costs)*	☐1 ☐ 2☐ 3 ☐4☐ 5
	S6 Unavailability of raw material – true and commercially induced.	☐1 ☐ 2☐ 3 ☐4☐ 5
	S7 Cash flow/cash management threat associated with small pharmaceutical companies and hospitals;	☐1 ☐ 2☐ 3 ☐4☐ 5

Considering the above structure, elements contributing to risks associated with **supply risks** are categorized into “quality risks” and “supplier risks”. Do you think this categorization is appropriate?

Risk element categories	Yes	No	Any comments
Quality risks			
Supplier risks			
Any other elements should be considered?			

- *Demand risks (i.e. the possibility of unexpected changes arising from market or*

downstream customers)

- *Capability risks*
- *Forecast risks*

Identified Risk Factors (Capability risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Capability risks *(the capabilities such as technical skills, knowledge and leadership competencies of individuals and the collective group responsible for managing the demand, plus the relationships within and outside organizations and individuals)*	S8 Capacity versus demand, inability of capacity to meet demand;	☐1 ☐ 2☐ 3 ☐4☐ 5
	S9 Demand triggered by the nurse, not the patient	☐1 ☐ 2☐ 3 ☐4☐ 5

Identified Risk Factors (Forecast risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Forecast risks	S10 Demand uncertainty	☐1 ☐ 2☐ 3 ☐4☐ 5
	S11 Wrong demand forecasting	☐1 ☐ 2☐ 3 ☐4☐ 5

Considering the above structure, elements contributing to risks associated with **demand risks** are categorized into “capability risks” and “forecast risks”. Do you think this categorization is appropriate?

Risk element categories	Yes	No	Any comments
Capability risks			
Forecast risks			
Any other elements should be considered?			

<u>Internal to the hospital</u> (i.e. the risk sources lie within the boundaries of the supply chain parties and range from labour to IT-system uncertainties).

- *Process risks (i.e. the risks lie in the sequences of value-adding and managerial activities undertaken by the firm).*
  - *Information risks*
  - *Logistics risks*
  - *Procurement risks*

Identified Risk Factors (Information risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Information risks	S12 Poor IT system, lack of data standardization; *(e.g. lack of information management platform)*	☐1 ☐ 2☐ 3 ☐4☐ 5
	S13 Asymmetries of the information, collaboration issues, restriction, not share information each department	☐1 ☐ 2☐ 3 ☐4☐ 5

Identified Risk Factors (Logistics risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Logistics risks *(the risks are associated to all the logistic activities in/or between each organizations)*	S14 Dispensing/picking error medication/packaging	☐1 ☐ 2☐ 3 ☐4☐ 5
	S15 Weak logistics service infrastructure (*e.g. Obsoleted equipment in the warehouse; Improper drug store environment and transportation facility, route etc.)*	☐1 ☐ 2☐ 3 ☐4☐ 5
	S16 Fragmentation of drug distribution processes	☐1 ☐ 2☐ 3 ☐4☐ 5
	S17 Inadequate buffer stock-JIT/Lean	☐1 ☐ 2☐ 3 ☐4☐ 5
	S18 Lack of visibility concerning placement and availability of stock	☐1 ☐ 2☐ 3 ☐4☐ 5

Identified Risk Factors (Procurement risks)		Important level very unimportant / minor unimportant / moderate / minor important / very important
Procurement risks	S19 Procurement Hubs-introduce more complexity, Long lead time; *(e.g. from placing the order until receiving)*	☐1 ☐ 2☐ 3 ☐4☐ 5
	S20 Contract problems with suppliers *(e.g. contracting treated as a commodity-big contracts equals big risk)*	☐1 ☐ 2☐ 3 ☐4☐ 5
	S21 Clinician's preference; *(e.g. lack the awareness of cost containment)*	☐1 ☐ 2☐ 3 ☐4☐ 5
	S22 High purchase price	☐1 ☐ 2☐ 3 ☐4☐ 5
	S23 High product and supplier/brand variety	☐1 ☐ 2☐ 3 ☐4☐ 5

Considering the above structure, elements contributing to risks associated with **process risks** are categorized into "information risks", "logistics risks" and "procurement risks". Do you think this categorization is appropriate?

Risk element categories	Yes	No	Any comments
Information risks			
Logistics risks			
Procurement risks			
Any other elements should be considered?			

- *Control risks (i.e. the assumptions, rules, systems and procedures that govern how an organization exerts control over the processes. In terms of the supply chain they may be order quantities, batch sizes, safety stock policies etc. Control risk is therefore the risk arising from the application or misapplication of these rules)*
  - *Strategic risks*
  - *Labour risks*

Identified Risk Factors (Strategic risks)		Important level: very unimportant / minor unimportant / moderate / minor important / very important
Strategic risks *(a possible source of loss that might arise from the pursuit of an unsuccessful business plan.)*	S24 Focus on short term SC planning than long term	☐1 ☐ 2☐ 3 ☐4☐ 5
	S25 Prioritization-conflict between patients/profits; *(e.g. doctors would advise patients to take a lot of unnecessary medical measures and drugs in order to increase the profits of hospital)*	☐1 ☐ 2☐ 3 ☐4☐ 5

Identified Risk Factors (Labour risks)		Important level: very unimportant / minor unimportant / moderate / minor important / very important
Labour risks	S26 Strikes and lack talents	☐1 ☐ 2☐ 3 ☐4☐ 5
	S27 Lack of incentive mechanism	☐1 ☐ 2☐ 3 ☐4☐ 5

Considering the above structure, elements contributing to risks associated with **control risks** are categorized into "Strategic risks" and "labour risks". Do you think this categorization is appropriate?

Risk element categories	Yes	No	Any comments
Strategic risks			
Labour risks			
Any other elements should be considered?			

<u>External to the supply chain network</u> (i.e.can be defined as events driven by external forcers such as weather, earthquakes, political, regulatory and market forces).

- *Environmental risks*
  - *Natural risks*
  - *Man-made risks*

Identified Risk Factors (Natural risks)		Important level: very unimportant	minor unimportant	moderate	minor important	very important
Natural risks	S28 External influences- disaster recovery; *(e.g. natural disaster)*	☐1	☐ 2	☐ 3	☐4	☐ 5
	S29 Unexpected disease outbreaks; *(e.g. emerging virus diseases)*	☐1	☐ 2	☐ 3	☐4	☐ 5
	S30 Unexpected changes in environment conditions	☐1	☐ 2	☐ 3	☐4	☐ 5

Identified Risk Factors (Man-made risks)		Important level: very unimportant	minor unimportant	moderate	minor important	very important
Man-made risks *(intentional or unintentional*	S31 Regulatory issues-manufacturing using licensing/change of standards/drug recalls	☐1	☐ 2	☐ 3	☐4	☐ 5
	S32 Rigorous government interventions; *(e.g. policy)*	☐1	☐ 2	☐ 3	☐4	☐ 5

acts that cause products or supply chains to react differently than originally intended. e.g. political instability, elections, labor strikes can completely shut down business and government operations)	S33 Lack of funds from government to the hospital	☐1 ☐ 2☐ 3 ☐4☐ 5
	S34 The requirement of environment protection	☐1 ☐ 2☐ 3 ☐4☐ 5

Considering the above structure, elements contributing to risks associated with **environmental risks** are categorized into “natural risks” and “man-made risks”. Do you think this categorization is appropriate?

