An integrated framework for improving supply chain performance

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An Integrated Framework for Improving Supply Chain Performance

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Preface

This thesis has been carried out in accordance with the regulations of the Sheffield Hallam University as a part of the requirements for the degree of Doctor of Philosophy. The contents of this research studying have been carried out by the author were supervised by Professor Terrence Perera between May 2014 to July 2018.

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I would like to thank Llamafot Support team for their support with Supply Chain Guru Software, and especially to Tin Leung who always offers outstanding assistance.

I sincerely thank my beloved family for their patience and support. They missed my attention and presence throughout the period of my study and for that I am truly indebted to them.

Dedicate

This thesis is dedicated to my late mother (Fatima), my father (Ali) and my brothers and sisters (Fouziya, Husain, Halima, Mohamed, Basma, Hana, and Abdu-Allah).

Last but not least, to my darling wife (Manani) for her patience and sacrifice during my PhD journey. To my beloved children (Abduerehman, and Ali) for their endless love.

Abstract

In 2009, Roland Berger Strategy Consultants [Roland Berger Strategy Consultants, (2009). Global SCM excellence study., p.5.] reported that 40% of 234 companies had the wrong priorities in regard to efficiency vs. responsiveness. In 2014, PricewaterhouseCoopers (PwC) and American Production and Inventory Control Society (APICS) [PwC and APICS, Sustainable supply chains: Making value the priority 2014] found that 76% of 500 supply chain executives identified sustainability as an important aspect of their supply chain. The results highlight the importance of achieving consistency between customer expectations, in terms of cost and service level, and supply chain performance in today's competitive business environment. Despite this, however, no integrated supply chain design framework exists to control majority of the important functions related to supply chain strategy, structure, process and performance.

The literature review showed that simulation is rarely considered at the strategic level, but the research experiments highlighted a number of ways in which simulation tools might be useful at this level, such as exploring the impact of strategic fit and decoupling points, and assessing different supply chain network configurations and policies.

This research contributes to knowledge by designing and developing a framework that integrates strategy, process and resources, and allows the use of simulation tools to consider the three dimensions of efficiency, responsiveness and sustainability concurrently during the design process. The proposed framework is validated using a hypothetical supply chain network. Simulation allows performance to be assessed under a range of scenarios. The simulation experiments showed that under the suggested policies, efficiency improved from 25.38% to 30.58% and responsiveness rose from 18.37% to 32.78%. However, they also indicated that while policies oriented towards improving responsiveness had a positive impact on sustainability, those oriented towards improving efficiency had a negative impact.

The significance of the research lies in its development of a supply chain design framework that could assist companies in achieving the optimum configuration of supply chain resources, thereby helping them reduce inventory, lower costs, enhance responsiveness and improve strategic focus in terms of design, execution and capital investments.

List of abbreviations

ABDS	Agent-Based Decision Support
ABM	Agent-Based Modelling
ADI	Inter-demand interval
AT	Agent Technology
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BPR	Business Process Reengineering
CASNs	Complex Adaptive Supply Networks
CLD	causal loop diagramming
CPFR	Collaborative Planning, Forecasting and Replenishment
CRS	Constant Returns to Scale
CV	Coefficient of Variation
DES	Discrete Event Simulation
ECM	Engineering Change Management
ERP	Enterprise Resource Planning
EM	Enterprise Modelling
ETO	Engineer-to-order
FEIs	Fast-Evolving Industries
GBOP	Generic-Bill-Of-Products
GSCF	Global Supply Chain Framework
GSCM	Green Supply Chain Management
HRM	Human Resource Management
JIT	Just-in-time
KPIs	key performance indicators
LARG	Lean, Agile, Resilient and Green)
LSCM	Logistics and Supply Chain Management
LT	Lead Time
MTO	Make-to-order
MTP	Make-to-plan
MTS	Make-to-stock
NPD	New Product Development
PDF	Probability Density Function
ROA	Return On Asset
RP	Reorder Point

List of abbreviations (Continued)

RQ	Reorder Quantity
SA	Sensitivity Analysis
SAP	System and Application Products
SC	Supply chain
SCD	supply chain design
SCG	Supply Chain Guru
SCI	supply chain integration
SCM	supply chain management
SCOR	Supply Chain Operations Reference Model
SCN	supply chain network
SCND	supply chain network design
SCS	supply chain strategy
SD	system dynamics
SM	Simulation Modelling
SPC	Statistical Process Control
SPSCs	Sustainability Performance in Supply Chains
SSCPM	supply chain performance measurement
SSO	Safety Stock Optimization
StDv	Standard Deviation
TO	Transportation optimization
TQM	Total Quality Management
VAR	value at risk
VMI	vendor Managed Inventory
VRM	Value Reference Model
VRP	Vehicle Routing Problems

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Chapter 1: Introduction

1.1 Background

Supply chains (SC) and logistics are the drivers of every economy. As global manufacturing has grown, effective and efficient SC and logistics management has become a key priority. Businesses are continually seeking to re-align their business models to ensure they serve their customers' needs better than their competitors. In this journey to improve customer service, businesses have used a wide variety of metrics to measure their performance, first in terms of efficiency and effectiveness, and more recently, in terms of sustainability. The emphasis now being placed on these three dimensions means that all three must be taken into account in the design of any SC.

Broadly speaking, the business of supply chain design (SCD) is to utilize resources efficiently in order to achieve defined outcomes. However, the literature review highlights that there is no general consensus among authors about how the concept should be defined. Baud-Lavigne (2012) and Melnyk (2014) defined SCD as the development, implementation and management of resources, processes and relationships across the SC. Mallidis, Dekker and Vlachos (2012) argued that SCD may be considered at two different levels: the strategic level and the tactical level, while Pistikopoulosb and Stuart (2013) and Leukel and Sugumaran (2013) argued that it has to support the company's strategic objectives. This lack of agreement about how to define SCD is the main reason why there is no comprehensive SCD framework; as Melnyk (2014) pointed out, numerous authors have focused on individual issues such as process, investment and structure, but no one has offered an overall framework to tie these issues together.

Chaharsooghi and Heydari (2011) emphasized that in highly turbulent environments, it is essential for the SC to focus on responsiveness to avoid losing customers. Accordingly, Wieland (2012) proposesd a model that enables companies to select from a range of SC strategies including agility, robustness, resilience and rigidity, depending on their assessment of risk probability and risk impact. Alfalla-Luqu, Medina-Lope and Dey (2013) extended this idea by building a conceptual framework (based on Fisher's (1997) prototypical efficient and market responsive configurations) that also included social and environmental issues, while Um et al. (2017) developed a conceptual model linking product variety management strategies with SC responsiveness and cost. However, a review of the relevant literature indicates that no one has developed a design framework in which all three categories are considered concurrently.

This has now become possible with the emergence of SC-specific simulation software that is powerful enough to consider efficiency, responsiveness and sustainability simultaneously. Researchers have already employed simulation as a tool to explore a range of SC issues; Chaharsooghi and Heydar (2009), for example, investigated the effects of lead time on SC performance, while Ilaria (2011) used simulation to develop a model for strategic decision making and to investigate operational issues such as inventory and transportation effects. Finally, Tseng, Gung and Huang (2013) used simulation to define the impacts of operator parameters on total cost, penalty cost, fill rate and on-time delivery. Shahi and Pulkki (2013), looked to further extend its application, argue for simulation-based optimization models to provide much better solutions than current industrial practice.

To sum up: while numerous researchers have discussed SCD, there is no consensus on how the concept should be defined. Furthermore, no frameworks have yet been presented that integrate all SC functions or aim to improve multiple dimensions of SC performance. This research seeks to address this gap by developing a framework that adopts a broad and integrated approach to SCD and then using hypothetical supply chain network to validate it.

1.2 Research Aim and Objectives

1.2.1 Aim

The research aims to develop an integrated Framework for improving supply chain performance

1.2.2 Objectives

The following are the main objectives of this research:

1. To carry out a comprehensive literature review to establish current knowledge and practice.
2. To review the use of simulation in SCD.
3. To identify appropriate key performance indicators (KPIs) to consider efficiency, responsiveness and sustainability concurrently.
4. To review currently available SCD frameworks.
5. To design a preliminary framework.
6. To evaluate and improve this framework.
7. To validate the framework in the virtual environment using the simulation tool.

1.3 Thesis Structure

The objectives mentioned in the previous section are addressed in six chapters of this thesis. This chapter offers a brief introduction to the aims and objectives of the research. Chapter Two presents a comprehensive literature review discussing the various methodologies that have been employed by previous researchers in SCD. This chapter discusses definitions of SCD, existing frameworks, SC strategies and performance metrics.

Chapter Three discusses the methodology employed in the study. It describes the process of developing an SC management framework and introduces the features of integrated SCD, including the strategic fit concept underlying the strategic model within the proposed framework, the SCOR model (used to clarify SC process configurations) and the supply chain network design (SCND) concept. Finally, the chapter discusses research techniques and tools including SC modelling, optimization and simulation.

Chapter Four presents the proposed integrated SCD framework. This consists of four different models, each of which performs a defined role within the overall SCD. The strategic objective model sets out four different SC strategies to meet customer requirements in both certain and uncertain business environments, taking into account SC capabilities and target performance levels. The process model (the Supply Chain Operations Reference Model – SCOR) assists managers in implementing the right policies to maximize resource utilization and achieve the SC's strategic goals. The network model clarifies the way in which various entities in the supply chain network (SCN) are associated with each other and how their processes interact to achieve the goals of the SC. Finally, the performance indicators model measures SC performance and defines the extent to which it is meeting its objectives.

Chapter Five describes the modelling and simulation process that was undertaken to verify the proposed framework. This process was conducted using Llamasoft's Supply Chain Guru (SCG) software.

Chapter Six summarises and discusses the main points obtained from the research before offering recommendations for further study.

Chapter 2: Literature Review

2.1 Introduction

This chapter reviews the literature pertaining to supply chain design (SCD) and other related topics in the field of supply chain management (SCM). In doing this, it focuses on those issues that are relevant to the current study, rather than attempting to cover multidisciplinary literature.

The survival of a modern business depends on the effectiveness of its supply chain (Farahani et al., 2014). In designing this chain, the aim should be to achieve a level of efficiency that maximizes overall value and gives the company an advantage over its competitors. Since the success of a supply chain is highly dependent on the alignment between strategy and design (Melnyk, 2014), it is essential to adopt an integrated methodology that takes into account strategy, resources and performance.

2.2 Supply Chain Management

The term “supply chain management” was first coined in 1982 when Keith Oliver, a consultant at Booz Allen Hamilton, used it in an interview with the *Financial Times*. Since then, its development as a discipline has occurred primarily in the industrial sector. Melnyk (2014) argueed that:

> “Supply chain management is a concept that has been born of practice, grown through need, and changed in response to various challenges, threats and opportunities. Consequently, until recently, it has largely not been theoretically grounded. Rather, attention has been devoted to understanding what supply chain management is (and is not), how it is related to similar approaches such as logistics, operations management and purchasing/sourcing management and how it affects performance”.

Figure 2.1 presents an overview of the scope of supply chain management.

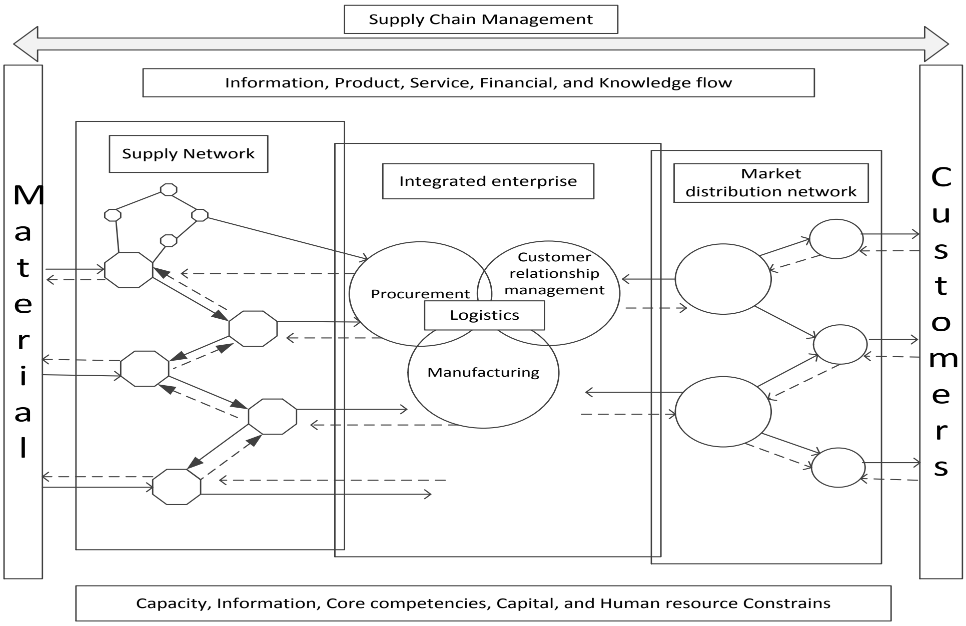


Figure 2. 1: Scope of supply chain management

Source: Bowersox, Closs, Cooper and Bowersox (2013)

Lu (2011) argued that as the business environment has changed, competition has become less a matter of organization versus organization than supply chain versus supply chain. As a result, a business's survival is no longer solely dependent on its ability to compete but rather on its ability to cooperate with others in the supply chain.

Wu, Melnyk and Flynn (2010) noted that supply chains have changed from being strategically decoupled and price-driven to strategically coupled and value-driven. They argue that:

> "This transition is not simply a 'happy accident'. Rather, it is the result of deliberate management action and strategic corporate investments aimed to procure, develop and configure the appropriate supply chain resources that will allow the firm to compete successfully in the marketplace".

The concept of supply chain design lies at the very heart of these investment decisions.

2.3 Supply Chain Design

Fine (1998) was the first to recognize that supply chain design (SCD) now goes beyond issues of make/buy, buyer-supplier relationships or vertical integration to encompass investment decision making. How a firm decides to distribute its investment across its various supply chains will affect the capabilities of each of these chains (Wu, Melnyk and Flynn, 2010) and shape the types of relationship that emerge between supply chain partners and the degree of transparency that is achieved (e.g. Closs and Mollenkopf, 2004; Janvier-James, 2012; Lambert, Cooper and Pagh, 1998; Samaranayake, 2005; Spens and Bask, 2002). Researchers have focused on SCD from both theoretical and empirical perspectives, but as Melnyk (2014) pointed out, many have focused on issues such as process, investments and structure without offering an overall framework to tie these aspects together. The following two sections discuss what the concept of supply chain design actually means and the frameworks that have been put forward for understanding this concept.

2.3.1 Concept and scope

Broadly speaking, the business of supply chain design is to utilize resources efficiently in order to achieve defined outcomes. However, the literature review highlights that there is no general consensus among authors about how the concept should be defined. Baud-Lavigne (2012) suggested that SCD may be considered at two different levels: the strategic level (e.g. the choice of production facilities, load/manufacturing capacities and technologies) and the tactical level (e.g. mid-term decision making on issues such as the choice of suppliers, the allocation of products to production facilities and the flow of each product and sub-assembly in the network) (Cordeau et al., 2006).

Leukel and Sugumaran (2013) appeared to take the strategic perspective with their argument that the supply chain has to be designed to support the strategic objectives of the firm, which they suggest involves making long-term decisions about products; process technologies; the number, location and capacity of SC nodes; production rates; and suppliers, markets and partners. Mallidis, Dekker and Vlachos (2012) also saw SCD as encompassing decisions about the number, location, capacity and operation of distribution centres/production facilities, and the selection of intermediaries and partners (suppliers, freight forwarders etc.). Melnyk (2014), meanwhile, defined supply chain design as identifying the desired strategic outcomes for the firm and developing, implementing and managing the resources, processes and relationships (within the firm and across the supply chain) that will make the attainment of these outcomes inevitable over time.

At the tactical level, Metta and Badurdeen (2013) argued that supply chain design involves identifying product design criteria (e.g. materials, functionality, components and interfaces) and evaluating their impact on SC configuration (e.g. the number and location of SC partners, their capabilities and capacities) to achieve optimum SC performance.Prasad, Venkatasubbaiah and Rao (2014) explained that the design should aim to maximize overall value in the SC by optimizing transportation, inventory, operating facilities and information flow.

Complicating the issue further, the perceived scope of the SC design process seems to have changed over the years. Speier et al. (2011) argued that SCD decision makers have historically focused on how to minimize the total landed cost, for example by considering carefully where to locate facilities such as plants and warehouses and by controlling materials acquisition, production, inventory and logistics costs. However, Closs and McGarrell (2004) claimed that over time, SCD objectives have gone beyond cost, with chains now being expected not only to operate within designated cost parameters but also to meet the unique service requirements of different customer segments. Indeed, these objectives have recently extended even further to include consideration of the dimensions of security, risk and sustainability.

Govindan, Fattahi and Keyvanshokooh (2017) defined three types of uncertain environment in which SCD decision makers must operate. In the first, the decision-making environment has random parameters whose probability distributions are known to the decision maker. These are called stochastic parameters and are described by either continuous or discrete scenarios. In the second, there are again random parameters, but the decision maker has no information about their probability distributions. Under this setting, robust optimization models are usually developed with the purpose of optimizing the worst-case performance of the SC network. The third type of environment is the fuzzy decision-making environment. This is characterized by ambiguity (there is no clear choice between multiple alternatives) and vagueness (boundaries between some domains of interest are not clearly delineated). In this context, fuzzy mathematical programming handles the planner’s expectations about the level of objective function, the uncertainty range of coefficients, and the satisfaction level of constraints.

2.3.2 Frameworks and models

Frameworks and models help researchers to see clearly the essential elements of their interested research and guiding the entire process of the research study in order to achieve its aim.

The framework developed by Toit and Vlok (2014) (see Figure 2.2) offered a simple graphical representation which divides SCD into different components, defines the components and shows the relationships between them. In this way, the framework helps users to make sense of a complex concept in a practical manner. The framework starts with organisational strategy, highlighting the importance of the alignment between this and SC strategy. The next object in the framework is SCM, through whose plans the SC strategy is implemented. SCM has three main components: SC participants, SC life-cycle activities and SC support functions. SC participants link to both SCM plans and life-cycle activities. Performance measurement acts as a feedback loop into continuous improvement, which impacts on both SC strategy and management. The different components within SCM are all affected by enablers that act across functions, activities and participants.

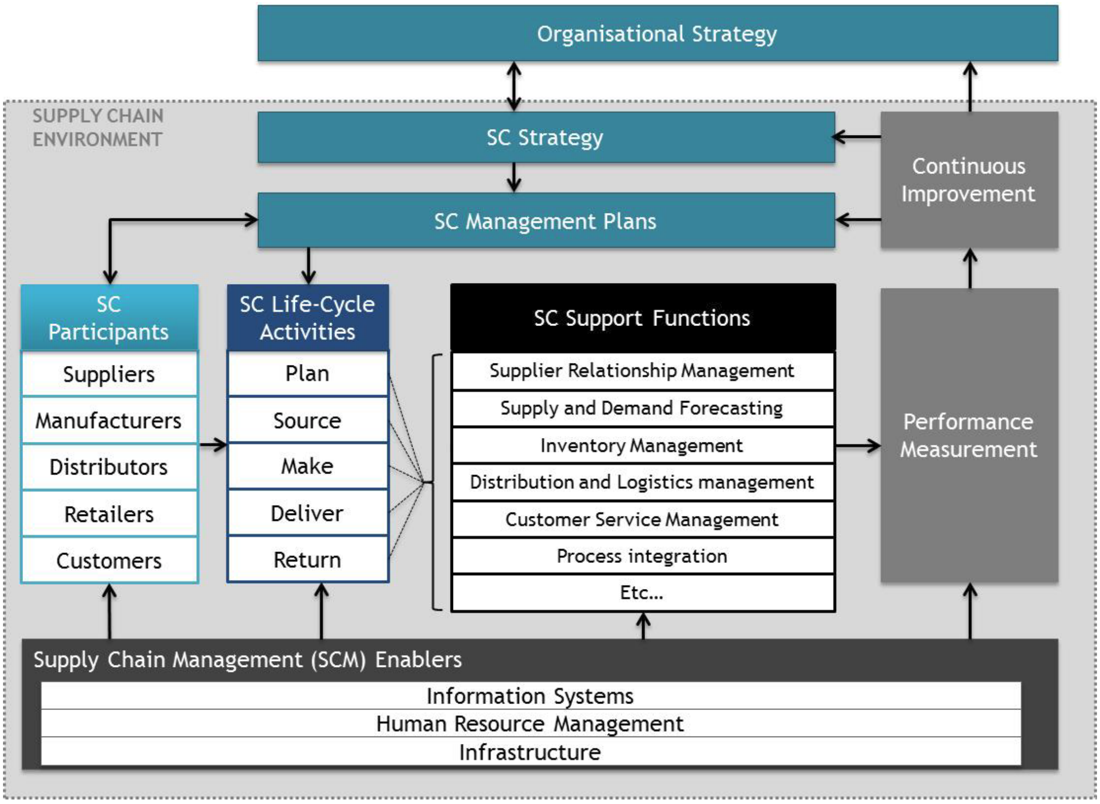


Figure 2. 2: Supply chain management framework

Source: Toit and Vlok (2014)

Naslund and Williamson (2010) presented the Supply Chain Operations Reference (SCOR) model, developed by the Supply Chain Council (SCC) and AMR Research in 1996. According to the SCC, the supply chain operations reference (SCOR) model may be used to identify, measure, reorganize and improve supply chain processes. They claimed that it:

> "…provides a unique framework that links business processes, metrics, best practices and technology features into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities" (Supply Chain Council, 2009).

The validity of the SCOR model has been confirmed by Zhou et al. (2011), whose empirical findings generally support the relationships it posits between supply chain processes (plan, source, make and deliver).

A number of authors have discussed the SCOR model; Huan, Sheoran and Wang (2004), for example, noted its integration of BPR, benchmarking and process measurement within a cross-functional framework and employed the analytic hierarchy process (AHP) to demonstrate its strength as decision-making tool. However, they also note that the model fails to consider change management or to supply quantifiable measurements of SC performance.

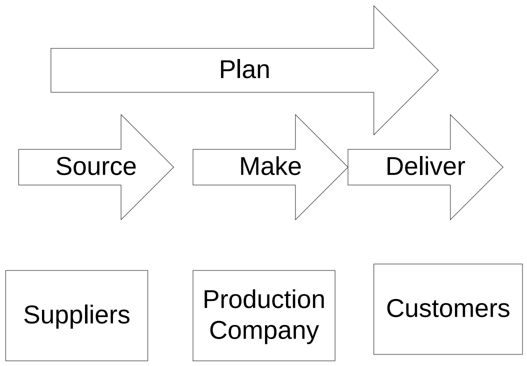


Figure 2. 3: SCOR map of the supply chain

Source: Kocaoˇglu, Gülsün and Tanya (2011)

Fronia, Wriggers and Nyhuis (2008), while acknowledged that the SCOR model initially provides as universal as possible a description of the supply chain, show how it might be extended to offer a more detailed framework for supply chain design. The models they offer give a clearer explanation of each SCOR process. When Long (2014) developed a hierarchical framework for modelling supply chain networks based on an improved version of the SCOR model, he found that these networks generally consist of several entities, each of which may be composed of several departments or workshops. This led him to argue that any supply chain network can be divided into four levels: the supply chain network level, the enterprise level, the workshop level and production. He suggests that any element at any level can be modelled using the five core processes from the SCOR model.

Other attempts at a framework include that by Ivanov (2009), who employed software to develop and validate a complex mathematical model with the aim of increasing the efficiency, consistency, implacability and sustainability of SCD decision making and showing the links between the design, planning and implementation functions. Ivanov pointed to the need for further work to investigate the relationship between business processes and information systems, and suggested that researchers should consider the flow of financial data between departments alongside the flow of materials and information.

A number of authors have proposed five-step models. For Hilletofth (2012), these steps are: develop a segmentation model, collect market information, then specify, select and implement supply chain solutions. For Corominas et al. (2015), they are: define SC objectives and conduct environmental analysis; define SC macrostructure (activity blocks and the relationships between these blocks); define SC mesostructure (product structure and production process); define SC microstructure (demand, production activities and transportation); choose SC configuration and implement. Finally, Marchesini and Alcântara (2016) proposed: identify logistics activities; characterize these activities according to need and their impact on customer value and logistics service; assign logistics activities to companies; identify any gaps in internal coordination and integration; measure the performance of logistics activities.

The framework proposed by Affonso, Liu and Zolghadri (2013) integrated product and supply chain design. It consists of identifying and evaluating product functions, defining relevant SC structures, identifying and evaluating potential suppliers, selecting suppliers, and finally defining the supply chain configuration.

Melnyk, Narasimhan and DeCampos (2014) claimed that supply chain design is shaped by three dimensions that have a hierarchical relationship: these are influencers, design decisions and building blocks. Influencers are those factors that impact on overall SC performance such as the desired SC outcomes and the global environment. Design decisions are the specific decisions that must be made regarding the supply chain as a whole (e.g. network design, sourcing strategies), while building blocks are the investments that are required to implement these decisions and build the supply chain.

