Framework for Embedding Optimisation and Simulation Tools in Supply Chain Management

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Declaration

I hereby declare that:

1. I have not been enrolled for another award of the University, or other academic or professional organization, whilst undertaking my research degree.

2. None of the material contained in the thesis has been used in any other submission for an academic award.

3. I am aware of and understand the University's policy on plagiarism and certify that this thesis is my work. The use of all published or other sources of material consulted has been properly and fully acknowledged.

4. The work undertaken towards the thesis has been conducted following the SHU Principles of Integrity in Research and the SHU Research Ethics Policy.

5. The word count of the thesis is 44,600.

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Abstract

Supply chain management (SCM) is a pivotal area for academic research due to its influence on businesses competing in today's complex global economy. To support the managers, the concept of SCM has been imperatively adopted by many business leaders to assist in designing, planning, controlling, and enhancing the network of facilities and tasks that comprise many stages of the supply chain.

In turn, Optimisation and Simulation Tools (OST) provide virtual environments to fine-tune this supply chain operational logic and processes to develop the best operational configurations and strategies before the execution of any real business planning or investment decisions.

However, the review of existing literature, survey, and interviews conducted using industry professionals and subject experts revealed that in most instances, these tools are typically deployed to address specific problems in isolation. Therefore, users are failing to reap their full potential.

Thus, the main aim of this research is to design and develop a novel framework that should enable businesses to embed these tools in their decision-making processes. Both quantitative and qualitative approaches are exploited in the research design and methodology to provide sound visibility and a clear path to achieve this research aim and objectives. Therefore, the proposed framework serves as a complete guide in Supply Chain Network Design (SCND) and Management, which helps the businesses, entrepreneurs, or any in the OST community to start their journey from scratch or over a re-design of any existing network. Such a proposal will stimulate and build the full confidence in the OST community to reap the maximum benefits in returns out of their investments over these tools.

The proposed Framework is validated by a set of subject and industry professionals through a survey questionnaire, and necessary refinements recognised are executed. Then at the end, the novel contribution to the knowledge, limitations that exist and direction for future research are also well presented.

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List of Abbreviations

BFA	Brownfield Analysis
CED	Cause-and-Effect Diagram
CTRD	Capture Transactional & Real-time Data
EWADE	Enterprise-Wide Awareness & Decision Execution
FLP	Facility Location Problem
FRDB	Foundation for a Relational Database
GFA	Greenfield Analysis
IO	Inventory Optimisation
MCQ	Matrix Coding Query
MDB	Modelling Database
MSCHPE	Monitor Supply Chain Health & Proactive Experiments
NO	Network Optimisation
OPT	Optimisation
OST	Optimisation and Simulation Tools
RBL	Robust Baseline
SC	Supply Chain
SCD	Supply Chain Design
SCDSS	Supply Chain Decision Support System
SCDT	Supply Chain Digital Twin
SCM	Supply Chain Management
SCND	Supply Chain Network Design
SCNDSO	Supply Chain Network Design Scope & Objectives
SCNRD	Supply Chain Network Re-Design
SCO	Supply Chain Operation
SIM	Simulation
TO	Transport Optimisation
TPP	Technology-Process-People

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Chapter 1

Introduction

If the future is certain, it would be quite straightforward to design, operate and succeed from a supply chain that was fully optimised for that certain future. In real life, however, the future is volatile, and a well-designed supply chain must be accommodating and fully competent in adjusting to a wide range of prospective dynamics, operational challenges, and issues and identifying what limits them from achieving further improvements onboard.

Numerous advanced software and hardware technologies have emerged today to analyze these dynamics, uncertainty, disruptions, and finetuning the performance with the increased competition in today's global economy. However, it has been recognised that the use of Optimisation and Simulation is the most promising and highly effective technologies to overcome most of these challenges in supply chain management.

Therefore, any optimisation or simulation application must be competent and provisioning measures featuring uncertainty in the supply chain analysis in the phases of design, operation, and redesign (enhancement). In this introductory chapter, the role of the supply chain and its complexities involved, how supply chain management evolved through the recent decades, and the emergence of optimisation and simulation tools are described. Then the aim and objectives of this research and the thesis structure are also presented.

1.1 Supply Chain (SC)

In today's competitive and uncertain global market, the role of SC in an organization is like the Nervous System (NS) in the human body. The way NS coordinates its actions and sensual information by communicating the signals back and forth to different parts of the body is, the same way SC controls its set of entities and processes connected throughout the network. Likewise, an inappropriate NS causes unusual behaviours in the human body, an inappropriate SC causes various problems to its organization's operations and performance. The supply chain is a network combined with several different entities such as suppliers, plants, distributors, retailers, customers, and many more different stakeholders.

The supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer (Christoper,1999). Mentzer et al., (2001) rephrased what La Londe & Masters have proposed; that a supply chain is a set of firms that pass materials forward, and normally several independent firms are involved in manufacturing a product and placing it in the hands of the end user in a supply chain raw material and component producers, product assemblers, wholesalers, retailer merchants, and transportation companies are all members of a supply chain. The supply chain is a network of organisations and processes (see Figure 1.1) wherein several various enterprises (suppliers, manufacturers, distributors, and retailers) collaborate (cooperate and coordinate) along the entire value chain to acquire raw materials, to convert these raw materials into specified final products, and to deliver these final products to customers (Ivanov et al., 2017).

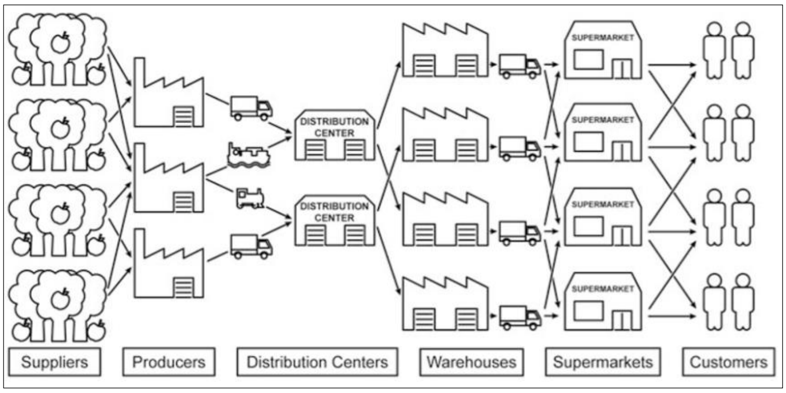


Figure 1. 1: Supply chain network of organizations and processes

Source: (Ivanov et al., 2017)

1.2 Supply Chain Design, Operations, and Management

To design and manage a supply chain successfully it is very crucial to know the interrelated nature of SCM and the steps need to proceed through. The following conceptual SCM framework (see Figure 1.2) consists of three closely interrelated elements: the supply chain network structure, the supply chain business processes, and the supply chain management components (Lambert & Cooper, 2000). Managing an SC is a complicated task and even managing logistics in SC, products/service flows, and related information, from point of origin to point of consumption is very challenging (Lambert et al., 1998).

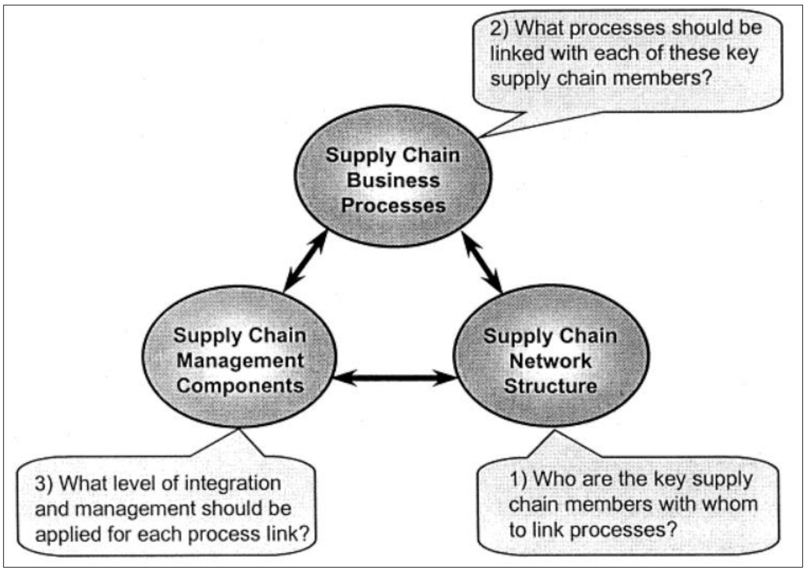


Figure 1. 2: Supply chain management framework: elements and key decisions

Source: (Lambert & Cooper, 2000)

Supply Chain Design (SCD)

Researchers and practitioners have primarily investigated the various processes of the supply chain individually. Recently, however, there has been increasing attention placed on the performance, design, and analysis of the supply chain as a whole (Beamon, 1998). Much of the research into supply chain design has focused on developing solutions where the implied objective function is to reduce cost and/or lead times. Yet, these are not the only outcomes driving supply chain design. Supply chains can be designed to achieve alternative outcomes such as increasing responsiveness, driving innovation, or improving sustainability. As the desired outcomes change, we can also expect the optimal supply chain design features and approaches to change (Melnyk et al., 2014).

Supply Chain Operations (SCO):

In Supply Chain Operation, the main task is making decisions. Primarily matching demand and supply by building a bridge between the customers and suppliers. The responsibilities of SCO managers are multi-faceted. The decision-making areas in SCO range from strategic to tactical and operative levels (see Figure 1.3). Strategic issues include, for example, determination of the size and location of manufacturing plants or distribution centres, decisions on the structure of service networks, factory planning, and design of the SC. Tactical issues include such decisions about production, transportation, and inventory planning. Operative issues involve production scheduling and control, inventory control, quality control, and inspection, vehicle routing, traffic and materials handling, and equipment maintenance policies (Ivanov et al., 2017).

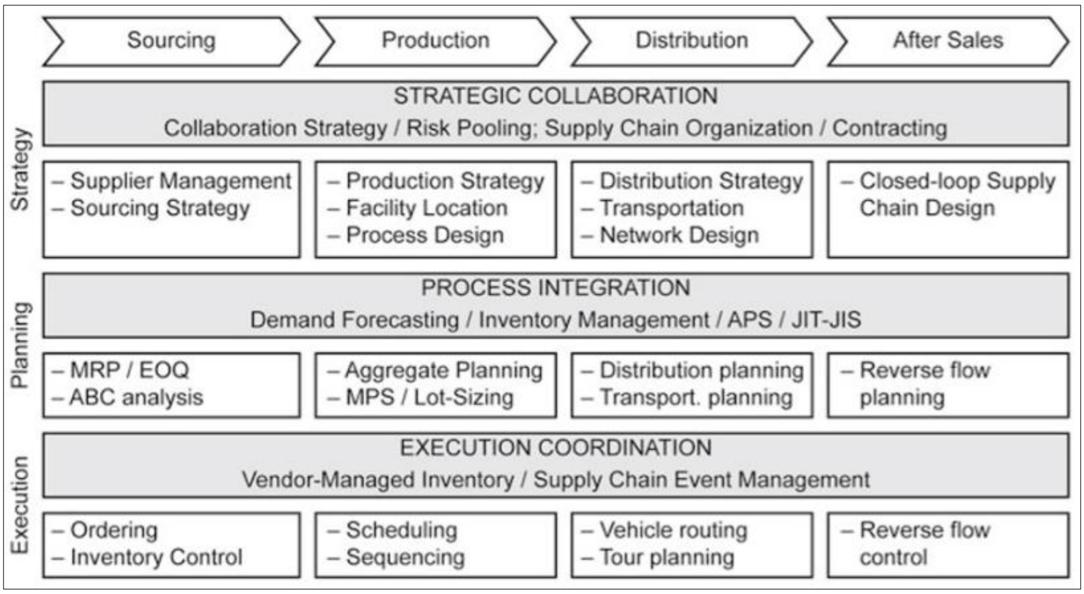


Figure 1. 3: Decision matrix in supply chain management

(Ivanov et al., 2017)

Supply Chain Management (SCM):

Supply chain management is the most expensive and complicated part of any business. Effective management of complex and global supply chains becomes a major condition for giving a positive impact on a company's financial performance. The importance of SCM for the SC network involves coordinating and integrating the constant flows both within and between all stages. There are three main flows related to SCM (see Figure 1.4) 1. Product flow: inventory, 2. Information flow: transmitting orders, update status delivery, etc. 3. Fund/finance flow: payment schedules, cost, and profitability (Othman & Mustaffa, 2012).

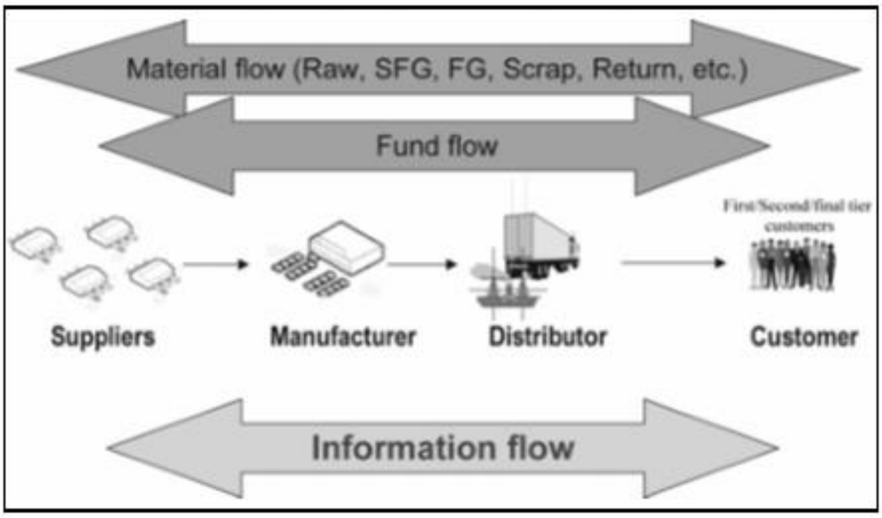


Figure 1. 4: Product/material, information, and fund flow across the supply chain

Source: (Othman & Mustaffa, 2012)

Supply Chain Management was first coined in (Kransdorff, 1982), when Keith Oliver, a consultant at Booz Allen Hamilton, used it in an interview with the Financial Times Since then, its development and growth as a discipline have occurred primarily in the industrial sector. 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, how it is related to similar approaches such as logistics, operations management, and purchasing/sourcing management, and how it affects performance (Melnyk et al., 2014).

In the late 1980s, Hewlett-Packard (HP) was alarmed by huge customer dissatisfaction with their order fulfilment process. To analyze and overcome this issue, HP formed an in-house team called Strategic Planning and Modelling (SPaM) and a model called Bubble Model (Lee & Billington, 1995).

> ‘’*Bubble Model*: Quantitative-based Methodology / Effective in capturing such costs as fixed overhead, equipment, transportation, and other variables. SPaM: Staffed with industrial and computer systems engineers and provided the capabilities in developing and introducing innovations in management science and industrial engineering’’.

HP was able to reap the benefits of Modelling their SC entities, process, timing, and costings, and ultimately that led them to strengthen the capabilities of their top management decision-making process to finetune their business process and sustain the market (Lee & Billington, 1995).

1.3 Supply Chain Modelling

Modelling is an essential process in understanding systems of all kinds. That model should describe the behaviour of some aspects of the system in a precise way (Tarokh & Golkar, June 2006). Making decisions in such a complex network of entities can be very challenging and calls for appropriate models and simulation studies (B. Behdani, 2012). Considering the broad spectrum of a supply chain, no model can capture all aspects of supply chain processes. To compromise the dilemma between model complexity and reality, a model builder should define the scope of the supply chain model in such a way that it is reflective of key real-world dimensions, yet not too complicated to solve. Also, a model builder needs to profile the potential risks involved in supply chain activities. Figure 1.5 Shows the taxonomies of supply chain Modelling (Min & Zhou, 2002).

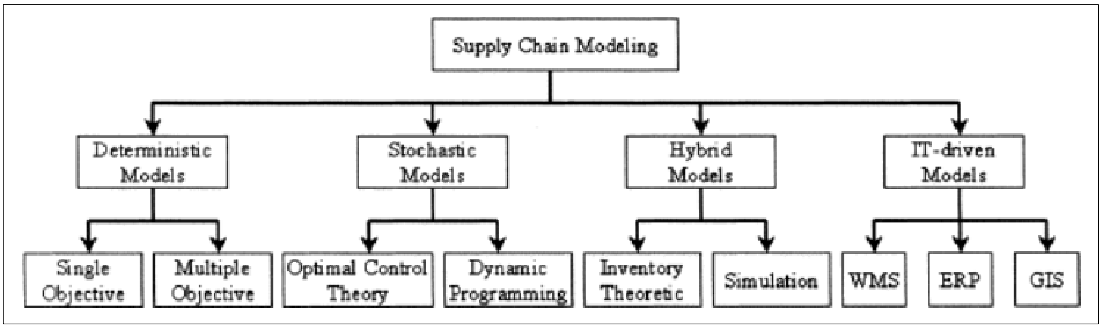


Figure 1. 5: Taxonomies of supply chain Modelling

Source: (Min & Zhou, 2002)

1.4 Need for this research

How SCM has evolved through the recent decades and prominently at present the requirement of sophisticated tools to get the design right first, make the Supply Chain Operations efficient, and achieve further enhancements (Redesign) are very demanding in this globally competitive economy.