Risk element categories	Yes	No	Any comments
Natural risks			
Man-made risks			
Any other elements should be considered?			

THANK YOU ONCE AGAIN FOR YOUR KIND PARTICIPATION IN THIS SURVEY.YOUR ANSWERS WILL BE KEPT CONFIDENTIAL

医疗供应链风险管理
问卷调查

尊敬的专家：

您好！我叫王磊。来自利物浦约翰莫尔斯大学(LJMU)物流和海洋研究所的博士研究生。我的研究课题是提出一种全新的、系统化和结构化的方法针对医院药品供应链过程中产生的风险因素进行识别、分析和控制。

对于占用您宝贵的时间我深感歉意。也同时非常的荣幸能够邀请您参加到我的研究课题当中。您对于医疗供应链管理和风险管理的宝贵经验将对此次问卷调查的起到非常重要的作用。同时需要强调的是，根据研究课题组的要求，本次调查的信息将会被严格的保密；其中所涉及到的相关单位及个人信息会采取匿名的方式。

本次调查需要 10 分钟左右的时间。如果您有任何问题，请通过电子邮件 L.Wang@2015.ljmu.ac.uk 联系我。您也可以通过电子邮件 J.Ren@ljmu.ac.uk 联系我的导师任军教授。

王磊

博士研究生

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基于前期的文献研究，我们将医疗药品供应链中存在的风险因为分为三个主要种类：1）供应链网络内部风险；2）医院内部风险；3)供应链网络外部环境风险。以下问题是针对所识别出的风险因素的重要性进行评分，并修改和添加遗漏的其他风险因素。

供应链网络内部风险 (此类风险产生于供应链网络内部，由组织成员之间相互作用引起)

供应风险 *(围绕供应链运营中的药品供应过程的潜在的和实际的风险)*

质量风险:

- (S1) 假药;

- (S2) 购买药品的质量不合格；

- (S3) 药品的易腐性，保质期周期短;

针对已识别出的质量风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
质量风险	S1 假药	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S2 购买药品的质量不合格	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S3 药品的易腐性，保质期周期短	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

供应商风险:

- (S4) 药品短缺;

- (S5) 药品供应商的地址偏远，非本地或者本国供应*(例如：进口药品会产生高额费用，由下单到收获的过程耗时长)*

- (S6) 原材料在市场上供应短缺，其中原因包括因商业诱导而导致采购困难

- (S7) 规模较小的药品供应商的现金流中断，缺乏可靠性；

针对已识别出的供应商风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
供应商风险	S4 药品短缺	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S5 药品供应商的地址偏远，非本地或者本国供应	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S6 医院与供应商之间的合作以短期为主，缺乏长期合作机制	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S7 规模较小的药品供应商的现金流中断，缺乏可靠性	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

需求风险 *(指供应链下游中不可预知的变化所导致的风险)*

能力风险:

- (S8) 医院整体实力与各科室需求不匹配，出现供不应求的情况；

- (S9) 需求由护理人员驱动而非患者，导致真实需求信息不正确而产生过量采购等问题；

针对已识别出的能力风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
能力风险	S8 医院整体实力与各科室需求不匹配，出现供不应求的情况	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S9 需求由护理人员驱动而非患者，导致真实需求信息不正确而产生过量采购等问题	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

预测风险:

- (S10) 需求不确定;

- (S11) 错误的需求预测;

针对已识别出的预测风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
预测风险	S10 需求不确定	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S11 错误的需求预测	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

医院内部风险 *(此风险来源在医院内部的供应链运营流程，如采购、物流、仓储等)*

流程风险 *(风险源产生于组织的增值和管理活动的流程中.)*

信息风险: *(一定概率由于信息的不正确、不完整或者非法访问而导致组织损失)*

- (S12) 落后的信息系统；单一的信息传送渠道；信息传输缓慢; *(例如：缺乏信息管理系统)*

- (S13) 各科室之间存在合作壁垒，科室之间信息不共享;

针对已识别出的信息风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
信息风险	S12 落后的信息系统；单一的信息传送渠道；信息传输缓慢	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S13 各科室之间存在合作壁垒，科室之间信息不共享	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

物流风险: *(指组织内部以及供应链成员之间的物流活动中产生的风险)*

- (S14) 医院内部药品的拣选、包装和运输出现错误;

- (S15) 物流服务基础设施薄弱（例如：药品库房中陈旧的设备, 不适当的药品储存环境和运输设备、路径）

- (S16) 分散的药品配送流程;

- (S17) 缓冲库存不足（运用 Lean/Just in Time 保持较低的库存水平）;

- (S18) 库存管理的可视化程度低;

针对已识别出的物流风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
物流风险	S14 医院内部药品的拣选、包装和运输出现错误	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S15 物流服务基础设施薄弱	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S16 分散的药品配送流程	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S17 缓冲库存不足（运用 Lean/Just in Time 保持较低的库存水平）	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S18 库存管理的可视化程度低	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

采购风险:

- (S19) 采购中心工作复杂性程度高，从采购到交货的流程过长；

- (S20) 与供应商的合同问题;

- (S21) 医生的个人偏好加重采购的成本；

- (S22) 过高的采购价格；

- (S23) 采购药品种类和供应商的数量过多;

针对已识别出的采购风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
采购风险	S19 采购中心工作复杂性程度高，从采购到交货的流程过长	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S20 与供应商的合同问题	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S21 医生的个人偏好加重采购的成本	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S22 过高的采购价格	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S23 采购药品种类和供应商的数量过多	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

控制风险

<u>战略风险</u>: *(战略行为影响整个供应链体系，战略风险可根据其战略特征得到。)*

- (S24) 医院将供应链管理视为短期效应，不重视供应链与物流管理的战略意义;

- (S25) 优先级-患者/利润冲突;

针对已识别出的战略风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
战略风险	S24 医院将供应链管理视为短期效应，不重视供应链与物流管理的战略意义	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S25 优先级-患者/利润冲突	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

***<u>人力风险</u>*:**

- (S26) 医护或后勤人员罢工;

- (S27) 缺乏激励机制;

针对已识别出的战略风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
人力风险	S26 医护或后勤人员罢工	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S27 缺乏激励机制	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