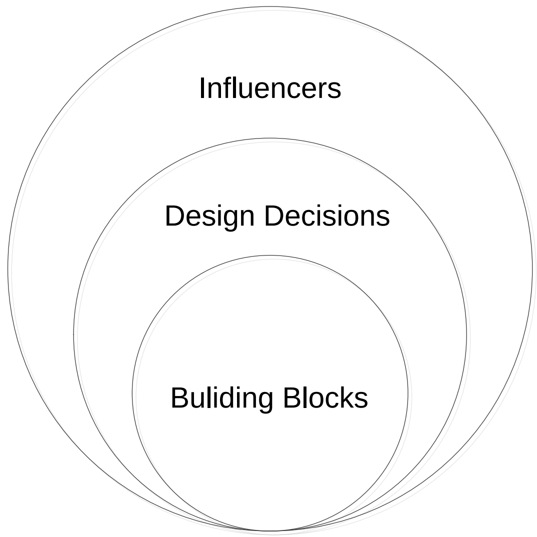


Figure 2. 4: Dimensions influencing supply chain design

Source: Melnyk, Narasimhan and DeCampos (2014)

Finally, Sabet, Yazdani and Leeuw (2017) developed a conceptual model specifically for SCM in fast-evolving industries (FEIs). Their model illustrates that the more important the supplied products/services are to a firm's core business, the more closely it must integrate with its suppliers to secure its value-creation processes and protect this core business. At the same time, if supply is associated with a high level of risk and uncertainty, the firm must aim for alignment, adaptability and agility within its SC.

It should be noted that whatever framework or model is applied, all SCD activities must be guided by the supply chain strategy to ensure that all decisions in the design stage contribute positively towards achieving the company's strategic objectives.

2.4 Supply Chain Strategy

Successful companies understand the value of focusing their energies on those dimensions where they can compete most effectively. In a survey of 234 companies from 16 countries, Roland Berger Strategy Consultants (2009) found that companies with supply chain fit achieve a Return on Assets (ROA) of 4-6% higher on average than companies without supply chain fit. Companies without supply chain fit tend to have the wrong priorities when designing their supply chain; companies with standardized products do not focus enough on cost, inventory management or utilization rates. On the other hand, companies with customized products often do not focus enough on flexibility, delivery reliability and service level improvement.

2.4.1 Strategic fit

Randall, Morgan and Morton (2003) examined the association between product demand characteristics and the initial investment in a supply chain at the time of market entry. Characterizing supply chains as responsive or efficient, they conclude that responsive market entry is associated with lower industry growth rates, higher contribution margins and higher technological demand uncertainty.

Chaharsooghi and Heydari (2011) discussed the concept of strategic fit in supply chain management, concluding that in highly turbulent environments it is essential for the SC to focus on responsiveness to avoid losing customers. Soni and Kodali (2011) explored the strategic fit between competitive strategy (CS) and supply chain strategy (SCS) in the Indian manufacturing industry by investigating the mediating role of SCS between CS and company/supply chain performance. Their findings reveal a causal relationship between CS and SCS and that the choice of both affects both business and supply chain performance. Wagne, Gross-Ruyke and Erhun (2012) also investigated the relationship between supply chain fit and the financial performance of the firm. Their findings indicate that the higher the supply chain fit, the higher the ROA of the firm, and that firms with a negative misfit perform worse than firms with a positive misfit.

2.4.2 Strategic supply chain management

Hwang (2010) discussed how to develop a supply chain's overall competitive strategic direction so as to optimize SC performance. His general SSCM framework comprises three stages, namely strategy formulation, strategy implementation and strategy evaluation. Alfalla-Luqu, Medina-Lope and Dey (2013) identified information integration, coordination and resource sharing, and organisational relationship linkage as the three major dimensions of supply chain integration (SCI) and analysed how these affect overall supply chain performance in terms of efficiency and responsiveness. The authors offer an integratived model that blends together elements of supply chain configuration, stakeholder management and capability development. Their analysis revealed that the nature of stakeholder exposure determines how social/environmental, technical and relational capabilities impact on social and environmental outcomes. Their framework builds on Fisher's (1997) prototypical efficient and market responsive configurations, expanding them to include social and environmental issues. Taking Apple/Foxconn as an example, they suggested that capabilities based upon responsiveness, such as product improvement and collaboration, may need to be supplemented with efficiency-oriented capabilities, such as process improvement and monitoring, to satisfy the demand for economic, social and environmental outcomes.

Wieland (2013) proposed a model that enables companies to select a supply chain strategy based on risk probability and risk impact. He identified four supply chain strategies – agility, robustness, resilience and rigidity – advising resilience where supply chain risk probability and impact are high, and rigidity where both values are low. When only risk impact is low, robustness is optimal, whereas agility is optimal when only risk probability is low.

Um et al. (2017), investigated the impact of product variety strategy on supply chain performance, developed a conceptual model that links product variety management strategies with supply chain responsiveness, cost and customer service in high- and low-customization environments. They found that product variety strategy influences supply chain cost and customer service performance only when mediated by internal and external responsiveness capabilities, and that its impact on performance depends on the level of product customization. In a low-customization environment, both supply chain flexibility and agility have a significant influence on cost efficiency, while in a high-customization environment, these dynamic capabilities have a significant influence on customer service.

Given the importance of environmental aspects in supply strategy, green supply chain strategy is discussed in a separate section.

2.4.3 Green supply chain strategy

Corporations are coming under increasing pressure to design their supply chains for sustainability. This means designing processes to use environmentally friendly inputs and to create outputs that can be recycled and that do not contaminate the environment. One approach has been proposed by Cabral, Griloand and Cruz-Machado (2011), who offered an integrated Lean, Agile, Resilient and Green (LARG) analytic network process (ANP) model to help companies choose the most appropriate practices and KPIs for their SCs. They presented a case study (based on a car manufacturer's supply chain) to showcase the model's ability to prioritise enablers, KPIs, practices and paradigms in complex situations.

Yu et al. (2014) extended previous green supply chain management (GSCM) research by developing and empirically testing a conceptual framework that investigated the relationships between iGSCM (internal GSCM, GSCM with customers and GSCM with suppliers) and multiple dimensions of operational performance in terms of flexibility, delivery, quality and cost. Varsei et al. (2014), meanwhile, offered a framework that adopts a multidimensional approach, considering economic, environmental and social dimensions.

Youn, Yang and Roh (2012) explored how Fisher's perspective of efficient versus responsive supply chains can be a stepping stone to the development of eco-efficient and eco-responsive supply chains. In an eco-efficient supply chain, the focus is on maintaining high environmental standards across the chain, while the emphasis in an eco-responsive supply chain is on collaboration among suppliers and distributors.

Gracia and Quezada (2016) proposed combining three analytical tools (analytic hierarchical process, fuzzy multi-objective optimization and clustering methods) for the strategy formulation process and integrating corporate and supply chain strategy on the basis of sustainability. The results from their case study indicated that the methodology is a valid tool for generating a coordinated strategy for the management of a sustainable supply chain.

The literature emphasizes the link between achieving a green supply chain and improving economic performance; the European Freight and Logistics (EF&L) and United Nations Commission for Latin America and the Caribbean (UNCLAC) (2014), for example, co-authored a study designed to demonstrate the direct link between sustainability and efficiency/cost reduction. However, there is as yet no integrated strategic framework available for achieving supply chain management that is both green and competitive. It is therefore the aim of this research to design and develop an integrated framework that encompasses not just the efficiency and responsiveness dimensions, but also that of sustainability.

The question of whether a company's supply chain strategy is indeed as efficient, responsive and sustainable as its designers intend can only be answered if it is continuously evaluated and improved. Simulation is an invaluable tool for observing and assessing the effectiveness of a company's strategic decision making.

2.5 Supply Chain Simulation

Researchers and practitioners in SCM employ a range of techniques to assess the impact and effectiveness of SCD decisions, including surveys, simulations, mathematical models, case studies and conceptual models. Simulation is considered a particularly valuable tool because it can be used to assess the potential cost of system changes and to model scenarios that would be difficult to apply in reality. Changes can be executed and systems can be observed, and the developments of years can be presented within hours. For these reasons, simulation is widely employed in SCM. In this study, simulation is used at the strategic level for the purpose of supply chain improvement, while followed sections investigate various simulation applications.

2.5.1 Design applications

As noted above, simulation is frequently used as a decision-making tool in supply chain design. Ilaria (2010) claimed that SCM integration is best pursued by adopting either an operative or an organizational approach. However, the way the SC is organized influences its performance. He employs an NK simulation model (in which N represents the decisions that SC firms should make and K the interdependencies among SC integration decisions), to identify the best forms of governance for tackling SC integration problems. Tako and Robinson (2012) concluded that both discrete event simulation (DES) and system dynamics (SD) have been used to model logistics and supply chain management (LSCM) issues. Hilletofth and La¨ttila (2012) investigated the use of agent-based decision support (ABDS) systems in the supply chain context, finding that they enable increased versatility in the system architecture, improve supply chain visibility and allow users to conduct experiments and what-if analyses.

Another application of simulations is evaluating supply chain networks. Li et al. (2010), argued that supply chains should be treated as complex adaptive supply networks (CASNs), modelled their evolution using complex adaptive system and fitness landscape theory. They then conducted a case study of the evolution of a supply network in the emerging Chinese market. Their results led them to suggest that external environmental factors and firm-internal mechanisms appear to be the dominant forces shaping the evolution of CASNs, with cost and quality considerations being the primary factors influencing their structure, complexity, centralization and formalization. Pirard, Iassinov-ski and Riane (2011) studied the problem of strategic network design in multi-site enterprises by modelling various supply network designs. Their simulation allows the computation of performance measures such as profitability and customer service, but the authors claim that the model could be improved by incorporating operational decision making, valuation of tardiness used in the allocation rules, transportation system capacity and the possibility of grouping orders. Finally, Porras and Zelaya (2012) offered a standardized simulation model for analysing distribution networks which is both designed to assist strategic decision making and can also take into account operational issues such as inventory and transportation effects.

Among those employing simulations to assess supply chain configurations, Persson and Araldi (2009) developed an Arena-based SCOR template, while Mittermayer and Rodrıguez-Monroy (2013) presented a simulation-based evaluation method for the comparison of different organizational forms and software support levels. They found that coordination schemes based only on ERP systems are a valid alternative in industrial practice, and that these schemes represent a significant saving in terms of IT investment. Indeed, the authors conclude that spending more on coordination does not always result in improved logistics performance. The results confirm the importance of considering all dimensions when evaluating SCM concepts and IT tools.

2.5.2 Supply chain enhancement applications

Eulalia et al. (2010) investigated the robustness of different tactical planning and control policies for a softwood supply chain using an agent-based environment. Their simulations were modelled using a novel agent-based methodology combined with a robust experimental design approach. Their results indicated that supply chain control levels play a role in defining robust service levels, while the planning horizon and the planning method have lower impact in this context. Ferreira and Borenstein (2011) presented an agent-based simulation framework for supply chain planning. The study sought to investigate the role regulation plays in SCs by modelling the actors involved in the regulation of SCs using normative agents to allow evaluating the potential benefits of alternative strategies for planning of regulated SCs. The authors suggest that the developed model can be expanded to consider logistics by adding new agents and control agents, and by adding and removing norms. Rashid and Weston (2012) presented an integrated methodology for modelling complex supply chains which deploys enterprise modelling (EM), causal loop diagramming (CLD) and simulation modelling (SM) techniques.

Reddi and Moon (2012) studied the interactions between the various new product development (NPD) and engineering change management (ECM) process parameters by modelling the processes and simulated the model to understand the parameter interactions. The results indicate that most of the variables and interactions among the variables have a significant influence on the NPD is lead time. Shahza and HadjHamou (2013) proposed the notions of generic-bill-of-products (GBOP) to implement the concept of sustainable mass customization. Simulation results provided an optimum GBOP, its respective segments and decisions on the opening or closing of the market segments to sustain mass customization efforts.

Simulation is a powerful tool for mitigating uncertainty; Colicchia, Dallari and Melacini (2010) identified a set of approaches (mitigation actions and contingency plans) for managing risk in order to enhance supply chain resilience. They then apply a simulation-based framework to assess the effectiveness of the proposed approaches. Shahi and Pulkki (2013) reviewed the literature related to supply chain models in the forest products industry, concluding that studies that focus on optimization are mostly deterministic in nature and do not account for uncertainty in either the supply of raw materials or the demand for forest products. They pointed to a need for the development of simulation-based optimization models that will meet industrial expectations and provide much better solutions than current industrial practice.

Simulations have also been used to improve performance. Chaharsooghi and Heydar (2009) investigated the effects of LT mean and LT variance on supply chain performance indices using simulations and multivariate models and found that LT variance has the stronger impact. This result may help practitioners develop investment strategies to reduce LT mean and variance. Finally, Vidalakis, Tookey and Sommerville (2011) used the simulation technique to investigate the applicability of logistics management in the construction sector. They utilized pre-existing data to build a model, which they then analysed using discrete-event simulation modelling. Their analysis shows that logistics costs are exponentially related to the level of material demand and the number of vehicle movements.

2.5.3 Supply chain operation applications

Simulation is considered an important tool in inventory management. Petrovic (2001) developed a simulation tool for analysing SC behaviour and performance in the presence of uncertainty. Fuzzy analytical models were employed to determine optimal order-up-to levels in a fuzzy environment, followed by a simulation model to evaluate SC performance over time at the order-up-to levels recommended by the fuzzy models. Lyu, Ding and Chen (2009) proposed three collaborative replenishment mechanism models for use in the collaborative supplier and store-level retailer environment. The models, which were developed based on a case grocery company, explore the impacts of different scenarios. The authors suggested further research is needed to discuss the multi-supplier and multi-store-level-retailer collaborative replenishment mechanism in which each supplier adopts an individual inventory control policy for different products.

Gumus, Guneri and Ulengin (2010) proposed a methodology for multi-echelon inventory management and presented a neural network simulation of a model which they claimed represents an improvement on similar models (demand and lead time are not constant and it allows orders that arrive out of phase to be expedited). Heath and Ciarallo (2010) presented an initial agent-based modelling (ABM) simulation of individual order pickers and their interactions to better understand the drivers affecting warehouse cost and operating efficiency. Their simulation demonstrated the ability of the ABM paradigm to be utilized in the development, testing and evaluation of new warehouse operating and design strategies at a level of detail and aggregation. Mula et al. (2013) proposed a simulation approach based on system dynamics for operational procurement and transport planning. Tseng, Gung and Huang (2013) focused on the application of the make-to-plan (MTP) supply chain strategy and agent technology (AT) based technique. The researchers defined the impacts of operator parameters (e.g. throughput improvement, forecast accuracy improvement, demand variability management and safety stock level adjustment) on total cost, penalty cost, fill rate and on-time delivery.

2.5.4 System Dynamics (SD) Simulation

SD is a continuous simulation approach which allows the quantities of interest or variables to change over time. This approach is concerned with overall (aggregate and trend) system behaviour under the influence of given policies (Abd El-Aal et al., 2008). Sabry and Beamon (2000) developed an integrated multi-objective SC model for use in simultaneous strategic and operational SC planning. They added decision analysis to the model to allow the use of a performance measurement system that covers cost, customer service levels (fill rates) and flexibility (volume or delivery). The model incorporates production, delivery and demand uncertainty, and provides a multi-objective performance vector for the entire SC network. Wilson (2004) applied SD simulation in order to investigate how transportation disruption between 2 echelons in a 5-echelon SC affects performance in both traditional SCs and vendor-managed inventory (VMI) systems.

The previous sections show that while simulation has been put to a variety of applications, it has only rarely been deployed in strategic supply chain management. It is therefore the aim of this study to use the technique at the strategic level for the purpose of supply chain design. To do this, the study employs the Supply Chain Guru software.

The fundamental objective of supply chain strategy is to ensure smooth flow at minimum cost. Since the measurement of SC performance is central to achieving this objective, this is the focus of the next section.

2.6 Supply Chain Performance

The identification of appropriate performance metrics is crucial for monitoring and improving supply chain performance. These metrics play an important role in setting objectives and determining future trends. Attempts have been made to survey the main performance metrics currently used in SCM (see Elrod, Murray and Bande, 2013; Gopal and Thakkar, 2012), and a number of authors have called for new measures to be introduced in response to the evolving business environment. Akyuz and Erkan (2010), for example, suggested that new performance measurement systems are needed to take account of qualities such as agility, flexibility, information productivity, business excellence and collaborative/partnership capacity. Kim, Kumar and Kumar (2010) developed a framework for assessing the comprehensive performance of supply chain partnerships (SCP). Their framework is based on the self-assessment dimensions and approaches of the business excellence model developed by the European Foundation for Quality Management (EFQM).

Drawing on his review of the literature, Leończuk (2016) compiled a list of the various indicators that have been proposed for measuring SC performance (see Table 2.1).

As outlined in Chapter 1, this research aims to focus equally on the dimensions of efficiency, responsiveness and sustainability. The following sections therefore discuss these three dimensions and their metrics in more detail.

2.6.1 Supply chain efficiency

The measurement of SC efficiency is vital, not just to give an insight into how the chain is performing but also to identify any problems in a timely fashion. Lichocik and Sadowsk (2013) attempted to explain the problem of supply chain management efficiency in the context of general theoretical considerations relating to supply chain management. The authors highlight the determinants and practical implications of supply chain management efficiency, concluding that efficiency means being cost-effective and streamlining processes while ensuring that service remains high quality. Mishra (2012) employed data envelopment analysis to measure SC efficiency in Indian pharmaceutical companies, using the constant returns to scale (CRS) assumption and variable returns to scale (VRS) assumption to calculate a technical efficiency score.

Danese and Romano (2011) analysed the impact of customer integration on efficiency and the moderating role of supplier integration by employing hierarchical regression analysis to test two hypotheses. The integration includes upstream and downstream operations in both suppliers and customer's sites. Their analysis revealed that supplier integration positively moderates the relationship between customer integration and efficiency, but did not support the hypothesis that in general, customer integration has a positive impact on efficiency. Where supplier integration is low, customer integration can even reduce efficiency.

Table2. 1: Categories and sub-categories of performance indicators

Perspective of Performance Indicators	Subdivision 1	Subdivision 2	Subdivision 3
Qualitative / quantitative	Qualitative	Customer satisfaction, flexibility, information and material flow integration, effective risk management, supplier performance	
	Quantitative	Associated with the cost	Cost, sales, profit, inventory, investment maximization
		Associated with the customer	Product lateness, fill rate, customer response time, lead time
		Related to productivity	Capacity utilization, resource utilization
Based on SCOR model	Related to process	Planning, sourcing, manufacturing, delivery and returns	
	Related to performance attributes	Reliability, responsiveness flexibility, cost and asset management efficiency	
Performance measure type	Resources	Goal: high level of efficiency	
		Purpose: impact on profitability	
	Output	Goal: high level of customer service	
		Purpose: avoiding the transition of customers to other supply chains	
	Flexibility	Ability to respond to a changing environment	
		Purpose: quick response to changes	

Cont. Table2. 2: Categories and sub-categories of performance indicators

Perspective of Performance Indicators	Subdivision 1	Subdivision 2	Subdivision 3
Level of the decision-making process	Strategic		
	Tactical		
	Operational		
Implementation Extent	Economic	Sales	
		Waste costs	
		Resource efficiency	
	Environmental	Compliance with environmental standards	
		Consumption of hazardous/toxic materials	
		Energy consumption	
	Social	Product image	
		Customer loyalty	
		Relationship with surroundings	
	Operational	Operating cost	
		Response time	
		Inventory turnover rate	
		Order fulfilment	

Source: Leończuk (2016)

2.6.2 Supply chain responsiveness

Modern supply chains must be able to respond rapidly, effectively and efficiently to changes in the marketplace if they are to endure and create competitive advantage (Adebambo and Adebayo, 2013). The relationship between responsiveness and competitive advantage is illustrated by Sukati et al. (2012), who found that supply chain integration positively impacts on the responsiveness and competitive advantage of the chain as a whole, and that supply chain responsiveness is positively associated with competitive advantage at firm level. Ghosh, Das and Deshpande (2014) offered an integrative framework that incorporates chain responsiveness, process integration, supply chain coordination and performance, but acknowledge that more research is needed to understand and explore the quantitative relationships between these constructs. Danes, Romano and Formentini (2012) argued that in supply networks, both external and internal integration practices have a significant and positive impact on responsiveness. However, since external integration has a bigger impact on company responsiveness than internal integration, they advised managers to adjust the level of adoption of integration practices according to the degree of supplier network internationalization.

Yi, Ngai and Moon (2011) asserted that supply chain responsiveness is best raised by reducing uncertainties and improving supply chain flexibility. The authors identify four types of flexibility strategy (laggard, conservative, agile and aggressive) that are adopted by SC participants in response to environmental uncertainties, and proposed a theoretical framework to assist managers in properly diagnosing and deploying these strategies. Singh and Sharma (2013), meanwhile, employed the analytical network process approach to decide where companies' priorities should lie in terms of flexibility. They concluded that organizations should give top priority to manufacturing, followed by customers and suppliers.

In their research model, Roh, Hong and Min (2013) set out the drivers, strategy, practices and performance outcomes associated with SC responsiveness. They suggested that the level of SC responsiveness is mainly influenced by firm size, industry characteristics and the customer and supplier bases rather than the location of manufacturing firms. The study showed that implementing a responsive supply chain strategy involves the integration of inter organization and sources (i.e. socio-relational and techno process integration) across the global supply chain to enhance pull production capabilities.

2.6.3 Supply chain sustainability

Environmental concerns such as climate change, environmental contamination and resource depletion are having an increasing impact on the activities of supply chains. The UN defines sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Cabral et al.,2011). As Baud-lavigne et al. (2012) explained, there was a growing focus on the ways in which human and economic activities have the potential to adversely impact the long-term sustainability of the planet.

Taticchi, Tonelli and Pasqualino (2013) aim to developed the body of knowledge in the area of sustainable supply chains by conducting a critical review of the literature addressing sustainable supply chain performance measurement (SSCPM). These authors analysed the evolution of the research field, revealing that it is immature but growing very quickly. Schaltegger and Burritt (2014) were among those contributing to this growth with their analytical framework for the assessment of approaches to the measurement and management of sustainability performance in supply chains (SPSCs). They outlined five SPSC designs which may be used individually or in combination, but acknowledge that some measures need systematic development (they explained that eliminating or replacing existing products and SC participants may create fundamental changes that cannot be captured with simple SPSC measures but may require a different set of indicators). Finally, Zailani et al. (2012), investigated the extent and impact on performance of environmental purchasing and sustainable packaging, found that the former has a positive effect on economic, social and operational outcomes, while the latter has a positive effect on environmental, economic and social outcomes.

2.6.4 Performance measures of efficiency, responsiveness and sustainability

As is evident from the previous sections, the researcher can choose from a wide range of performance metrics. Table 2.3 lists those metrics that are most relevant to the dimensions addressed in the current research, proposed framework; SC performance is assessed using the efficiency, responsiveness and sustainability indicators, they are defined as following:

- Efficiency is measured using the profit to revenue ratio indicator (calculated by dividing cross profit by revenue).
- Responsiveness is measured using the average fill quantity rate (calculated as the ratio of demanded items filled from available inventory to the total number of items demanded over a particular period).
- Sustainability, although sustainability is a broad concept that encompasses economic, social and environmental concerns, the proposed framework focuses only on the environmental aspect, measuring it in terms of CO2 emissions.

Table 2. 3 Attributes and measures of efficiency, responsiveness and sustainability

Source	Performance Attribute	Measures
SCOR (version 11)	Reliability	Perfect order fulfilment
	Responsiveness	Order fulfilment cycle time
	Agility	Upside supply chain flexibility
		Upside supply chain adaptability
		Downside supply chain adaptability
		Overall value at risk (VAR)
	Cost	Total cost to serve
	Asset Management Efficiency	Cash-to-cash cycle time
		Return on supply chain fixed assets
		Return on working capital
Behrouzi, Wong and Behrouzi (2011) & Ambe (2014)	Delivery and reliability	Perfect order fulfilment from suppliers
		On-time production
		On-time delivery to customers
		Perfect order fulfilment to customers
		Customer delivery lead time
		Fill rates
	Flexibility	Volume flexibility
		Product-mix flexibility
		Delivery flexibility
Rao (2014)	Sustainability	Proportion of reusable/recyclable materials to total material input
		Raw material efficiency
		Proportion of cost of energy in production to total value of output
		Volume of air emissions per year (NOx, SOx, CO2, VOC, etc.)
		Use of vehicles that run on renewable energy, electricity and natural gas

2.7 Conclusions

The chapter demonstrates that while numerous researchers have discussed SCD, there is still much to do in this area, this is summarized as following:

1. Although researchers have addressed various aspects of SCD, including strategic and operational SCD, SCN design, and designing for performance improvement, there is still no consensus on how the concept of SCD should even be defined.
2. A number of frameworks have considered some of these functions, no single framework has yet been presented that ties all of these functions together (Melnyk, 2014).

   This research aims to address this gap by developing an integrated SCD framework that considers strategy, process, network and performance concurrently.
3. Although the aim of SC strategy is generally to improve efficiency and customer service across the chain while keeping negative environmental impacts to a minimum, no framework has yet been developed that captures all of these performance dimensions. Accordingly, the proposed framework seeks to improve SC performance in terms of efficiency, responsiveness and sustainability.
4. The review indicates that despite simulation's importance as a tool for evaluating and improving SC outcomes, it has rarely been exploited in the field of strategic SC management. This research uses a simulation tool to build and simulate different supply chain scenarios.

Chapter 3 sets out the methodology that was employed to develop the framework, while Chapter 5 presents the results of the simulation that was run to validate it.