According to (Le et al., 2020) the SCM software applications are still focusing on material and resources management with the internal SC integration. Due to the lack of collaboration among the SC participants, strategic decisions related to building a partnership, IT-based planning, and logistics-based planning are not conducted in the phase of planning and design. This common practice reduces the effectiveness and the flexibility of the SC ability in terms of responding to uncertainties occurring across the SCM phases.

Then (Pause et al., 2020) also argue that businesses are hoping for immense growth opportunities through digitalization, networking, and new technologies. Therefore, the degree of maturity of a company's digitization is of particular relevance to check the company's status. Consequently, further characteristics must be developed in this respect to determine the degree of maturity of digitization within a supply chain.

Fu & Henderson (2017) made a strong statement saying that academics should make additional efforts to reach out to commercial simulation software developers to learn what is needed in practice, and to explore potential joint work.

When the preliminary research was carried out during the stage of research problem/topic formalization, evidently it reflected a gap in research work that exists particularly in the proposed area of research, and in such that arouses and paved the solid grounds to carry out this research without any reluctance. ‘’Optimisation and Simulation Tools’’ is not a new-found topic in the field of SCM but it’s reflected that the depth and the amount of research work conducted so far, specifically to analyze the current usage, barriers which prevent SCM professionals from using and reaping the full potential of out of these tools is very limited. In addition to that, despite the existence of a range of frameworks in the literature in terms of the application of OST in various domains in SCM, there is a lack of a robust framework that ties all the aspects mentioned above together as a complete reference (Application Domains, Barriers, Success Factors, Implementation Process, etc.). Therefore, both the research gap and the novel contribution of knowledge which should be provided by the proposing framework are identified clearly in terms of what are the potential application domains of OST in SCM, exiting barriers that prevent using and reaping the full potential out of these tools, and how to embed these OST in business and decision-making process successfully. Consequently, this proposing novel framework can be used as a complete reference for a smooth process of steps to embed the full potential use of these tools either SC Design from the scratch or Re-Design activities whilst gaining a better ROI for the investments in such.

1.5 Research aims and objectives

Aim:

Design and develop a framework to embed optimisation and simulation tools in the supply chain management context, which help the concerned community reap the full potential by using these in their business decision-making process to achieve operational excellence and resilience.

Objectives:

1. Literature review to identify the recent developments of the proposed research and the research gap.

2. Conduct a survey questionnaire and interviews to investigate the current behaviour and limitations over the application of optimisation and simulation tools.
3. Identify potential barriers. construct a structured approach to address them and fulfil critical success factors over OST deployment.
4. Design and develop the preliminary framework.
5. Validate and refine the proposed framework with the subject and industry experts.
6. Write up the thesis and defend it successfully.

1.6 Research questions

The key research questions which have been addressed in this study can be aggregated into two, which laid the foundation for this research.

1) What are the key barriers which prevent using and reaping the full potential of Optimisation and Simulation Tools in Supply Chain management?
2) What would be the best approach to overcome these barriers by embedding these tools in the business decision-making process which will lead to achieving operational excellence and supply chain resilience?

1.7 Research methodology

Whilst chapter 3 present the research methodology in detail, this paragraph aims to outline three major stages of the research program.

Stage 1: Identifying the preliminary gap, significance of the research, and setting the building blocks for the proposing framework

During the submission of an initial research proposal, the significance of the research, preliminary research gap and research aim, and objectives were presented strongly. Then Research started with a strong literature review followed by a survey questionnaire and a few interviews. That paved a solid foundation for identifying the research gap in a very broader aspect and setting the building blocks for the proposing framework.

Stage 2: Importance of deploying multiple tools, methods, and approaches in terms of data collection, analysis, and visualization

Followed the mixing method for robust data collection & analysis in both quantitative and qualitative manner. A deductive approach is used to make a clear path from extracting the essence from the necessary theory to proposing a well-structured framework. Multiple tools and methods have been used in both collection and analysis of data. Why specific methods, tools, and approaches have been deployed based on the category of participants have been well explained in chapter 3.

Stage 3: Design and develop the framework followed by a verification and validation phase with input from industry and subject experts

To experience the pragmatic barrier over using optimisation and simulation, personally carried out hypothetical model building using the software Supply Chain Guru® and attended international simulation and Modelling conferences. Once the preliminary framework is designed, validation and necessary refinement have been executed accordingly.

1.8 Thesis structure

Ch. 1: Introduction: As a steppingstone to the area of research focus; an introduction to SC design, operations, and complexity involved in the recent usage are described.

Ch. 2: Literature Review: A review of past literature is presented to illustrate the emergence of OST in terms of Modelling, decision making, and problem-solving in logistics and SCM. How OST has been successfully implemented yet the barriers to implementation and challenges existing in today's SCM are well described by using some real case studies which highlight the gap and need for this research. [Research Question 1 is partially covered].

Ch. 3: Research Methodology: Provide how robust the way research method and approach have been utilized to conduct this research followed by a detailed illustration of how and why these specific data collection tools, methods, and techniques have been used in different stages of the research with multidisciplinary data sources, respondents, and participants.

Ch. 4: Survey Questionnaire and interview analysis: With a sound literature review that shows the gap existing in current research; to strengthen that evidence further by collecting more data, a survey questionnaire and a few semi-structured interviews have been conducted. Then, as a result, a full-scale Cause-Effect-Diagram (EFD) has been constructed which acted as the blueprint for designing and developing the framework. [Research Question 1 fully is covered].

Ch. 5: Design and development of the Framework: Addressed all the categories of primary and secondary causes of EFD constructed in Ch. 4 and developed a well-structured approach as a framework name ‘‘OSTiSCM’’ which provides step-by-step guidance in embedding these OST in SCM for a maximum ROI over the investment decision an achieve SC resilience. [Research Question 2 is fully covered]

Ch. 6: Validation and refinements: Checked the robustness of the proposed through a sound validation by a set subject and industry experts to seek any potential enhancement that could be done before final submission. Recognized some valid concerns and necessary refinements have been executed over the proposed.

Ch. 7: Conclusions: As everything in a nutshell the summary of research findings, how the proposed adds novel contribution to knowledge, limitations exits, and recommendations for the future, and how the proposed ‘‘OSTiSCM’’ can be enhanced to shift to the next level has been explained.

Chapter 2

Literature Review

2.1 Introduction

There is an immense growth in recent years in the applied research that examine OST in SCM due to its influence on today's competitive global economy. The main objective of this chapter is to showcase how the focussed research of OST emerged, yet the gap which was the motivation and led to pursue this research to ''Design and develop a novel framework for embedding OST in SCM''.

According to Dossou (2018), Hallikas et al.(2019) and Shao et al.(2021), a substantial number of publications and reviews present digital supply chains and the advantages that digitalisation carries (Barykin et al., 2021).

As observed by Hussein et al. (2021) their systematic analysis shows that OSC-SC problems have been solved frequently by a variety of solution methods such as optimisation (25%), simulation (13%), and building information Modelling (BIM) (9.5%). However, researchers tend more to integrate multiple solution methods (35%) to address the complexities of OSC-SC problems.

Nguyen et al. (2021) emphasised that because data availability is a key prerequisite for Data Analytics for Supply Chain Management (DA-SCM), Viet et al. (2018) focused on data and information sources existing in supply chains to highlight data assets as well as technical challenges at stake. In terms of techniques, most have focused on statistical analysis, simulation, and optimisation but little attention has been given to advanced analytics models.

By giving a start with an overview of the research work which has been done in terms of SC design, operation, and redesign, the significance of decision-making in such activities will be highlighted. In turn to help this decision-making process the use of SC Modelling and the emergence of Optimisation and Simulation Tools (OST) are illustrated. Then the review of the research work including some real business case studies which showcase the application domains of these OST, successful applications & approaches, and a few frameworks which have been developed so far have been highlighted. In the latter, with the identification of the full potential of these OSTs and the existing barriers which prevent organizations use such, the research gap is presented with the concluding remarks.

2.2. Supply Chain Design and Management: Challenges

With the inception of the Supply Chain Operation Reference (SCOR) Model in 1996 by the Supply Chain Council (SCC), it allows firms to perform very thorough fact-based analyses of all aspects of their current supply chain by providing a complete set of supply chain performance metrics, industry best practices, and enabling systems' functionality (Huan et al., 2004).

Supply Chain Management, which is today has never been more complicated, dynamic, and unpredictable. Achieving a well-planned and purpose-driven supply chain management is what every organization in today's competitive market is keen in get onboard. Therefore, a value-driven supply chain that is coupled to the strategic priorities of the firm is the result of considerate management action and strategic corporate investments aimed to procure, develop and configure the appropriate resources, processes, and metrics that define that firm's supply chain as briefly explained with their findings in (Melnyk et al.,2014).

As explained by Garcia & You (2015) achieve truly sustainable solutions, a supply chain should be designed and operated such as to maximize economic potential, minimize environmental impact, and maximize social benefit (see Figure 2.1).

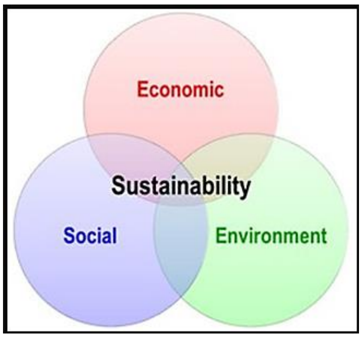


Figure 2. 1: Supply chain solutions and sustainability

Source: (Garcia & You, 2015)

Garcia & You (2015) emphasized that in an atmosphere of intense global competition, advantages that can be provided by the integration 0f planning levels (Strategic, Tactical & Operational) could be critical to a company's success (see Figure 2.2). Thus, future supply chain design must consider integrated optimisation across multiple temporal scales.

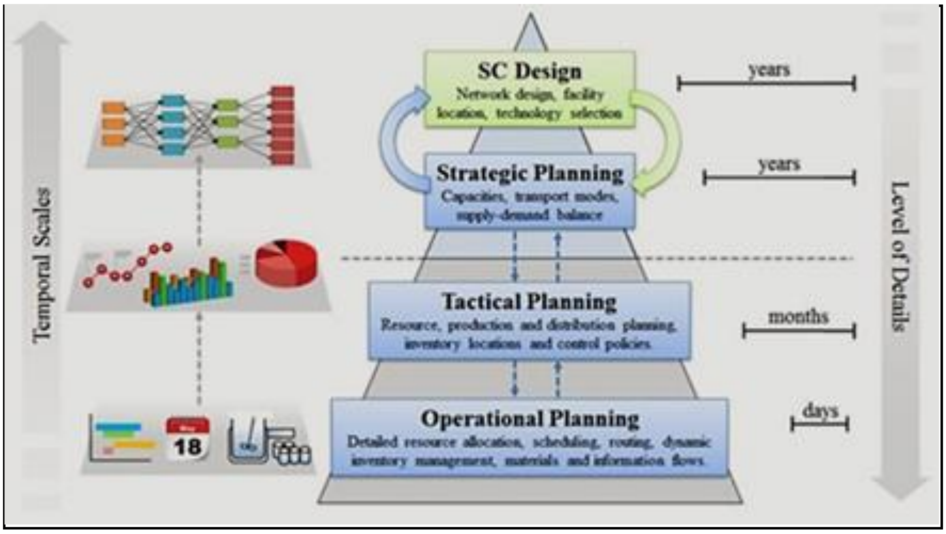


Figure 2. 2 A supply chain design and operations problem span many levels and temporal scales

Source: (Garcia & You, 2015)

Since SCM is a very broader topic when it comes to reviewing and analyzing the challenges which have been described in recent research studies, the best way to do that is to split the scope into parts. The main objective of the subsections (2.2.1 to 3) is to pinpoint in each phase what are the specific challenges organizations and their decision makers facing, the significance, and the integration which should exist (see Figure 2.3).

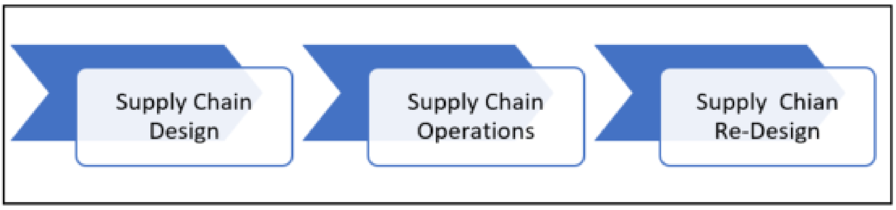


Figure 2.3: Journey of supply chain design to supply chain re-design

2.2.1 Supply Chain Design Challenges

Supply chain design is the process of determining the supply chain infrastructure—the plants, distribution centres, transportation modes and lanes, production processes, etc. that will be used to satisfy customer demands. These studies are strategic in scope, use a time horizon of many months or years, and typically assume little or no uncertainty with the data (Harrison, 2004).

The location of a multibillion-dollar automobile assembly plant cannot be changed because of changes in customer demands, transportation costs, or component prices. Modern distribution centres with millions of dollars of material handling equipment are also difficult, if not impossible, to relocate except in the long term. Inefficient locations for production and assembly plants as well as distribution centres will result in excess costs being incurred throughout the lifetime of the facilities, no matter how well the production plans, transportation options, inventory management, and information sharing decisions are optimized in response to changing conditions (Daskin, Snyder, & Berger, 2005).

The two main constituting elements of the supply chains are "product" and "supply chain operations", which are highly interrelated across more than one dimension. Many of the drawbacks in the success and sustainability of supply chains often relate to the segregation of these dimensions (Sharifi, Ismail, & Reid, 2006).

Supply chain network design decisions are usually strategic and once implemented they are difficult to reverse. When the design decisions are in effect, many decision parameters, such as demands and costs, may change dramatically. Bad locations of facilities, such as plants and DCs, can result in inefficiency and extra costs even if the production, inventory, and shipment plans are well optimized (Shen, 2007).

The strategic configuration of the SC is a key factor influencing efficient tactical operations and therefore has a long-lasting impact on the firm. Furthermore, the fact that the SC configuration involves the commitment of substantial capital resources over long periods makes the SC design problem an extremely important one (Azaron, Brown, Tarim, & Modarres, 2008).

Supply chain design has a higher influence on the supply chain performance measures compared to integration and information sharing. To obtain the desired performance from a supply chain, the number of suppliers and their capacities, distribution channels, and the entire chain should be suitably arranged for meeting the current and potential needs of the customers, and the costs along the supply chain (inventory holding, transporting, operating, etc.) should be minimized. A well-designed supply chain in terms of locations, distances, capacities, and planning can provide a competitive advantage for the firms in that specific chain (Sezen, 2008).

A key decision in logistics management is the selection of the transportation mode and carrier to move the firm’s inbound and outbound freight. Within manufacturing firms, transportation costs average 20 per cent of total production costs. Mode choice and carrier selection are part of the decision-making process in transportation that includes identifying relevant transportation performance variables, selecting the mode of transport and carrier, negotiating rates and service levels, and evaluating carrier performance (Waller et al., 2008).

It is the unfortunate reality that some critical parameters such as customer demand, price, and manufacturing capacity are not known with certainty. If the supply chain designed by the decision maker is not robust concerning the uncertain environment, the impact of performance inefficiency (i.e., delay) could be devastating for the organization (Pan & Nagi, 2010).

The decision to use a certain transportation channel influences the lead time to deliver a product which is often an indicator of customer service level. The availability of different channels to transport the product between a pair of facilities is a feature of modem logistics services. Transportation choices are differentiated by parameters of time and cost. Commonly, these parameters are negatively correlated with shorter times for the most expensive alternatives (Olivares-Benitez et al.,2012).

The strategic decisions focus on the design of an efficient supply chain intending to achieve the organization's overall objectives and increase its competitive advantage such as supply chain configuration, resource allocation, production technology selection, supply and demand contracts, number of, location, and capacity of sites, sustainability issues (Sharma et al., 2013).