供应链网络外部环境风险 *(可以定义为由供应链外部环境因素如自然灾害、宏观经济、政府政策等产生的风险)*

自然灾害风险:

- (S28) 外部影响-灾难恢复缓慢；

- (S29) 突发性重大疫情爆发；

- (S30) 环境状况出现意外变化；

针对已识别出的自然灾害风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
自然灾害风险	S28 外部影响-灾难恢复缓慢	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S29 突发性重大疫情爆发	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S30 环境状况出现意外变化	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

人为制造风险:

- (S31) 监管问题-制造许可使用/更改标准/药品召回；

- (S32) 严格的政府干预；

- (S33) 医院缺乏政府的资金拨给;

- (S34) 环境保护的需求得不到改善；

针对已识别出的人为制造风险因素，您认为在医疗供应链当中，这些风险各自的重要性得分是多少？另外还有哪些风险未被考虑在内？

(1=完全不重要; 2=不重要; 3=不是很重要; 4=一般重要; 5= 比较重要; 6=很重要; 7=非常重要)

识别出的风险因素		影响程度
人为制造风险	S31 监管问题-制造许可使用/更改标准/药品召回	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S32 严格的政府干预	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S33 医院缺乏政府的资金拨给	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
	S34 环境保护的需求得不到改善	☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
您是否认为还有其它因素？		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7
		☐1 ☐ 2☐ 3 ☐4☐ 5 ☐ 6☐ 7

再次感谢您在此次调查中提供的帮助

您的回答将会被保密

APPENDIX TWO

Questionnaire used in Survey B for the purpose of Fuzzy AHP in Chapter six

Research on Risk Management for Healthcare Supply Chain in Hospital Questionnaire

Dear Sir/Madam,

My name is Lei Wang, who is currently the PhD candidate at the Liverpool Logistics Offshore and Marine Research Institute (LOOM) in Liverpool John Moores University. My research topic is “Research on risk management for healthcare supply chain in hospital”. The research aims to propose a novel risk management methodology to identify, evaluate and mitigate the risk factors in hospital supply chain. The purpose of the questionnaire is to evaluate the risk factors for determining of their priority (weight) of concern.

I would be very pleased if you can take part in this study in view of your professional knowledge in risk management, supply chain management or in hospital. The information gathered in this survey will be treated in the strictest confidence, as this has always been the policy of the Liverpool John Moores University. The questionnaire is anonymous, thus your response can not be attributed to you or your organization.

If you have any questions about this study, please feel free to contract me either email L.Wang@2015.ljmu.ac.uk or by phone. You also can contact my supervisor, Dr Jun Ren, at (44)1512312236, or by email j.ren@ljmu.ac.uk

Yours faithfully,

Lei Wang,

PhD Candidate,

Liverpool Logistics Offshore and Marine Research Institute (LOOM)

Tel: +(44)7510535904 or (86)13223898880

Email: L.Wang@2015.ljmu.ac.uk

Room 121, James Parsons Building

Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK

Section A: Respondent Profile

1. What is the type of your organization?

Pharmaceutical Manufacturer	Pharmaceutical distributor (pharmaceutical company)	Hospital (Procurement department; Material management department etc.)	Other
☐	☐	☐	☐

2. What is your job title? (optional)

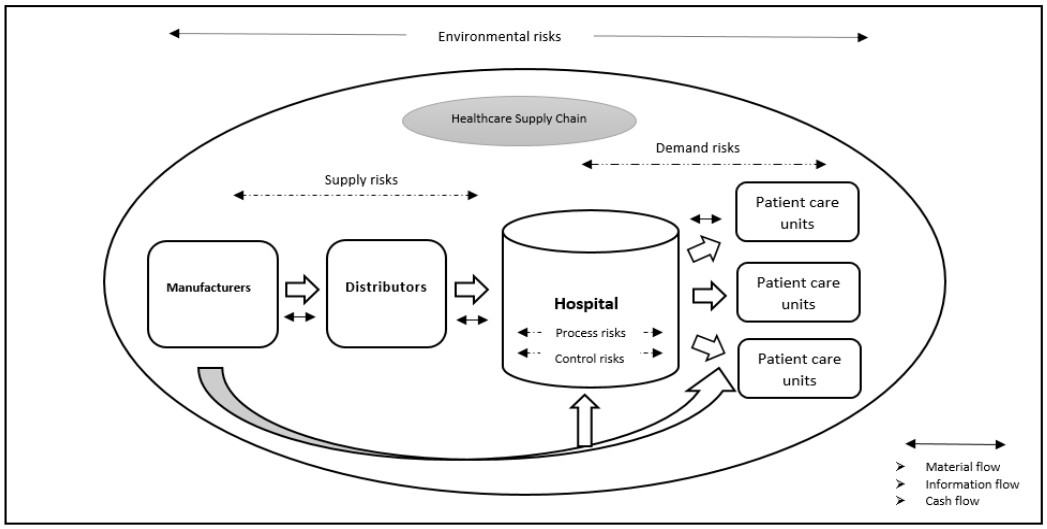
3. _____

3. For how many years have you worked in the healthcare industry or healthcare supply chain?

☐1-5 years ☐6-10 years ☐11-15 years ☐16-19 years ☐≥20 years

Section B: Analytical Hierarchical Process (AHP)

Part A: Introduction and Explanation



For your opinion as an expert, the pair-wise comparison scale can be used to assess or express the importance of one element over another. The linguistic judgements and their explanations used for evaluating the importance of the elements in pair-wise comparison shown in Table 1.

Table 1. Linguistic judgements for fuzzy AHP

Linguistic judgements	Explanations
Equal importance (Eq)	Two activities contribute equally to the objective
Weak importance (Wk)	Experience and judgement slightly favour one over another
Strong importance (St)	Experience and judgement strongly favour one over another
Very strong importance (Vs)	An activity is favoured very strongly over another
Absolute strong importance (As)	The evidence favouring one activity over another is of the highest possible order of affirmation

<u>Part B:</u> Questionnaire

1) Regarding the three main criteria, in your opinion what is the relative importance of the risk factor in healthcare supply chain (HCSC)?

<u>Key definitions:</u>

- *External to the hospital but internal to the supply chain network* (*i.e.* arise from interactions between organizations within the supply chain)
- *Internal to the hospital* (*i.e.* the risk sources lie within the boundaries of the supply chain parties and range from labour to IT-system uncertainties.)
- *External to the supply chain network* (*i.e.* can be defined as events driven by external forcers such as weather, earthquakes, political, regulatory and market forces)

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
External to the hospital but internal to the supply chain network	☐	☐	☐	☐	☐	☐	☐	☐	☐	Internal to the hospital
External to the hospital but internal to the supply chain network	☐	☐	☐	☐	☐	☐	☐	☐	☐	External to the supply chain network
Internal to the hospital	☐	☐	☐	☐	☐	☐	☐	☐	☐	External to the supply chain network

2) Regarding the sub-criteria, in your opinion what is the relative importance of the risk factor under "external to the hospital but internal to the supply chain network"?