Chapter 3: Research Methodology

3.1 Introduction

The research methodology comprises the sequence of steps that are taken by the researcher to answer the research problem (Kothari, 2004). In this case, the research was conducted in two main stages. The first of these was the development of an integrated framework for supply chain design. The framework includes proposed models for supply chain strategy, processes, resources and performance. The strategic model studies consistency between customer needs and supply chain capabilities; the process model is based on the SCOR model; the resource model investigates the elements that make up the supply chain network; and the performance model offers sets of measurements for efficiency, responsiveness and sustainability. The second stage using hypothetical supply chain network to validate the proposed framework. The modelling employed statistical tools, probability distributions (to model the uncertain variables) and sensitivity analysis (to vary variables for the purpose of building different scenarios).

3.2 Development of Supply Chain Management Frameworks

In the following, key frameworks in Supply Chain management are discussed.

Although the term is frequently used in the SCM literature, there seems to be a lack of consensus about what a framework actually is. As Chapter 4 presents a proposed framework, it is essential to discuss the general concept and how they are developed.

A framework is a set of basic assumptions or fundamental principles of intellectual origin in which discussions and actions can proceed (Popper, 1994). Very often, the terms model and framework are used interchangeably, but for the purpose of this research, the two are regarded as distinct concepts. The framework is made up of four models; these answer “what is” questions, while the overall framework answers “how to” questions. Soni and Kodali (2013) suggest that a framework should: depict the complete structure of relationships between elements of the system under study (not just identify the elements that make up the system); describe the steps/stages/sequence of activities that need to be undertaken to achieve the designated purpose; and describe the activities connecting the various elements within the framework.

3.2.1 Characteristics of SCM framework in general

Soni and Kodali (2013) reviewed a number of SCM framework articles and propose a framework that possibly suggests a way to achieve coherency in use of SCM frameworks. They noticed a massive use of sets of elements (or constructs) in SCM frameworks and tried to find out a possible set of standard constructs that make SCM by the aid of SCM professionals, the efforts were directed towards finding out the broad area, a particular construct may belong. This broad area is referred as a pillar of SCM and that leads to emergence of a comprehensive SCM framework (see Figure 3.1).

At the top of the framework is the mission and vision of the company. This informs its competitive strategy, whether this is based on cost structure or product differentiation. Once the competitive strategy and its priorities have been established, the company then formulates a supply chain strategy that will promote supply chain efficiency and effectiveness.

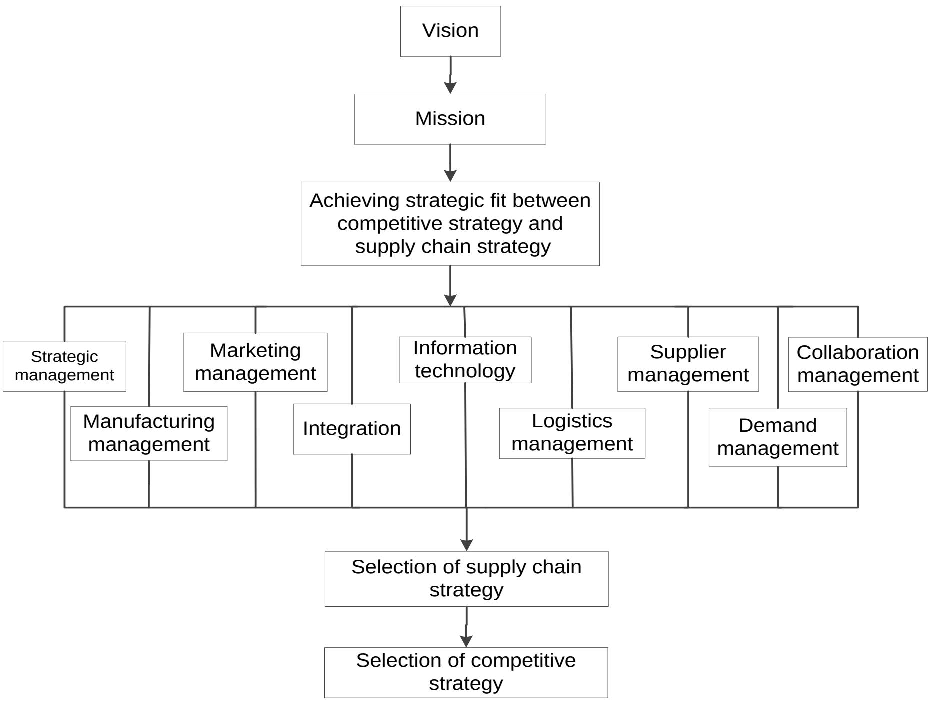


Figure 3. 1: Characteristics of SCM framework in general

Source: Soni and Kodali (2013)

Once the supply chain strategy is in place, the SCM pillars are used to build the capabilities of the chain and help the organization achieve its mission and vision. However, this will only happen if a strategic fit is achieved between its competitive strategy and supply chain strategy.

3.2.2 Method of developing a SCM Strategy

The supply chain strategy is part of the company's overall business strategy, but unlike most company strategies, it requires the coordination and commitment of many different firms (Ambe and Badenhorst-Weiss 2011), they suggested that developing a strategic SCM framework involves three steps: understanding the market and customer demand; defining the company's core competencies; and choosing the most appropriate strategy (see Figure 3.2).

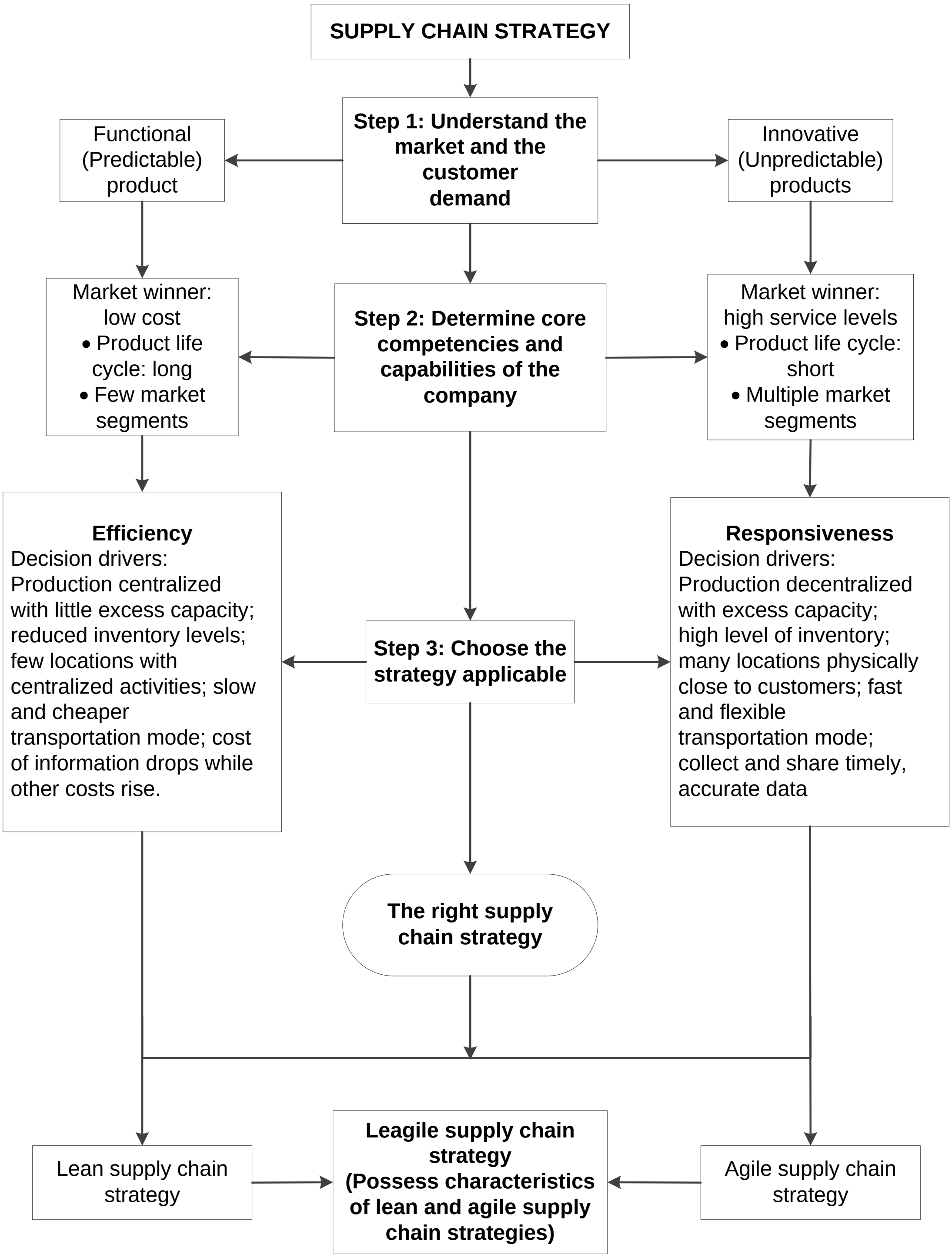


Figure 3. 2: Method of developing SCM Strategy

Source: Ambe and Badenhorst-Weiss (2011)

Step 1: Understand the market and the nature of customer demand: Six key market variables determine the attributes of a supply chain structure: volume, time, variety, service level required, price and rate of change, innovation and new product development. If it to choose the right type of supply chain strategy, an organization must understand both its customers and supply chain uncertainty. Supply chain uncertainty is strongly affected by product life cycle; new products have higher supply uncertainty because design and production processes are still evolving, whereas mature products tend to have less supply uncertainty. Different market requirements demand different kinds of supply chain. Choosing the wrong strategy for a product may lead to mismatch in the supply chain. Mismatch is the root cause of supply chain problems.

Step 2: Define core competencies and capabilities of a supply chain: Supply chains have different characteristics, but all supply chains have two important attributes: cost and service. Supply chain capabilities include the ability to respond to a wide range of demanded quantities, meet short lead times, handle a large variety of products, build highly innovative products, meet a high service level and handle supply uncertainty. Where products are predictable, the ability to produce these products at low cost becomes the dominant consideration. The capabilities of a supply chain are determined by the trade-off, its participants are prepared to make, between responsiveness and cost. The so-called efficient frontier marked the lowest possible cost that can be achieved for a given level of responsiveness.

Step 3: Choose the applicable strategy: The level of responsiveness that can be achieved in the supply chain depends upon the level of cost incurred; raising costs lowers efficiency but increases responsiveness. To achieve complete strategic fit, an organization must ensure that all its functions maintain consistent strategies that support the competitive strategy. All sub-strategies within the supply chain, such as manufacturing, inventory and purchasing, need to be consistent with the supply chain level of responsiveness to reduce uncertainties and cost while satisfying the end customer's needs .

A supply chain can be lean (efficient), agile (responsive) or a combination of the two. An organization can achieve a competitive advantage by strategically employing a leagile supply chain model that minimizes cost and maintains stability while still being flexible and responsive to customer demand. This model will allow the organization to compete on innovation, cost, service and quality.

3.3 The proposed conceptual SC framework

The literature review revealed that there is no standard methodology for designing supply chains; some researchers discuss SCD in terms of strategic objectives (e.g. how to design supply chains to be lean, agile or sustainable), others focus on SC network design (i.e. the number, location, capacity and operation of different supply chain nodes) and still others argue that SCD involves identifying product design criteria and evaluating their impact on SC configuration.

It is the position of this research to take into account all of these perspectives in the design of the proposed framework, as the various functions they describe are mutually complementary; the strategic model assists the chain in achieving efficiency and responsiveness, process model employs SCOR model that determines process configurations, the network model determines the resources that are required to deliver the defined strategy, while the performance model shows whether the SC is achieving its objectives.

The aim is to develop an integrated framework that incorporates the various kinds of strategy SCs can use to achieve their goals along with the process configurations and networks they can employ to implement these strategies. The theoretical fundamentals of the proposed framework are shown in Figure 3.3 and discussed in the following sections.

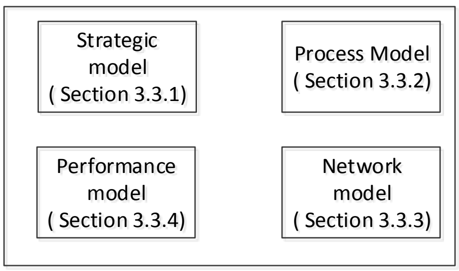


Figure 3. 3: The components of the proposed SC framework

The strategic fit concept is employed to explain the strategic role of the framework, the SCOR model to clarify supply chain configurations and performance, and the supply chain network design concept to illustrate how supply chain networks are structured.

3.3.1 Supply chain strategy: achieving strategic fit

Supply chain management requires the strategic management of the various aspects of the coordination process, including information, technology, distribution, products, raw materials, finance and, most of all, relationships. Successful companies understand that they cannot compete effectively in all dimensions but know where to focus their energies.

The survival of the supply chain depends on the consistency between customer expectations (what customers want) and SC performance (what the chain is able to deliver). This is the concept of strategic fit: the company must ensure that its supply chain capabilities enable it to meet the needs of its customers. Evidently, the company must have a clear understanding of what these needs and capabilities are (Chopra and Meindl, 2007).Strategic fit requires the competitive and supply chain strategies of the company to have aligned goals. There are three steps to achieving strategic fit (Chopra and Meindl, 2007):

3.3.1.1 Understanding customer needs

Customer demand can vary in a number of ways: for example, lot quantity may vary from small (e.g. customised or emergency orders) to large planned orders, while response time (the amount of time that customers are willing to wait for orders) may be longer for customized products. A company may have to hold a wide range of products to appeal to different customer segments, particularly if the business environment is unstable. A high level of product availability usually requires high inventory levels and more detailed and frequent information sharing, reducing competitive advantage. On the other hand, customers who expect a high level of service, more product variety and short response times tend to be less sensitive to product price. Customer demands regarding product innovation tend to vary according to product purpose, with less being expected of functional products than of consumed products.

All of these attributes can be combined in one key metric: implied demand uncertainty. Unlike demand uncertainty, which reflects the uncertainty of customer demand for a product, implied demand uncertainty describes the uncertainty only for that portion of demand that the supply chain plans to satisfy based on the attributes the costumer desires.

3.3.1.2 Understanding the supply chain's capabilities

Creating strategic fit is about finding the supply chain strategy that best meets the demand a company has targeted, given the uncertainty it faces. If it is to find the balance between responsiveness and efficiency that best supports its competitive strategy, the company must have a clear understanding of the logistics and cross functional drivers that affect SC capability. These are:

- Facilities: where the product is stored or fabricated. Decisions regarding the role, location, capacity and flexibility of facilities have significant impact on the supply chain's performance.
- Inventory: changing inventory policies can dramatically alter the supply chain's efficiency and responsiveness. High inventory levels, for example, can increase a company's responsiveness and raise service levels but may reduce its efficiency.
- Transportation: the SC may employ multiple combinations of modes and routes, each with its own performance characteristics. This has a direct impact on SC efficiency and responsiveness; faster transport modes, for example, may make the chain more responsive, but as they tend to be more expensive they are also less efficient.
- Information: managers must use the available data and analysis concerning facilities, inventory, transportation, costs, prices and customers to make the supply chain more efficient and responsive. For example, using information to better match supply and demand will improve responsiveness while keeping production and distribution costs down.
- Sourcing: the choice of who will perform a particular supply chain activity such as production, storage or transportation can impact on both responsiveness and efficiency. Opting to source some products from a far distant supplier because this is cheaper may improve a company's efficiency but it will also compromise

its responsiveness. Going back to the supplier with small or urgent orders is likely to increase transportation costs.

- Pricing: pricing affects the behaviour of the buyer of the goods or services, thus affecting supply chain performance. For example, if a haulage company varies its charges based on the lead time demanded by the customer, it is likely that customers who value efficiency will order early and customers who value responsiveness will be willing to wait and order just before they need the product to be transported.

3.3.1.3 Achieving strategic fit

The goal of strategic fit is to target high responsiveness for a supply chain facing high implied uncertainty, and efficiency for a supply chain facing low implied uncertainty. An increase in implied uncertainty from customers and supply sources is best dealt with by improving the responsiveness of the supply chain (see Figure 3.4). To achieve a high level of performance, companies should aim to move their competitive strategy and supply chain strategy towards the zone of strategic fit.

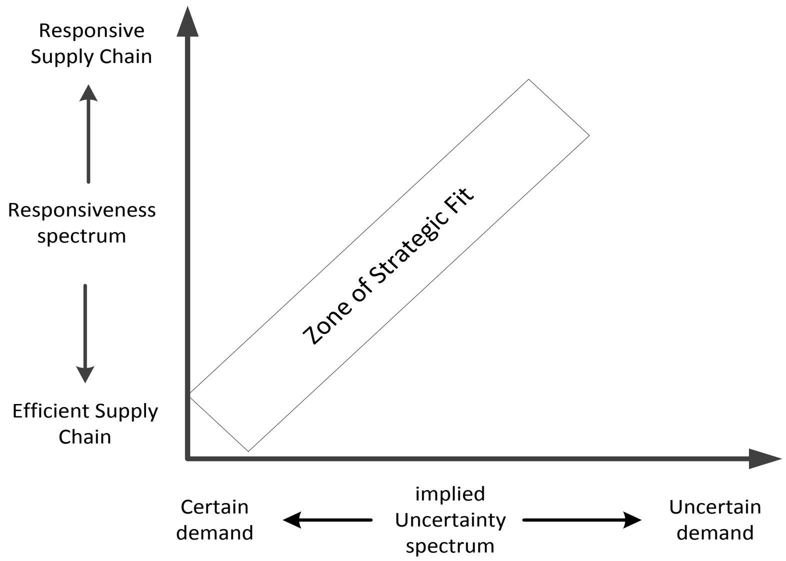


Figure 3. 4: Finding the zone of strategic fit

Source: Chopra and Meindl (2007)

Strategic fit is the optimum combination of efficiency and responsiveness; achieving it requires companies to have a clear understanding of their customers' needs (in terms of both demand characteristics and certainty) and the capabilities of the SC. Designing the right combination of logistics drivers is vital for achieving responsiveness and efficiency, first in the company and then across the supply chain as a whole. The company must ensure that all its functions are implementing consistent strategies, and that these support the company's competitive strategy. Figure 3.5 presents the process by which strategic fit is achieved.

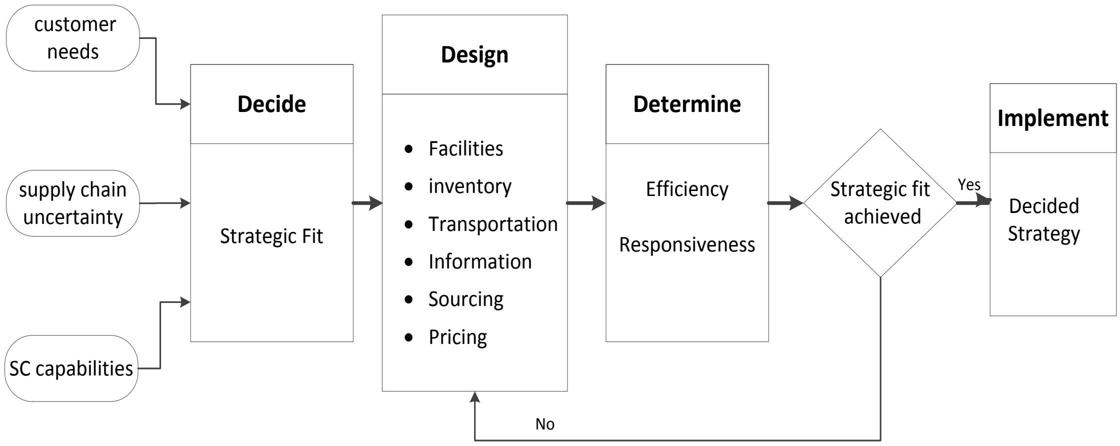


Figure 3. 5: Process of achieving strategic fit

The strategy of any single supply chain member is closely connected with those of the chain's other members, both upstream and downstream. A given level of responsiveness can be achieved within the chain by adjusting the respective roles played by each stage; for example, allowing one stage to absorb most of the uncertainty will make it more responsive, while at the same time allowing upstream and downstream stages to become more efficient. Table 3.1 presents multiple options for designing supply chain drivers; different designs can be directed to achieve specific strategies and SC outcomes.

Table 3. 1: Supply chain strategies and designs

Design of SC drivers	**Efficient / Responsive Strategy** for supplier, manufacturer, distributor and retailer	**SC measurements**	**SC aim**
Facilities: • Single / multiple facility location (plant, warehouse, retailer). • Flexible / inflexible process. • Product / function-focused process. • Low / high investment in facilities. **Inventory:** • Low / high inventory level. • Finished products, parts or raw materials. **Transportation:** • Slow cheap / fast expensive transportation modes. • Low-cost full truckload / higher-cost less than full truckload quick shipments. • Fixed / flexible numbers and types of trucks. **Information:** • Pull process (rely on information) / push process. • Low / high level of information sharing. **Sourcing:** • In house / out sourcing. **Pricing:** • Low, steady / high, changeable price.	**Efficient Strategy** • Low costs • Limited items • Varying supply time • Fixed batch size **Responsive Strategy** • High costs • Quick response • Various items • Short and fixed delivery time • Varying batch size	• KPIs of whole SC • KPIs of SC members	Desired outcome

Based on: Chopra and Meindl (2007)

3.3.2 Supply chain operations reference (SCOR) model

The supply chain operations reference model (SCOR) is the product of the Supply Chain Council (SCC). The model provides a unique framework that links business processes, metrics, best practices and technology into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities. The SCOR model consists of four major sections (SCC, 2012): performance (standard metrics to describe process performance and define strategic goals), processes (standard descriptions of management processes and process relationships), practices (management practices that produce significantly better process performance) and people (standard definitions for the skills required to perform supply chain processes). These four sections are discussed below.

3.3.2.1 Performance

The performance section of SCOR consists of two types of elements: performance attributes and metrics. A performance attribute is a grouping of metrics used to express a strategy. An attribute itself cannot be measured; it is used to set strategic direction. Examples of business strategies applied to supply chains include superior performance for supply chain reliability and advanced performance for agility. Metrics measure the ability of a supply chain to achieve these strategic attributes. Superior performance for reliability can be expressed in the performance objective: perfect order fulfilment: X%. Reliability is the performance attribute and perfect order fulfilment is the metric. Benchmarking is a commonly used method to calculate the value of X in the reliability example. Table 3.2 shows the performance attributes and metrics used within the SCOR model.

Table 3. 2: Performance attributes and metrics in SCOR

Performance Attribute	Definition	Level-1 Strategic Metric
Reliability	The ability to perform tasks as expected. Reliability focuses on the predictability of the outcome of a process. Typical metrics for the reliability attribute include: on-time, the right quantity, the right quality.	• Perfect order fulfilment
Responsiveness	The speed at which tasks are performed. The speed at which a supply chain provides products to the customer. Examples include cycle-time metrics.	• Order fulfilment cycle time
Agility	The ability to respond to external influences, the ability to respond to market place changes to gain or maintain competitive advantage. SCOR agility metrics include flexibility and adaptability.	• Upside supply chain flexibility • Upside supply chain adaptability • Downside supply chain adaptability • Overall value at risk
Costs	The cost of operating the supply chain processes. This includes labour costs, material costs, management and transportation costs. A typical cost metric is cost of goods sold.	• Total cost to serve
Asset management efficiency (assets)	The ability to efficiently utilize assets. Asset management strategies in a supply chain include inventory reduction and in-sourcing vs. outsourcing. Metrics include inventory days of supply and capacity utilization.	• Cash-to-cash cycle time • Return on supply chain fixed assets • Return on working capital

3.3.2.2 Practices

The practices section, formerly known as best practices, provides a collection of industry-neutral practices companies have recognized for their value. A practice is a unique way to configure a process or a set of processes. The uniqueness can be related to the automation of the process, a technology applied in the process, special skills applied to the process, a unique sequence for performing the process, or a unique method for distributing and connecting processes between organizations. SCOR recognizes that several different practices may exist within any organization. These practices may be classified as emerging practices, best practices, standard practices, and declining practices.

3.3.2.3 Process

The model is organized around the five primary management processes of plan, source, make, deliver and return. Planning processes balance aggregate demand and supply to develop the course of action which best meets sourcing, production and delivery requirements, while source processes are concerned with the procurement of goods and services to meet planned or actual demand. Make processes transform products into their finished state to meet planned or actual demand, while deliver processes provide the finished goods and services to meet planned or actual demand. This typically involves the management of orders, transportation and distribution. Finally, return processes are concerned with the returning of (or the receiving of returned) products for any reason. These processes extend into post-delivery customer support. Figure 3.6 shows the five SCOR processes distinguished by process type/ category.