As emphasized by Melnyk et al., (2014) supply chain design needs to comprehend three levels of analysis (see Figure 2.4). (1) Influencers: higher-level considerations such as the business and political environment, the business model employed, the firm’s desired outcomes, and the supply chain life cycle. (2) Design decisions: Social, behavioural, and physical/structural design elements that define a supply chain. (3) Building blocks: Inventory, transportation, capacity, and technology decisions that are used to implement the supply chain. Supply chain design needs to comprehend these three levels of analysis.

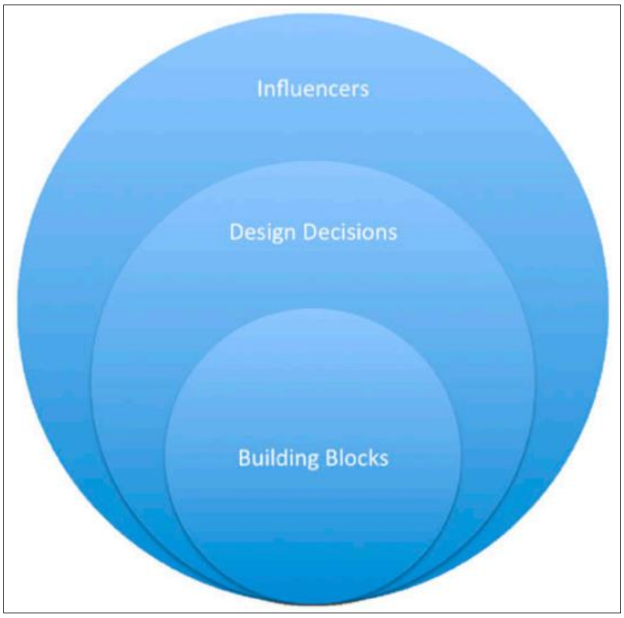


Figure 2. 4: Three levels of factors influencing supply chain design

Source: (Melnyk et al., 2014)

A supply chain's true potential is set by its design, not by its planning applications. There are numerous supply chain cost-saving opportunities that are hidden just below the surface at most companies and today's savvy executives are using supply chain design software to find them (Brzoznowski, 2014).

Despite various research advances in supply chain design, there are several challenges which include, but are certainly not limited to can be illustrated as follows (see Table 2.1) Sustainability assessment that aims to quantitatively compile the material and emissions flows that occur throughout the lifetime of a product and analyze the environmental impacts of those flows (Garcia & You, 2015).

SC Design Challenges		
Multi-Scale	Multi-objective and sustainability	Multi-player
• Modelling • Optimisation • Uncertainty • Computational tools	• Supply chain design criteria • LCA (Life Cycle Assessment) & optimisation approach	• Extra Modelling and computational challenges • Different players with their objectives

Table 2. 1: Supply chain design challenges – Multi-scale, objective & player

Source: (Garcia & You, 2015)

(Krægpøth et al.,2017) they have done a research study with the participation of 39 experts (30 industrial enterprises, 4 senior supply chain consultants, and 5 supply chain management professors) and have identified the key drivers and barriers of SC Design (see Figure 2.5).

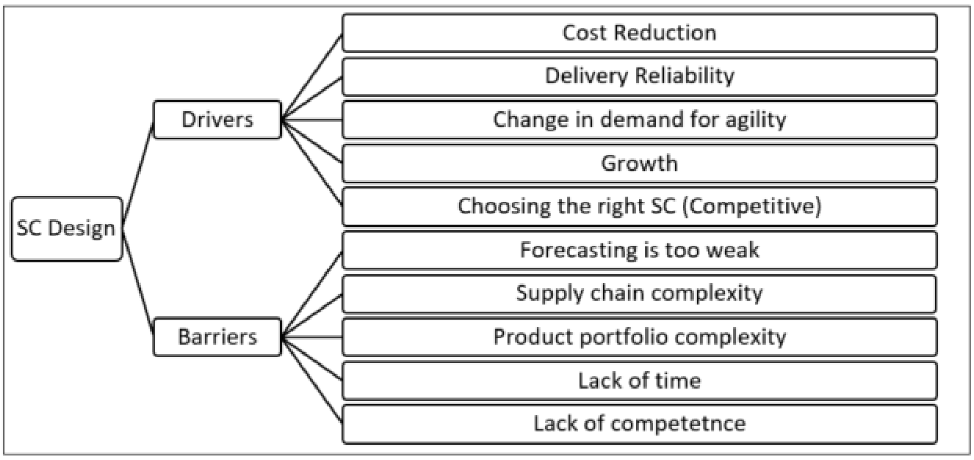


Figure 2. 5: Key drivers and barriers of SC Design

Source: (Krægpøth et al.,2017)

Recent studies in the field of big data analytics have come up with tools and techniques to make data-driven supply chain decisions. Analyzing and interpreting results in real time can assist enterprises in making better and faster decisions to satisfy customer requirements. It will also help organizations to improve their supply chain design and management by reducing costs and mitigating risks. (Govindan, Cheng, Mishra, & Shukla, 2018). The optimal placement of safety stocks is an important decision when designing the supply chain as it has a direct impact on the service quality. The decisions on where to locate facilities and where to place the safety stocks in these facilities are interdependent by nature. In this context, the integration of these decisions leads to a more efficient design of the supply chain (Puga, Minner, & Tancrez, 2019).

The SC disruption revival policies must be developed for the transition from the recovery to the disruption-free operations mode. A revival policy is meant to mitigate the negative impact of disruption tails and stabilize the ordering control policies and performance in the SC. Thus, recovery policies should not be limited to the disruption period only. They should also consider the post-disruption period and be included in SC design decisions (Ivanov, 2019).

The design of a supply chain is an integral part of any organization's competitive footprint, but it can also be influenced by the decisions that managers make when confronted by major disruptions, such as trade wars or global pandemics. The impact of COVID-19 and associated events that occurred recently will immensely change the way designing future global supply chains. This is a good eye-opening for the future state of global sourcing, the unique nature and a combined “demand and supply shortage” bullwhip effect, the resurrection of lean and local production systems, and the development of risk-recovery contingency strategies to deal with pandemics (Handfield, Graham, & Burns, 2020).

In today’s uncertain markets, supply, manufacturing, and distribution need to be properly coordinated to reduce disruption risks and increase the SCN robustness and its ability to recover from disruptions. The SCN Design (SCND) problem is further complicated by many other requirements, such as the need for efficiency in the use of resources, the awareness of their impact on the SCN, and the flexibility to rapidly adapt to changes in the market and demands (Cavone et al., 2020).

The all above reviewed challenges can be summarised as per their domain and nature in a table like below (see Table 2.2).

Supply Chain Design Challenges	
Domain (Area)	**Description (Nature)**
Scope	SC Strategy (Clear scope)
Network & Capacity	Location/ Capacity (Changes to SC design decision later is very costly)
Process & Configuration	Configuration / integration
Design time	Longer times for planning, Modelling, designing, and processing
Design Complexity	Multi-scale and complex Modelling, optimisation & simulation
Disruptions	Supply Chain Pre, During, and Post disruption (identifications, controlling, and recovery)
Objective's complexity	Multi Objectives
Stakeholders & Decision making	Multiple players and objectives cause multi-dimensions decision making
CSR	CSR globally, sustainability, Future concerns, Emissions
User's Competency	Knowledge & Skills in SC design
Budget	Financial constraints
Data	Data limitation (Source, Quality, and quantity)
Technology	Computational constraints

Table 2. 2 Multifaceted supply chain design challenges

2.2.2 Supply Chain Operations Challenges

Managing supply-chain operations is critical to any company's ability to compete effectively in the global marketplace. SCOR Model becomes very attention-grabbing and starting point for improved supply-chain management to achieve operational improvements (Stewart, 1997). A more sophisticated operation will generate additional measures (Gilmour, 1998).

The objective of Supply Chain Operations Planning (SCOP) is to coordinate the release of materials and resources in the supply network under consideration such that customer service constraints are met at minimal cost (de Kok & Fransoo, 2003).

Since the integration of actors and transaction efficiency are fundamental for developing and maintaining a competitive supply chain, we are concerned that SMEs will face substantial challenges without the adoption of technology-based planning and control methods. The question that arises is how SMEs can proceed to implement such methods when they often lack the necessary organizational, financial, and human resources (Vaaland & Heide, 2007).

Consider supplier-related disruptions that could shut down a plant (supplier bankruptcy) or drastically reduce capacity (the fire at Ericsson). These types of disruptions not only stop the flow of goods, but also the production of goods, whereas a transportation disruption stops only the flow of goods and, in that sense, is probably less severe. In case of any transportation disruption, efforts should be made to identify alternative routes, alternative modes of transportation, alternative suppliers who do not share the same route, or transhipment strategies between warehouses. Also build up a buffer of inventory if a warning of an impending transportation disruption is received (Wilson, 2007).

Operations of different entities in a long supply chain are restricted by different sets of objectives and constraints. Performance improvement of the long supply chain considering the main objectives of on-time delivery, quality assurance, and cost minimization are highly interdependent (Jain, Benyoucef, & Bennett, 2008).

The strategic decisions that directly concern operations can be grouped in to decision areas that represent different domains of the enterprise. The decision areas differ somewhat from author to author, but there seems to be an essential agreement that capacity, facilities, technology, vertical integration, workforce, quality, production control, and organization are areas that matter for operations strategy (Netland & Alfnes, 2011).

The primary routes are the most efficient routes based on the transportation costs, mode-transfer costs, and shipment delivery time requirements. An alternate shipment route is entirely distinct from its corresponding primary route and is for use during a transportation interruption which may result in the unavailability of the primary route (Ishfaq, 2012).

In recent trends with a rapid change in consumer buying preferences, the retail supermarket is growing very fast. The sustainability of this industry depends on the performance of its supply chain and a balance between responsive and efficient warehouse operations which contain a fundamental set of activities in common which are (i) Product receiving, (ii) Put away, (iii) Storage, (iv) Order picking, (v) Packaging, (vi) Sortation & Accumulation and (vii) Unitizing & Shipping (Saleheen et al.,2014).

The distribution or transportation of products is a significant component of supply chain operations. It is essential then to implement optimal distribution policies to lower logistics costs of the supply chain, but economic performance cannot be the only concern in distribution logistics. For instance, transportation has the most hazardous effects on the environment among supply chain operations, and certain distribution conditions may have related social impacts (see Figure 2.6), such is the case of delivery time windows which could reflect longer delivery routes and may require that drivers work overtime. Seeing that transport management must deal with the mode of transport selection, infrastructure, load planning, routing, and scheduling operations, substantial efforts would be required to improve economic, environmental, and social performance (Vega-Mejía et al.,2016).

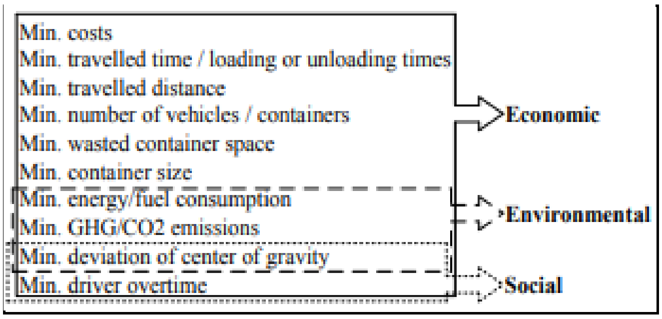


Figure 2. 6: Classification of optimisation criteria

Source: (Vega-Mejía et al.,2016)

On the enterprise operation side, carbon emissions are mainly caused by production and transportation activities. Many countries and regions have enacted various policies to reduce carbon emissions. During the production process, it is a general way for an enterprise to raise the production rate by remanufacturing and investing in green technology equipment under strict emissions constraints. During the transportation process, the enterprise usually implements measures such as vehicle route optimisation, improving the utilization rate of vehicles, and cooperating distribution with Third-party logistics (3PL) to reduce the emissions in the transportation process (Li, Su, & Ma, 2017).

A supply chain with multiple buyers leads to a hike in demand and for satisfying them, a high standard production manufacturing system is required. A predetermined production rate in a supply chain model with economic production lot size is quite inappropriate for this type of situation as the production rate can be changed in some cases to fulfil the demand of customers. The rate of production has an impact on maintaining process quality. Manufacturing quality deteriorates with an increasing rate of production (Sarkar et al.,2018).

The data quality problem is a common issue, and it affects demand forecasting in fashion supply chain operations significantly. Without the availability of high-quality data, demand forecasting will not be good and hence the related operations such as inventory planning will all be negatively affected (Choi & Luo, 2019).

SC lead-time is one of the systematic characteristics in any firm that needs to pay attention to when determining resilience performance since the negative effects of lead-time cause following such as (1) Propagation of the severity of supply disruption and resume of the pre-disruption state (2) Disrupts the balance between supply and demand when demand uncertainty amplifies (3) Amplifies the effect on the order rate peak and order variance increase (4) The length/speed of recovery performance post disruption (5) The effectiveness and the condition of the backup supply In (Chang & Lin, 2019).

Many drug manufacturing plants are situated in tropical zones of Asia, where sea, air, and rail connectivity infrastructures are intricate, thus posing enormous challenges for transportation. Based on the Global Cold Chain Report published by IQPC/Cold Chain IQ, dramatic growth has been anticipated for the cold-chain logistics market in 2017 with increases of 57 per cent in emerging markets, 46 per cent in Asia, 21 per cent in Europe, and 18 per cent in North America. Therefore, given product mobility during sales, the transportation business shall be on the rise in the coming years (Kumar & Jha, 2019).

The current global interest in improving the use of ever-scarcer natural resources calls for the re-alignment of supply chain operations to include not only economic factors but environmental and social factors as well. Two of the most important supply chain activities that logistics managers must deal with are the planning and improvement of the packing and distribution of products. Although the optimisation of these two activities has been thoroughly studied utilizing Vehicle Routing Problems and Packing Problems, their analysis is often done separately and, in most cases, they consider only the economic decisions (Vega-Mejía et al.,2019).

Transportation has irreparable effects on the environment; Consumption of resources, toxic effects on ecosystems and humans, noise, and emissions of greenhouse gases (GHG) and pollutants are examples of these risks. The Vehicle Routing Problem (VRP) is part of a series of problems that are associated with determining a set of routes in which each vehicle starts moving from a particular warehouse, serving a set of specified customers, and returning to the same warehouse (Saad & Bahadori, 2019).

Disruption-driven changes in SC behaviour may result in a backlog and delayed orders, the accumulation of which in the post-disruption period we call “disruption tails”. The transition of these residues into the post-disruption period causes post-disruption SC instability, resulting in further delivery delays and non-recovery of SC performance. A smooth transition from the contingency policy through a special “revival policy” to normal operations mode partially mitigates the negative effects of disruption tails (Ivanov, 2019).

The demand management in the context of highly seasonal products is extremely challenging and the forecast accuracy could never achieve optimal performance when elaborating the tactical plan. Therefore, the supply chain needs to be flexible and responsive to be able to face unforeseen events and act promptly on the operational level (Németh & Gobbo, 2020).

Although generous return policies have been shown to have marketing benefits, such as a higher willingness to pay and a higher purchase frequency, counterbalancing these benefits is an increased volume of consumer returns, which presents significant operational challenges for both retailers and original equipment manufacturers (OEMs).

Since accurate return forecasts are inputs into strategic and tactic decision support tools for operations managers, advancements in better forecast accuracy can yield significant savings from the return management practice (Shang et al.,2020).

The all above reviewed challenges can be summarised as per their domain and nature in a table like below (see Table 2.3).

Supply Chain Operation Challenges	
Domain (Area)	**Description (Challenge)**
Sourcing	Sourcing dependency (Myopic Decisions & Dependency)
Production	Production process failures
Transportation	Transportation (Re-routing, alternate routes. Alternate modes)
Distribution	Distribution channel
Leadtime	Leadtime / Oder fulfilment
Warehousing	Warehousing / Inventory
Demand	Demand variation
Periods	Multi-period (Seasonal / multiple states of operations: normal, busy, idle)
Resilience	Disruptions / Breakdowns / Risk management/ Post disruption recovery
Returns	Return processes management and obtaining accurate return forecast
Recycling /disposal process & Re-manufacturing	Providing accurate information for OEM – remanufacturing using the usable components of returns which leads a huge time and cost savings and a faster disposal process of unusable components.

Table 2. 3: Supply chain operation challenges

2.2.3 Supply Chain Redesign Challenges

As emphasized by Van Der Vorst et al., (2002) supply chain re-design challenges can be categorized in for dimensions (see Figure 2.7). The presence of uncertainty stimulates the decision maker to create safety buffers in time, capacity, or inventory to prevent a bad chain performance. These buffers will restrict operational performances and suspend competitive advantage. The use of one or several of these redesign strategies will alter the logistical chain scenario, i.e., the design of and logistical way of working in the supply chain.