- *Supply risks* (*i.e.* adversely affects inward flow of any type of resource to enable operations to take place or the transpiration of significant and/or disappointing failures with inbound goods and service)
- *Demand risks* (*i.e.* the possibility of unexpected changes arising from market or downstream customers)

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Supply risks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Demand risks

3) Regarding the quality and supplier risks, in your opinion what is the relative importance of these two risks under supply risks in HCSC?

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Quality risks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Supplier risks

4) Regarding the capability and forecast risks, in your opinion what is the relative importance of these two risks under demand risks in HCSC?

- *Capabilities risk* (*i.e.* the capabilities such as technical skills, knowledge and leadership competencies of individuals and the collective group responsible for managing the demand, plus the relationships within and outside organizations and individuals)

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Capability risks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Forecast risks

5) Regarding the information, logistics and procurement risks, in your opinion what is the relative importance of these two risks under process risks in HCSC?

- *Logistics risks* (*i.e.* the risks are associated to all the logistic activities in/or between each organizations)

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Information risks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Logistics risks
Information risks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Procurement risks
Logistics risks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Procurement risks

6) Regarding the sub-criteria, in your opinion what is the relative importance of these risks under quality risks in HCSC?

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Counterfeiting	☐	☐	☐	☐	☐	☐	☐	☐	☐	Poor quality in the purchased drugs from suppliers
Counterfeiting	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time limit of drug, product perishability,
Poor quality in the purchased drugs from suppliers	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time limit of drug, product perishability,

7) Regarding the sub-criteria, in your opinion what is the relative importance of these risks under capability risks in HCSC?

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Capability versus demand; inability of capacity to meet demand	☐	☐	☐	☐	☐	☐	☐	☐	☐	Demand trigged by the nurse, not the patient

8) Regarding the sub-criteria, in your opinion what is the relative importance of these risks under logistics risks in HCSC?

- *Weak logistics service infrastructure* (*i.e.* obsolete equipment in the warehouse; Improper drug store environment and transportation facility, route)

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Dispensing/ picking errors medication/ packaging,	☐	☐	☐	☐	☐	☐	☐	☐	☐	Weak logistics service infrastructure
Dispensing/ picking errors medication/ packaging	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of visibility concerning placement and availability of stock
Weak logistics service	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of visibility concerning

infrastructure										placement and availability of stock

9) Regarding the sub-criteria, in your opinion what is the relative importance of these risks under procurement risks in HCSC?

- *Procurement Hubs-introduce more complexity, Long lead time* (*i.e.* from placing the order until receiving)
- *Clinician's preference* (*i.e.* lack the awareness of cost containment)

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
Procurement Hub-introduce more complexity, long lead time	☐	☐	☐	☐	☐	☐	☐	☐	☐	Clinician's preference
Procurement Hub-introduce more complexity, long lead time	☐	☐	☐	☐	☐	☐	☐	☐	☐	High purchase price
Procurement Hub-introduce more complexity, long lead time	☐	☐	☐	☐	☐	☐	☐	☐	☐	High product and supplier/brand variety
Clinician's preference	☐	☐	☐	☐	☐	☐	☐	☐	☐	High purchase price
Clinician's preference	☐	☐	☐	☐	☐	☐	☐	☐	☐	High product and supplier/brand variety

High purchase price	☐	☐	☐	☐	☐	☐	☐	☐	☐	High product and supplier/brand variety

10) Regarding the sub-criteria, in your opinion what is the relative importance of these risks under natural risks in HCSC?

	Absolute Strong Importance	Very strong importance	Strong importance	Weak importance	Equal importance	Weak importance	Strong importance	Very strong importance	Absolute Strong Importance	
External influences-disaster recovery	☐	☐	☐	☐	☐	☐	☐	☐	☐	Unexpected disease outbreaks
External influences-disaster recovery	☐	☐	☐	☐	☐	☐	☐	☐	☐	Unexpected changes in environment conditions
Unexpected disease outbreaks	☐	☐	☐	☐	☐	☐	☐	☐	☐	Unexpected changes in environment conditions

THANK YOU ONCE AGAIN FOR YOUR KIND PARTICIPATION IN THIS SURVEY.

YOUR ANSWER WILL BE KEEP CONFIDENTIAL.

医疗药品供应链风险管理问卷调查

尊敬的专家：

您好！我叫王磊。来自利物浦约翰莫尔斯大学(LJMU)物流和海洋研究所的博士研究生。我的研究课题是提出一种全新的、系统化和结构化的方法针对医院药品供应链过程中产生的风险因素进行识别、分析和控制。

本次问卷的目的是：

针对已经识别出存在于医疗供应链中的风险因素，根据专家的经验与意见对其风险因素之间的重要性大下进行比较，并最终得到各个风险因素的优先级权重。

对于占用您宝贵的时间我深感歉意。也同时非常的荣幸能够邀请您参加到我的研究课题当中。您对于医疗供应链管理和风险管理的宝贵经验将对此次问卷调查的起到非常重要的作用。同时需要强调的是，根据研究课题组的要求，本次调查的信息将会被严格的保密；其中所涉及到的相关单位及个人信息会采取匿名的方式。本次调查需要 5-10 分钟左右的时间。如果您有任何问题，请通过电子邮 L.Wang@2015.ljmu.ac.uk 联系我。您也可以通过电子邮件 J.Ren@ljmu.ac.uk 联系我的导师任军教授。最终的研究成果将无偿分享给您和您所在的单位。

王磊

博士研究生

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Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK