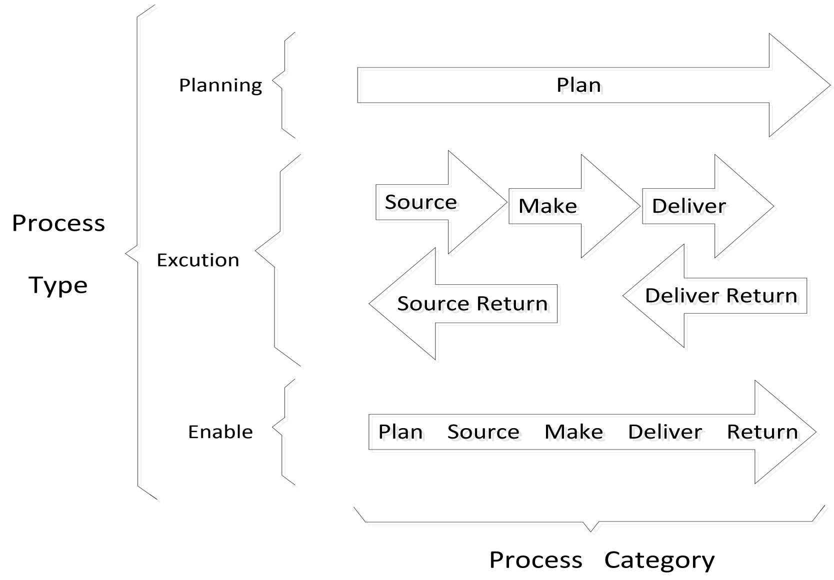


Figure 3. 6: SCOR process type and category

Planning processes balance aggregated demand and supply and generally occur at regular intervals. Execution processes are triggered by planned or actual demand and involve changing the state of materials and goods. They generally involve scheduling/sequencing, transforming products and moving them onto the next process. Enabling processes focus on preparing, maintaining and managing the information and relationships on which the planning and execution processes rely.

Zhou et al. (2001) stated that the SCOR model includes four levels of process detail. Level 1, the top level (process type), defines the scope and content of the SCOR and is where the performance targets are set. Level 2 is the configuration level (process categories); this level defines the configuration of planning and execution processes in the material flow. Standard approaches include make-to-stock (MTS) (production is based on sales forecasts e.g. the fashion industry), make-to-order (MTO) (the customer defines the specs and the product is manufactured to order e.g. tailoring) and engineer-to-order (ETO) (the customer defines the specs and the factory buys materials, designs and manufactures the product e.g. manufacture of lifts).

Level 3 (the process element level) determines the company's ability to compete successfully in its chosen markets. It comprises: process element definitions, process element information inputs and outputs, process performance metrics, best practices (where applicable), the system capabilities required to support best practice, and systems/tools. Finally, level 4 (the implementation level) defines the specific practices the company needs to implement to achieve competitive advantage and to adapt to changing business conditions.

Figure 3.7 shows the hierarchical structure of the SCOR model with specific boundaries regarding of process scope.

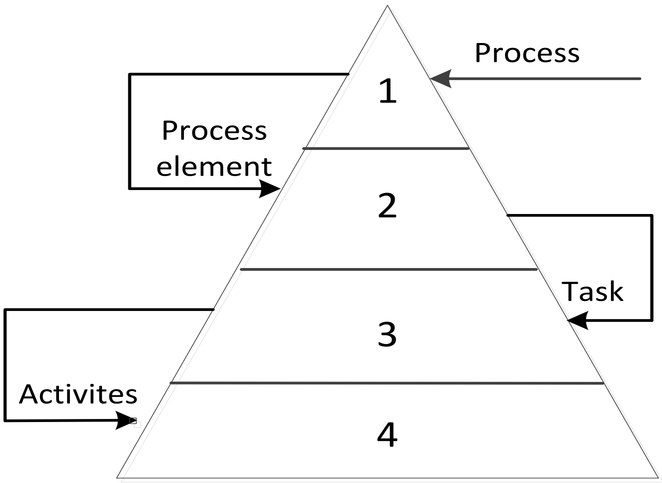


Figure 3. 7: SCOR process hierarchy

3.3.2.4 People

The people section of the SCOR model, which was introduced in SCOR 10, provides a standard for describing the skills that are required to perform tasks and manage processes. These standard definitions focus on aptitude, experience, training and competency level. SCOR recognizes five commonly accepted competency levels: trainee (untrained beginner, no experience, requires and follows detailed written instructions), beginner (performs the work with limited situational perception), competent (understands the work and can determine priorities to reach goals), proficient (oversees all aspects of the work and can prioritize based on situational aspects) and expert (intuitive understanding, able to apply experience patterns to new situations).

3.3.3 Supply chain network design

Network design involves determining the elements, numbers, locations and material flow quantities within the supply chain. The term "supply chain" implies that there is only one player at each stage of the chain, but in practice, manufacturers may source materials from a range of suppliers and work with several different distributors. In other words, most supply chains are more accurately described as networks (Chopra and Meindl, 2004). An SC network is made up of suppliers, manufacturers, distribution centres and retailers; it comprises a series of processes and stages, which starts with the material/information supplier and ends with the customer. Mid-stage participants play a dual role as the customer of the next stage and supplier of the previous stage.

Wang (2009) claims that SC network design is one of the company's biggest strategic tasks and central to the long-term efficiency of the whole SC. It involves working out the optimal number, capacity, layout and type of factories, warehouses and distribution centres required, setting up distribution channels and calculating the quantity of materials which will be consumed in the production process, the quantity of materials which will be transported from suppliers to customers, and the quantity of materials which will be produced. Figure 3.8 shows the different stages that make up a typical supply chain.

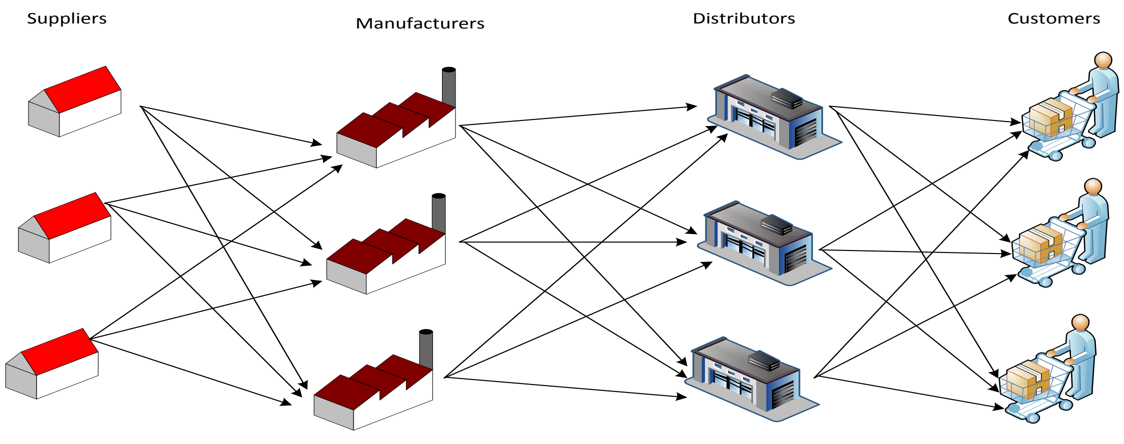


Figure 3. 8: Multi-echelon supply chain network

Long (2014) describes supply chain networks as consisting of several entities ranged from upstream to downstream. Each entity is composed of several departments or workshops, which are in turn made up of several production units. SC networks may therefore be divided into four levels: the supply chain network level, the enterprise level, the workshop level and the production unit level. Long argued that any entity in any level can be modelled using the SCOR model's five core processes to obtain its required function by selecting different process elements and determining different parameters. He proposed a hierarchical framework with four levels, each of which consists of several elements. Elements in the upper level can be decomposed into a set of elements in the lower level, while elements in the lower level can be aggregated to form an element in the upper level. The integrated supply chain design framework proposed in this study draws on Long's framework (see Figure 4.1).

3.4 Research Techniques and Tools

3.4.1 Conceptual techniques

A conceptual framework may be defined as a network of interlinked concepts that together provide a comprehensive understanding of a phenomenon. Jabareen (2009) argued that rather than offering a theoretical explanation, as do quantitative models, conceptual frameworks provide full understanding of all the concepts proposed and the interrelationship amongst them. Conceptual frameworks may be developed and constructed through a process of qualitative analysis. This study's conceptual framework for improving SC management, presented in Chapter 4, addresses a gap in the literature by integrating the strategy, process, network and performance functions.

3.4.2 Supply chain modelling

When a company is designing a new logistics network, it will take into account its objectives, all the decision variables such as network structure, facility location and service requirements, and supply chain constraints.

Extraneous information should be omitted in order to limit the complexity of the model (Min and Zhou, 2002). No model can capture all aspects of supply chain processes, so the model should be defined in such way that it answers the question it is designed for. In this study, modelling was used to create a hypothetical supply chain in the virtual environment. There are three stages to the modelling process (Fitkov-Norris, 2010). These are discussed below.

3.4.2.1 Model identification

The first step is to identify the model objectives and the best approach for modelling a particular event. This stage also includes defining the model boundaries (i.e. the key variables, scope and time frame). Min and Zhou (2002) explained that the main objects likely to feature in a SC model are customer service (may be represented by product availability and response time), monetary value (generally defined as a ratio of revenue to total cost and measured in terms of asset utilization, ROI or cost), information transactions (the sharing of information in real time allows supply chain partners to coordinate their actions and integrate SC processes) and risk (SC integration helps mitigate risks such as risk of quality failure or risk of information failure).

3.4.2.2 Building the model

The second step is the building of the model. This involves representing the real world links between the variables of interest in an appropriate format. This can be done using a quantitative approach such as linear programming or a qualitative approach such as a structural dependency representation using causal diagrams. This stage comprises the identification of supply chain decision variables, the collection of supporting data, and the identification of supply chain constraints.

Supply chain decision variables: Since decision variables generally set the limits on the range of decision outcomes, they are functionally related to supply chain performance. Thus, the performance measures (or objectives) of a supply chain are generally expressed as functions of one or more decision variables. Decision variables might include (but are not limited to) (Min and Zhou, 2002):

- Location: determining where plants, warehouses (or distribution centres (DCs)), consolidation points and sources of supply should be located.
- Allocation: determining which warehouses (or DCs), plants and consolidation points should serve which customers.
- Network structuring: centralizing or decentralizing the distribution network and determining which combination of suppliers, plants, warehouses and consolidation points should be utilized.
- Policies: determining how the supply chain will achieve its objects. Policies include sourcing policies (e.g. make or source), transportation policies (e.g. full/less than full truckload) and inventory policies (e.g. periodic review-based or level of units maintained).
- Number of facilities and equipment: determining how many plants, warehouses and consolidation points are needed to meet the needs of customers and market segments.
- Number of stages (echelons): determining the number of stages that will comprise a supply chain.
- Service sequence: determining delivery or pickup routes and schedules for vehicles serving customers or suppliers.
- Volume: setting the optimal purchasing volume, production and shipping volume at each node of the supply chain.
- Inventory level: determining the optimal amount of inventory to be stored at each supply chain stage.
- Size of workforce: determining the number of truck drivers or order pickers needed for the system.
- The extent of outsourcing: determining which and how many suppliers should be used for long-term outsourcing contacts.

Collection of supporting data: If the company is to make the correct decisions concerning decision variables, it must collect all the relevant data about product demand, customer value, transportation costs, transportation times, warehousing costs, inventory costs, production costs and procurement costs etc.

Identifying supply chain constraints: Min and Zhou (2002) defined supply chain constraints as limitations that restrict the range of decision alternatives open to the firm. These constraints may affect the feasibility of some decision alternatives. They may include the company's financial, production, supply or technical capacity (or those of another SC member), service compliance issues (e.g. delivery time windows, manufacturing due dates and the number of driving hours permitted for truck drivers) and the extent of demand (the company may have to balance its demand against supply capacity at the preceding stage).

3.4.2.3 Model analysis and interpretation

The third step in the modelling process involves the derivation of solution(s) for the mathematical equations and/or simulation of the dependencies between variables, in order to answer the particular questions set out at the beginning of the process. This step may also involve a number of extra steps such as model validation. In this study, supply chain optimization was employed to identify the best solution for the model, which was then evaluated by means of simulation.

3.4.3 Supply chain simulation

Whereas an optimized solution is only valid for a defined scenario, a simulation model can treat different scenarios in order to find an optimal solution. A solution derived from a simulation can therefore be made more sensitive to environmental changes than a solution obtained through optimization. Simulation can be defined as the process of creating a model of an existing or a proposed system (e.g. a project, a business, a forest) in order to identify and understand those factors which control the system and/or to predict its future behaviour (El-Aal et al., 2008). In this research, the SCG software package was used as a simulation tool to investigate the impact of different SCD scenarios on efficiency, responsiveness and sustainability performance.

3.4.4 Supply chain evaluation and what-if analysis

Optimization is: “Narrowing your choices to the very best when there are virtually innumerable feasible options and comparing them is difficult” (Institute of Operations Management and Management Science). An important component of SCD is determining how to achieve an effective design, given a performance measure or a set of performance measures (Beamon, 1998). Optimization models answer questions about plant location, product mix, choice of technology, distribution methods, inventory planning and control, choice of suppliers, configuration and reverse logistics (El-Aal et al., 2008). In this study, the focus was on finding optimum/near optimum values for the inventory and transportation variables in the studied supply chain.

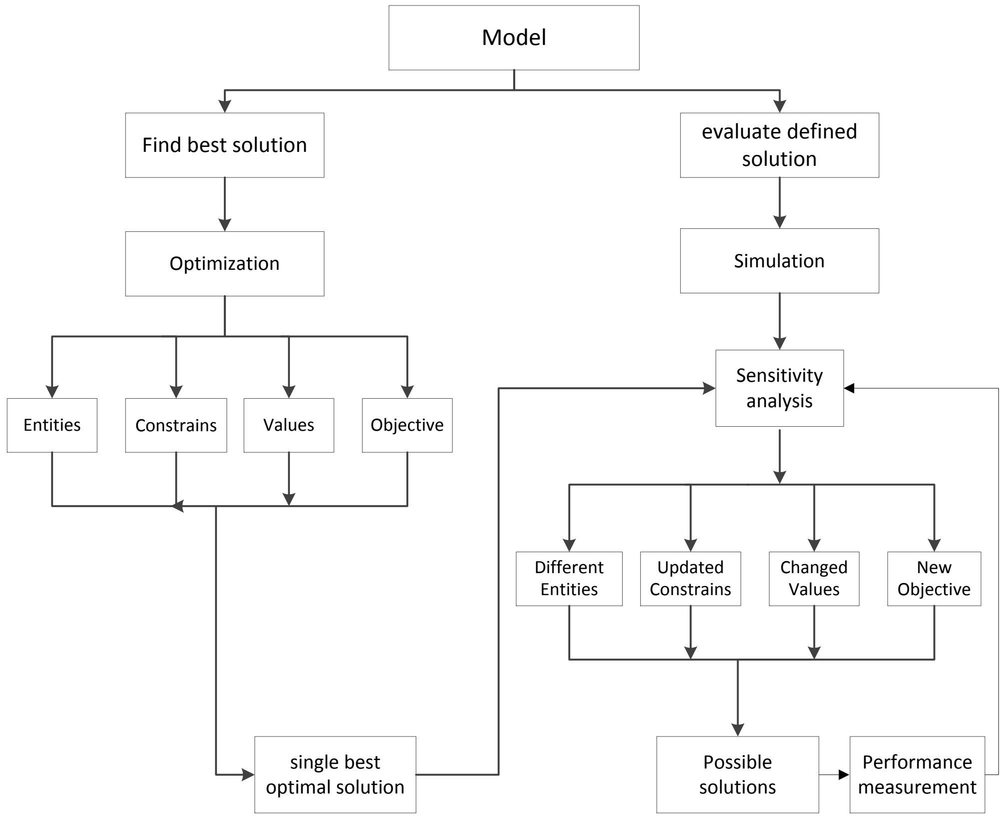


Figure 3. 9: Supply chain modelling techniques

3.4.5 Statistical distribution

The type of statistical distribution, together with the distribution parameters (mean, standard deviation, minimum and maximum values), define a probability density function (PDF) for a random variable. A PDF describes the distribution of possible values that a random variable may assume, for a hypothetical, infinite set of observations of the variable. Usually, the features of the population under investigation can be summarized by the parameters. Hence, the research problem usually becomes an investigation of the values of parameters. Since these population parameters are unknown, sample statistics are used to make inferences about them.

In this research, statistical distributions were used to model different demand patterns. Syntetos et al. (2005) characterized demand as intermittent, erratic or lumpy. A demand is intermittent when it appears randomly with many time periods having no demand; an erratic demand pattern is characterized by highly variable demand size; and lumpy demand is both intermittent and erratic. The authors quantify the categories using two parameters: average inter-demand interval (ADI) and squared coefficient of variation (CV^2).The cut-off values are set as ADI = 1.32 and CV^2 = 0.49, as shown in Figure 3.10.

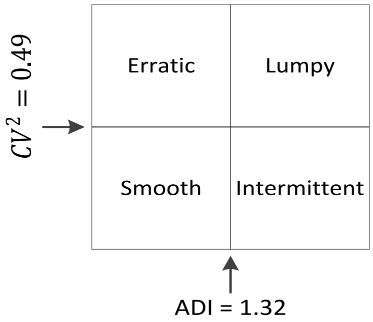


Figure 3. 10: Categorization of demand patterns

Source: Syntetos et al. (2005)

3.4.5.1 Normal distribution

Normal distribution is the most common type of probability density function (PDF). For a normal distribution, about 68% of observations should fall within one standard deviation of the mean, and about 95% of observations should fall within two standard deviations of the mean. Normal probability density function, demonstrating standard deviation ranges, is shown in Figure 3.11 (Evans, 2000).

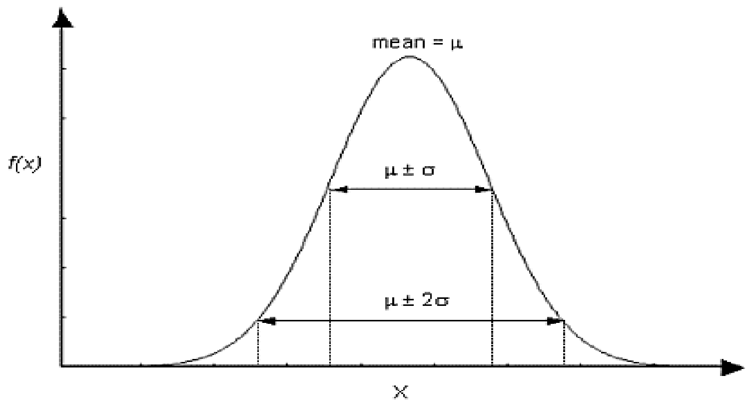


Figure 3. 11: Normal probability density function

Source: Forbes (2011)

Parameters: The mean (μ) is specified as a real number and the standard deviation (σ) is specified as a positive number.

Range: (-∞, +∞)

Mean: μ

Variance: σ^2

3.4.5.2 Bounded normal distribution

A truncated normal distribution can be defined by setting the desired minimum and/or maximum values for the variable. For practical purposes, if the minimum and maximum values are at least three standard deviations away from the mean, a complete normal distribution will be obtained. If the minimum/maximum values are less than three standard deviations away from the mean, the distribution will be visibly truncated (Duncan, 2000).

3.4.5.3 Lognormal distribution

If a random variable has a lognormal distribution, then its natural logarithm has a normal distribution. This is the meaning of the term lognormal. The lognormal distribution can only be used for variables which are always positive. A lognormal distribution can be useful for modelling variables such as cohesion, which may have a large peak in the distribution near zero and then narrow off gradually for larger values. Figure 3.12 illustrates lognormal probability density functions (Evans, 2011).

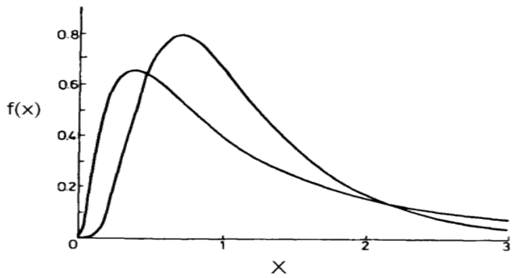


Figure 3. 12: Lognormal probability density functions

Source: Forbes (2011)

Parameters: The mean ($\mu l > 0$) is specified as a real number and the standard deviation ($\sigma l > 0$) is specified as a positive number.

Range: [0, +∞)

Mean: μl

Variance: $\sigma^2 l$

3.4.5.4 Poisson distribution

The Poisson distribution is applied when counting the number of rare but open-ended events. An example might be the number of faults in a batch of materials. It is also used to represent the number of arrivals, say, per hour, at a service centre. In practice, arrival rates may vary according to the time of day or year, but a Poisson model will be used for periods that are reasonably homogeneous. The mean and variance are equal and can be estimated by observing the characteristics of actual samples of "arrivals" or "faults" (Evans, 2011).

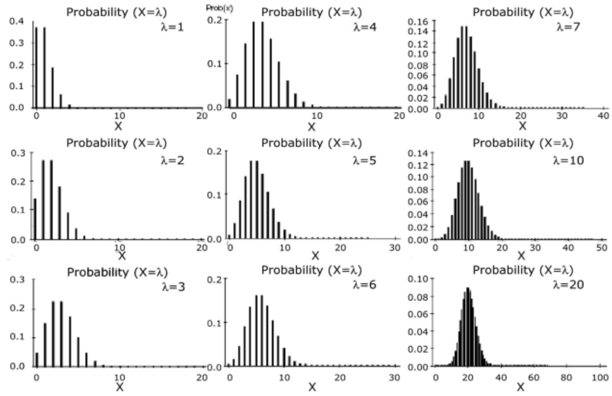


Figure 3. 13: Poisson distribution for λ= 1, 2, 3, 4, 5, 6, 7, 10, and 20.

Source: Hoffman (2015)

Parameters: The mean (λ) is specified as a positive real number.

Range: {0,1,…}

Mean: λ

Variance: λ

3.4.6 Sensitivity analysis

The parameter values and assumptions of any model are subject to change and error. Sensitivity analysis (SA), broadly defined, is the investigation of these potential changes and errors and their impacts on conclusions to be drawn from the model (Pannell, 1997). Sensitivity analysis has many uses, including decision making, improving understanding of a system, and model development. Pannell (1997) argues that the technique may be used to test the robustness of an optimal solution, identify sensitive or important variables, investigate sub-optimal solutions, assess the riskiness of a strategy or scenario, and understand relationships between input and output variables. In this research, it was used to understand the influence of specific factors on SC performance.

Sensitivity analysis is particularly valuable where parameters are uncertain, as it can highlight both the circumstances under which the optimal solution will change and how these circumstances will affect the optimal solution. However, the modeller needs to determine what changes to make in order to obtain the required information. These changes might include any or all of the following: the contribution of an activity to the objective, the objective itself (e.g. minimizing risk of failure instead of maximizing profit), constraint limits (e.g. the maximum availability of a resource), the number of constraints (e.g. adding or removing a constraint designed to express the personal preferences of the decision maker for or against a particular activity), and technical parameters (Pannell, 1997). Whichever items the modeller chooses to vary, many different aspects of the model output can be observed; for example, the value of the objective function and the values of decision variables.

Sensitivity analysis starts with a list of the key factors or parameters. If the aim is to estimate the likely profitability of a project, these factors might be market growth rate, market share, selling price and the costs of direct labour and direct materials. The most likely values are then attached to each of these parameters and used to predict the most likely level of profits. The effect is then calculated of varying the values of all or a selected few of these parameters. This may be done by working out what the impact would be if all the values varied equally by, say, 1, 3 or 5 per cent. Different incidences of variation between the values may be calculated if appropriate. The outcomes of the alternative assumptions are listed and a subjective assessment made of their likelihood. Finally, the modeller draws conclusions regarding what if any actions are required to make the achievement of the better outcomes more likely.

3.5 Conclusions

This chapter discussed the methodology that was employed to develop the proposed framework. It presents the main SC components and characteristics, and the method for developing supply chain strategy, before describing the conceptual fundamentals of the proposed framework. These are the strategic fit concept (employed to fulfil the strategic role of the framework in achieving consistent strategy in terms of efficiency and responsiveness), the SCOR model (to clarify supply chain policies and process configurations) and the supply chain network design concept (to illustrate how supply chain networks are structured). Finally, the chapter discusses the techniques and tools that were utilised to refine and validate the framework: modelling, optimisation and simulation. Probability distributions were also utilised to model different demand patterns, and sensitivity analysis was used as a basis for building simulation scenarios.

Chapter 4: The proposed Integrated Supply Chain Design Framework

4.1 Introduction

As highlighted in the literature review (see section 2.7), previous studies have failed to identify essential linkages of SCD (i.e. strategy, process and network). Accordingly, this research proposes an integrated approach that combines all the most important elements within one framework. The proposed framework (shown in Figure 4.1) is composed of four different models, each of which performs a defined role. It takes into account the following considerations:

1. Resources: are all those physical investments that make up the SCN, including production entities, warehouses and distribution centres, as well as all means of transporting materials from suppliers to manufacturing centres and on to the end consumer. All decisions regarding resource location, capacity and technology must be directed towards achieving the strategic objective of the SC.

2. Processes: covers management policies for ensuring that resources are maximized to achieve the SC's strategic goal. The SCOR model is considered the standard template for SC processes (plan, source, make, deliver and return). The model defines the best process configurations for different levels of the SCN to support selected strategy in achieving the supply chain outcomes.

3. Relationships: covers the ways in which various entities within the SCN are linked and how their processes interact to achieve the goal of the SC. The proposed framework uses a network model to show how these relationships might be structured more effectively.