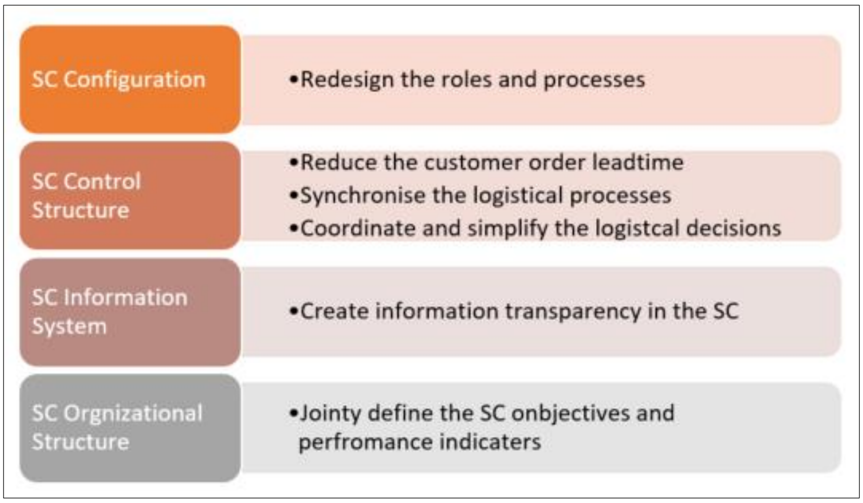


Figure 2. 7: Supply chain re-design challenges

Source: (Van Der Vorst et al., 2002)

Supply chain redesign involves complex competencies such as integration with suppliers and customers to create value as well as the acquisition of external information and its transformation into practices capable of producing marketable outputs. These competencies are contextually specific. In service-focused firms, customers co-create value in an integrative environment with the firm and its suppliers. Product-focused firms create value in the product before its delivery, requiring the firm to acquire and transform customer information into value offerings (Dobrzykowski et al., 2011).

While value creation is shaped by external drivers such as market volatility, technology, product and service offering, and disruption, it can be stymied by the internal stresses arising from the need to minimize costs, limitations in process redesign, and waste minimization, and the unavailability of knowledge capital. The emergence of novel business paradigms – non-applicability of the traditional laws of supply and demand, the dominance of negative externality effects, and anomalies of high growth rate coexisting with high supply side uncertainty – must be recognized in transforming supply chains (Chakravarty, 2014).

According to Sharfuddin & Sawicka, (2016) response to current customers' needs are not only the key to a successful business but predicting future needs and developing new ideas, and incorporating innovative ways of operations allow organizations to meet future challenges effectively and efficiently. Therefore, organizations need to monitor their logistics activities, reduce disadvantages and introduce innovative solutions to maintain a competitive edge and fulfil customer needs. This approach to redesigning the supply chain network can be presented as a procedure, composed of the following 3 phases (see Figure 2.8).

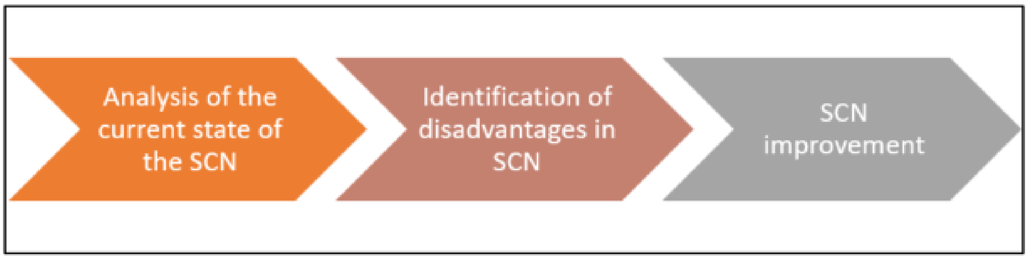


Figure 2. 8: Approach to re-designing a supply chain network

Source: (Sharfuddin & Sawicka, 2016)

The dynamic business environment forces companies to secure a competitive (Re)-Design of their supply chains. During the last two decades, companies have faced complexity in their supply chains currently with increased global operations. Organizations and companies operating in a fast-clock speed business environment need to design and redesign their supply chain often and fast to achieve temporarily competitive advantages (Krægpøth et al.,2017).

The SC structure is often changed according to a strategic business growth plan. Managers may have to shut down some facilities, open some new ones, or change their applications. These demands that the firm either design a new supply chain from scratch or redesign the existing supply chain with consideration of its current infrastructure. However, it is more realistic to take the existing infrastructure into the consideration and redesign the SCs rather than designing entirely new ones. Redesigning an SCN is a long-term strategic decision that considers the inherent level of market risk, cost of capital, and price and demand uncertainty. Although managers are conscious of covering demand and price uncertainty in the market, the selection of an appropriate method in an SCN with many operational elements is still questionable. (Jahani et al.,2018).

According to El Mokrini et al. (2018), the decision to redesign a distribution network is rarely simple. It requires taking into consideration many factors that affect all stakeholders along the supply chain. A distribution network specifically includes several components that need efficient integration. Decision makers are usually faced with the problem of selecting the most appropriate distribution network amongst alternative ones. In their study, it's well described what are the possible evaluation criteria (weight and rate) when it comes to selecting the best out of all alternatives (see Figure 2.9).

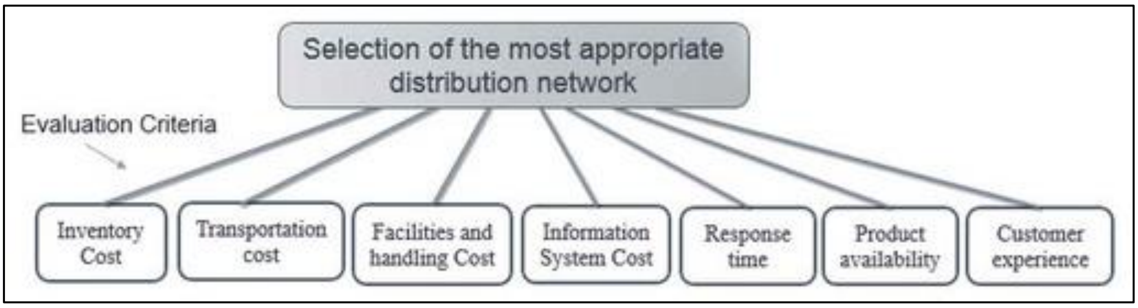


Figure 2. 9: Evaluation criteria in selecting the most appropriate distribution network

Source: (El Mokrini et al.,2018)

The new structure of the SCN will impose substantial changes in the elements of the budgeted statements. The main changes stem from financing the new design and determining the necessary loan amount in addition to the company's available cash. From the stockholders' or creditors' viewpoint, financial managers must present the company's revised statements after employing the new design. As the balance sheet and income statement interact and overlap in several ways, the model evaluates the effect of new products across interactions by maximizing the total equity (Jahani et al.,2019).

In (Bianchini et al.,2019), with the model they have developed, it was well described how necessary it is a redesign the supply chain for companies who aim to develop new business opportunities in the market. Focusing on purchasing and procurement processes, the model application aims at the individuation of suppliers involved in the critical paths, then at the development of a hypothesis of possible alternative strategies, and, finally, at a lead-time reduction. Therefore, the outcome is an optimized purchasing system, aligned with company strategies, which guarantees benefits in terms of costs and lead-time reduction, and the elimination of non-added value activities.

Many Japanese manufacturing companies are actively producing, selling, and trading through their overseas bases. However, in recent years, there has been a change in the environment surrounding the supply chain, with rising labour costs in China, quality problems, and fluctuating exchange rates. In addition, due to the rising sophistication of consumer demand and the advancement of technology, among other factors, Japanese firms had to relocate their production bases. Thus, reshoring, by which the manufacturing industry returns to the domestic market, and nearshoring, by which the production base shifts to neighbouring countries, are regarded as extremely important strategies (Kainuma et al.,2019).

The lack of collaboration and visibility between inbound and outbound transportation leads to lost opportunities in taking advantage of empty vehicles. Empty vehicles are non-value-adding sources of Green House Gas (GHG) Customers are increasingly demanding supply chains that consider environmental issues as well as economic. According to the European Commission (2016), in 2014, the transportation sector was responsible for almost 25% of all GHG emissions in Europe, and road transport contributed over 70% of this. Their goal is to reduce road transport by 60% from 1990-2030 (Andreassen et al.,2019).

The changes in the political environment, new technologies, and consumer behaviour often require that firms respond by redesigning their supply chains to adapt. Is the existing network design still optimal? Should the use of third-party warehousing be increased? Is the level of automation in warehousing and transportation still appropriate? Should changes be made to sourcing countries, suppliers, or ports of entry? Moreover, as competitors also change in response to uncertainty, it is important to change promptly to stay ahead. What matters to firms in such changing environments is their capacity to closely monitor and predict change and to redesign supply chains accordingly (Zinn & Goldsby, 2019).

Today, firms are facing enormous pressure to restructure, redesign, and rethink where and how products are produced, inputs are sourced, and customer demand is fulfiled. The drivers for this change include all the usual factors, such as market volatility, cost differentials, and technology disruption. Additionally, there are unknowns concerning government policies that affect both cross-border trade and local processes. This has led to the current situation where we are experiencing a trade war, with governments looking to optimize the domestic portion of the supply chains that operate in their jurisdiction. At the same time, companies are striving to optimize their specific global supply chains, which operate in multiple jurisdictions and generate extensive cross-border flows of goods, money, information, and control (Cohen & Lee, 2020).

Regarding reverse logistics supply chain network redesign, sustainable goals including economic, environmental, and social dimensions are usually considered. However, many enterprises face a problem that is how to implement the recovery of used products into their existing forward logistics networks. In this case, it is necessary to redesign a novel sustainable reverse logistics supply chain network by reconstructing the existing facilities into hybrid processing facilities (Gao & Cao, 2020).

2.3 Model-based problem solving and decision making

The research literature on supply chain management is rapidly growing, offering different classifications of supply chain models. Depending on the operational level of the problem, supply chain models are broken down into strategic, tactical, or operational hierarchies (Shahi & Pulkki, 2013).

Hamta et al., (2015) have re-emphasized the importance of decision-making levels and their impact over different planning horizons which had been already explained by Vidal and Goetschalckx (1997) as in SCM multi-levels of decisions are to be made on the time horizon with multiple objective functions. The decision levels can be categorized as long-term decisions (strategic level), mid-term decisions (tactical level), and short-term decisions (operational level).

A real management problem is the initial point of the decision-making process (see Figure 2.10). The model can be solved with the help of existing algorithms within a reasonable time. Small instances can be solved with the help of Excel Solver, but for real data, a professional solver such as CPLEX, Lindo, AMPL, Matlab, GAMS, Gurobi, and

XPRESS exist. Then the software calculates the solution which should be analyzed by decision-supporting quantitative methods (Ivanov et al.,2017).

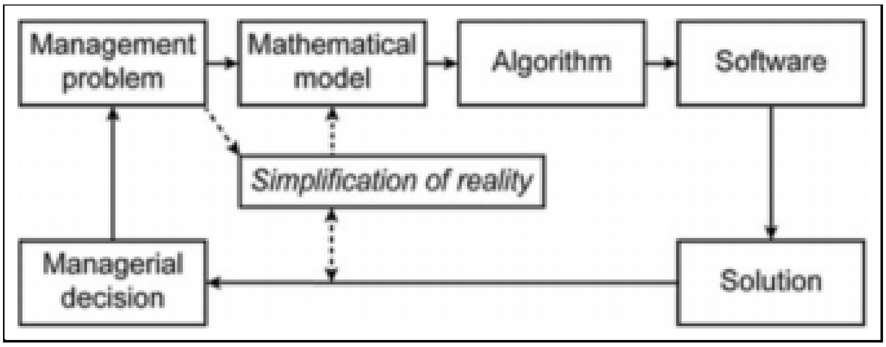


Figure 2. 10: Model-based decision-making process

Source: (Ivanov et al.,2017)

Ivanov et al., (2017) emphasized this by giving an example like; the facility location problem where we are given demand in some markets, possible locations and capacities of new facilities, fixed costs of having a facility in the SC, and transportation costs from each location to each market. We must decide where to locate the facilities and which quantities should be shipped from the facilities to the markets.

Current trends like e-business, e-commerce, e-logistics, and outsourcing activities are increasing both: the competitive pressure and the complexity of the behaviour of involved systems and their processes. Its inherent complexity creates the need for a Modelling and analysis framework. Modelling real-world problems can yield large and complex models and the way models are structured should accommodate the way SCs are structured, in reality (Arns et al.,2002). Supply chain Modelling approaches can be classified into two main types such as analytical (Optimisation) and simulation models (Othman & Mustaffa, 2012).

Ivanov & Dolgui (2021) emphasized the trend of a combination of model-based and data-driven approaches allows uncovering the interrelations of risk data, disruption modelling, and performance assessment and then the SC shocks and adaptations amid the COVID-19 pandemic along with post-pandemic recoveries provide indisputable evidence for the urgent needs of digital twins for mapping supply networks and ensuring visibility.

As per Simao et al. (2021) majority of the structures were shown from a theoretical perspective with limited practical implementation; thus, there is still a lack of empirical studies in this field. Also, he explains how Mishra et al. (2018) highlighted the limitation of the mathematical and simulation models used for modelling and analysing an SC. The authors argue that more research is needed to develop proper models that are inclusive and easy to use by both academics and professionals.

Aldrighetti et al. (2021) categorised the existing knowledge based on decision-making problems, which can be instructive for a convenient association of a particular SCND problem to a modelling domain according to network-wise, supply-side and demand-side perspectives. Then how their analysis focuses on the costs specifically induced by disruption risks, resilience investments, different SCM dimensions (i.e., social impact, environmental impact, responsiveness, and risk-aversion) and the associated multi-objective modelling settings along with disruption risks in SCND models.

2.3.1 Optimisation Models

Mathematical programming techniques, maximize certain benefits by optimising the strategic design and/or operational policies of the supply chain. Although analytical models are useful in many cases, they are often too simplistic to be of practical use for complex supply chains (Tarokh & Golkar, June 2006). Optimisation models consider the supply chain at specific instances in time and do not take on a dynamic view, as is the case with simulation models. (Persson & Araldi, 2009).

The optimisation is an analysis method that determines the best possible option for solving particular operations or SC problems. The optimisation has been a very visible and influential topic in the field of SCOM. The drawback of using optimisation is the difficulty in developing a model that is sufficiently detailed and accurate in representing the complexity and uncertainty of SCM while keeping the model simple enough to be solved (Ivanov et al.,2017).

In the world of optimisation, the factors (i.e., input parameters and/or structural assumptions) become decision variables and the responses are used to model an objective function and constraints. Whereas the goal of experimental design is to find out which factors have the greatest effect on a response, optimisation seeks the combination of factor levels that minimizes or maximizes a response (subject to constraints imposed on factors and/or responses) (April et al.,2003).

2.3.2 Simulation Models

In the area of design of experiments, the input parameters and structural assumptions associated with a simulation model are called factors. The output performance measures are called responses. For instance, a simulation model of a manufacturing facility may include factors such as the number of machines of each type, machine settings, layout, and the number of workers for each skill level. The responses may be cycle time, work-in-progress, and resource utilization (April et al.,2003). Capture realistic supply chain characteristics and allow the evaluation of the impact of policy changes carried out by one or more supply chain members. Hence, simulation models can be used as an important first step toward realistic optimisation (Tarokh & Golkar, June 2006).

Simulation is more suited for representing random effects used for simulation-based optimisation and predicting the dynamic behaviour of supply chains (Persson & Araldi, 2009). Simulation imitates the behaviour of one system with another. By making changes to the simulated SC, one can gain an understanding of the dynamics of the physical SC. A simulation is an ideal tool for further analysing the performance of a proposed design derived from an optimisation model (Ivanov et al.,2017).

It is well explained by Othman & Mustaffa (2012) that Simulation models usually are either static or dynamic. Then these can be further divided into two types: *Deterministic model:* No randomness and uncertainty are considered if using of so that the problem is relatively simple to solve. *Stochastic model:* Define as having a random variable or being uncertain. This nature of problems may become complex to solve analytically and need some simulation methods, generally called stochastic simulation to estimate the performance of the system. *The static model* is a time-independent view of the system, while the *dynamic model* is a time-dependent view of the system (see Figure 2.11).