第一部分：受访者基本情况

1. 请问您所在的单位是以下哪一个？

医药制造企业	医药批发企业	医药零售企业	医院	其它
☐	☐	☐	☐	☐

4. 请问您的职位是什么？（可选）

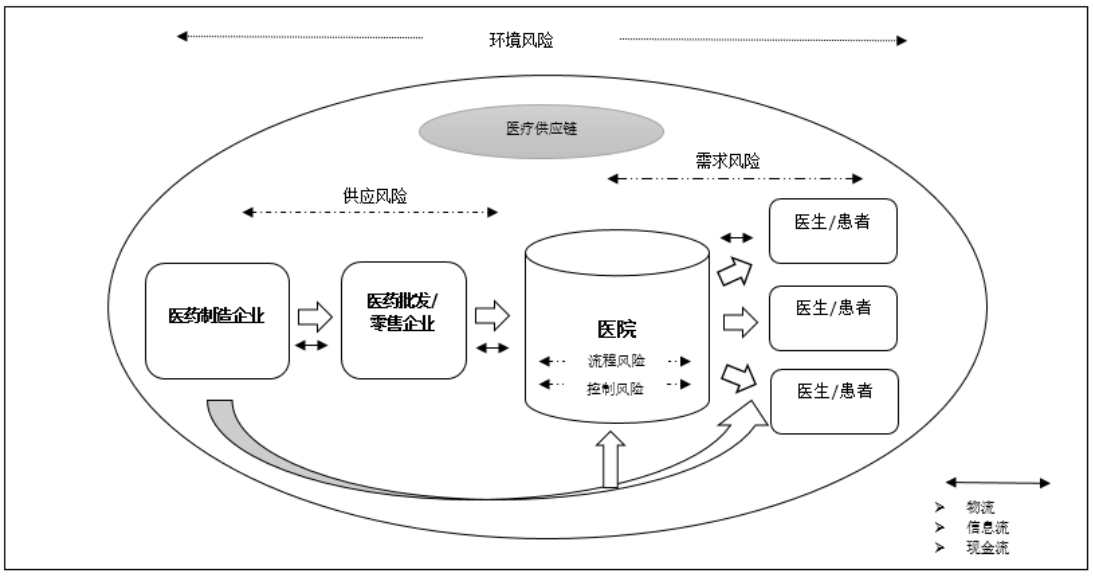
_____

3. 请问您从事医药物流和供应链的工龄多久？

☐1-5 年 ☐6-10 年 ☐11-15 年 ☐16-19 年 ☐≥20 年

第二部分：风险因素之间权重大小对比

1）简介与解释



根据您的观点对各个风险因素之间的重要性进行两两比较打分。评分标准列在表格 1 中。

表格 1. 风险因素两两比较评分标准

评分标准	解释
同等重要	两个风险的重要性同等重要
稍微重要	其中一个风险比另一个风险稍微重要
稍强重要	其中一个风险比另一个风险稍强重要
非常重要	其中一个风险比另一个风险非常重要
极端重要	其中一个风险比另一个风险极端重要

2） 问卷内容

I. 针对整个医疗供应链，根据您的意见对以下三个部分的风险因素的重要性进行对比。

含义解释：

- **供应链网络内部风险**

(此风险产生于医疗供应链成员之间，例如医药批发商与医院之间， 医药制造商与医药批发商之间产生的风险)

- **医院内部风险**

(此风险产生于医院内部，例如采购风险，物流配送风险等)

- **供应链网络外部风险**

(此风险产生于供应链网络外部，例如自然灾害，国家法律法规，政策等)

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
供应链网络内部风险	□	□	□	□	□	□	□	□	□	医院内部风险
供应链网络内部风险	□	□	□	□	□	□	□	□	□	供应链网络外部风险
医院内部风险	□	□	□	□	□	□	□	□	□	供应链网络外部风险

II. 针对供应链网络内部风险，根据您的意见对以下两个风险的重要性进行对比。

- **供应风险** *(围绕供应链运营中的药品供应过程的潜在的和实际的风险)*
- ***需求风险*** *(指供应链下游中不可预知的变化所导致的风险)*

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
供应风险	□	□	□	□	□	□	□	□	□	需求风险

III. 针对供应风险，根据您的意见对以下两个风险的重要性进行对比。

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
质量风险	□	□	□	□	□	□	□	□	□	供应商风险

IV. 针对需求风险，根据您的意见对以下两个风险的重要性进行对比。

- **能力风险** *（医院整体实力与各科室需求不匹配，出现供不应求的情况；缺乏需求信息，有关客户需求和市场等的信息不完整等)*

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
能力风险	□	□	□	□	□	□	□	□	□	预测风险

V. 针对医院内部流程风险，根据您的意见对以下三个风险的重要性进行对比。

- **流程风险** *(风险源产生于组织的增值和管理活动的流程中.)*
- **信息风险** *(一定概率由于信息的不正确、不完整或者非法访问而导致组织损失)*
- **物流风险** *(指组织内部以及供应链成员之间的物流活动中产生的风险)*

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
信息风险	□	□	□	□	□	□	□	□	□	物流风险
信息风险	□	□	□	□	□	□	□	□	□	采购风险
物流风险	□	□	□	□	□	□	□	□	□	采购风险

VI. 针对质量风险，根据您的意见对以下三个风险的重要性进行对比。

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
假药	□	□	□	□	□	□	□	□	□	购买药品的质量不合格
假药	□	□	□	□	□	□	□	□	□	药品的易腐性，保质期周期短
购买药品的质量不合格	□	□	□	□	□	□	□	□	□	药品的易腐性，保质期周期短

VII. 针对能力风险，根据您的意见对以下两个风险的重要性进行对比。

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
医院整体实力与各科室需求不匹配	☐	☐	☐	☐	☐	☐	☐	☐	☐	需求由护理人员驱动而非患者， 导致真实需求信息不正确从而产生过量的采购等问题

VIII. 针对医院内部物流风险，根据您的意见对以下三个风险的重要性进行对比。

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
医院内部药品的拣选，包装和运输出错	☐	☐	☐	☐	☐	☐	☐	☐	☐	物流服务基础设施薄弱
医院内部药品的拣选，包装和运输出错	☐	☐	☐	☐	☐	☐	☐	☐	☐	库存管理的可视化程度低
物流服务基础设施薄弱	☐	☐	☐	☐	☐	☐	☐	☐	☐	库存管理的可视化程度低

IX. 针对医院内部的采购风险，根据您的意见对以下四个风险的重要性进行对比。

- **采购中心工作复杂性程度高，从采购到交货的流程过长**
- **医生的个人偏好加重采购的成本** *(医生有各自对于药品使用的偏好，医生更多关注药效而忽视药品价格)*

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
采购中心工作复杂性程度高	□	□	□	□	□	□	□	□	□	医生的个人偏好
采购中心工作复杂性程度高	□	□	□	□	□	□	□	□	□	过高的采购价格
采购中心工作复杂性程度高	□	□	□	□	□	□	□	□	□	采购药品的种类和供应商的数量过多
医生的个人偏好	□	□	□	□	□	□	□	□	□	过高的采购价格
医生的个人偏好	□	□	□	□	□	□	□	□	□	采购药品的种类和供应商的数量过多
过高的采购价格	□	□	□	□	□	□	□	□	□	采购药品的种类和供应商的数量过多

x. 针对供应链网络外部自然风险，根据您的意见对以下三个风险的重要性进行对比。

	极端重要	非常重要	稍强重要	稍微重要	同等重要	稍微重要	稍强重要	非常重要	极端重要	
外部影响-灾难恢复缓慢	□	□	□	□	□	□	□	□	□	突发性重大疫情爆发
外部影响-灾难恢复缓慢	□	□	□	□	□	□	□	□	□	环境状况出现意外变化
突发性重大疫情爆发	□	□	□	□	□	□	□	□	□	环境状况出现意外变化

再次感谢您在此次调查中提供的帮助

您的回答将会被严格保密

APPENDIX THREE

Questionnaire used in Survey C for the purpose of ISM model in Chapter six

Research on Risk Management for Healthcare Supply Chain in hospital

Questionnaire

Dear Sir/Madam,

My name is Lei Wang, who is currently the PhD candidate at the Liverpool Logistics Offshore and Marine Research Institute (LOOM) in Liverpool John Moores University. My research topic is “Research on risk management for healthcare supply chain in hospital”. The research aims to propose a novel risk management methodology to identify, evaluate and mitigate the risk factors in hospital supply chain. The purposes of the questionnaire is to develop contextual relationships to analyze the inter-relationships among healthcare supply chain risk factors.