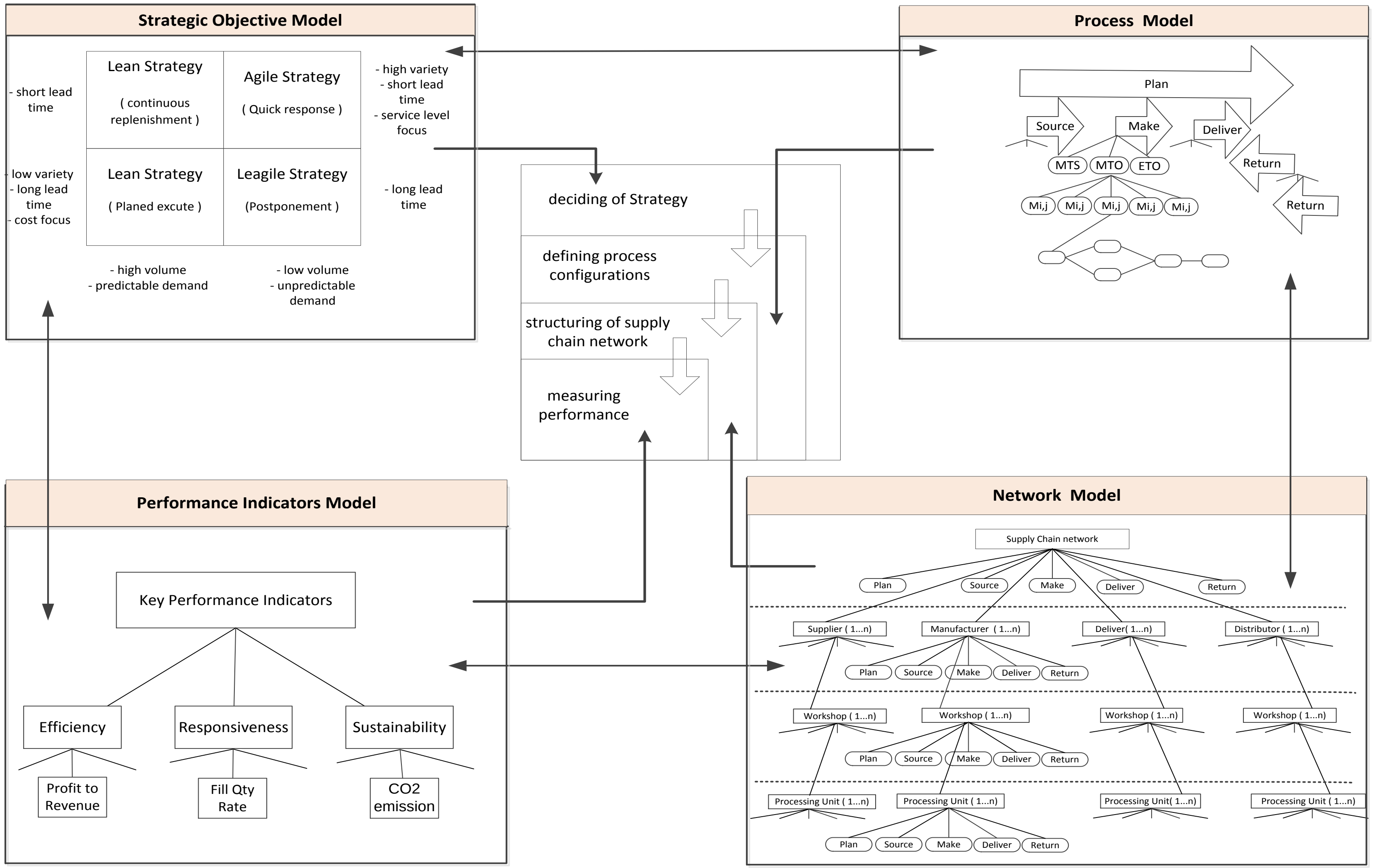


Figure 4. 1: The Proposed Integrated supply chain design framework

4.2 Strategic Objective Model

The strategic objective model outlines the ways in which different SC strategies attempt to meet customer requirements while still taking into account demand uncertainty and SC capabilities and performance. Several strategic models are offered in the literature, including those by Ivanov (2010), who proposed a model to support decision making on SC strategy, design, tactics and operations; Hwang (2010), who focused on the role of cost leadership, differentiation and focus in shaping overall strategic direction; and Sabet, Yazdani and Leeuw (2017), who considered the role of uncertainty and product importance in shaping SC strategy. However, as none of these models take into account the market environment, the proposed framework is instead based on Christopher’s (2006) modeled, which recommends strategies for different demand characteristics.

4.2.1 Demand characteristics

Since customer demand is the main driver of strategic SC decision making, it is essential to understand the features of this demand and how they affect SC performance.

Uncertainty

Demand uncertainty focuses on the difficulty of predicting customer demand. Lee (2002) distinguished between functional products, which generally have long product life cycles and therefore stable and predictable demand, and innovative products, which tend to have a short life and therefore more unpredictable demand. Obviously, different supply strategies are required for the two categories of products. Functional products tend to offer less product variety than innovative products, which are often trend-led or produced to respond to customer demands for wider choice. Companies have three safety buffers for handling these uncertainties: safety inventory, safety capacity and safety time. These buffers are used to reduce variations in the SC and meet customer demand for better service at lower cost.

Lead Time

The order lead time limits the extent to which the supply chain can be order-driven. If a very short order lead time is required, it may be necessary to make-to-stock (MTS) and provide local warehousing or vendor-managed inventory. In some cases, however, it is not possible to MTS because the product is customized or provided in such wide variety that finished stocks are not economically viable. In this case, the product is made-to-order (MTO) and the manufacturing process may require buffers in terms of excess manufacturing capacity and raw material stocks to support a short order lead time.

Reducing product development lead time means that a product can get to market earlier. This has a number of important advantages: the sales life of the product is extended; a higher price can be charged; new customers can be won; and a high market share can be won by building upon the initial lead. Moreover, by reducing overall lead time, product complexity and process set-up times, the production of a particular product can be scheduled more frequently with smaller production batches. This improves the variety of products available to a customer over a given time (Kampen, and Donk, 2014).

Variety

Cooper and Griffiths (1994) stated that: “Issues of variety and complexity are strongly linked.” An increase in external variety (i.e. in the choice being offered to the end customer) has implications for the level of internal variety that will be required of the SC (Kampen, and Donk, 2014).

Increasing variety makes logistics operations more complex and so increases both direct and indirect costs, though these may be mitigated to some degree by redesigning systems. Ideally, variety should be increased only when it adds value.

Variability

Where the demand for a product is stable and significant, SC members may be able to rely on a small supply base to provide a high volume of standard ship-to-stock components and materials (Kampen, and Donk, 2014) . These high volumes can be leveraged to reduce ordering frequency, allowing a more efficient operation in which inventory turns are high and there is little exposure to excess and obsolete inventory. However, if customer demand is volatile, for example because the product is specialized, a low-volume approach is more sensible. SC members who are forced to rely on a wide range of suppliers, each producing unique components, are particularly exposed to the risk of excess or obsolete inventory.

4.2.2 Suggested strategies

Birhanu, Lanka and Rao (2014) argued that providing the right degree of responsiveness and efficiency simultaneously is difficult, since increased responsiveness is generally perceived to come at the expense of efficiency, and vice versa. The strategic objective model presents four SC strategies, allowing managers to choose the option that is best suited to the combination of supply/demand conditions they face.

Lean strategy (plan and execute)

This is the most appropriate strategy where demand is high-volume, low-variety and predictable, and lead times are long. Materials, components and products can be ordered in advance and manufacturing and transportation facilities can be optimized (Christopher, 2006).

Lean strategy (continuous replenishment)

In cases where demand is predictable and replacement lead times are short, a lean strategy of continuous replenishment is possible. At its extreme, products are replaced as they are sold or used (Christopher, 2006). Christopher, Peck and Towill (2006) suggested that point-of-sale data facilitates this strategy as it allows vendors to manage their own inventory and rapidly replenish individual stores.

Agile strategy (quick response)

Christopher (2000) defined agility as the ability of an organization to respond rapidly to changes in demand both in terms of volume and variety. Where demand is unpredictable and lead times are short, the SC can adopt a quick-response strategy such as MTO. Agile SCs must be capable of reading and responding to real demand, virtual which is information-based rather than inventory-based. Processes are integrated, with buyers and suppliers working collaboratively and products being developed jointly, and SC members sharing common systems and information. The agile SC is network-based; individual businesses are no longer competing as stand-alone entities but as part of a larger chain (Christopher, 2006).

Leagile strategy (postponement)

Leagile strategy is an option where lead times are long and demand is unpredictable, highly variable and outside the organization's control. A hybrid lean/agile strategy requires the SC to be "decoupled"; strategic inventory is held in some generic or unfinished form, with the final configuration being completed rapidly once the real demand is known. If the final physical configuration cannot be postponed in this way, it may be possible to postpone the distribution of the product instead by holding it in fewer locations and using express transportation to move it to the final market or point of use once the actual demand is known. The goal of the hybrid strategy should be to build an agile response upon a lean platform by following lean principles up to the decoupling point and agile practices after that point (Christopher, 2006).

4.3 Process Model

Davenport et al. (1995) defined a business process as a set of activities with specified business outcomes for customers. SC processes may thus be defined as the set of activities by which material is moved through the SCN. A variety of process models have been highlighted in the literature and are employed in industry, including SCOR (Supply Chain Operations Reference Model), GSCF (Global Supply Chain Framework), CPFR (Collaborative Planning, Forecasting and Replenishment), VRM (Value Reference Model) and SAP (System and Application Products). These models cover a range of areas such as organizational cooperation within the SC, product development, inventory management and manufacturing operations. SCOR was selected to represent the process dimension within the proposed framework because it encompasses a wide range of policies that are suitable for use in different business environments and because it clarifies the relationship between SC processes and network structure.

4.3.1 Supply chain processes

Plan

Planning processes balance aggregate demand and supply to develop the sequence of actions which best meet sourcing, production and delivery requirements. An important part of SC planning is the running of full-stream supply/demand simulations. What-if analysis helps firms to prepare for various possible scenarios. Sharing of the resulting information is crucial to rebalance the chain and improve performance (Fawcett et al., 2011).

Source

Sourcing processes are critical because they connect manufacturers with suppliers. (Dong et al., 2001) showed that the benefit companies gain by giving the bulk of their business to a few suppliers and using long-term contracts outweighs the costs. Just-in-time (JIT) delivery from suppliers is also considered a good sourcing practice. The benefits of JIT delivery have been widely documented.

Make

The make process covers the transformation of raw materials into finished goods to meet SC demand in a timely manner. Relevant practices highlighted in the literature include JIT production, total quality management (TQM) and human resource management (HRM). JIT production practices include pull systems, cellular manufacturing, cycle time reduction, agile manufacturing strategy and bottleneck removal; TQM practices include statistical process control (SPC) and continuous improvement programmes; and HRM practices emphasize employee teamwork and workforce capabilities.

Deliver

Delivery processes are a critical part of SC management. Effective processes rely on SC partners sharing real-time information, which enhances visibility and improves order tracking. Agility is an important competence; other best delivery practices identified by the SCOR model include employing a single contact point for all order inquiries, order consolidation and the use of automatic identification.

4.3.2 Process configurations for lean strategy

The primary emphasis in lean strategy processes is on minimizing costs and maximizing production and logistics efficiency. Lean principles were originally aimed at improving manufacturing processes by eliminating waste but were extended to cover the development of a set of associated logistics tools. Lean SCs typically require close, collaborative relationships between manufacturers and suppliers because of the large-volume, long-term commitments involved.

Source-to-stock

The intention of source-to-stock is to maintain a pre-determined level of inventory for certain materials, sub-assemblies or products. The process involves ordering, receiving and transferring raw material items, sub-assemblies, products and/or services based on aggregated demand requirements.

Make-to-stock

The production processes for mature, highly standardized products focus primarily on achieving low-cost operations, which is typically accomplished with high-volume transformation. Production processes may be continuous if large numbers of similar products are required; alternatively, large batch processes allow some variety.

Deliver-to-stock

Manufacturers in these supply chains tend to push products onto retailers and to rely heavily on distribution centres and retailers to deliver products to consumers in the most cost-efficient manner. The multi-layered nature of lean supply chains makes efficient operations and information sharing challenging. Consequently, this type of supply chain is the most liable to the bullwhip effect.

4.3.3 Process configurations for agile strategy

An agile SC may have fewer opportunities to practise lean principles, but it should still look for efficiencies wherever possible. One way to achieve efficiency is by establishing collaborative relationships with key suppliers, as this not only ensures reasonably priced, high-quality raw materials but can also improve delivery times. However, these relationships should not be allowed to compromise the flexibility of the chain; it must be able to reduce the number of suppliers it deals with if it considers this to be necessary.

Source-to-order

Source-to-order inventory is ordered specifically for customer orders. To ensure satisfied customers, delays are minimized by purchasing raw materials in large quantities from multiple suppliers and maintaining a large inventory of work in progress units and other components. In the case of unique or very low-volume products, the engineer-to-order process might be utilized if raw materials need to be sourced specifically for the product.

Make-to-order

These products are usually customized from a combination of standardized components and additional elements that are specifically produced to meet individual customer requirements. In agile supply chains, the raw material and components may already be on hand (to ensure quick customization), but actual production does not begin until the customer’s order is received. Job shop or project processes ensure the right balance between efficient and flexible production by allowing different designs to be produced from a small number of components.

Deliver-to-order

There may be no distributors or retailers in this type of process to allow for a faster response to customer requests, as well as easier sharing of information among SC members. Distribution flexibility is critical as the availability of a range of delivery options with multiple carriers reduces the likelihood of late deliveries.

4.3.4 Process configurations for leagile strategy

The major management challenge in terms of leagile SC processes is achieving timely production and delivery at low cost while still offering wide product variety. Assemble-to-order processes are commonly utilized to allow a limited number of choices in the configuration of the final product. In order to offer customers a number of options, companies typically delay the final assembly of products until orders are received.

Make assemble-to-order process

Production processes are designed to produce standardized components in appropriate batch sizes, which are then assembled to fulfil individual customer orders. Since products are only differentiated after the decoupling point, components can be used for multiple products, reducing inventory and total production lead time. On the other hand, the reliance on standardized components limits the degree of customization possible for individual products.

Source/deliver assemble-to-order process

The assemble-to-order supply chain is typically controlled by the firms doing the assembly. These firms send the end products to the retailer/dealer for delivery to the end customer or directly to the end customer. Adopting a postponement strategy and shipping inventory direct to the customer can help companies improve their on-time delivery of complete orders, achieve more reliable and shorter lead times, introduce new products more quickly, reduce inventory costs and stabilize transportation costs. On the other hand, it can raise shipping costs, as it involves shipping in smaller quantities and using faster transport modes to reduce lead time (Balland and Lindholm, 2012).

4.3.5 An overall map for implementing supply chain policy

The framework takes a demand-driven approach; it assumes that SCs are designed to satisfy certain demand characteristics. The main featured strategies are lean, agile and leagile. For each of these, a specific configuration of policies must be implemented for the SC to achieve its strategic objectives.

In the case of lean strategy, the aim is to lower costs and find the most efficient way of utilizing the available resources. SC capabilities tend to be pre-planned well in advance, unvarying, and fixed with no excess capacity. Functions are operated within these capability restrictions: production is massive and standard; inventory is high-level and unvaried; transportation processes utilize low-cost modes, adopt a full truckload policy, and aim for the quickest possible transport time. In contrast, agile strategy aims to meet unpredictable customer demand in a short time and to achieve perfect fulfilment. The SC's resources tend to be variable, varied and excess. Production is varied, low-volume and has a short process time. Inventory is kept at a low level by means of postponement or quick response, with products being transported using fast and flexible modes.

Chapter 5 discusses the modelling and simulation for the framework, showing how it was used to model and simulate various demand characteristics and different SC policies in order to achieve certain objectives. Table 4.1 shows how the SC policies discussed above can be implemented for each of the featured strategies.

Table 4. 1: Supply chain policies for sourcing, manufacturing and delivery

Demand Characteristics				Supply Chain Strategy	SC Policies	Activities	Supply Chain Capabilities				
Qty	Vari. ety	Lead Time	Cert. ainty				Sched.	Capacity	Production	Inventory	Transportation
high	low	long or short	high	Efficiency: • Low cost • Asset utilization • Perfect order fulfilment	Source To Stock	• Schedule product deliveries • Receive product • Transfer product	• Preplanned • Rigid • Long period	• Fixed • Unvaried • No excess	• Standard • High volume • Large lot size • Low setup time • Push and mass production process	• High • Unvaried • Planned or continuous replenishment policy	• Low-cost mode • Reduce transportation time • Utilize assets (FTL)
					Make To Stock	• Demand forecasting • Define production rate (U/T) • Define capacity level (U/T) • Issue required materials • Order scheduling • Carry out production activity • Release product to deliver • Waste disposal					
					Deliver To Stock	• Receive order • Determine delivery date • Consolidate orders • Plan product load and shipment • Receive product • Ship product • Verify product received by customer					
low	high	short	low	Agility: • Satisfy unpredictable orders in short time • High level of service	Source To Order	• Schedule product deliveries • Receive product • Transfer product	• Based on order • Flexible • Short period	• Variable • Varied • Excess	• Group of products • Low-volume • Small lot size • Low setup time • Pull and batch production process	• Low • Varied • Postponement or quick-response policy	• Fast mode • Flexible mode (LTL)
					Make To Order	• Enter customer order • Define production rate (WH/T) • Define capacity level (WH/T) • Issue required materials • Order scheduling • Carry out production activity • Release product to deliver • Waste disposal					
					Deliver To Order	• Receive and configure order • Determine delivery date • Consolidate orders • Plan product load and shipment • Receive product • Ship product • Verify product received by customer					

4.4 Network Model

Most studies in the area of supply chain network design (SCND) focus on one particular objective; for example, those addressing lean SCND focus on how to establish the optimal number and location of members so as to minimize overall SC costs (Shen, 2007). Those focusing on agile/responsive SCND aim to reduce products' time to market while achieving minimum total cost. In this category are Gunasekaran et al. (2015), who listed networking of partnering firms, information technology and knowledge management as the three major enablers of SC responsiveness. Finally, studies investigating sustainable SCND look at how SCs can be designed so that they meet current requirements without impacting on future generations. Neto et al. (2008) identified transportation, manufacturing, use of products, testing and end-of-use activities as all having a major impact on not just the economic but also the environmental performance of logistics networks.

The framework presented in Figure 4.1 draws on Long's (2014) hierarchical network model, itself based on the SCOR model, to arrive at a multiple objective network that integrates with SCOR to achieve different process policies. The network model shows that each SCOR process in network entities in the upper level can be decomposed into a set of five processes of lower level elements.

In the SCOR model, decomposition and aggregation are carried out based on process, but the proposed network model accomplishes the decomposition and aggregation based on both the entity and the process. Therefore, a simulation tool was used to integrate the SCOR process with the dynamic complex SCN. In order to fulfil the mentioned integration, two steps needed to be carried out in the SCN modelling. The first step was to determine the structure model with the proposed hierarchical framework that mainly describes the modules composing the SCN and their relationships without involvement of process element selection. The second step was to fulfil the structure model with corresponding functions using the simulation tool.

4.4.1 Drivers affecting supply chain network design

Strategic decision making in SCND is affected by a number of drivers. Those related to demand are discussed in section 4.2.1; this section describes other drivers and their impacts on SC decisions at the global level.

Completeness (item fill rate)

Item fill rate refers to the probability of having a product in stock when an order arrives. Where demand is volatile and unpredictable, selecting the most appropriate SC structure is particularly important as it affects the overall delivery reliability within the network (Lovell, Saw and Stimson, 2005). Centralizing inventories can help pool the risk and increase delivery reliability.

Delivery frequency

This is defined as the number of deliveries performed within a certain time unit (e.g. week, month or year). A high-frequency policy keeps inventory holding costs low but increases transportation costs. In these circumstances, efficiency and economy will be maximized if distribution is kept local. Low delivery frequency will incur lower transportation costs, which is preferable in global supply chains where goods must travel long distances.

Endowment of purchased items

This driver defines the availability of resources. Some countries/regions have geographical, technological or underground sources advantages and availability, while others face scarcity and the risk of “running out”. If this is the case, manufacturing facilities should be located near suppliers with the easiest and cheapest access to the required resources. This may mean locating these facilities overseas.

Source quality

In the same way that availability issues can force a firm to look further afield for suppliers, it can also be forced to source from foreign suppliers if domestic resources do not satisfy its quality standards.

Table 4.2 summarizes the various SC drivers and analyses their impact on SCN strategy and SC performance.

Table 4. 2: Impact of supply chain drivers on network strategy

Drivers	Direct effects	Suitable strategy	Strategy results	Effect on SC performance		
				Efficiency	Respon.	Sustain.
High product variety	• Wider inventory and suppliers • Increased replenishment lead time	Centralization	• Reduced duplication • Higher transportation costs	Increased (unless trans. cost is higher than inv. cost in case of decentralization strategy)	- ive	+ ive
Short lead time	• Adapt to changes quickly • Intro. new products quickly	• Locate plants near to market • Local distribution	Shorter lead times	- ive	+ ive	+ ive
Unpredictable demand	• Less accurate forecasting • Impact of lost sales greater with innovative products	• Locate distribution facilities closer to market	• Shorter lead times • Pooling the demand variations from different areas	- ive	+ ive	+ ive
High demand variability	Increases cost because high levels of safety stock are required	Decentralization to achieve responsiveness and agility	More responsive to changeable customer requirements	- ive	+ ive	+ ive
	Increases demand volatility, especially in a more global SC	Centralization	Reduces the impact of variation	+ ive	- ive	- ive

Cont. Table 4.2: Impact of supply chain drivers on network strategy

Drivers	Direct effects	Suitable strategy	Strategy results	Effect on SC performance		
				Efficiency	Respon.	Sustain.
High delivery frequency	• Lower inventory holding costs • Higher transportation costs (more frequent and fewer full loads)	Local distribution	• Increased delivery frequency • Reduced transportation distance	+ ive	+ ive	+ ive
High rate of completeness (item fill rate)	Fewer stock outs	Centralization (among inventories)	Pooled risk and increased reliability	- ive	+ ive	+ ive
Endowment of purchased items	Resources advantages and availability	Overseas manufacturing where required resources are unavailable locally	Easier and cheaper access to resources	+ ive	+ ive	+ ive
Source quality	Improved product quality	Global sourcing when domestic resources are not up to quality standards	Achieves quality standards	+ ive	+ ive	Reduction in local sourcing but increase in global sourcing

4.4.2 SCN configuration

Companies seeking to develop a global SC strategy must decide where to source raw materials and components, where to locate manufacturing facilities and which markets to serve. The answers to these three strategic questions will determine SC configuration; that is, whether the key functions within the operational process (sourcing, manufacturing and distribution) are located locally or globally. The decision where to locate these functions is critical. A number of factors must be taken into account, such as intended market, supply chain capabilities and competitive strategy. Global SCNs are complicated and need a high level of investment, but they are crucial if businesses are to take advantage of the cost, quality and availability advantages of foreign sources. On the other hand, a local SC is the most efficient way of serving the local market as it allows savings in transportation and inventory costs. Sourcing raw materials and components from local suppliers also reduces lead time and enables the firm to respond more quickly to the market. Table 4.3 presents various SCN configurations and their associated characteristics.

The table presents a number of strategies for combining efficiency and responsiveness. When SC design is entirely global, strategic emphasis tends to be given to high-volume production as a way of mitigating transportation and inventory costs. Where the SC is entirely local, on the other hand, lead time is short and only a low inventory level is needed to serve the market. In both local and global SCs, responsiveness requires increasing transportation frequency and consequently costs. Those chains that do not require frequent transportation will incur lower transportation costs and find it easier to pursue efficiency.

Table 4. 3: Network configurations

Supply chain configurations			Characteristics
Supply	Manufacturing	Distribution	
Global	Local	Global	Huge investment, complex and sophisticated products
Global	Global	Global	Highest level of complexity in terms of organization management, planning and coordination; tends to be adopted by global and large-scale companies
Global	Global	Local	Global sourcing is inevitable, large volume in local market to be served
Global	Local	Local	Exploits cost, quality and availability advantages of foreign sources in order to serve local market in best way possible
Local	Local	Local	Low complexity and internalized cost efficiency; adopted by companies which have rigid manufacturing facilities, high inventory cost and high transportation cost
Local	Global	Local	Short lead time, meets customer needs better; local advantages in terms of low labour cost, low taxes, better environmental norms and regulations
Local worldwide	Local worldwide	Global	Global brands use “unique” local suppliers to add value; global distribution to be close to foreign markets
Local	Local	Global	Adopted by strong global brands; local roots add value

Where the SC combines global manufacturing with local distribution, the former raises efficiency while the latter reduces efficiency (because it incurs higher inventory and transportation costs) but raises responsiveness. If manufacturing is located locally and serves both local and global markets, the SC can be efficient and responsive within the local market and efficient in the global market due to high inventory and transportation costs.

4.5 Performance Indicators Model

The last model included in the framework is a performance indicators model. This measures SC efficiency, responsiveness and sustainability and determines the extent to which the chain is achieving its objectives.

4.5.1 Efficiency performance indicators

Cost

A critical performance indicator, cost is tracked more carefully and comprehensively than any other aspect of competitive performance. SC costs include all costs associated with operating the SC, including the costs of planning, sourcing, material landed, production, order management, fulfilment and return.

Asset management

This refers to an organization's ability to manage its assets so that it is able to satisfy demand. Three indicators that measure SC asset management efficiency are cash-to-cash cycle times, inventory days of supply and asset turns. Asset turns are calculated by dividing revenue by total assets, including both working capital and fixed assets (Bolstorff and Rosenbaum, 2007).