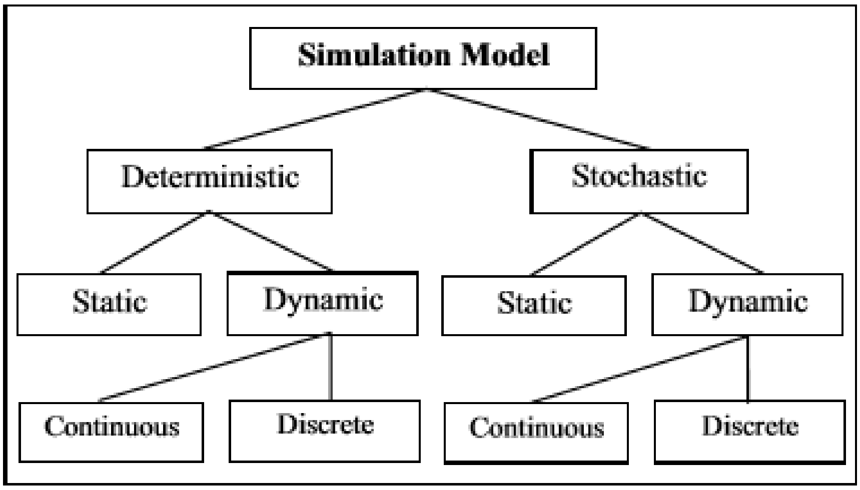


Figure 2. 11: Classification of Simulation Model

Source: (Othman & Mustaffa, 2012)

However, in the modern supply chain, most of the problems are usually complex (dynamic and stochastic nature). Discrete simulations (usually discrete-event simulations or Monte-Carlo simulations) are frequently used as a methodology instead of continuous simulation since the SC system is usually faced with discrete variables and stochastic behaviour (Othman & Mustaffa, 2012).

The optimisation of simulation models deals with the situation in which the analyst would like to find which of possibly many sets of model specifications (i.e., input parameters and/or structural assumptions) lead to optimal performance (April et al.,2003).

2.3.3 Role of Optimisation-Simulation for better decision making

In terms of decision making which spreads across from Strategic to Tactical to Operation level planning horizons why it is appropriate to apply Analytical Methods first and then Simulation Methods in decision-making is a very significant question.

As per a very clear explanation by Ivanov et al., (2017) both analytical and simulation methods have certain application areas, advantages, and disadvantages, addressing diverse problems. When addressing the specific areas of problems, the level of detail involved in strategic, tactical, and operational level decision making and the static and dynamic behaviour varies (see Figure 2.12).

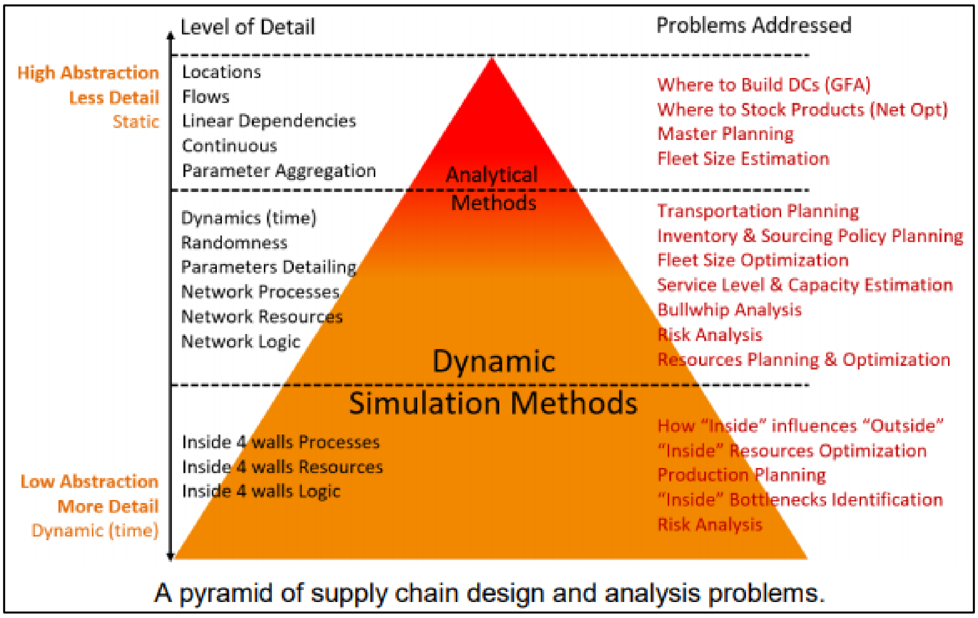


Figure 2. 12: A pyramid of supply chain design and analysis problems

Source: (Ivanov et al.,2017)

You can optimize the supply chain's facility locations and then simulate their inventory control policies, transportation, and sourcing rules. You will start at the strategic level by using a green field analysis (GFA), sometimes called a centre-of-gravity analysis, to define your supply chain design. During the second stage, you will use other parameters: such as transportation costs, real routes, and feasible facility locations and perform network optimisations. As your problem statements become more detailed, your simulations can include combinations of inventory control, sourcing, transportation, and production policies'' (Ivanov et al.,2017).

According to Jahangirian, Taylor, & Young (2010) in the modelling and simulation (M&S) community it is widely known that M&S can assist in identifying cost savings. When modellers and decision makers need a very quick, yet decisive answer to their needs at the time of an investment, it is interesting to know how various M&S techniques work in terms of cost-effectiveness (see Figure 2.13). Simulation techniques demand more man hours and hardware requirements while producing reliably high profits (if successful) while Mathematical modelling techniques, on the other hand, impose some assumptions that would normally simplify the solution. Therefore, a general guide would be to see the suitability of mathematical modelling techniques first, before a simulation attempt is to be made

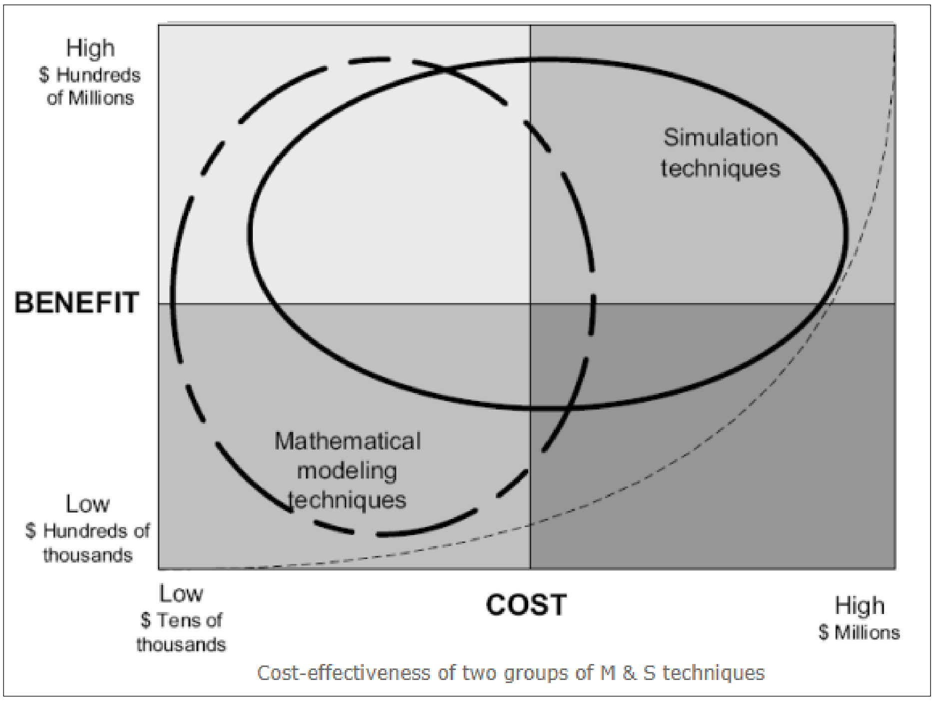


Figure 2. 13: Cost-effectiveness of two groups of mathematical modelling & simulations

Source: (Jahangirian, Taylor, & Young, 2010)

The dimensions of the grounds behind this can be illustrated as per the research outcomes of (Ivanov et al.,2017) who explain one dimension as the level of problems addressed and the details reflect decision making. Then as per (Jahangirian, Taylor, & Young, 2010) the other dimension is the consideration of trade-offs between the time, and resources must invest and the cost and benefits in return (see Figure 2.14).

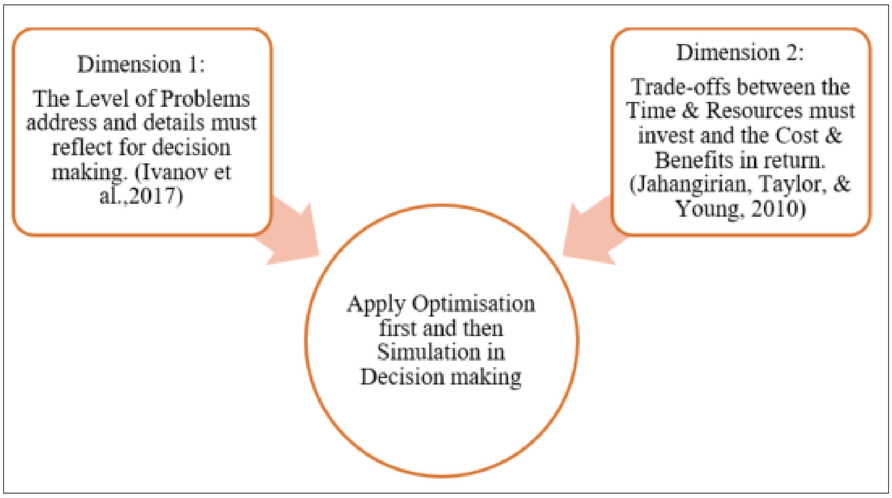


Figure 2. 14: The grounds for applying optimisation first and then simulation in decision making

The comprehensive study conducted by Llaguno et al. (2022) emphasised that supply chains are becoming increasingly sophisticated and vital for many firms' competitiveness. Nevertheless, their interrelated, complex, and global nature also makes them more vulnerable to the risk of their operations being interrupted. Their proposed conceptual framework is analysed and validated over a simulation analysis model. This ultimately helps analyse the ripple effect on supply chains, which occurs when disruption in one node spreads throughout the supply chain and impacts its performance, design, and planning parameters. Then a conceptual framework (see Figure 2.15) is proposed which includes the main characteristics and perspectives of the ripple effect on supply chains, and the possible proactive and reactive measures to mitigate its effects and recover from serious disruptions.

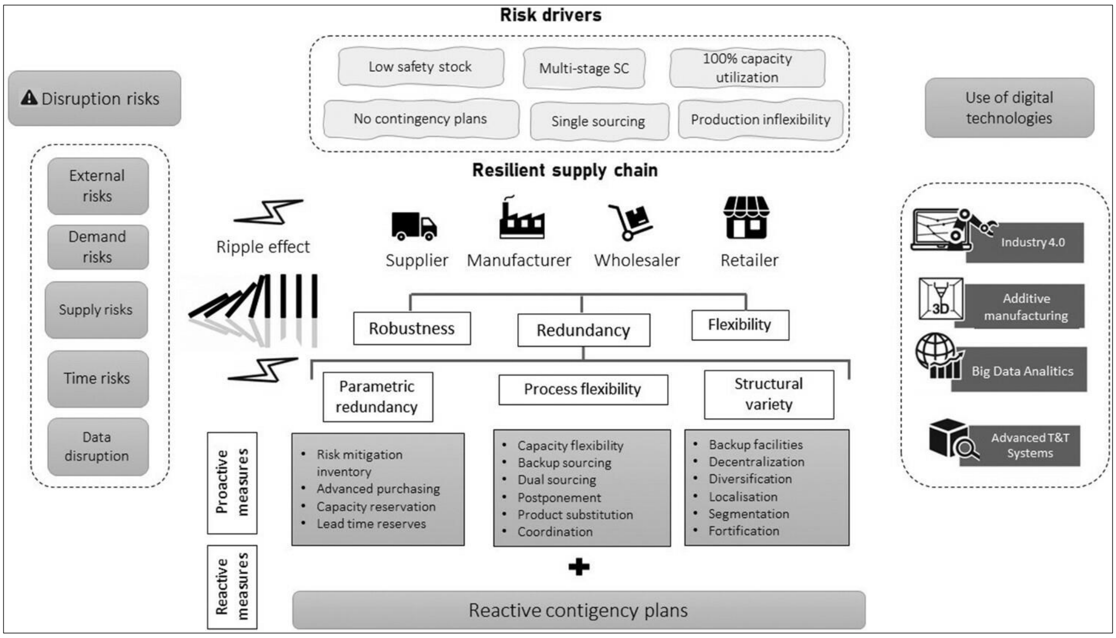


Figure 2.15: Conceptual framework for the resilient supply chain – A simulation analysis model

Source: (Llaguno et al.,2022)

Mogale et al. (2022) emphasised that closed-loop supply chains (CLSCs) are essential for maximising the value creation over the entire life cycle of a product. That seeks to optimise total cost and carbon emissions generated by production, distribution, transportation, and disposal activities over the end-to-end nodes of a CLSC by deploying their model (see Figure 2.16).

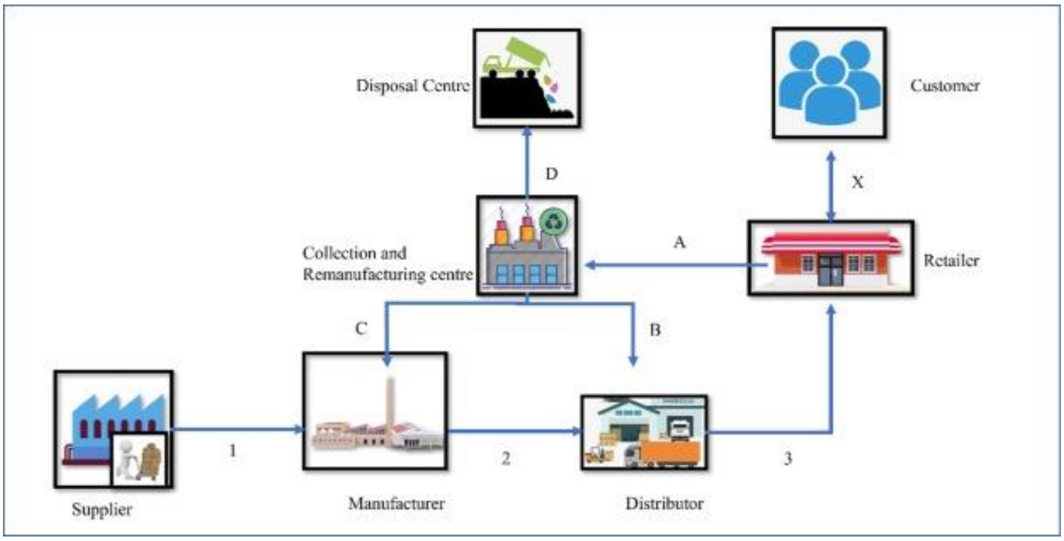


Figure 2. 16: Application of Optimisation in a closed-loop supply chain network nodes: Schematic representation

Source: (Mogale et al., 2022)

Biswas & Narahari (2004) developed a Model called DESSCOM (decision support for supply chains through object modelling). By deploying this, the constructs can be modelled at the required granularity to aid in strategic, tactical, and operational decisions. The modelling process starts with the identification of structural objects and policy objects in the network. The network configuration can be updated at any point in time by adding or altering various objects of the supply chain without having to take recourse to cumbersome programming efforts. The models thus created can be used in the analysis of the system under various scenarios. DESSCOM can therefore be used to optimize the system and evaluate performance measures under different scenarios. The development time for various models is considerably reduced. These models are used to provide inputs for various tools of the decision workbench (see Figure 2.17).