I would be very pleased if you can take part in this study in view of your professional knowledge in risk management, supply chain management or in hospital. The information gathered in this survey will be treated in the strictest confidence, as this has always been the policy of the Liverpool John Moores University. The questionnaire is anonymous, thus your response can not be attributed to you or your organization.If you have any questions about this study, please feel free to contract me either email L.Wang@2015.ljmu.ac.uk or by phone. You also can contact my supervisor, Dr Jun Ren, at (44)1512312236, or by email j.ren@ljmu.ac.uk

Yours faithfully,

Lei Wang,

PhD Candidate,

Liverpool Logistics Offshore and Marine Research Institute (LOOM)

Tel: +(44)7510535904 or (86)13223898880

Email: L.Wang@2015.ljmu.ac.uk

Room 121, James Parsons Building

Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK

Section A: Respondent Profile

1. What is the type of your organization?

Pharmaceutical Manufacturer	Pharmaceutical distributor (pharmaceutical company)	Hospital (Procurement department; Material management department etc.)	Other
☐	☐	☐	☐

5. What is your job title? (optional)

_____

3. For how many years have you worked in the healthcare industry or healthcare supply chain?

☐1-5 years ☐6-10 years ☐11-15 years ☐16-19 years ☐≥20 years

Section B: Interpretive Structural Modelling (ISM)

The occurrence of one risk gives rise to multiple risks resulting into a domino effect which makes it very importance for the managers to control these risks before they occur. The following questions are related to analyze the inter-relationships among the identified risk factors.

Contextual relationship = **leads to** What to enter in the cells:

1) Enter **1** when the column influences the row and the row not influences the column
2) Enter **2** when the column influences the row and the row not influences the row
3) Enter **0** when there is no relation between the row and the column
4) Enter **3** when row and column influences each other

Risk factors	S11	S10	S9	S8	S7	S6	S5	S4	S3	S2	S1
S1 Counterfeiting											
S2 Capability versus demand, inability of capacity to meet demand											
S3 Dispensing/picking errors medication/packaging											
S4 Shortage of drug, unavailability of drugs on the market											
S5 Poor quality in the purchased drugs from suppliers											
S6 Weak logistics service infrastructure											
S7 Poor IT system, lack of data standardization											
S8 Lack of visibility concerning placement and availability of stock											
S9 High purchase price											
S10 Clinician's preference											
S11 High product and supplier/brand variety											

THANK YOU ONCE AGAIN FOR YOUR KIND PARTICIPATION IN THIS SURVEY.

YOUR ANSWER WILL BE KEEP CONFIDENTIAL.

医疗药品供应链风险管理问卷调查

尊敬的专家：

您好！我叫王磊。来自利物浦约翰莫尔斯大学(LJMU)物流和海洋研究所的博士研究生。我的研究课题是提出一种全新的、系统化和结构化的方法针对医院药品供应链过程中产生的风险因素进行识别、分析和控制。

本次问卷的目的是：

针对已经识别出存在于医疗供应链中的风险因素，根据专家的经验与意见对其风险因素之间的相互影响关系进行评估。

对于占用您宝贵的时间我深感歉意。也同时非常的荣幸能够邀请您参加到我的研究课题当中。您对于医疗供应链管理和风险管理的宝贵经验将对此次问卷调查的起到非常重要的作用。同时需要强调的是，根据研究课题组的要求，本次调查的信息将会被严格的保密；其中所涉及到的相关单位及个人信息会采取匿名的方式。

本次调查需要 5-10 分钟左右的时间。如果您有任何问题，请通过电子邮件 L.Wang@2015.ljmu.ac.uk 联系我。您也可以通过电子邮件 J.Ren@ljmu.ac.uk

联系我的导师任军教授。最终的研究成果将无偿分享给您和您所在的单位。

王磊

博士研究生

Liverpool Logistics Offshore and Marine Research Institute (LOOM)

Tel: 13223898880

Email: L.Wang@2015.ljmu.ac.uk or wlthegreat24@hotmail.com

Room 121, James Parsons Building

Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK

第一部分：受访者基本情况

1. 请问您所在的单位是以下哪一个？

医药制造企业	医药批发企业	医药零售企业	医院	其它
☐	☐	☐	☐	☐

6. 请问您的职位是什么？（可选）

_____

3. 请问您从事医药物流和供应链的工龄多久？

☐1-5 年 ☐6-10 年 ☐11-15 年 ☐16-19 年 ☐≥20 年

第二部分：解释结构模型法

一个风险的发生会引起其他多个风险，继而在组织中产生多米诺效应。下列问题是针对于风险之间的相互影响关系进行评估。

相互之间的关系= **导致**

填入方块中的数字各自代表的意思：

5) 填入 1 表示纵列中的风险因素会影响或导致横行中的风险因素，但横行中的风险因素不会影响或导致纵列中的风险因素。
6) 填入 1 表示横行中的风险因素会影响或导致纵列中的风险因素，但纵列中的风险不会影响或导致横行中的风险因素。
7) 填入 0 表示纵列和横行中的风险因素互不影响。
8) 填入 3 表示纵列和横行中的风险因素互相影响。

注：由于篇幅原因，横行中的风险因素仅以数字代替，例如 S11 表示**采购药品的种类和供应商的数量过多。**

风险因素	S11	S10	S9	S8	S7	S6	S5	S4	S3	S2	S1
S1 假药											
S2 医院整体实力与各科室需求不匹配											
S3 医院内部药品的拣选，包装和运输出错											
S4 药品短缺											
S5 购买药品的质量不合格											
S6 物流服务基础设施薄弱											
S7 落后的信息系统；单一的信息传送渠道；信息传输缓慢											
S8 库存管理的可视化程度低											
S9 过高的采购价格											
S10 医生的个人偏好 *(医生有各自对于药品使用的偏好，医生更多关注药效而忽视药品价格)*											
S11 采购药品的种类和供应商的数量过多											

再次感谢您在此次调查中提供的帮助。

您的回答将会被严格保密。

APPENDIX FOUR

List of Semi-structured Interview Questions for the purpose of Chapter seven

1. What is your job titles?

   _____

2. The number of years in your organization:

   _____years and _____months

3. The number of employee or beds in your organization: _____

4. Is your organization concerned about supply chain risks?

   _____

5. Have you had any issues or incidents in the past 12 months resulting in supply chain disruption to your organization or to any other customer?