4.5.2 Responsiveness performance indicators

Responsiveness refers to how quickly the SC is able to deliver products to the customer. It is measured as the time that elapses from a customer's order being received to completed delivery (order fulfilment lead time) (Cohen and Rousell, 2012).

4.5.3 Sustainability performance indicators

Sustainability indicators measure the impact of SC processes on the environment. Common indicators include: proportion of reusable/recyclable materials to total material input, raw material efficiency, proportion of cost of energy in production to total value of output, volume of air emissions per year (NOx, SOx, CO2, VOC, etc.) (Rao et al., 2008).

Table 4.4 summarizes the performance indicators utilized in the proposed model

Table 4. 4: Indicators of supply chain performance

Performance Attribute		Indicators	Sub-indicators
Efficiency	Cost	Total cost to serve	• Planning cost • Sourcing cost • Material landed cost • Production cost • Order management cost • Fulfilment cost • Returns cost
	Asset management efficiency	• Cash-to-cash cycle time • Return on supply chain fixed assets • Return on working capital	
Responsiveness		Order fulfilment cycle time	• Source cycle time • Make cycle time • Deliver cycle time • Deliver retailer cycle time
Sustainability		• Reusable/recyclable materials to total material input • Raw material efficiency • Cost of energy to total value of output • Air emissions (NOx, SOx, CO2, VOC, etc.)	

4.6 Conclusions

Previous SC design efforts have only been able to achieve partial improvement in SC performance because they focus on isolated aspects of performance (e.g. cost or service) and do not take into account the complexities of the business environment. Crucially, they do not integrate strategy, process, network and performance into a single framework. The proposed framework addresses this problem by covering different aspects of SC performance and combining strategies to achieve the optimal levels of efficiency, responsiveness and sustainability throughout the whole supply chain.

The framework integrates the four key elements of strategy, process and resources. The strategic objective model suggests four SC strategies that can be deployed in response to different combinations of supply/demand conditions to achieve set goals and objectives. The process model then shows how these strategies can be implemented through different process configurations. It allows each entity in the SCN (e.g. supplier, manufacturer, distributor and retailer) to be modelled to ensure that SC resources are being deployed in accordance with the chosen policies and strategy.

The framework was subjected to modelling and simulation in order to validate it and demonstrate its applicability. Chapter 5 discusses the methodology that was employed, and presents the results of the modelling and simulation.

Chapter 5: Supply Chain Design: Modelling and Simulation

5.1 Introduction

This chapter describes the process through which the proposed framework, described in Chapter Four, was validated. This involved using the framework to design an SC for a hypothetical case study company and then using the Supply Chain Guru (SCG) software program to assess the performance of this design in terms of efficiency, responsiveness and sustainability. The first part of the chapter describes the building of a baseline model in SCG, the optimization process and the deployment of the program's simulation function to test the framework's performance under a range of demand scenarios. The second part of the chapter presents and discusses the results of the modelling and simulation stages and considers the extent to which they validate the framework.

5.2 Background

The SCG software package allows a single network model to be optimized and simulated without user interaction. It integrates network optimization, safety stock optimization, transportation optimization and simulation functions into a single SC optimization and simulation tool (see Figure 5.1), enabling companies to improve cost, service, sustainability and risk mitigation.

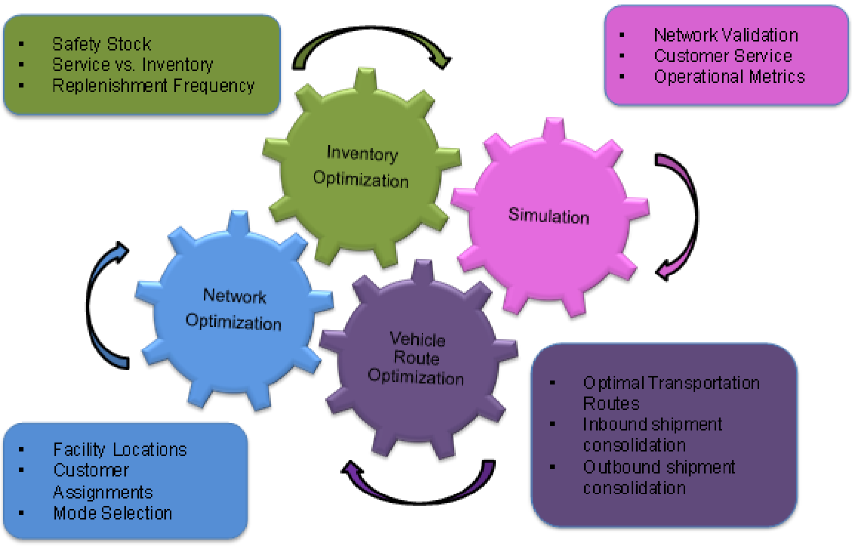


Figure 5. 1: Integrated solutions of Supply Chain Guru

The network optimization function determines the optimal network structure, flows and policies required to meet a defined demand, while the safety stock optimization function calculates the required safety stock, compares inventory cost to the achieved service level, and recommends inventory policy and associated parameters. The transportation optimization function aims to consolidate shipments through vehicle routing to minimize mileage, thereby reducing transportation costs. Finally, the simulation function allows the real-world system to be modelled over time for the purposes of validation and assessment.

5.3 Building the Supply Chain Guru Model

The SCG model consists of six main components: products, sites, demand, sourcing policy, transportation policy and inventory policy. This section discusses the data required for each of these components.

5.3.1 Products

Products are a key element in any SC model. Travelling across the nodes and lanes of the network, they are generally sourced, manufactured and shipped at defined cost and delivered to customers at a price to generate revenue. They can be represented by attributes such as name, value, price, weight and cubic volume.

5.3.2 Sites

Sites are essential within the SCN. The nodes between which products flow around the network, they may be customers, distributors, centres, factories, suppliers or ports. They may be defined in the model by name, type (e.g. existing facility, potential facility or customer) or location (address, geographic coordinates etc.).

5.3.3 Demand

Demand is central to the SCN because it describes the relationship between products and customers that drives the flow of the model. Demand information is sent through the network via sourcing policies until a facility in the network can satisfy the demand. The product is then sent back to the demanding customer via transportation policies. The demand relationship has four key elements: customer, product, quantity and time (i.e. when the customer places the order, though due date may also be factored into the simulation to determine whether a shipment is on time).

5.3.4 Sourcing policy

Sourcing policies link customers, distributors, manufacturers and suppliers, defining where a product is acquired from and determining the behaviour of source site, destination site and product. Sourcing policies can be represented in the model by attributes such as: source (origin of product), site (destination requesting the product), method by which a source is selected (e.g. make, multiple source or single source – see Table 5.1), product and lead time (time required before a request can be satisfied).

Table 5. 1: Types of sourcing policy

Sourcing Policy	Description
Single Source	Replenishment orders are filled by only one source facility
Multiple Sources	Multiple source policies vary; they may based on: - most inventory at potential suppliers - defined preference - random probabilities - split according to defined ratios - Fastest Path - Close to Due Date
Source by Transfer	Replenishment orders are never placed, regardless of inventory levels
Make	Allows for production by filling incoming orders within the site. Make policies include: - Make by Schedule - Make (Single Process): the first process that has enough capacity is selected - Make (Order of Preference) - Make (Process - Probability) - Make (Single BOM): the first BOM that has enough capacity is selected - Make (BOM - Probability)

5.3.5 Transportation policies

Transportation policies define how products travel through the network and the behaviour of the source site and destination site. Each non-production sourcing policy requires at least one corresponding transportation policy to allow for flow between the two sites. Every transportation policy must consider the source site, the destination site, the mode of transport between the two, and time. SCG provides a range of transportation policies to model the many different modes of transportation seen in any SC. Table 5.2 presents the most common transportation policies.

Table 5. 2: Types of transportation policy

Transportation Policy	Description
Parcel	Product bundles are shipped immediately
LTL (Less than Truckload)	Product bundles are not aggregated
Full TL (Full Truckload)	Product bundles are aggregated to Full TL for shipment
Aggregate Container	Product bundles are assembled into containers for simpler shipping

5.3.6 Inventory policies

Inventory policies define the relationship between products and sites. Because all non-customer sites have the potential to hold inventory, a policy must be defined to specify how the inventory is held. Inventory policies must have the following elements: site name, product name, initial inventory, reorder point (RP – the stock level at which to place another order), reorder amount/order up to quantity (RQ – the amount of product to order at each reorder) and reorder policy (the method by which reorders are placed). Inventory policies are the method by which RQ, RP and review period levels are set. Potential inventory policies include:

R,Q: a fixed replenishment point/fixed replenishment quantity inventory policy. When the inventory level on-hand falls below a certain replenishment point, R, the site will generate a replenishment order for a certain quantity, Q, of this product. Figure 5.2 presents R,Q policy.

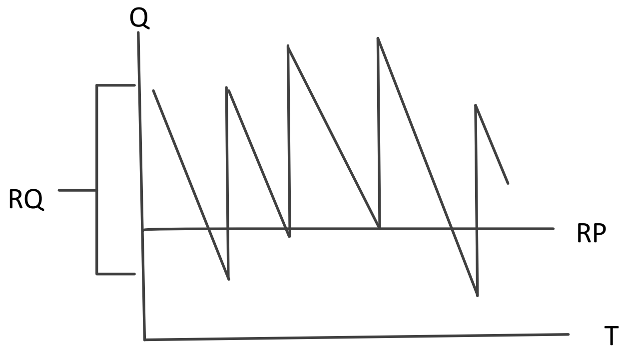


Figure 5. 2: R,Q policy

Demand flow: a one-for-one replenishment policy; if one product is shipped, one is ordered to replace. This means that every order that arrives at a site for a certain product will generate a request for a replenishment order for the exact same quantity. Figure 5.3 presents demand flow policy.

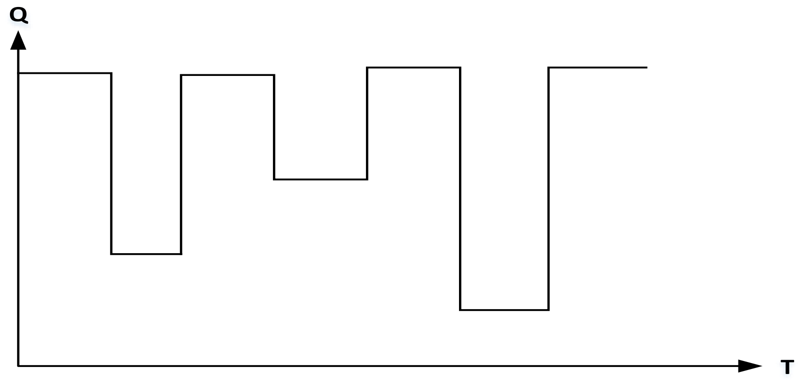


Figure 5. 3: Demand flow policy

Although it seems straightforward, demand flow represents complex behaviour, especially when combined with review period. Setting a review period can produce batching as replenishment orders accumulate during the review period and are filled at its end.

S,s: a minimum/maximum inventory policy. When the inventory level on-hand falls below a minimum, s, the site will generate a request for a replenishment order that will restore the on-hand inventory to a target, or maximum, number, S. Figure 5.4 presents S,s policy.

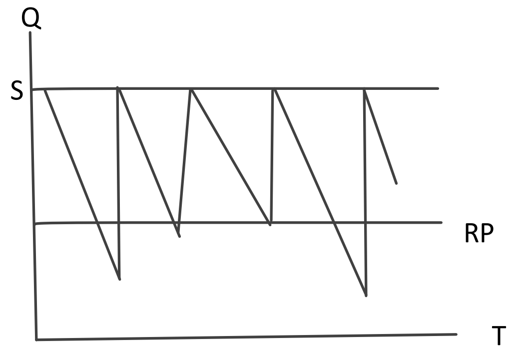


Figure 5. 4: S,*s* policy

T,S: periodic review order up to level is relatively simple and reflects real-world practice to a great extent. This policy is preferred in an intermittent demand context. SCG uses this policy to handle the lumpy demand class. The periodic policy provides the convenience of regular ordering days for the stock list and for the supplier who can plan efficient routing of the delivery vehicles.

Base stock: is preferable when economies of scale in the supply system are negligible relative to other factors. If individual units are very valuable, for example, holding and backorder costs may outweigh any fixed order costs. A base stock policy is also recommended for a slow-moving product (one with a low demand rate) where the economics of the situation rule out large batch sizes.

5.4 Supply Chain Guru: Modelling, Optimization and Simulation

This section discusses the steps involved in applying the SC modelling and simulation to the chosen case study. The section begins by introducing the case study SC before outlining the steps taken to build the baseline model and optimize the inventory and transportation functions. It then describes how the simulation scenarios were built and run to develop solutions for multiple SCD configurations.

5.4.1 Case study

The case study is a hypothetical SC manufacturing children's clothing, (see figure 5.5). The case study focuses specifically on a boys' cotton clothing set. Although the SC was created for the purpose of the study, the data used were taken from real websites; for example, production data were taken from the website of a real manufacturing company producing the same product, while transportation data were taken from a real haulage company. These data are presented in the input data tables in section 5.4.3.

Figure 5. 5: Supply chain of the case study

5.4.2 Overall method

The SCG modelling method comprised a sequence of steps, as described below (see Figure 5.6).

1. **Demand modelling**

   As there were no historical demand data for the study's hypothetical SC, probability distributions were employed to generate different demand patterns (e.g. predictable and unpredictable). Normal distribution was used to create smooth demand, lognormal distribution to produce erratic demand, bounded normal distribution to generate lumpy and slow demand, and Poisson distribution to produce slow, low variable demand.

2. **Demand analysis**

   The demand analysis tool was then used to classify the nature of this demand (e.g. as smooth, erratic, slow or lumpy) according to defined statistical criteria (see Figure 5.9).

3. **Safety stock optimization (SSO)**

   Once demand analysis had been completed, the safety stock function was run to calculate the required stock under the recommended inventory policy and its associated parameters (reorder point, reorder quantity). SSO was run for both predictable demand (smooth) and unpredictable demand (lumpy), with three scenarios in each demand category.

4. **First-run simulation**

   In the absence of comprehensive real data, this step allowed the model to generate shipment details for use in the transportation optimization (TO) function (see Figure 5.15). The simulation ran three different time scenarios for each volume scenario, generating nine different shipment details in order to be populated to Transportation optimization function.

5. **Transportation optimization (TO)**

   This provided a range of solutions in terms of routes, vehicles and shipment optimization, allowing the user to choose the most cost- and logistics-efficient. Transportation optimization involved the following sub-steps:

   - Shipment details were divided into inbound and outbound and optimized separately (SCG does not support whole shipment optimization).
   - Any unrouted shipments, which mostly happens because of vehicles capacity, were split manually and re-entered.
   - All shipments could then be delivered and transportation optimization could be completed.

The focus on finding optimal solutions for inventory and transportation reflects the impact of these functions on SC efficiency and responsiveness. In inventory's case, SSO is employed to study the effect of demand volume on efficiency and responsiveness under a range of demand size scenarios. Similarly, TO is used to find the transportation solution that will best solve several scenarios for the length of time required to meet demand. Having optimized the problem in terms of inventory and transportation, the resulting data were used to run a second-run simulation.

6. **Second-run simulation**

   This final step aimed to simulate different demand patterns (e.g. predictable and unpredictable) under different scenarios (e.g. changes in the demand level and time period) and to develop alternative solutions in each scenario to raise efficiency or responsiveness as required.

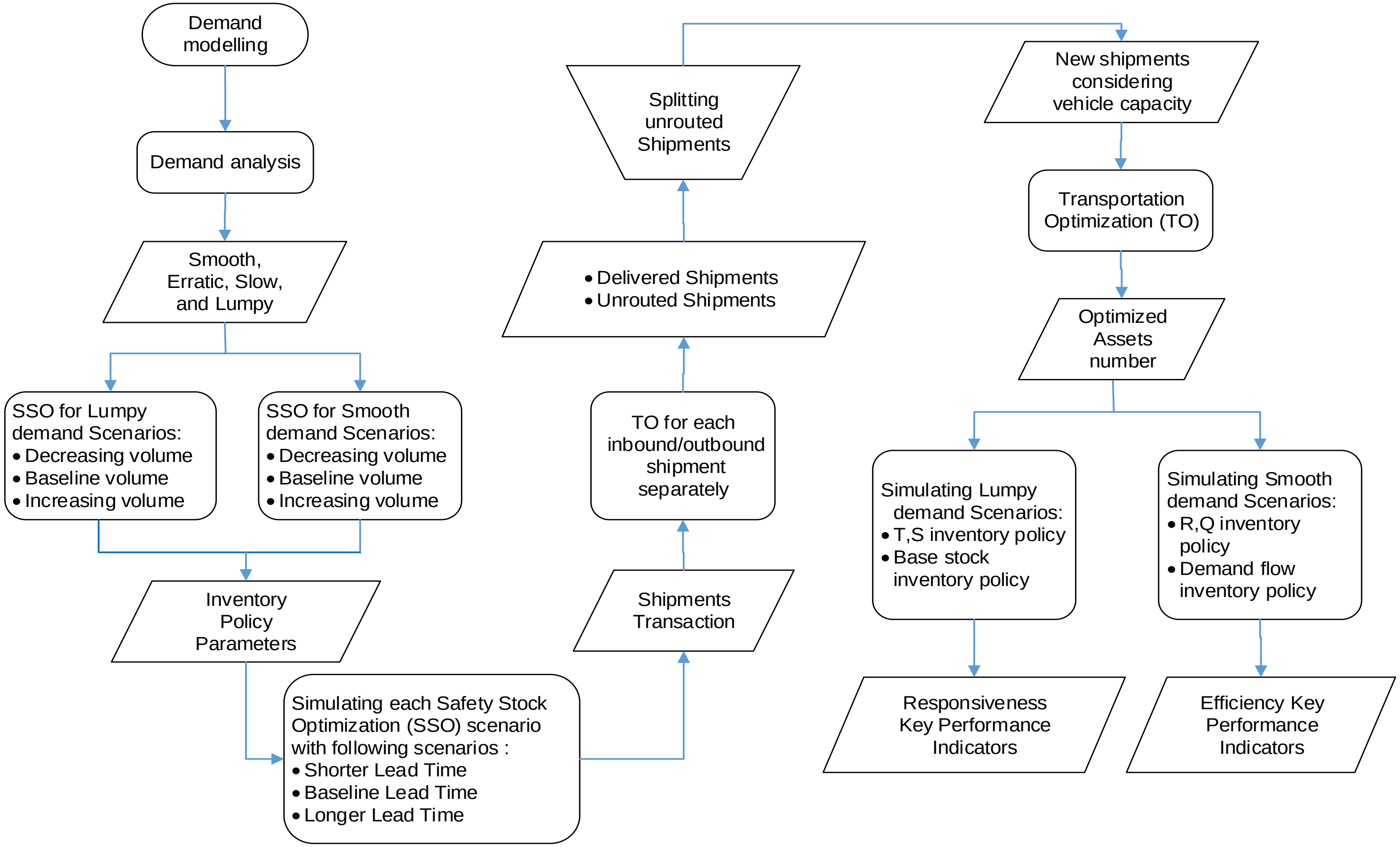


Figure 5. 6: SCG modelling and simulation method

5.4.3 Baseline model

A baseline model allows comparison between current SC performance and the results produced by the simulation under different scenarios. This allows the user to test changes and plan for improvements (see Figure 5.7).

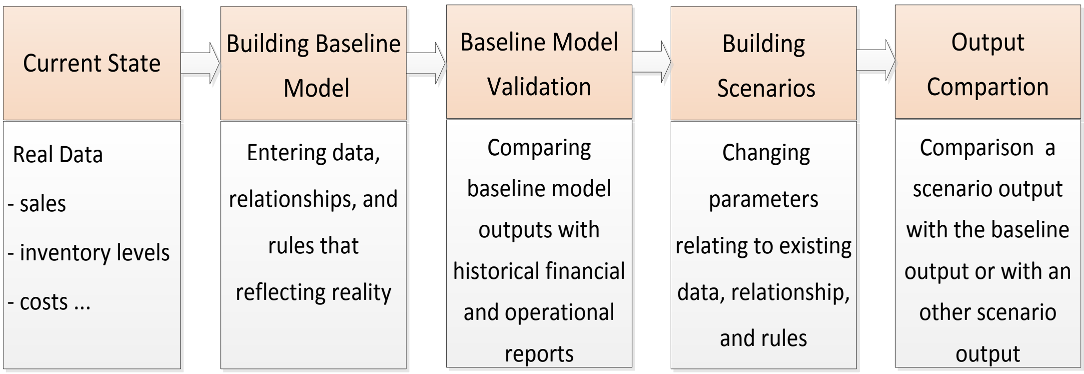


Figure 5. 7: Using a baseline model

The baseline model imitates reality by replicating the real-life relationships between variables. The accuracy of this imitation is confirmed by comparing the model's performance with the real-life chain's historic performance under identical conditions. Once validated, the model can be employed to assess and improve the real-life SC. Figure 5.8 shows example inputs and outputs for a baseline model.

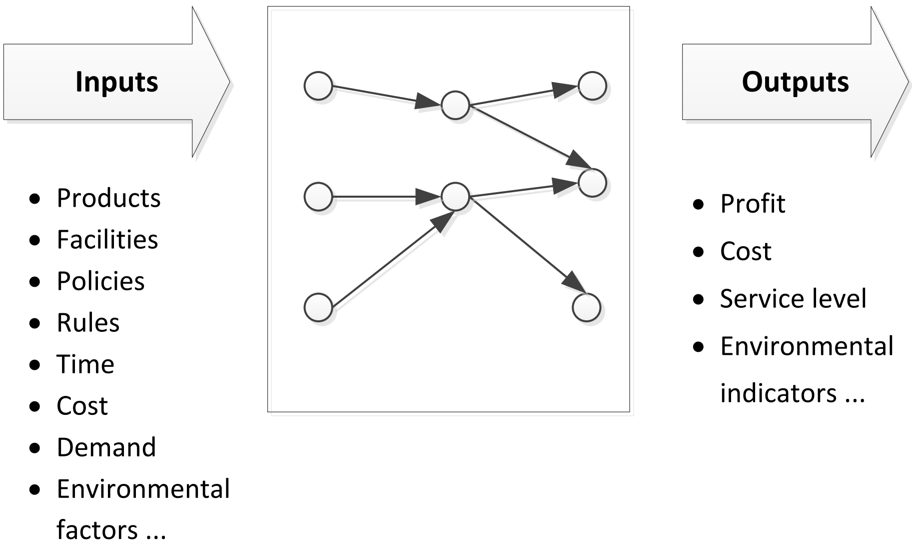


Figure 5. 8: Baseline model inputs and outputs

Tables 5.3 to 5.9 present the data inputs that were used in the baseline model for this case study.

Table 5. 3: Model data inputs - product

Name *	Value ($)	Price ($)	Weight (Kg)	Cubic (m^3)
P	7.5	9	0.75	0.02
R1	0.65	0.65	0.5	0.0133
R2	0.35	0.35	0.25	0.0066
R3	0.35	0.35	0.1	0.0001

P: End product   R: Raw material

Table 5. 4: Model data inputs - demand

Product Name	Site Name	Quantity*	Order Time	Occurrence	Time Between Orders	Unit Price ($)
P	DIS1- Karachi	N(1000,70)	1/1/2018	INF	10 Days	9
P	DIS2- Shanghai	N(1000,50)	1/1/2018	INF	10 Days	9
P	DIS3- London	N(1000,150)	1/1/2018	INF	10 Days	9

* Based on normal distribution N (μ, σ)

Table 5. 5: Model data inputs - sourcing policy

Source Name	Site Name	Product Name	Sourcing Policy	BOM Name	Source Lead Time	Production Time*
	SUP1 New Delhi	R1	Make		1 Day	N(9,2) Day
	SUP2 Tokyo	R2	Make		1 Day	N(5,1) Day
	SUP3 Jakarta	R3	Make		1 Day	N(8,2) Day
	MAN- Beijing	P	Make	P_BOM	1 Day	N(8,2) Day
SUP1 New Delhi	MAN- Beijing	R1	Single Source		8 HR	
SUP2 Tokyo	MAN- Beijing	R2	Single Source		8 HR	
SUP3 Jakarta	MAN- Beijing	R3	Single Source		8 HR	
MAN- Beijing	DIS1- Karachi	P	Single Source		8 HR	
MAN- Beijing	DIS2- Shanghai	P	Single Source		8 HR	
MAN- Beijing	DIS3- London	P	Single Source		8 HR	

* Based on normal distribution N (μ, σ)

Table 5. 6: Model data inputs - bill of material (BOM)

Name	Product Name	Quantity	Type
P_BOM	R1	1	Component
P_BOM	R2	2	Component
P_BOM	R3	1	Component

Table 5. 7: Model data inputs - transportation policy

Source Site	Destina. tion Site	Product Name	Mode Rule	Source Policy	Cost ($)*	Ship. Size	Distan. ce	Tran. Time (day)	Asset Nam e
SUP1- New Delhi	MAN- Beijing	R1	First	LTL	0.9	2400	11815	19	A1
SUP2 - Tokyo	MAN- Beijing	R2	First	LTL	0.0016	4836	1296	4	A2
SUP3- Jakarta	MAN- Beijing	R3	First	LTL	0.13	319200	5736	9	A3
MAN- Beijing	DIS1- Karachi	P	First	Full TL	0.31	1596	10478	17	A4
MAN- Beijing	DIS2- Shanghai	P	First	Full TL	0.43	1596	1220	2	A5
MAN- Beijing	DIS3- London	P	First	Full TL	5.30	1596	20360	30	A6

* Transportation cost per unit

Table 5. 8: Model data inputs - transportation assets

Name	Units	Unit Fixed Cost ($)	Quantity Fill Level	Quantity Capacity	Speed (Distance / H)	Home Asset Base
A1	7	2165	1920	2400	26	SUP1-New Delhi
A2	25	506	3869	4836	14	SUP2 -Tokyo
A3	17	641	255360	319200	27	SUP3- Jakarta
A4	7	500	1277	1596	26	MAN- Beijing
A5	7	686	1277	1596	26	MAN- Beijing
A6	7	8500	1277	1596	29	MAN- Beijing

Table 5. 9: Model data inputs - inventory policy

Site Name	Prod. Name	Inven. Policy	Reorder Point	Reorder Qty	Initial Inven.	Safety Stock Basis	Service Req.	DOS Window
SUP1-New Delhi	R1	R,Q				Days Of Supply	0.95	25
SUP2 - Tokyo	R2	R,Q				Days Of Supply	0.95	25
SUP3-Jakarta	R3	R,Q				Days Of Supply	0.95	25
MAN-Beijing	P	R,Q				Days Of Supply	1.00	25
MAN-Beijing	R1	R,Q				Days Of Supply	1.00	25
MAN-Beijing	R2	R,Q				Days Of Supply	1.00	25
MAN-Beijing	R3	R,Q				Days Of Supply	1.00	25

5.4.4 Optimization of baseline model

The baseline model was optimized for two main functions, inventory and transportation. SSO was run to find optimum inventory policy solutions, while TO was run to find the optimum level of transportation resources required.