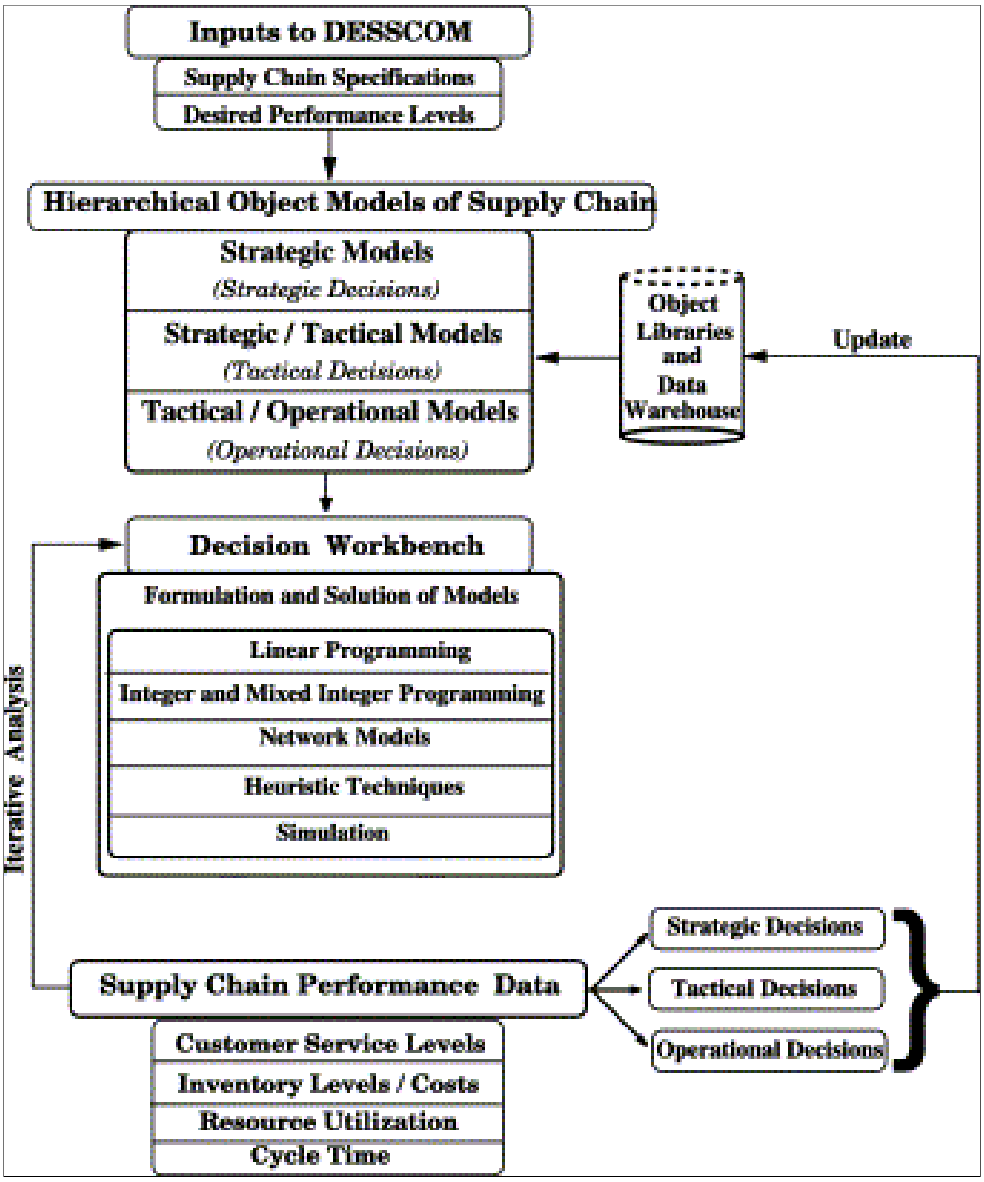


Figure 2. 17: The architecture of the DESSCOM-Model

Source: (Biswas & Narahari, 2004)

The proposed model by Amin-Tahmasbi et al. (2022) is motivated by a factory-less concept and by providing a dynamic decision-making solution under a multi-period time horizon. Within their model, it’s determined the optimal replenishment number of production facilities using multi-objective functions which include minimisation of the total cost, rejected and late delivery units and, maximisation of the assessment score of the selected suppliers. Thus, this dynamic decision model is significant for the cost-efficient management of companies’ supply chain networks.

2.4 Emergence of Optimisation & Simulation Tools (OST)

Supply chain management incorporates the use of analysis tools such as system dynamics, optimisation, and simulation. software ARENA is a commercial simulation tool that can be used for simulation modelling in various applications. An integration of SCOR and ARENA provides the supply chain analyst with a comprehensive and dynamic tool (Persson & Araldi, 2009). Optimisation continues to be one of the most exciting areas within simulation because it greatly enhances the utility of simulation modelling by helping users make complex decisions amid uncertainty (Boesel et el., 2001). The history of optimisation and simulation goes far older than 60 years. Even though the term has not been in common usage at the beginning; progressively seeking better solutions is arguably the whole purpose of the users and has experimented with input parameters throughout its history (Fu & Henderson, 2017).

The following case is a high-dimensional problem which is well described by the elegant use of OST

> "The Kroger Co. is the largest grocery retailer in the United States. It operates 2,422 supermarkets and 1,950 in-store pharmacies. The simulation-optimisation system was implemented in October 2011 in all Kroger pharmacies in the United States and has reduced out-of-stocks by 1.6 million per year, ensuring greater patient access to medications. It has resulted in an increase in revenue of $80 million per year, a reduction in inventory of more than $120 million, and a reduction in labour cost equivalent to $10 million per year" (Zhang et al. 2014).

2.4.1 Use of Optimisation in SCM

Geunes & Pardalos (2003) emphasised that during the past decade, two relatively new application areas have attracted the attention of a growing number of researchers who specialize in applying optimisation techniques to large-scale real-world problems. The now well-known areas of supply chain management and financial engineering have provided extremely rich contexts for the definition of new large-scale optimisation problems, the solutions of which can provide substantial value to organizations.

Aslam & Amos (2010) explained that supply chains are in general complex networks composed of autonomous entities whereby multiple performance measures at different levels, which in most cases conflict with each other, have to be taken into account. Then their research led them to review and identify the need for multi-objective and multi-level optimisation (MLO) framework for SCM, which considers not only optimisation of the overall supply chain, but also for each entity within the supply chain. According to their framework shown in Figure 2.18, only feasible solutions from the process level optimisation will be considered and sent to the operation level optimisation. In this way, all the process level entities will only send their internal optimized solutions, containing the process settings that will be incorporated in the operation level optimisation.

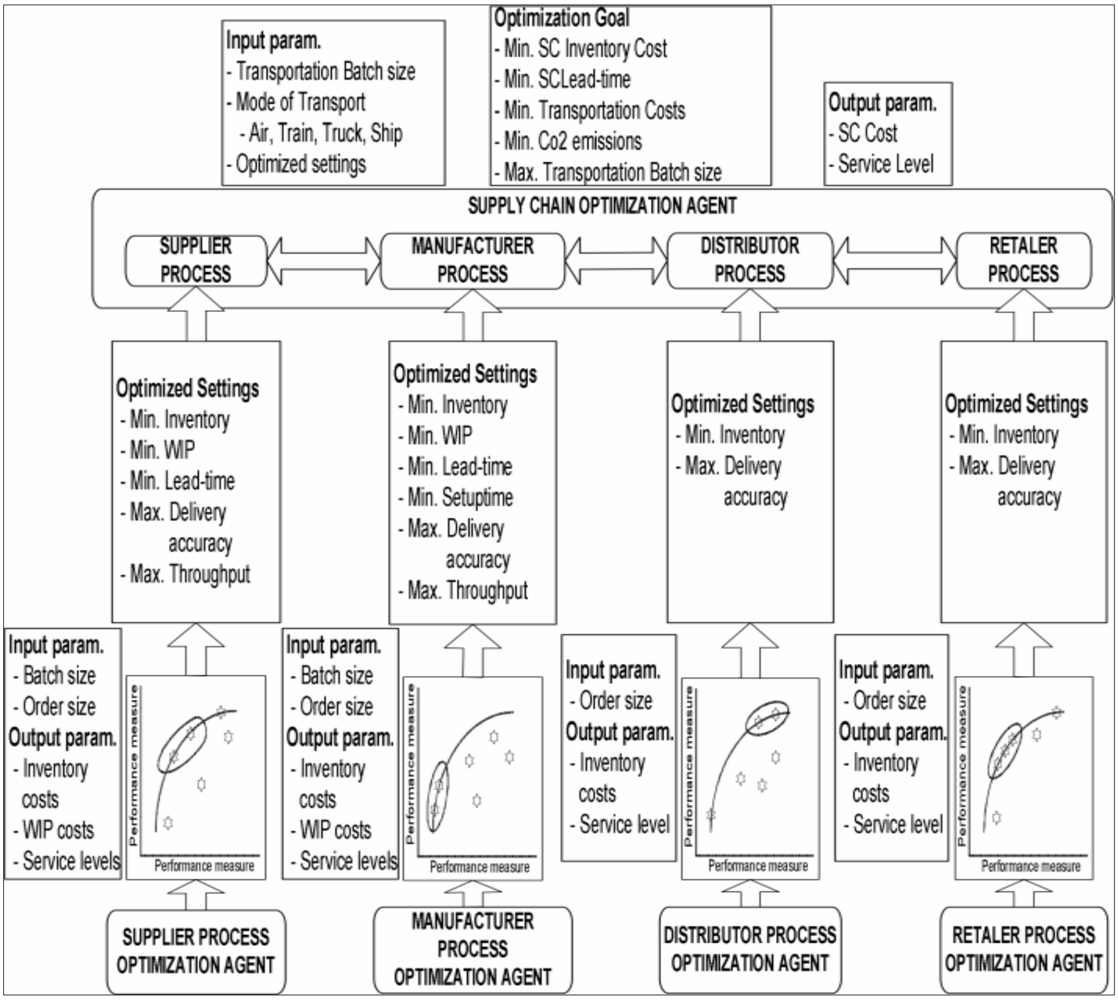


Figure 2.18: Multi-Level Optimisation

Source: (Aslam & Amos, 2010)

As per research work conducted by Torkornoo &Hou (2013), SC optimisation is the process of finding "what's best" out of a feasible set of solutions while meeting the business constraints of a supply chain. For example, “There are many ways to transport products from Chicago to LA, but not all of them are created equal. If your objective is to minimise transportation costs, then “what’s best” may be to use commercial trucks or trains. If your objective is to minimize transportation time, then air freight may be your best bet. The optimisation is also a way to reach the efficient frontier’’ Also, they have emphasised below the application domains of optimisation in business:

- Network design: identify the best network to serve your customers
- Inventory positioning: identify the best inventory position
- Sourcing decisions: minimize the total costs of making products at manufacturing plants and shipping to end customers to meet all demand
- Risk management: identify the best strategy to minimise potential disruption

Gulley (2016) has explained that supply chain optimisation is the application of processes and tools to ensure the optimal operation of a manufacturing and distribution supply chain. This includes the optimal placement of inventory within the supply chain, minimizing operating costs. Supply chain optimisation addresses the general supply chain problem of delivering products to customers at the lowest total cost and highest profit.

According to Lacomme et al. (2018), production planning and routing is the key feature in a supply chain since the coordination of these two functions significantly impacts the customer service level. In return, the framework they have developed deals with an extension of the integrated production and transportation scheduling problem (PTSP) by considering the production and transportation scheduling problem with multiple vehicles (PTSPm) to optimise supply chains. This approach proves it is possible to solve the two problems in a coordinated way and permits obtaining a better solution than the classical approach, where the two problems are solved sequentially. Also, this is an advantage of an indirect representation of the solutions using a split-based approach with search space alternation between Transportation Scheduling Problem (TSP) solutions, Vehicle Routing Problem (VRP) solutions and PTSPm solutions.

The quantitative planning tool developed by Yahya et al. (2021) was used to plan and optimise biomass supply chains based on carbon reduction targets. This works in three stages: Carbon Emission Pinch Analysis (CEPA), mathematical optimisation, and multi-stakeholder analysis. CEPA is used to determine the minimum amount of biomass to achieve carbon reductions. Then, mathematical optimisation is used to optimise the biomass supply chain based on the carbon reduction target. The optimisation step considers the use of new biomass power plants and co-firing existing power plants.

Ozçelik et al. (2021) examined the ripple effect on the system performance of the reverse supply chain (RSC) network and introduced a robust optimisation model for designing strong RSC networks to cope with the uncertainties caused by the ripple effect. The design decisions, including worker and vehicle assignments, facility opening, and recovered products, attempt to be optimised in the context of green logistics to obtain a robust RSC design. The scope of the case study is limited to the northern region of Turkey, which is a potential landslide site due to the heavy rainfall. The proposed robust model (see figure 2.19) is run 112 times with different weight uncertainty values. According to the results, the robust solutions are computationally tractable; however, the price of robustness is higher than expected to protect the constraints against violation when the Probability of Constraints Violation (PoV) is set to 1%. ss

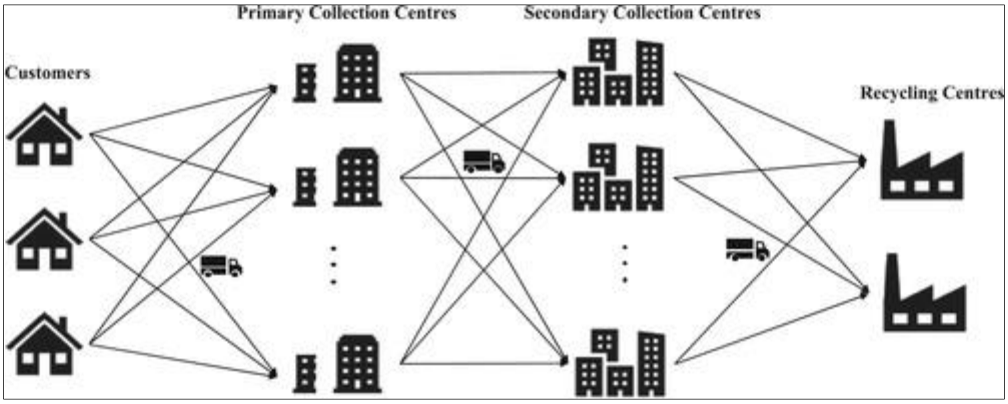


Figure 2.19: The schematic representation of Robust optimisation for the ripple effect on reverse supply chain

Source: (Ozçelik et al., 2021)

2.4.2 Use of Simulation in SCM

Although optimisation has been the analytical tool of choice for supply chain analysis, there are business scenarios where variance plays such a large part that optimisation will not paint a realistic of the business. In these cases, simulation should be used. Using simulation will allow the user to understand the total cost of variance on the business, including labour variance, material obsolescence, material shortages, capital shortages, and most importantly, the demand forecast variance. These problems are common for any business that serves a dynamic market (Ingallis, 1998).

The use of simulation is a proven decision support tool in operational practice for production planning and control, whenever a complex system of target figures, control parameters and disturbance variables are present, the number of system components results in a complex system behaviour over time. It is hardly feasible to handle this complexity by analytical methods and to give tractable mathematical formulations (Römer, 2021).

SC simulation is the action of walking/stepping through the details of a process in a controlled, often virtual, environment based on specific rules (What-if) to replicate the way a system works, usually to gain a better understanding of the system. Thus, the true value of a simulation model is in providing a virtual sandbox for doing what-if analyses, which help decision makers identify the impact of different variables on an organization's supply chain (Torkornoo, Hou, 2013).

By using simulation, managers can create a model of their supply chain systems and test various levels of input that can emulate real-life inconsistencies. The simulation models can become a component of the analysis methodology and become a great partner with supply chain management software. Then, by taking the scenarios created by the supply chain tool and running them through the simulation model to test for flexibility, managers can eliminate unrealistic solutions and pinpoint a defined set of preferred solutions well explained (Tarokh & Golkar, June 2006).

According to (Othman & Mustaffa, 2012) continuing developments of technology day after day increase the development of decision-making tools for simulating processes and that can be performed in three different ways as follows,

- Spreadsheet simulation
- Simulation software packages (one of the major concerns which lead to this research)
- Simulation programming language.

Simulation is the best practice to evaluate the system performance close to a real situation. However, simulation solely is not enough to achieve an optimal result and needs to corporate-with optimisation tools and techniques. It further emphasizes that a method of 'simulation' and 'optimisation' has been used by researchers nowadays related to finding the best solution for the decision-making process in the SCM field.

With the use of simulation technology, it is possible to reproduce and test different decision-making alternatives upon more possible foreseeable scenarios, to determine in advance, the level of optimality and robustness of a given strategy. Realizing the potential of supply chain simulation, academics and practitioners alike have developed many supply chain simulation tools to assist modellers, explained by (Tarokh & Golkar, June 2006) and concluded their findings with the use of Simulation Tools as follows.

- Testing Hypotheses about how the real System works
- Better understand supply chain dynamics
- Diagnose problems and evaluate possible solutions
- Identify the best Management Policies
- Optimize operations
- Mitigate risk factors
- explain the bullwhip effect
- Improve performances of forecasting techniques
- Predict the effect of changes and supply chain performance
- Experiment with the new designs or policies before implementation.

In (Othman & Mustaffa, 2012) argue that simulations are often used as a model of a real system to evaluate output responses. However,

"Simulation itself is not an optimizer". A simulation process needs to communicate with some optimisation module (or decision optimizer) to provide feedback on the progress of the search for the optimal solution''.

''The integration between both optimisation and simulation has been created for solving many real complex problems (uncertainty). The optimisation of simulation models deals with the situation in which the analyst would like to find which of possibly many sets of model specifications (i.e., input parameters and/or structural assumptions) lead to optimal performance. The integration between simulation model and optimizer allowed us to effectively analyse and easily solve the problem.'' The black-box approach of simulation optimisation based on metaheuristic methodology can be shown as follows (see Figure 2.20).