   _____

6. In your opinion, list the main risks in hospital supply chain regarding to five risk factors （demand, supply, process, control and environmental risks）:

   _____

7. Does your organization have the formal mechanisms for identifying and documenting risks facing your area? If you answered “yes”,

   - How long it has been implemented?

_____

   - What elements does your risk management program cover?

_____

   - As circumstances change, risks may also change. How often is your risk factors identification reviewed and undated?

_____

   - Do you think what is the key factor in execution the mechanisms?

_____

8. If you do not have formal risk factors identification mechanisms, how do you ensure coverage of key risks?

   _____

9. Does your organization operate risk management strategy so far? If you answered “yes”,

   - How long it has been implemented?

   _____

- Which department or procedure are using the strategy?

_____

- For your opinion, what are the advantages and disadvantages for using the strategy in your organization?

_____

10. The hospital supply chain is constituted by three main components which are procurement, warehouse and transportation activities. So for your opinion, which component is more high risk than other two?

    _____

11. Does the decision maker play the key role for managing risks in your organization?

_____

APPENDIX FIVE

Questionnaire used in Survey D for the purpose of TOPSIS method in Chapter seven

Research on Risk Management for Healthcare Supply Chain in Hospital Questionnaire

Dear Sir/Madam,

My name is Lei Wang, who is currently the PhD candidate at the Liverpool Logistics Offshore and Marine Research Institute (LOOM) in Liverpool John Moores University. My research topic is “Research on risk management for healthcare supply chain in hospital”. The research aims to propose a novel risk assessment methodology to identify, evaluate and mitigate the risk factors in hospital supply chain. The purpose of the questionnaire is to examine the best solutions for the risk mitigation of the healthcare supply chain in hospital sector.

I would be very pleased if you can take part in this study in view of your professional knowledge in risk management, supply chain management or in hospital. The information gathered in this survey will be treated in the strictest confidence, as this has always been the policy of the Liverpool John Moores University. The questionnaire is anonymous, thus your response can not be attributed to you or your organization.If you have any questions about this study, please feel free to contract me either email L.Wang@2015.ljmu.ac.uk or by phone. You also can contact my supervisor, Dr. Jun Ren, at (44)1512312236, or by email j.ren@ljmu.ac.uk

Yours faithfully,

Lei Wang,

PhD Candidate,

Liverpool Logistics Offshore and Marine Research Institute (LOOM)

Tel: +(44)7510535904 or (86)13223898880

Email: L.Wang@2015.ljmu.ac.uk

Section A: Introduction and Explanation

Based on the findings from the previous survey, the following factors have been weighted by the experts as the most importance risks:

- **S1 Counterfeiting**
- **S2 Capability versus demand; inability of capacity to meet demand** (*e.g. not able to response the demand, procurement is not sufficient to copy with demand. Lack of human resource(inherent efficiencies and recruitment and retention problems with the pharmacy profession), lack of information accuracy; the number of lifts is limited, and it is not capable to support the delivering process during the rush hour)*
- **S3 Dispensing/picking errors medication/packaging** (*e.g. Manually operate; delay delivery, urgent delivery; sound-alike or look-alike drug names, similarities in the outer appearance of medicines' packages and labeling as well as unclear or incomplete labeling information; high delivering frequency per day; handwritten prescription leads to various types of medication error such as prescribing error, transcribing error, pre-dispensing and dispensing error.)*
- **S4 Shortage of drugs**
- **S5 Poor quality in the purchased drugs from suppliers**
- **S6 Weak Logistics service infrastructure** (*e.g. Obsolete equipment in the warehouse; Improper drug store environment and transportation facility, route, inefficient cold chain management during transportation affects the quality and stability of temperature-sensitive products)*
- **S7 Poor IT System, too much information, lack of data standardization** (*e.g.* slowly information transmission and single transmission channel; *lack of information management platform, manual process, lack of standardized product identification (RFID, QR code), Lack of product traceability and integrated system with suppliers, limited information system which covering logistics activities.)*
- **S8 Lack of visibility concerning placement and availability of stock**
- **S9 High purchase price**
- **S10 Clinician's preference** (*e.g. lack the awareness of cost containment)*
- **S11 High product and supplier/brand variety** (*e.g. high stock levels*)

We further need to determine which relevant risk mitigation solutions has become the key strategic consideration. The following 9 appropriate risk management strategies have been identified through the empirical studies from both UK and China hospitals. For your opinion as an expert, please kindly give your comments about the performance of following mitigation solutions with respect to manage each risk factor.

Section B: Questionnaire

Q1. With respect to manage **S1 Counterfeiting**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management *e.g. appropriate distribution route and used temperature-monitoring devices*	☐	☐	☐	☐	☐
Information Technology System *e.g. Data standardization, information sharing, drugs traceability, integrated IT platform, RFID, EDI*	☐	☐	☐	☐	☐
Collaboration *Vertical and Horizontal (e.g. clinical staff engagement, supplier relationship management; GPO, etc)*	☐	☐	☐	☐	☐
Inventory Management *e.g. Consignment stock, visibility, Drugs expiry date management, Just-in -time*	☐	☐	☐	☐	☐
eProcurement Strategy *(the application of technology to automate the exchange of procurement information through the SC)*	☐	☐	☐	☐	☐
Outsourcing *e.g. Stock replenishment, maintenance and repairs; outsourcing non-core services*	☐	☐	☐	☐	☐
Agility *e.g. out of hours, urgent deliveries; responsiveness; flexibility*	☐	☐	☐	☐	☐
Capability Management *e.g. Staff training, set up a central control of logistics activities to manage people*	☐	☐	☐	☐	☐
Single Sourcing *e.g. long-term contract with only one supplier*	☐	☐	☐	☐	☐

Q2. With respect to manage **S2 Capability versus demand**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q3. With respect to manage **S3 Dispensing/picking errors medication/packaging**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q4. With respect to manage **S4 Shortage of drugs**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q5. With respect to manage **S5 Poor quality in the purchased drugs from suppliers**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q6. With respect to manage **S6 Weak logistics service infrastructure**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q7. With respect to manage **S7 Poor IT system, too much information, lack of data standardization**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q8. With respect to manage **S8 Lack of visibility concerning placement and availability of stock**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q9. With respect to manage **S9 High purchase price**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q10. With respect to manage **S10 Clinician's preference**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

Q11. With respect to manage **S11 High product and supplier/brand variety**, please determine the importance of each risk mitigation strategy.