Safety stock optimization (SSO)

Safety stock is buffer stock that is maintained to mitigate the risk of stock-outs due to uncertainties in supply and demand. It insures against variability in demand and lead time. Prior to SSO, demand analysis must be performed to propagate customer demand to upstream sites, calculate demand statistics and classify demand into different categories. SSO helps the user identify demand characteristics and determine whether demand is intermittent or non-intermittent, smooth, erratic, slow or lumpy. Figure 5.9 presents the statistical parameters underlying these classifications.

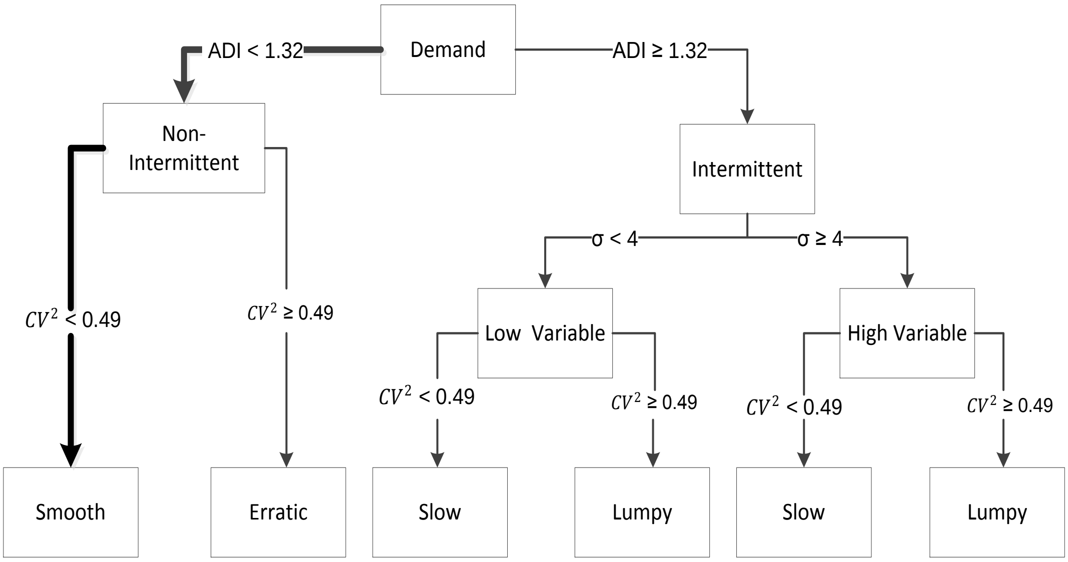


Figure 5. 9: Demand classification

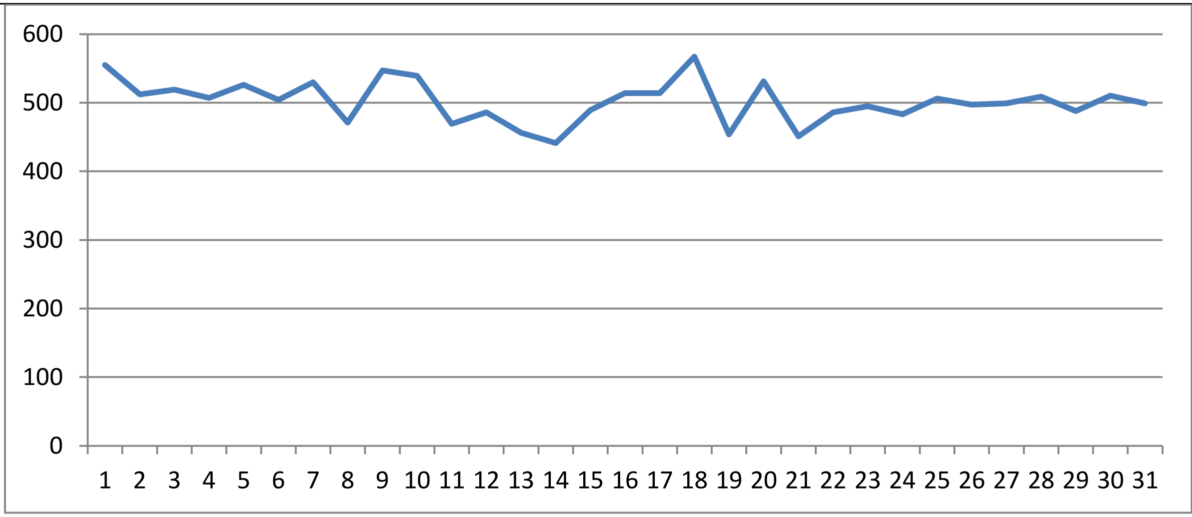
Table 5.10 shows one of demand analysis outputs for the baseline model in this study; that is, the customer demand profile.

Table 5. 10: Customer demand profile

Customer Name	Prod. Name	Intermittency	Demand Class	Inter-demand Interval Mean	Non-Zero Demand CV^2	Non-Zero Demand Std Dev
DIS1-Karachi	P	Non-Intermittent	Smooth	1	0.03	532.7293
DIS2-Shanghai	P	Non-Intermittent	Smooth	1	0.02	471.9285
DIS3-London	P	Non-Intermittent	Smooth	1	0.03	1100.874

Demand analysis was performed to model a range of demand patterns, as shown in Figures 5.10 – 5.14.

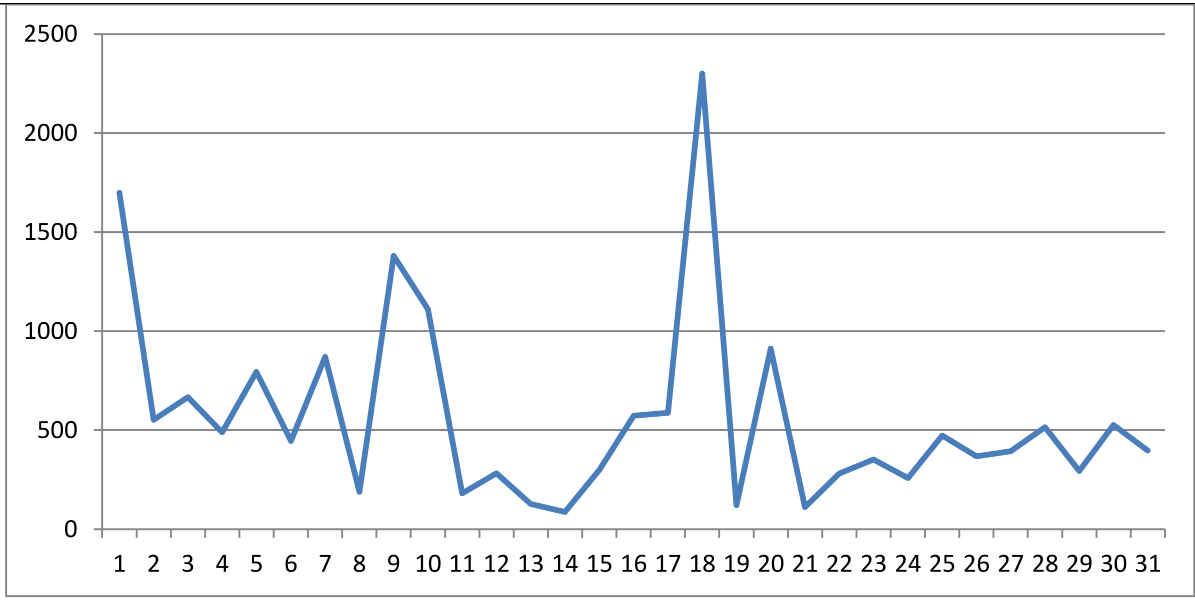
DIS	Normal
Mean	500
StDv	25
-	-
-	-



Intermittency	Non Intermittent
ADI	1
CV^2	0.0037
Demand Class	Smooth
-	-

Figure 5. 10: Smooth demand

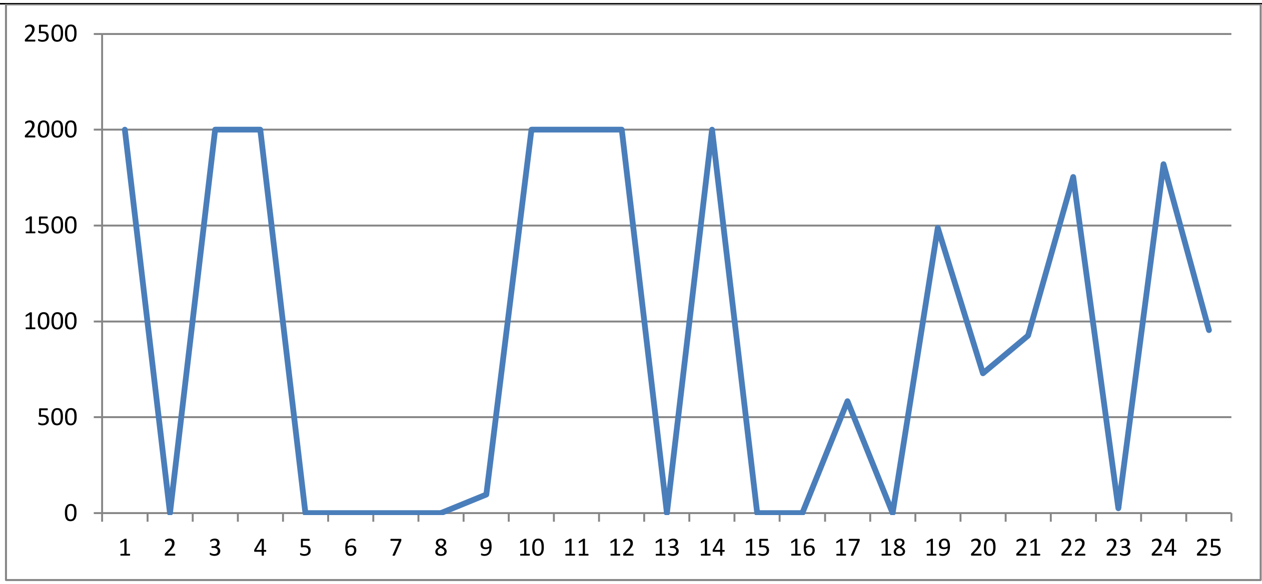
DIS	Lognormal
Mean	6
StDv	0.65



Intermittency	Non Intermittent
ADI	1
CV^2	0.74
Demand Class	Erratic

Figure 5. 11: Erratic demand

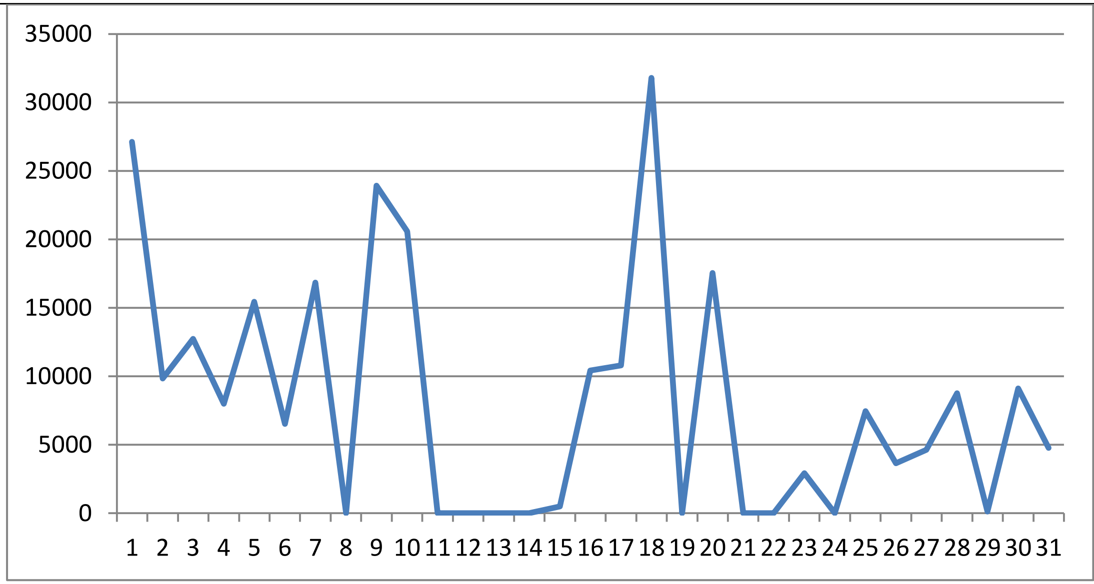
DIS	Bounded Normal
Mean	1000
StDv	2000
Min	0
Max	2000



Intermittency	Intermittent
ADI	1.43
CV^2	0.190
Non-Zero StDv	660
Demand Class	Slow Highly Variable

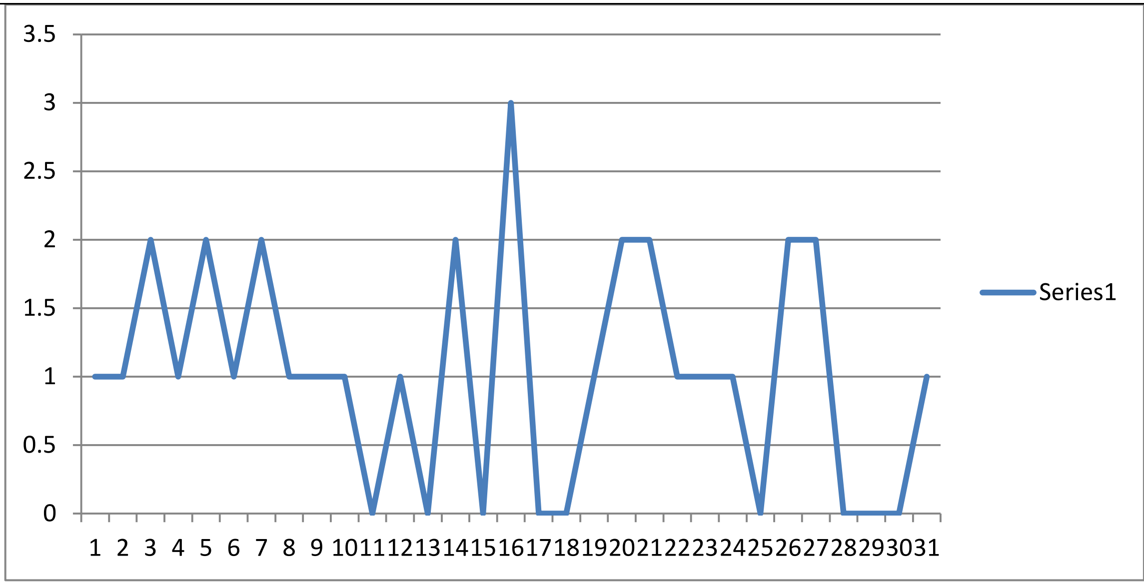
Figure 5. 12: Slow demand

DIS	Bounded Normal
Mean	5000
StDv	10000
Min	0
Max	50000



Intermittency	Intermittent
ADI	1.43
CV^2	0.547
Non-Zero StDv	8518
Demand Class	Lumpy Highly Variable

Figure 5. 13: Lumpy demand



DIS	Poisson		Intermittency	Intermittent
Mean	0.9		ADI	1.42
			CV^2	0.167
			Non-Zero StDv	0.56
			Demand Class	Slow Low Variable

Figure 5. 14: Slow demand

SSO also helps the user determine when to replenish inventory (RP) and by how much (RQ) in order to optimize inventory holding cost and reduce the risk of stock-out. The SSO function in SCG recommends an inventory policy that optimizes inventory cost and service level for a given demand pattern. Table 5.11 presents the inventory policy recommended in the baseline model for the case study supply chain.

Table 5. 11: Inventory policy summary

Site Name	Prod. Name	Recommended Policy	Parameter1 (R)	Parameter2 (Q)
MAN- Beijing	P	R,Q	0	3796
MAN- Beijing	R1	R,Q	12252	14425
MAN- Beijing	R2	R,Q	7662	6074
MAN- Beijing	R3	R,Q	6885	6833
SUP1-New Delhi	R1	R,Q	0	3796
SUP2 -Tokyo	R2	R,Q	0	7592
SUP3- Jakarta	R3	R,Q	0	3796

Transportation optimization (TO)

TO allows the user to resolve the vehicle routing problems (VRP) associated with the consolidation of shipments into multi-stop routes. The aim is to minimize the total transportation cost by finding the optimum number of vehicles (assets) required for the routed shipments. The first step in this process is to generate a shipment transaction table from the simulation model. Figure 5.15 shows the shipment transaction table generated for the case study company, assuming a smooth demand scenario.

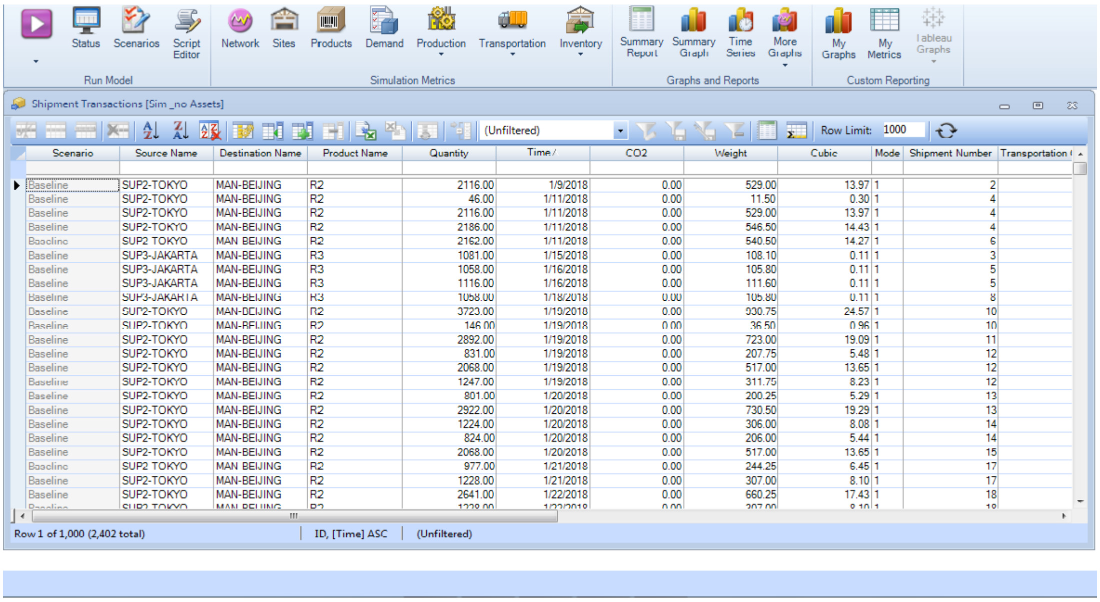


Figure 5. 15: Shipment transactions excluding assets

The shipment table is then separated into two: inbound shipments of raw materials from all suppliers (R1, R2 and R3) and outbound shipments of products (P) for distributors. These are fed into the TO model for a first-run simulation (see figure 5.6). The important output from this step is the identification of unrouted shipments – these are usually the result of limited vehicle capacity. Figure 5.16 shows an unrouted shipment table for the case study company.

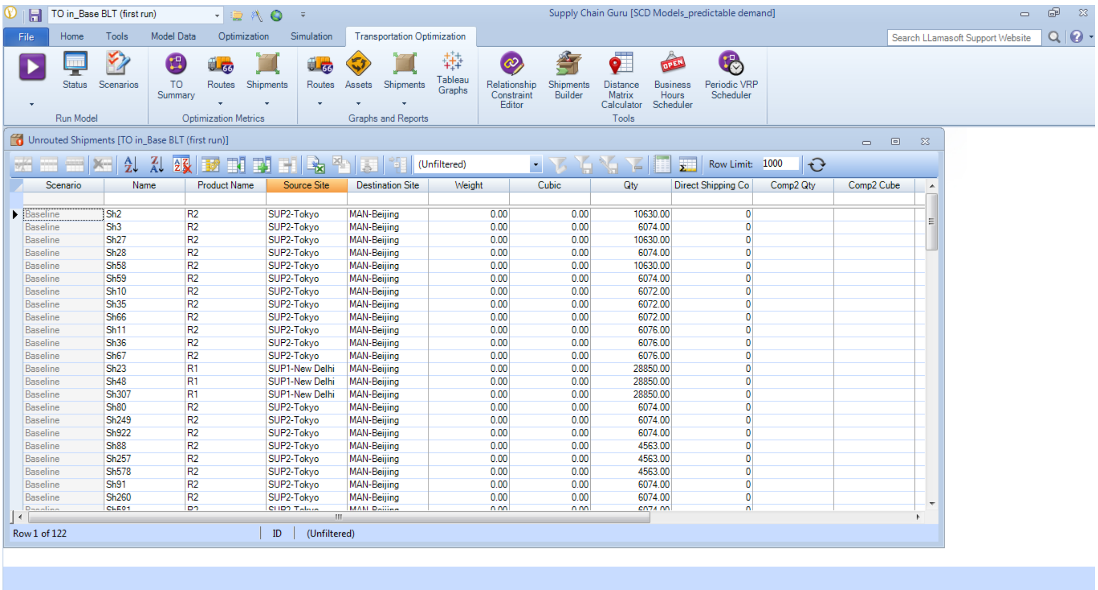


Figure 5. 16: Unrouted shipment table

In order to find the accurate optimized asset number, unrouted shipments should be split manually as SCG does not support this function. Once this has been done, the input shipment is adjusted accordingly and TO can be run again to find the optimum asset number. Figure 5.17 shows the asset summary table obtained from the inbound TO model for the case study company.

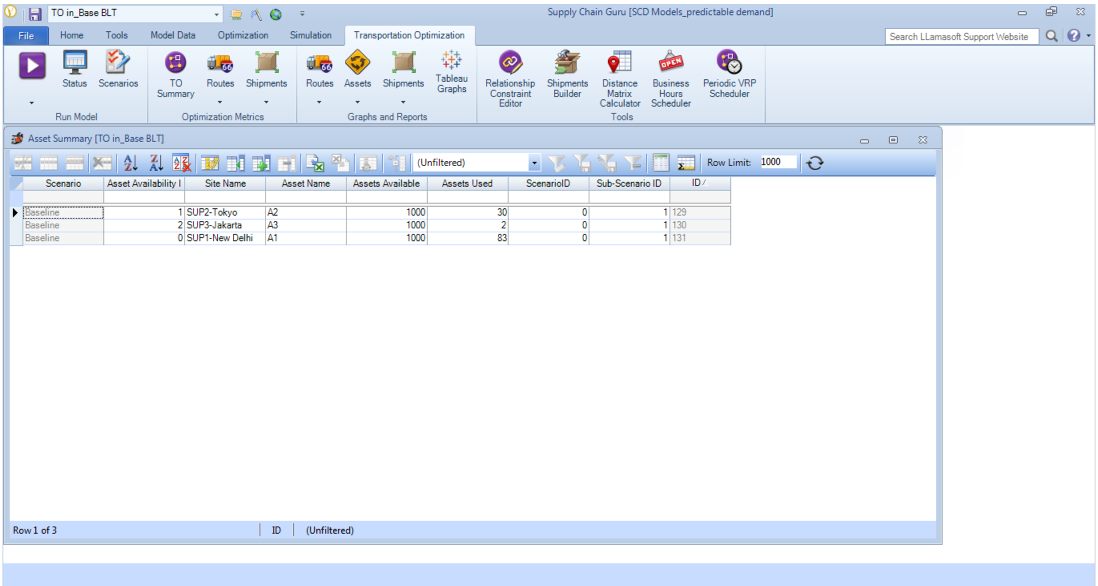


Figure 5. 17: Asset summary table

5.4.5 Simulation scenarios in the baseline model

Having identified policy parameters and achieved optimized solutions for the inventory and transportation functions, the next step was to build a range of simulation scenarios to test the framework's ability to deal with certain and uncertain demand characteristics.