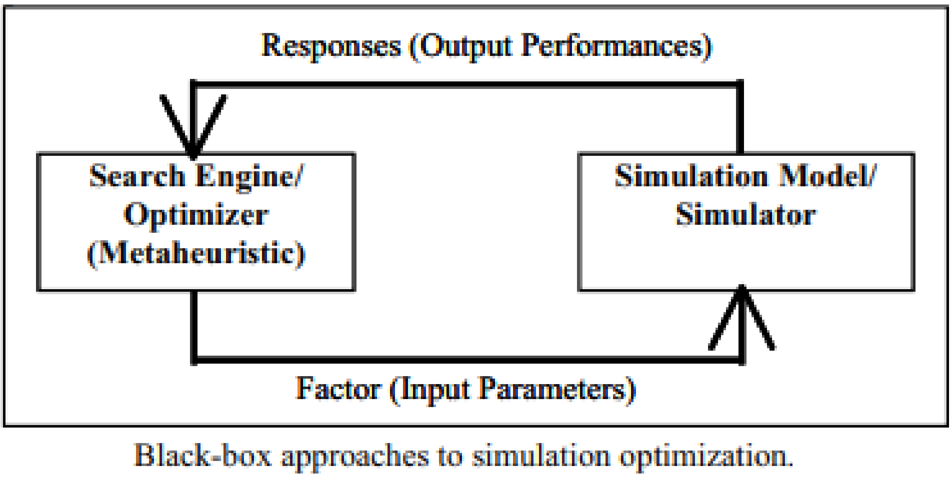


Figure 2. 20: Black-box approach to simulation optimisation

Source: (Othman & Mustaffa, 2012)

The main difference is that heuristics are problem-specific methods (created to solve a particular problem and probably nothing else) while meta-heuristics are problem-independent methods that can be applied to a wide range of problems. According to (Suh & Park, 2017) ‘’The heuristic approach that finds the optimal alternative based on the expertise, experience, and intuition of the decision-maker is the most common method in feedback-based decision-making. The meta-heuristics designate a computational method that optimizes a problem by iteratively trying to improve a candidate solution about a given measure of quality.

In the past decades, simulation and optimisation have played significant roles in solving complex problems in Supply Chain Operation Management (SCOM). Successful examples include production planning and scheduling, supply chain design, and routing optimisation, to name a few. However, many problems remain challenging because of their complexity and large scales, and/or uncertainty, and stochastic nature (Ivanov et al.,2017).

Supply Chain Management is a complex process as it involves a lot of activities like purchasing, production, inventory management, logistics and transportation. To manage this complexity, simulation software can be used as they mimic real-life situations, and they will help managers in making superior decisions on areas like facility location, transportation choice and inventory model choices. A critical analysis of the case studies was conducted, and the results reveal that simulation is a powerful tool that can be used in modelling complex supply chain activities. Simulation models however fail to provide optimum solutions for decision variables inherent in predefined objectives. Therefore, integrating optimisation models would offer the best likely alternatives for decision-makers (Maina & Mwangangi, 2020).

2.5 OST Application Domains in SCM

Before jumping straight to review the potential application domains of Optimisation and Simulation Tools (OST) it's always worth it to review how these tools were developed, what are the key pillars (Success factors and methods) considered by the developers, development, and the growth of integration of Optimisation and Simulation which are commercially available today for our use.

Simulation can be used to determine the state of certain controllable inputs to a system that will cause system outputs to be at their most favourable or optimal condition. The optimizer would use model inputs and outputs as well as user-supplied information to determine an optimal solution. The optimizer would possess the requisite intelligence to determine an appropriate optimisation method for a given problem. Dennis Pegden and Michael Gately were among the first to report the linking of an optimisation algorithm with a commercially available simulation package (Bowden & Hall, 1998).

Bowden and Hall 1998 extended the work of Dennis E. Smith (1973) by proposing six distinct domains (see Figure 2.21) to address when developing future simulation optimisation tools (Boesel et al.,2001).

- **The Interfaces Domain:** addresses both the interface between the optimizer and the user and the interface between the optimizer and the simulation model.
- **The Problem Formulation Domain:** addresses the construction of the objective function and constraints.
- **The Methods Domain:** addresses those optimisation methods used to optimize simulated systems.
- **The Classification Domain:** addresses the analysis and classification of a given optimisation problem to select the appropriate optimisation method(s).

- **The Strategy and Tactics Domain:** addresses the employment of simulation optimisation to make the most efficient use of computing resources.
- **The Intelligence Domain:** considers the intelligence embedded in the solver to select the strategic approach and tactical employment of various techniques based on the problem classification.

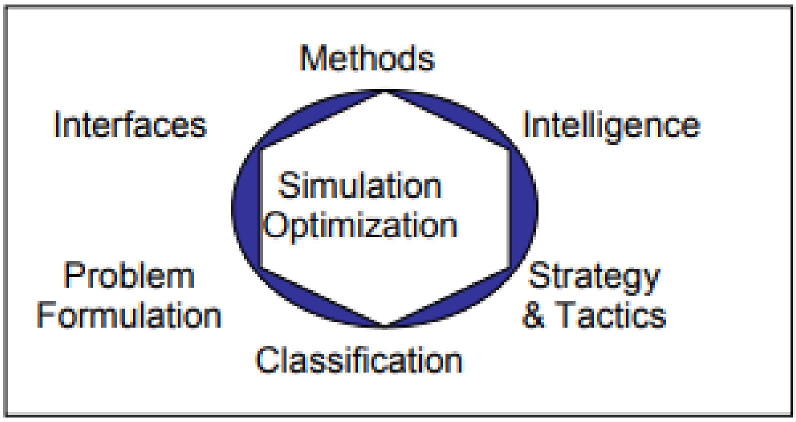


Figure 2. 21: The Domains of Simulation Optimisation

Source: (Boesel et al.,2001)

Several simulation software vendors have introduced optimizers that are fully integrated into their simulation packages. Simulation practitioners now have access to robust optimisation algorithms, and they are using them to solve a variety of "real world" simulation optimisation problems as explained by Akbay (1996). Although these simulation optimisation packages are based on better optimisation algorithms than those available in the late 1970s (Schwefel, 1995), further improvements can be made to this important area of simulation (Bowden & Hall, 1998).

Recommendations are often made for improvements to optimisation algorithms that will improve the method's performance for a specific situation. See Carson and Maria (1997) for a review of methods. Although this work is useful, a framework is needed that unifies research and development across all relevant domains — the search methods, statistical methods, user interfaces, and strategies associated with simulation optimisation. The synergy created by these systems' view of simulation optimisation can lead to better optimisation tools for practitioners (Boesel et al.,2001).

The combination of simulation and optimisation, essentially unheard of in practice a decade ago, is much more accessible today, thanks in large part to the development of commercial optimisation software designed for use with existing simulation packages. Despite this growth, untapped applications abound (Boesel et al.,2001).

Businesses today are very tempted by the latest Optimisation and Simulation Tools, Methods and potential application domains which made a huge impact on the way today the Supply Chain (SC) gets designed and how to utilize and integrate these successfully to get the products to their customers faster and at a lower cost. Predominantly the application of these OSTs in SCM can be identified in the following domains (see Figure 2.22).

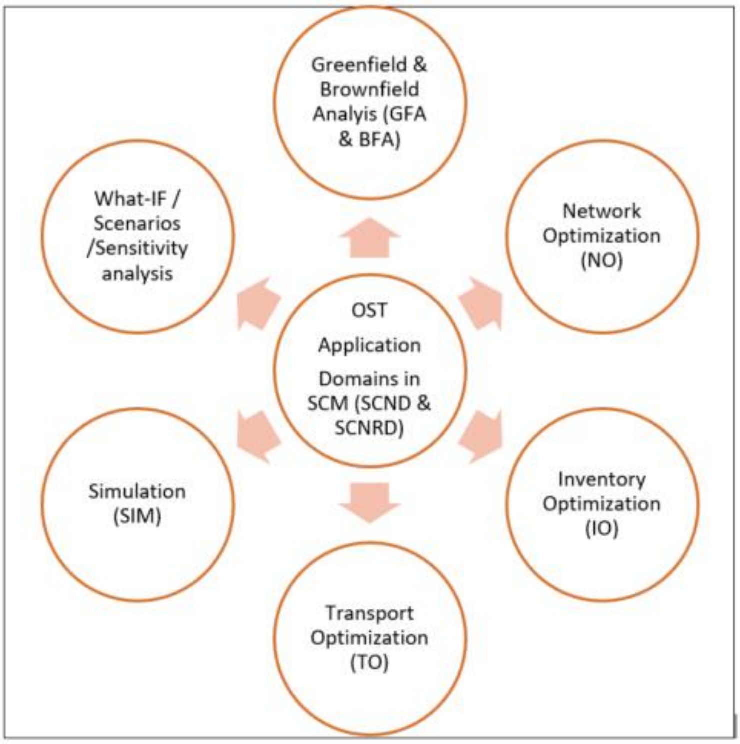


Figure 2. 22: Application domains of OST in SCM

2.5.1 Greenfield Analysis (GFA) & Brownfield Analysis (BFA)

In the early days of supply chain planning, this is known as the centre of gravity method which enormously help to solve the Facility Locating Problem (FLP). This is the analysis to find out the optimal locations when there are no candidates in hand (from the scratch) and use the power of optimisation to come up with the best options in the concerned geographical area. But comparing to GFA the Brownfield analysis for the network which already exists and has a location in hand while trying to solve an FLP. Thus, BFA is more attached to Supply Chain Network Re-Design (SCNRD). It's recognised that the literature that exists regarding these two Optimisation Tools is very rare for some reason.

2.5.2 SC Network Design (SCND)

Supply chain network design (SCND) deals with strategic decisions such as deciding on the number, location, capacities, and technologies of facilities to be opened, changes to existing facilities, and supplier selection. In addition, it includes tactical decisions such as production and shipping plans as well as material flows through the network (Salem & Haouari, 2017).

Green" supply chain network design problem where an initial investment in environmental protection equipment or techniques should be determined in the design phase. This investment can influence the environmental indicators in the operations phase. With such a concern, the decisions on facility location and capacity allocation have to be integrated with the decision on environmental investment. The reverse logistics network design problem focuses on setting up some special facilities (i.e., recovery centres) to enable the recycling initiatives or optimizing the network configurations in a close-loop network (Wang, Lai, & Shi, 2011).

Supply chain network design (SCND) is one of the most crucial planning problems in supply chain management (SCM). Nowadays, design decisions should be viable enough to function well under complex and uncertain business environments for many years or decades. Therefore, it is essential to make these decisions in the presence of uncertainty, as over the last two decades, many relevant publications have emphasized its importance (Govindan et al.,2017).

Recent years have been characterized by a rapid enrichment of these mathematical model solutions. Rich models now handle multiple levels in the logistics network, multiple periods, products, technologies, transportation modes and types of facilities. They integrate capacity constraints, tactical decisions, and complex product flows. Thus, Supply Chain Network Design (SCND) can be considered the meeting point of the academic facility location problem and the real-life SCND problem (Eskandarpour et al.,2015).

The supply chain network under investigation entails suppliers, mobile and fixed warehouses, distribution centres, and customers from a supply chain network design perspective. A realistic problem is considered in which facilities and routes between them are subject to disruptions and might become inaccessible in the aftermath of disasters. We present a bi-objective robust optimisation model that is resilient to disaster scenarios. The proposed model integrates strategic and tactical decisions and aims to minimize the time and cost of delivering products to customers after the occurrence of a disaster, while it considers the possibility of multiple disruptions in facilities and routes among them (Diabat et al.,2019).

2.5.3 SC Network Re-Design (SCNRD)

SCNRD is concerned with any refinement in the existing SC network configuration. As stated above while GFA performs to find the optimal locations from scratch BFA is performed to restructure or expand the existing network configuration (Closing or opening a new DC, Mergers & Acquisitions may lead to operating one centralised facility rather than two). So that s a connection and compliment by BFA over SCNRD.

The existing SCN has several operational factories, existing DCs and markets. Employing a product launch plan, some new products are projected to be sold in some new expected and existing markets. As a result, a new SCN structure with some new DCs is required. The SCN redesign model enables us to quantify and use the risk of uncertain demand and price in the markets simultaneously. The categorised and detailed parts of total cost and revenue can improve financial analysis for SC managers (Jahani et al.,2018).

2.5.4 SC Network Optimisation (NO)

According to (Shapiro, 2004, p. 4) Supply chain network optimisation refers to models supporting strategic and tactical planning across the geographically dispersed network of facilities operated by the company and those facilities operated by the company’s vendors and customers (Tognetti et al.,2015).

For most node enterprises of the container supply chain, such as inland yards, container terminals and shipping lines, two major and very interdependent issues must be simultaneously addressed. The first issue is delivering containers with very short lead times at a customer-acceptable cost. The second issue is sharing effective, high-quality, and timely information. The most pursued objective in the container supply chain network optimisation model is the minimization of total supply chain service cost, which consists of four parts: (1) total shortage cost, (2) total transportation cost, (3) total handling cost, (4) total storage cost and (5) total overstock cost (He, Huang, & Chang, 2015).

The scientific and technical objectives of ONE (Optimisation methodology for Networked Enterprises) request the development of a fully validated decision support tool for the assessment, design, and optimisation of enterprise networks concerning economic, social, and environmental criteria. The tool focuses on decision-making at the strategic/tactical level. It allows a holistic approach with a continuous view of the whole network, realizes the coupling of simulation and optimisation and supports the consideration of social and environmental impacts coming along with certain network configurations as well as the explicit management of uncertainty and risk (Ding et al.,2004).

The essence of effective supply chain network operation is a multi-objective optimisation process under the constraints of internal and external factors. These objectives include speed, flexibility, quality, cost, service, and other indicators according to the actual situation. Because of the different natures of supply chain networks, the target selection and the weight setting will be very different, which is closely related to the organisational ways, decision structure, and decision-making model of supply chain networks (Fu & Chen, 2017).

An optimisation model is developed for a supply chain network with the main objective to minimize the total cost of the network and pollutants emissions to the environment. Minimizing the number of production facilities to satisfy a total customer demand minimizes the total cost. It is observed that a route with more hurdles decreases the responsiveness and results in a tedious delivery of paper reels to the demand points. It is always preferred to select a route with no such hurdles i.e., maximum traffic factor value. Retailers are assigned to production facilities based on the production rates of the facilities. A single facility may or may not satisfy all the retailers even if it is closer to the retailers than other facilities (Razaullah et al.,2017).

Closed-loop supply chain (CLSC) is a new concept and practice, which combines both traditional forward supply chain and reverse logistics to simultaneously maximize the utilization of resources and minimize the generation of waste. In this paper, a stochastic CLSC network optimisation problem with capacity flexibility is investigated. The proposed optimisation model can appropriately handle the uncertainties from different sources, and the network configuration and decisions are adjusted by the capacity flexibility under different scenarios (Yu, Solvang, & Sun, 2019).

2.5.5 SC Inventory Optimisation (IO)

Inventory management is known to be an important aspect of supply chain models. The methodologies used in inventory optimisation intend to reduce the cost of the supply chain by controlling the inventory in the desired manner so that the members of the supply chain will not be affected by abundance or shortage of stock (Mittal et al., 2018).

According to Daniel & Rajendran, (2005) the way optimisation and simulation complement each other in base stock optimisation provides good insights into the application of IO. One of the important aspects of supply chain management is inventory management because the cost of inventories in a supply chain accounts for about 30% of the value of the product. A genetic algorithm (GA) is proposed to optimize the base-stock levels to minimize the sum of holding and shortage costs in the entire supply chain. Simulation is used to evaluate the base-stock levels generated by the GA.

As explained by Farasyn et al., (2011) over the past 10 years, Procter & Gamble has leveraged its cross-functional organizational structure with operations research to reduce its inventory investment. Savings were achieved in a two-step process. First, spreadsheet-based inventory models locally optimized each stage in the supply chain. Because these were the first inventory tools installed, they achieved significant savings and established P&G’s scientific inventory practices. Second, P&G’s more complex supply chains implemented multi-echelon inventory optimisation software to minimize inventory costs across the end-to-end supply chain.

According to Saad & Bahadori, (2016), the use of concept fractal over these OSTs and how that helps in determining the optimum cycle stock for each level fractal is well explained. The proposed framework consists of two levels: top and bottom-level fractals.