	Important level				
Risk Mitigation Strategies	Very Poor	Poor	Medium	Good	Very good
Logistics Management	☐	☐	☐	☐	☐
Information System	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
eProcurement Strategy	☐	☐	☐	☐	☐
Outsourcing	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Capability Management	☐	☐	☐	☐	☐
Single Sourcing	☐	☐	☐	☐	☐

THANK YOU ONCE AGAIN FOR YOUR KIND PARTICIPATION IN THIS SURVEY.

YOUR ANSWER WILL BE KEEP CONFIDENTIAL.

医疗药品供应链风险管理

问卷调查

尊敬的专家：

您好！我叫王磊。来自利物浦约翰莫尔斯大学(LJMU)物流和海洋研究所的博士研究生。我的研究课题是提出一种全新的、系统化和结构化的方法针对医院药品供应链过程中产生的风险因素进行识别、分析和控制。本次问卷的目的是评价不同风险控制策略在面对不同的风险因素时的重要程度。

对于占用您宝贵的时间我深感歉意。也同时非常的荣幸能够邀请您参加到我的研究课题当中。您对于医疗供应链管理和风险管理的宝贵经验将对此次问卷调查的起到非常重要的作用。同时需要强调的是，根据研究课题组的要求，本次调查的信息将会被严格的保密；其中所涉及到的相关单位及个人信息会采取匿名的方式。

本次调查需要 10 分钟左右的时间。如果您有任何问题，请通过电子邮件 L.Wang@2015.ljmu.ac.uk 联系我。您也可以通过电子邮件 J.Ren@ljmu.ac.uk

联系我的导师任军教授。

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第一部分：简介

根据此前的调查研究，我们识别出以下存在于医院供应链之中最重要的 11 个风险因素：

S1 **假药**

S2 **医院整体实力与各科室需求不匹配** *（例如：不能够有效及时地对满足需求，出现供不应求的情况； 相应的工作人员缺乏；缺少准确信息；在需求高峰期时，电梯的数量不足，不能够及时将药物配送的各个科室等）*

S3 **医院内部药品的拣选，包装和运输出错** *（例如：手动操作容易引起操作失误；相似包装的药品或者不清晰的条形码信息容易造成药品拣选，配送出错；每个工作日中高批量的配送等）*

S4 **药品短缺**

S5 **购买药品的质量不合格**

S6 **落后的物流服务设施** *（例如：药品库房设备陈旧；不适当的药品储存环境和运输设备，路径； 冷链控制不当等）*

S7 **落后的信息系统，过量的信息，缺乏药品数据标准化** *（例如：信息传送缓慢，单一的信息传送渠道；缺乏同意的信息服务平台；自动化操作程度低； 缺乏统一的药品代码； 缺乏药品的可追踪性以及与供应商的信息系统不整合等）*

S8 **库存管理的可视化程度低**

S9 **过高的采购价格**

S10 **医生的个人偏好加重采购的成本** *（医生有各自对于药品使用的偏好，医生更多关注药效而忽视药品价格）*

S11 **采购药品的种类和供应商的数量过多** *（例如：过高的库存量造成浪费等）*

针对于以上 11 个高风险因素，我们通过在英国和中国的医院内部进行实证研究，识别出 10 个相应的风险管理策略。请您以专家的观点对其在管理不同的风险时的重要程度进行打分，并提出不同的改进意见。

第二部分:问卷部分

问题一:针对降低 S1 假药的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理 *例如：合理的运输路径，采取先进的温度控制设备提高冷链效率等*	☐	☐	☐	☐	☐
信息技术系统 *例如：数据标准化，信息共享，药品的可追溯性，先进的信息系统等*	☐	☐	☐	☐	☐
注重合作 *例如：医院内部各个科室之间以及医院与上游供应商之间建立长期有效的合作机制，临床医生参与采购等物流活动等*	☐	☐	☐	☐	☐
库存管理 *例如：库存可视化管理；药品期效管理;JIT 库存管理等*	☐	☐	☐	☐	☐
电子采购战略 *例如：采购流程电子化，信息化等*	☐	☐	☐	☐	☐
外包 *例如：将医院内部非核心的物流活动外包给第三方管理；二级库房外包等*	☐	☐	☐	☐	☐
敏捷管理 *例如：针对突发事件进行快速反应等*	☐	☐	☐	☐	☐
能力管理 *例如：注重员工技能培训(采购，配送，拣选等)*	☐	☐	☐	☐	☐
单一化采购 *例如：只与一家大的药品供应商建立长期合作，其供应商提供医院内部药品用量的 90%以上，降低多向采购带来的质量等问题*	☐	☐	☐	☐	☐

问题二:针对降低 S2 医院整体实力与各科室需求不匹配的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	□	□	□	□	□
信息技术系统	□	□	□	□	□
注重合作	□	□	□	□	□
库存管理	□	□	□	□	□
电子采购战略	□	□	□	□	□
外包	□	□	□	□	□
敏捷管理	□	□	□	□	□
能力管理	□	□	□	□	□
单一化采购	□	□	□	□	□

问题三:针对降低 S3 医院内部药品的拣选,包装和运输出错的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	□	□	□	□	□
信息技术系统	□	□	□	□	□
注重合作	□	□	□	□	□
库存管理	□	□	□	□	□
电子采购战略	□	□	□	□	□
外包	□	□	□	□	□
敏捷管理	□	□	□	□	□
能力管理	□	□	□	□	□
单一化采购	□	□	□	□	□

问题四:针对降低 S4 药品短缺的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题五:针对降低 S5 购买药品的质量不合格的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题六:针对降低 ***S6*落后的物流服务设施**的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题七:针对降低 **S7 落后的信息系统,过量的信息,缺乏数据标准化**的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题八:针对降低 S8 库存管理的可视化程度低的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题九:针对降低 S9 过高的采购价格的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题十:针对降低 S10 医生的个人偏好加重采购的成本的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

问题十一:针对降低 S11 采购药品的种类和供应商的数量过多的风险,请问以下各风险策略的重要程度。

	重要程度				
风险管理策略	非常差	差	一般	好	非常好
物流管理	☐	☐	☐	☐	☐
信息技术系统	☐	☐	☐	☐	☐
注重合作	☐	☐	☐	☐	☐
库存管理	☐	☐	☐	☐	☐
电子采购战略	☐	☐	☐	☐	☐
外包	☐	☐	☐	☐	☐
敏捷管理	☐	☐	☐	☐	☐
能力管理	☐	☐	☐	☐	☐
单一化采购	☐	☐	☐	☐	☐

再次感谢您在此次调查中提供的帮助

您的回答将会被严格保密