Smooth demand scenarios (efficient strategy)

Smooth demand, which is characterized by a high level of certainty and high-volume quantities, generally requires that a lean strategy be implemented. According to the strategic objective model in the proposed framework, lean strategy can be applied by adopting different inventory policies depending on the required demand lead time. A plan and execute policy, for example, suits a long demand lead time, while a policy of continuous replenishment is more appropriate where demand lead time is short. SCG's best option for a plan and execute inventory policy under conditions of smooth demand is R,Q (see section 5.2.6), as it ensures sufficient inventory (R) and replenishment by quantity (Q) where R,Q values are set according to demand level and lead time. A demand flow policy, on the other hand, ensures that inventory is continuously replenished by ordering a quantity equal to the amount withdrawn.

Variable demand scenarios (responsive strategy)

Variable demand is characterized by uncertainty and a high level of variability. Since lumpy demand is considered the most uncertain and changeable type, and therefore the most difficult to satisfy, this was the scenario modelled in the simulation. The proper strategic response to this type of demand is agile or leagile, depending on the level of certainty and volumes involved, and the most appropriate inventory policies are postponement and quick response. Postponement suits uncertain, variable demand with a long lead time (SCG suggests T,S inventory policy for downstream sites and S,s policy for upstream sites), while quick response is more appropriate where customers are not willing to wait long for their orders. In this situation, SCG recommends base stock policy, which ensures continuous review of inventory levels and immediate inventory replenishment, allowing a rapid response to customer demand.

Impact of implemented strategy on SC sustainability

SC sustainability was measured in terms of CO_2 emissions. In real life, CO_2 emissions come from various sources, but as transportation is responsible for a large proportion of the total CO_2 produced by SC activities, this was the only metric used in the simulation. SCG provides input data related to CO_2 emission calculations; in the case study, CO_2 was calculated based on weight-distance.

5.5 Results of modelling and simulation

5.5.1 Performance results from the baseline model

Table 5.12 depicts the current performance of the case study company, as reflected in the results from the baseline model.

Table 5. 12: Results from baseline model

Performance Aspect	Performance Indicator	Replications of Indicators Result					
		1	2	3	4	5	Avg.
Efficiency	Profit to Revenue (%)	31.57	31.90	31.08	31.78	31.65	31.60
Responsiveness	Avg. Fill Qty Rate (%)	39.91	39.82	39.64	40.70	40.91	40.20
Sustainability	CO2 Emissions (kg)	734	721	739	731	726	730

5.5.2 Optimization of results from baseline model (predictable demand)

Table 5.13 shows various scenarios of predictable demand volume for the baseline model. These were modelled using normal distribution for different values of mean and standard deviation. The baseline mean was based on real demand data from a similar manufacturer, while the standard deviation was chosen to generate a smooth predictable demand pattern (see Figure 5.9). Based on the baseline model data, the other values assumed in order to generate increased and decreased demand scenarios.

Table 5. 13: Different scenarios of predictable demand volume

Demand Volume/ Distributors	DIS1	DIS2	DIS3
Baseline Demand	N(1000,70)	N(1000,50)	N(2000,150)
Increased Demand	N(2000,140)	N(2000,100)	N(4000,300)
Decreased Demand	N(500,35)	N(500,25)	N(1000,75)

Optimization of inventory parameters

The same scenarios were then optimized to find the optimized inventory parameters for each scenario (see Table 5.14).

Table 5. 14: Optimized inventory parameters for different predictable demand scenarios

Sites	Products	Baseline Demand		Increased Demand		Decreased Demand	
		R	Q	R	Q	R	Q
SUP1	R1	0	3796	0	3309	0	1898
SUP2	R2	0	7592	0	6618	0	3796
SUP3	R3	0	3796	0	3309	0	1898
MAN	P	0	3796	0	3309	0	7213
	R1	12252	14425	10688	12574	6126	3037
	R2	7662	6074	6686	5295	3831	3417
	R3	6885	6833	6007	5956	3443	6833

R: Reorder point Q: Reorder quantity

Optimization of transportation assets

This optimization was carried out for a range of lead time scenarios where lead time was assumed to be restricted to transportation time. Table 5.15 shows the assumed lead time values.

Table 5. 15: Different scenarios for transportation lead time

Destination	Baseline Lead Time (BLT) (days)	Longer Lead Time (LLT) (days)	Shorter Lead Time (SLT) (days)
SUP1- MAN	19	27	8
SUP2 - MAN	4	6	2
SUP3 - MAN	9	14	5
MAN - DIS1	17	25	9
MAN – DIS2	2	3	1
MAN – DIS3	30	45	15

The optimized asset number was established for each lead time and demand volume scenario, as shown in Table 5.16.

Table 5. 16: Optimized transportation asset numbers for different predictable demand scenarios

Asset Name	Baseline Demand	Increased Demand		Decreased Demand	
	BLT	LLT	SLT	LLT	SLT
A1	83	62	48	22	43
A2	30	27	15	6	16
A3	2	2	5	3	5
A4	21	13	17	9	10
A5	9	4	6	3	5
A6	48	27	34	15	20

Performance results from the optimized baseline model

Once the baseline model had been optimized in terms of inventory and transportation functions, the optimum values were fed into the model and a simulation run to get performance indicators (see Table 5.17).

Table 5. 17: Performance of optimized baseline model

Performance Aspect	Performance Indicator	Replications of Indicators Result					
		1	2	3	4	5	Avg.
Efficiency	Profit to Revenue (%)	31.57	31.90	31.08	31.78	31.64	31.78
Responsiveness	Avg. Fill Qty Rate (%)	45.28	46.31	45.79	46.10	45.89	45.87
Sustainability	CO2 Emissions (kg)	717	694	715	714	706	709

Optimization of results under scenarios of unpredictable (lumpy) demand

The validation process also involved repeating the same steps for various scenarios of unpredictable demand. Table 5.18 shows the demand values for three scenarios. These were modelled using Bounded Normal (BN) distribution and Bounded Lognormal (BL) distribution. The distribution types and their related parameters including mean, standard deviation, minimum value, and maximum value were chosen in order to generate an unpredictable lumpy demand pattern (see Figure 5.9).

Table 5. 18: Different scenarios of unpredictable demand volume

Demand Volume / Distributors	DIS1	DIS2	DIS3
Baseline Demand	BL(2500,10000,0, 5000)	BN(2900,45000,0, 21000)	BN(2000,10000,0, 10000)
Increased Demand	BL(5000,20000,0, 10000)	BN(5800,90000,0, 42000)	BN(4000,20000,0, 20000)
Decreased Demand	BL(1250,5000,0, 2500)	BN(1450,22500,0, 11500)	BN(1000,5000,0, 5000)

Optimization of inventory parameters

Table 5.19 shows the optimized R and Q values for a range of unpredictable demand scenarios.

Table 5. 19: Optimized inventory parameters for different unpredictable demand scenarios

Sites	Products	Baseline Demand		Increased Demand		Decreased Demand	
		R	Q	R	Q	R	Q
SUP1	R1	0	5755	0	11510	0	2976
SUP2	R2	0	11510	0	23019	0	5951
SUP3	R3	0	5755	0	11510	0	2976
MAN (Manufacturer)	P	2427	5755	4853	11510	1294	2976
	R1	53006	21868	106011	43735	27305	11306
	R2	4853	14061	9705	28120	2587	7348
	R3	23019	10359	46038	20717	11931	5356

R: Reorder point Q: Reorder quantity

Optimization of transportation assets

Optimized transportation asset numbers for different unpredictable demand scenarios are shown in Table 5.20.

Table 5. 20: Optimized transportation asset numbers for different unpredictable demand scenarios

Asset Name	Baseline Demand			Increased Demand			Decreased Demand		
	BLT	LLT	SLT	BLT	LLT	SLT	BLT	LLT	SLT
A1	63	54	95	129	127	164	44	35	54
A2	28	24	27	19	40	44	18	16	18
A3	3	3	4	3	2	4	3	3	4
A4	12	12	11	13	12	16	4	9	10
A5	9	8	8	6	8	12	5	7	8
A6	20	18	21	25	21	39	19	17	24

Performance results from the optimized unpredictable (lumpy) baseline model

Again, the optimized values were entered into the model and a simulation run to get performance indicators. These are shown in Table 5.21.

Table 5. 21: Performance of optimized unpredictable demand baseline model

Performance Aspect	Performance Indicator	Replications of Indicators Result					
		1	2	3	4	5	Avg.
Efficiency	Profit to Revenue (%)	40.57	40.69	41.02	34.55	37.90	38.94
Responsiveness	Avg. Fill Qty Rate (%)	22.33	23.80	20.83	30.60	30.10	25.53
Sustainability	CO_2 Emissions (kg)	966	920	929	642	739	939

5.5.3 Simulation results for efficient, responsive and sustainable SCD scenarios

This section presents the results of the simulations investigating different aspects of SC performance. Table 5.22 shows what happened when efficiency strategies (R,Q and demand flow) were implemented under six different scenarios of predictable demand, while Table 5.23 shows the results of implementing responsiveness strategies (T,S and base stock) under six different scenarios of unpredictable demand. Table 5.24 shows the results of the simulation investigating the environmental impact (i.e. the sustainability) of these strategies under the various scenarios. The mentioned tables present performance results by using the suggested policies within the developed framework, these results were summarized and presented in section 5.5.5 to validate the framework.

Table 5. 22: Performance of efficiency strategies under scenarios of predictable demand

Scenario No	Demand Volume	Lead Time	Utilized Policy	Performance Indicator	Replications of Indicators Result					
					1	2	3	4	5	Avg.
1	Lower	SLT	R,Q	Profit to Revenue (%)	29.42	30.10	29.83	29.90	30.05	29.86
2	Base	BLT	R,Q	Profit to Revenue (%)	31.90	32.37	31.64	31.60	31.41	31.78
3	Higher	LLT	R,Q	Profit to Revenue (%)	32.00	32.87	32.68	32.35	31.94	32.37
4	Lower	LLT	Demand Flow	Profit to Revenue (%)	25.42	25.48	25.47	25.50	25.033	25.38
5	Base	BLT	Demand Flow	Profit to Revenue (%)	28.12	28.13	28.14	27.80	27.84	28.00
6	Higher	SLT	Demand Flow	Profit to Revenue (%)	30.60	30.60	30.79	30.39	30.52	30.58

Table 5. 23: Performance of responsiveness strategies under scenarios of unpredictable demand

Scenario No	Demand Volume	Lead Time	Utilized Policy	Performance Indicator	Replications of Indicators Result					
					1	2	3	4	5	Avg.
1	Higher	SLT	T,S	Avg. Fill Qty Rate (%)	27.30	32.00	26.50	45.44	36.76	33.60
2	Base	BLT	T,S	Avg. Fill Qty Rate (%)	28.61	31.30	29.26	50.19	39.67	35.80
3	Lower	LLT	T,S	Avg. Fill Qty Rate (%)	31.14	34.56	32.63	46.26	40.87	37.10
4	Higher	LLT	Base Stock	Avg. Fill Qty Rate (%)	13.52	15.45	13.16	26.63	23.10	18.37
5	Base	BLT	Base Stock	Avg. Fill Qty Rate (%)	22.33	23.79	20.83	30.6	30.10	25.53
6	Lower	SLT	Base Stock	Avg. Fill Qty Rate (%)	31.75	32.78	30.47	33.68	35.23	32.78

Table 5. 24: Sustainability performance of efficiency and responsiveness strategies under different scenarios of predictable and unpredictable demand

Scenario No	Strategy	Utilized Policy	Dem. Volume	Lead Time	Performance Indicator	Replications of Indicators Result					
						1	2	3	4	5	Avg.
1	Efficiency	R,Q	Lower	SLT	CO2 Emission (kg)	602	593	597	591	591	595
2			Base	BLT		717	694	715	714	706	709
3			Higher	LLT		1016	1003	1027	1031	1017	1019
4		Demand Flow	Lower	LLT	CO2 Emission (kg)	704	699	707	705	701	703
5			Base	BLT		870	861	876	871	867	869
6			Higher	SLT		1210	1190	1220	1202	1209	1206
7	Responsiveness	T,S	Higher	SLT	CO2 Emission (kg)	1460	1383	1415	830	1024	1222
8			Base	BLT		907	867	879	595	692	788
9			Lower	LLT		659	637	641	501	541	596
10		Base Stock	Higher	LLT	CO2 Emission (kg)	1532	1455	900	1475	1104	1293
11			Base	BLT		966	920	929	642	739	839
12			Lower	SLT		678	670	682	524	572	625

5.5.4 Discussion of results

This section discusses the results presented in the previous section. Table 5.10 shows the results of the demand analysis for the baseline model. This is smooth, as demand is non-intermittent (ADI < 1.32) (see Figure 5.8). Figures 5.10 through to 5.14 show different demand classes that were modelled to simulate various SC designs.

Table 5.14 shows the optimized reorder point (R) and reorder quantity (Q) for different predictable demand scenarios. It can be observed that the inventory cost of raw material has moved downstream at MAN site side, allowing suppliers to be more efficient and rendering MAN more responsive. Table 5.14 also shows that the values of R and Q generally decrease when demand volume decreases but not when it increases, suggesting that the optimum solution is sensitive to the former but not the latter. It can be observed from Table 5.19 that optimized values of R and Q are generally proportional to demand volume, given that if demand increases, ROP and Q also increase so as to mitigate uncertainty risks. In terms of optimized transaction assets, Tables 5.16 and 5.20 show that asset number is generally proportional to demand volume but inversely proportional to lead time. Where lead time is short, it may be necessary to increase the asset number, and therefore the cost, in order to respond to customer demand.

Table 5.17 shows that performance is better in the optimized model than in the baseline model. This is especially the case with responsiveness performance, where avg. fill qty rate increases from 40% up to 45%. This value can be improved even further if the SC can bear higher cost and reduced overall efficiency. Against this backdrop, it is important that SC managers consider various scenarios and select the one which best meets the SC strategy and requirements of their enterprise. It is perhaps surprising that efficiency was slightly higher in the optimized unpredictable demand baseline model (see Table 5.21) than in the optimized predictable demand model (Table 5.17). One explanation for this is that in the unpredictable demand model, a large enough increase in demand volume can generate enough revenue to offset fixed costs. On the other hand, service level is lower in the unpredictable demand model because of the higher level of uncertainty.

5.5.5 Validation of the proposed framework

The framework suggests that the adoption of lean strategy through the implementation of a plan and execute policy is the best approach where demand is predictable, volume is high and lead time is long. The output of the simulation supports this; as indicated in Table 5.25, efficiency improves significantly as demand volume and lead time increase.

Table 5. 25: Profit to revenue (%) under lean strategy, plan and execute policy (R,Q)

Demand volume/Lead time	Lower volume	Baseline volume	Higher volume
Shorter lead time	29.86	--	--
Baseline lead time	--	31.78	--
Longer lead time	--	--	32.37

In instances where demand is predictable, volume is high but lead time is short, the framework suggests that a continuous replenishment policy is a more suitable lean strategy. This is again supported by the simulation, which shows efficiency is improving when the demand volume is higher and the lead time is shorter (see Table 5.26).

Table 5. 26: Profit to revenue (%) under lean strategy, continuous replenishment policy (demand flow)

Demand volume/Lead time	Lower volume	Baseline volume	Higher volume
Longer lead time	25.38	--	--
Baseline lead time	--	28.00	--
Shorter lead time	--	--	30.58

Where demand is unpredictable, volume is low and the lead time is long, the framework suggests that the optimal approach is to adopt a leagile strategy such as postponement. This finding is in line with the simulation outputs, which show responsiveness is improving as demand volume declines and lead time extends.

Table 5. 27: Avg. fill qty rate (%) under leagile strategy, postponement policy (T,*S*)

Demand volume/Lead time	Higher volume	Baseline volume	Lower volume
Shorter lead time	33.60	--	--
Baseline lead time	--	35.80	--
Longer lead time	--	--	37.10

Where demand is unpredictable, volume is low and the lead time is short, the framework suggests that an agile strategy, implemented in the form of a quick response policy, is the best way to optimize SC performance. The simulation supports this, showing that responsiveness improves as demand volume declines and lead time shortens (see Table 5.28).

Table 5. 28: Avg. fill qty rate (%) under agile strategy, quick response policy (base stock)

Demand volume/Lead time	Lower volume	Baseline volume	Higher volume
Shorter lead time	32.78	--	--
Baseline lead time	--	25.53	--
Longer lead time	--	--	18.37

Table 5.24 indicates that policies oriented towards improving efficiency tend to reduce the sustainability of the SC, while those policies that are geared towards responsiveness tend to have the opposite effect. These results are in alignment with the proposed framework's assumption that the search for efficiency negatively affects sustainability, but that this is not the case when implementing responsive strategy.

5.6 Conclusions

This chapter described how the SCG program was employed to validate the proposed framework. It discusses the steps involved, including the creation of a baseline model describing the current performance of the case study company, the use of the program's SSO and TO functions to optimize the model, and the simulations that were run using the optimized model to assess SC performance under a range of scenarios and policies. The chapter concluded by presenting the results of these simulations and showing how they validate the developed framework.

Chapter 6: Conclusions, Recommendations, Contributions to knowledge and Future work

6.1 Introduction

Previous SCD research has focused on developing frameworks that aim to improve some rather than all aspects of SC performance. This framework takes a more integrated approach to SCD by incorporating the strategy, process and resource dimensions, thereby enabling the assessment and improvement of SC performance across multiple areas. This chapter summarizes the findings of the research before discussing how it contributes to knowledge and offering suggestions for further study.

6.2 Summary of Findings

- **No consensus among authors on what SCD means**

Although the concept of SCD has been known since 1998, no one has yet produced a widely accepted definition of either the concept or its scope. Much research has been carried out in this field, most of which has historically focused on questions such as facility location, and whether SCD should consider only operational dimensions such as scheduling and resource allocation, or whether it should also encompass strategic issues. Recently, however, the scope of SCD research has extended to cover service requirements, SC security, risk and sustainability. A number of researchers have discussed SCND from the perspective of process, investments and structure.

- **There is no single framework that addresses all three dimensions of efficiency, responsiveness and sustainability**

SCs must reconcile the competing pressures of responsiveness, which usually incurs higher cost, and cost-efficiency, which is often achieved at the expense of market responsiveness. Efficiency is also likely to be impacted by the growing pressure to meet “green” demands and operate sustainably. Any attempt at optimization must therefore consider all three dimensions simultaneously, but so far no one framework has been developed to improve all three performance aspects. The closest so far has been Ambe and Badenhorst-Weiss's framework, which considers efficiency and responsiveness.

- **No integrated framework has been developed to tie the important aspects of SCD together**

The literature review demonstrates that no one has yet produced a framework integrating the strategy, process and network aspects of SCD. The framework proposed in this study comprises a strategic model, a process model and a network model, each of which performs a defined but complementary role. Together, they offer an integrated model of SCD.

- **Need for the development of a simulation-based framework in strategic SCD**

Numerous researchers have employed simulation tools to investigate SCs at the operational level, examining areas such as inventory management, production planning and management, performance measurement, location and transportation, warehouse operations and process improvement. At the strategic level, however, this approach has only been used to investigate complex adaptive supply networks (CASN) and the impact of SC integration on responsiveness. The current research responds to this gap by developing a simulation-based framework that integrates SC strategy, process and resources in one applicable template.

- **The proposed framework contains a strategic model that offers strategies for different demand characteristics and market environments**

A few models have been designed that aim to assist SCs in achieving multiple objectives, but these models do not differentiate between market environments or give any guidance on the best strategy for any given objective. Christopher's model (2006), upon which the strategic model proposed in this framework was based, suggests different strategies for different environments, but it remains conceptual; it was not implemented or validated.

- **SCOR model has been utilized to represent the process element within the framework since it identifies policies for different business environments**

The strategic model recommends the strategy that is most appropriate given the desired objectives and the prevailing business environment. SCOR suggests the most suitable policies and process configurations to complete the sourcing, making and delivering functions in such a way as to achieve this strategy.

- **The framework utilizes Long's model to design a multiple-objective network that integrates with SCOR to achieve different process policies**

To facilitate integration, the network model was designed to allow the network to be operated to implement SCOR policies; each entity in the SCN (e.g. supplier, manufacturer, distributor, retailer) can be modelled using the suggested process to ensure that SC resources are employed in accordance with the chosen policies and strategy.

- **The results of the modelling and simulation validate the framework:**
    - The optimized inventory model (see Table 5.14) demonstrates that the optimum strategies for the case study SC are lean strategy for supplier sites (allowing it to keep stock levels at a minimum) and agile strategy for the manufacturer (allowing it to keep enough stock to immediately satisfy any unpredictable demand). The SC can adopt a leagile strategy by decoupling the supplier and manufacturing sites. It can attain efficiency and responsiveness by building an agile response upon a lean platform – that is, by following lean principles up to the decoupling point and agile practices after that point.
    - Transportation asset number is proportional to demand volume and inversely proportional to lead time (see Tables 5.16 and 5.20). In Table 5.16, where demand is predictable, total transportation cost

increases with demand volume, but cost per unit decreases because assets are being utilized more efficiently. This case supports the adaptation of an efficient strategy, as suggested in the proposed framework. On the other hand, where demand is unpredictable (see Table 5.20), a responsive strategy is advised; the aim should be to achieve short lead time, regardless of the increase in transportation cost.

- Table 5.21 shows that efficiency is slightly higher in the unpredictable demand scenario than in the predictable demand scenario. This unexpected result may be explained by the fact that an increase in the volume of unpredictable demand can generate significant revenue, which can potentially offset fixed costs. This opportunity is less likely in the predictable demand scenario.

- Verification and validation of the proposed framework was a vital part of this project, as the findings of the experiment would have been useless if the framework did not perform as expected. All the results obtained support the framework:

  - Efficiency improves significantly when demand volume is high and lead time is long (Table 5.25).
  - Efficiency also improves when demand volume is high and lead time is short (Table 5.26).
  - Responsiveness improves when demand volume is low and lead time is long (Table 5.27).
  - Responsiveness also improves when demand volume is low and lead time is short (Table 5.28).
  - An efficient strategy reduces sustainability, while a responsive strategy improves sustainability (Table 5.24).

6.3 Contributions to Knowledge

The proposed SCD framework integrates strategy, process and resources and allows the use of simulation tools to investigate efficiency, responsiveness and sustainability concurrently during the design process. Demand-driven, it assumes that SCs are designed to satisfy certain demand characteristics. The proposed framework comprises a strategic model, a process model, a network model and a performance model, each of which performs a defined role but integrates with the others.

The strategic objective model seeks to identify the most effective way of meeting customer requirements, taking into account SC capabilities and uncertainty. Its main strategic offerings are lean, agile and leagile strategies. Where demand is predictable, SCs are advised to adopt a lean strategy; if lead time is short, they may implement a continuous replenishment policy of replacing products as they are sold or used, but where lead time is longer, a plan and execute policy may be more appropriate.

In either scenario, the process model suggests that companies following lean strategy should adopt a make-to-stock policy in which processes are configured so as to reduce costs and make the maximum use of available resources. SC capabilities tend to be pre-planned for long periods of time, unvaried, and fixed with no excess capacity. Since SC functions must operate within these capability restrictions, production is massive and standard, inventory is high level and unvaried, and transportation processes utilize low cost modes (e.g. Full TL) and seek to reduce transport time as much as possible.

Conversely, the aim in agile strategy is to satisfy unpredictable customer demand with short lead times and perfect fulfilment. In this case, the process model suggests a make-to-order policy in which resources are variable, varied and excess. Production policy is characterized by product variety, low product volume and short process time. Inventory is kept low but varied, postponement or quick response policies are the norm, and transportation modes are fast and flexible. Lastly, in the leagile strategy option, the process model suggests a make/assemble-to-order policy. This is a combination of make-to-stock and make-to-order policies.

The third component within the framework is the network model. This has four levels: the SCN level, the enterprise element level, the workshop element level and the production unit element level. All of these resources and the associated decision making (e.g. regarding locations, capacities and technologies) are directed towards achieving the strategic objectives of the SC using the policies suggested by the process model.

The last component in the framework is the performance model, which aims to measure SC performance and show the extent to which the SC is achieving its objectives of efficiency, responsiveness and sustainability.

6.4 Limitations and Future Work

The primary limitation of the study was the lack of real-life data about existing SCs, as this prevented the researcher from running further simulations to investigate other aspects of SCD. SCG's newness to the market was also a problem in that firstly, it affected some of the research modelling tasks (e.g. it was not possible to use more than one probability distribution to model a certain type of demand as this function is still under development) and secondly, a considerable proportion of the available research time had to be spent learning to master the software to the necessary level.

As far as future study is concerned, the lack of a common research approach to SCD raises questions about the extent to which this research is consonant with SCD practice in industry. Investigation is required of the extent to which research is supporting real-life practice, and the factors that shape this practice.

The literature review shows that simulation is rarely employed by researchers investigating SCs at the strategic level, so more research is needed to determine whether simulation-based research is making any contribution to SC practice, especially at this level, where simulation is vital. The modelling and simulation work done in this research reveals a number of ways in which the application of SCG could be extended:

- To apply the concept of strategic fit by examining empirically the optimum strategy each SC member should adopt to improve overall SC performance.

- To model different process configurations by designing SC capabilities to implement specific strategies (see Table 4.1).
- To identify the best SCN configurations in terms of centralization and decentralization strategy and business location (global, local or both) (see Tables 4.2 and 4.3).
- To further explore the interaction between the framework models, such as how process policies assist in achieving SC strategy, and the impact of different SCN configurations and decoupling point locations on strategy achievement.

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