Fractals in the bottom level analyse demand, optimise safety stock, and recommend an inventory policy. Then transmit output to the top-level fractal to investigate the effect of different replenishment frequencies to determine the optimum cycle stock for each fractal at the bottom level by integrating the inventory holding costs and transportation costs to minimise the logistics cost.

As Jeavons et al., (2017) due to the huge amount of working capital held by stock in ‘’Shell’’ an interdisciplinary project team has produced a tool, based on advanced analytical methods, that helps assets optimise stock levels and purchase strategies. This approach reduces the risk of deferment due to stock outs and prevents excessive stock carrying costs. It also supports on-time execution of maintenance schedules and so helps to maximise asset uptime.

Again, another example has been given by Xue et al., (2019) of how OST has been applied to inventory optimisation of perishable goods which is a very crucial product category with time due to its nature of deterioration. The taste and freshness of perishable foods decrease dramatically with time. Effective inventory management requires an understanding of market demand as well as balancing customers’ needs and preferences with products’ shelf life. Experimental results show that the proposed methodology combining discrete event simulation and particle swarm optimisation is effective for inventory management of highly perishable foods with variable customer demand.

Brunaud et al., (2019) have explained how simulation complements the given results by optimisation by providing good intuitions to select the best inventory policy. To minimize cost, optimisation models are used to prescribe optimal stock plans. The computational efficiency of models including the (s,S) or the (r,Q) policy is similar. As expected, the simulation results favour the (r,Q) policy because continuously reviewing the inventory allows reacting faster against demand increases.

2.5.6 SC Transport Optimisation (TO)

Generally, optimisation methods are more and more frequently utilised to manage logistic chains because their results bring proposals to improve business processes. Advantages of optimisation methods include the reduction of costs of transport charges, storage, or production processes. Besides the economic merit of the optimisation process, there also increases the efficiency of time needed for logistic operations execution. The aim of the optimisation is focused on more effective utilisation of transport means, technologies, and human resources (Pečený et al.,2020).

It's well emphasized by Yan & Zhang, (2015) why its significant is to study how transportation costs can be optimized in logistics enterprises. The transportation costs of logistics enterprises are influenced by the fixed costs and variable costs involved in the transportation process. However, transportation costs are more closely related to time-window constraints, which are governed by customers' arrival times. Logistics enterprises must pay penalties when time-window constraints are violated, and this causes increases in transportation costs (see Figure 2.23).

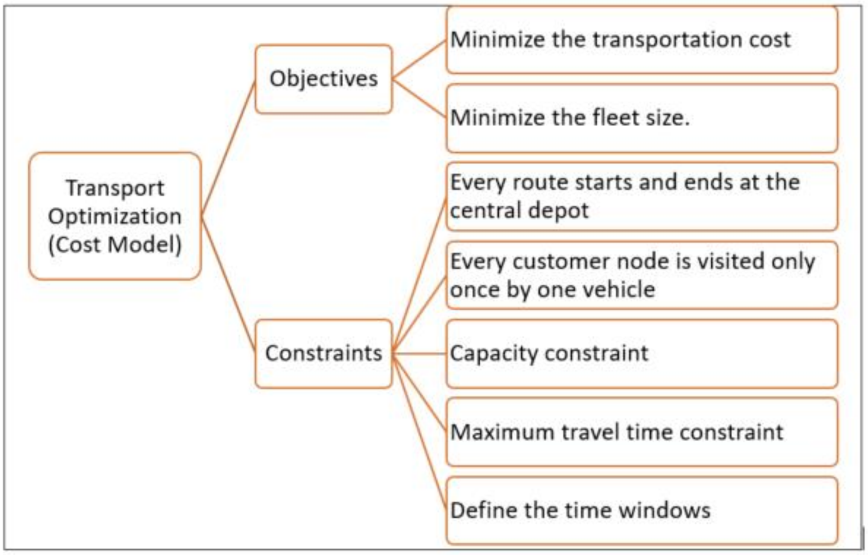


Figure 2. 23: Transport Optimisation Cost Model: Objectives and Constraints

Source: (Yan & Zhang, (2015)

ICT changes, leading to more effective collaborative capabilities are providing increased possibilities for companies to work more closely together to reduce logistics costs, eliminate inefficiencies and deliver service excellence, within a more robust business model framework. Reducing miles where vehicles are lightly loaded or empty, slicker turn-around times, and optimising the planning of the fleet are all critical if hauliers are to improve deployment and make the most of their assets. This will also contribute to more sustainable distribution (Doukidis et al., 2007)

Zhang, Janic, & Tavasszy, (2015) presented a freight transport optimisation model that simultaneously incorporates multimodal infrastructure, hub-based service network structures, and the various design objectives of multiple actors. Consequently, multiple transport modes are available, thus requiring that the choice of mode and terminal be considered when solving routing problem(s). While evaluating different transport options, the potential cost efficiencies realized by better utilization of capacities of corridors, terminals, fleets, and vehicles need to be considered. Policy packages combining multiple types of policies show better network performance as compared with the optimal performance resulting from a single policy type.

Container multimodal transport is a form of combined transport organization aimed to optimise the overall cargo transport. The optimal organization of various transport modes in a container multimodal transport system directly concern the time, cost, and quality of the cargo transport. To describe the optimal organisation problem, an optimisation model based on dynamic programming is presented and is satisfied with reality constraints. Then, a dynamic programming algorithm is proposed to obtain the optimal combination strategy of transport modes (Hao & Yue, 2016).

However, for creating any optimisation models, the input variables are important: the means of transport available (their capacity, performance, fuel consumption) and the transport options realizable. For transport optimisation, the following criteria have been selected: time consumption per 1 m3, cost per 1 m3 and fuel consumption per 1 m3. When choosing the optimal alternative, other optimisation factors can play a part, such as the quality of the work carried out and the damage caused concerning the service parameter (Gejdoš et al.,2018).

2.5.7 SC Simulation & What-If-Analysis

Among the techniques supporting a multi-decisional context, as a supply chain (SC) is, simulation can undoubtedly play an important role, above all for its main property to provide what-if analysis and to evaluate quantitatively benefits and issues deriving from operating in a co-operative environment rather than playing a pure transaction role with the upstream/downstream tiers (Terzi & Cavalieri, 2004).

According to the explanation given by Persson & Olhager, (2002) over evaluating alternative supply chain designs concerning quality, lead times, and costs; simulation provides much better insights due to the relationship between these two parameters difficult to solve by analytical methods. Their second objective, increase the understanding of the interrelationships among these and other parameters, relevant to the design and operations of a supply chain. To capture these relationships, we use a simulation model, since the interrelationships among parameters are difficult to model analytically in a mathematical model.

According to Petrovic, (2001) simulation is chosen because SC performance measures, such as SC fill rate and total cost, cannot be obtained analytically due to the presence of various sources of uncertainty and the complexity of the relations describing SC processes.

Simulation is the best tool to address the problems which required detailed dynamic statistics over any supply chain behaviour which can be solved by optimisation. When the analysis is required to bring variability, randomness, and dynamic interactions between the elements of the supply chain Simulation is ideal in such.

For instance, if the analyst needs to see any specific time series stats over the business process logic simulation provides such in detail: on a particular day, the orders in progress, capacities of the facilities, in transit flows, inventory carrying cost, etc. So, these stats provide good intuitions to fine-tune the network level policies as in manufacturing, sourcing, transportation, inventory, transportation and capacities in the fleet, assets, etc. Then constructing a set of scenarios with different parameters that provide a better platform for a what-if analysis ultimately which helps to conclude the decisions with a robust sensitivity analysis over alternatives.

There are lots of drawbacks experienced by the supply chain planners in the real business context. The real challenge they face may be the tools that they are geared with do not support analysis up to their expectations, for instance, the systems they use may not support the multiple simulation scenarios testing and it's heavy and time-consuming. Therefore, the simulation tools provide the ability to construct multiple scenarios instantly and perform the analysis of any changes (see Figure 2.24) in demand/supply, sourcing, production throughput, product/mix, distribution, transport mode asset/mix, disruptions, risks etc. associated to you supply chain are very attractive and substantial to be resilient for the future uncertainty.

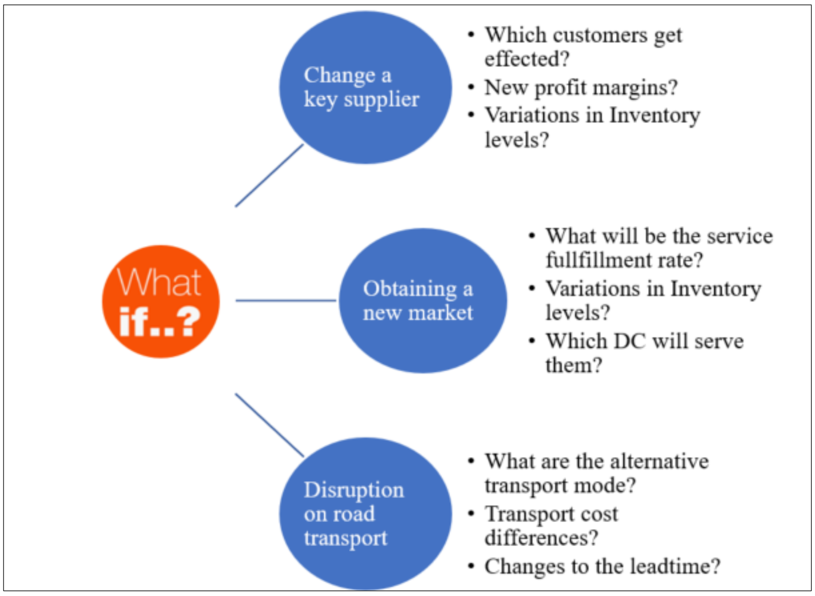


Figure 2. 24: Power of simulation over what-if analyses challenges in SCM

2.6 Successful application of OST

The first subsection is placed to present a selection of real case studies covering diverse supply chain sectors, which showcase how optimisation and simulation have been applied successfully in specific problem-solving in business processes. The second subsection presents a few reviews of research which showcase the trend of businesses trying to embed these tools rather in a broader picture into their SCs and trying to reap the full potential of these tools but the research work which has been carried out on this so far is very limited. The following structure (see Figure 2.25) provides a breakdown of application OST in terms of specific problems.

Figure 2. 25: Breakdown of Successful application of OST in SCM as in specific problems

2.6.1 Real case studies

2.6.2.1 Supplier Selection

Article /source: (Ding, Benyoucef, & Xie, 2005)

Industry: Textile

Case study description: A multi-national textile supply chain, which consists of several suppliers. A part of the supply chain, boots distribution by the textile company located in Europe is considered. Suppliers are located in the Far East, Asia, and Europe. Manufacturing is outsourced hence there is no plant.

Problem and motivation of application OST: Supplier portfolio optimisation due to first, the current order-to-delivery lead-time is relatively long because of the long distance between the Far East and Europe, using sea transport as the principal carrier. Second, demand for the products has a high seasonality and stockout frequently happens.

Case objectives: Redesign the supply chain by selecting the appropriate supplier(s) and transportation modes (While considering the cost of purchasing, Transportation, inventory, and penalties for missed orders)

Tools/methods used: Genetic Algorithm (GA) optimizer for supplier selection decisions, a discrete-event simulator (DES) for operational performance evaluation and a supply-chain modelling framework.

Results obtained: From a set of potential suppliers and combinations of transportation modes one supplier is selected with two transportation mode combinations. Concerning the order assignment ratio, around 73.7% f order quantity (the bigger part) is transported via sea to Europe, while a small part is transported by plane.

2.6.2.2 Inventory redundancy and transportation restructuring

Article /source: (Carvalho et al.,2012)

Industry: Automotive

Case study description: The Automaker plant is in Portugal and is responsible for the production of four different models of vehicles, with an installed capacity for over 180,000 vehicles per year. All vehicles produced are customized according to the end customer's requirements, namely body colour, interior trim, instrument panel, and engine characteristics. The automaker manages its operations in a virtual zero stocks environment, and with a highly customized, demanding production environment. To obtain high-quality components and materials, with low cost and high reliability in deliveries, the automaker developed long-term relationships with about 670 suppliers.

Problem and motivation of application OST: The disturbance affects the transport of a material between two SC entities, causing a flow interruption for some days. Assess the suitability of strategies to improve SC resilience to overcome the negative effects of disturbance.

Case objectives: Decision-making on keeping redundancy in stock (buffer stock) and flexibility in restructuring the existing transport in case of any disturbance occurs (While minimising Leadtime and total cost)

Tools/methods used: Arena simulation software and Microsoft Excel

Results obtained: Both strategies are effective in reducing the negative effects of the disturbance on SC performance. The transportation flexibility strategy makes the supply chain more resilient to disturbance compared to the inventory redundancy strategy.

2.6.2.3 Plants and Distribution Centres consolidation

Article /source: (Saif & Elhedhli, 2016)

Industry: Processed Meat

Case study description: MLF is the largest producer of prepared meats in Canada with revenues of over $3 billion in 2014. Demand originates from the province of Ontario's 20 largest cities. Two plants produce 4 product varieties. Products ship from plants to DCs to retailers in 40'/20' reefer containers and smaller trucks (conventional or electric).

Problem and motivation of application OST: Strong commitment towards sustainability as demonstrated by its environmental sustainability program that has GHG emissions reduction as one of its pillars

Case objectives: Restructure its supply chain that involves the consolidation of plants and distribution centres (DCs), aiming to achieve significant savings by minimizing the total cost - including capacity, transportation, and inventory costs - and the global warming impact.

Tools/methods used: Simulation-optimisation algorithm and simulation (Cplex and Matlab)

Results obtained: Fewer DCS kept open and assign close-by retailers to open DCs to utilize electric trucks for shipping. The contribution of the transportation component to the total cost decreases slightly as the environmental objective weight is increased, which can be attributed to the increased use of the less polluting, yet more expensive, electric trucks. The gross storage area of the DCs decreases as fewer DCs are opened due to the well-known risk pooling effect. The primary trade-off, in this case, is between capacity and transportation cost, whereas the inventory cost is comparatively insignificant because of the low-cost nature of the products.

2.6.2.4 Facility optimal location and distribution network

Article /source: (Sobottka et al.,2017)

Industry: Food Manufacturing

Case study description: A food manufacturer in Europe, the production network consists mainly of the production facility itself, multiple suppliers in Europe and multiple customers, which are supermarket chains in Europe. The transports are conducted with trucks - the deliveries to the production facility are executed by the suppliers and the finished goods are shipped to the customers by the producer.

Problem and motivation of application OST: Planning of a new factory with increased production capacity to support the expected growth in the company's business.

Case objectives: Optimising the logistics network (one out of three objectives from the entire case study is considered) The key indicators are: costs (costs of production, logistics costs quality costs), network indicators (lead-time, delivery service level), production site indicators (site performance, infrastructure) and sustainability indicators (CO_2 Emissions, usage of renewable energy). These indicators were built into the simulation model to provide decision support.

Tools/methods used: AnyLogic software (inbuilt Geographic Information Systems [GIS] is used for realistic routes and transports for every truck)

Results obtained: Scenario A two specialized production sites, and scenario B with a single, larger production site. In both scenarios the supplier- and customer network is identical. Within these basic scenarios, different locations for the production site(s) were also evaluated. The results indicate that scenario B with centralized production achieves higher overall performance, according to the key indicators. The most important difference is the 1 million kilometres shorter (20% reduced) annual accumulated transport distance, with an associated reduction of CO_2 emissions by 13%, all within a simulated time of two years while simultaneously informing the search for an optimized factory location. The reduction is mainly due to the eliminated transport between the production sites and the changes in transport lengths between the production plant, its suppliers, and customers.

2.6.2.5 Transportation and Vehicle Routing

Article /source: (Mejjaouli & Babiceanu, 2018)

Industry: Perishable Food

Case study description: A firm buys fresh produce strawberries from several "Shipping Points" in California and ships the produce to Dallas, TX and Atlanta, GA to be sold in "Terminal Markets." The firm makes three full truckload shipments (38,000 lbs.) to Dallas and one shipment to Atlanta every week. Technologies such as Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN) are positioned to have a significant impact on the way cold supply chains are operated.

Problem and motivation of application OST: Taking decisions based on strict monitoring, evaluating of actual transportation conditions, location of shipped products against requirements, initial route, and terminal market geographical location.

Case objectives: To optimize the overall cost by investigating the impact of stopping the transportation of presumed spoiled produce and of rerouting produce shipments at simulated checkpoints.

Tools/methods used: IBM CPLEX optimisation for testing the optimisation models using actual logistics data (full truckload, shipping points, end markets, distance, $/mile for transportation, harvest periods, weekly demand)

Results obtained: Employing the stopping and rerouting transportation models, for a spoilage probability ranging from 1% to 10%, the corresponding savings opportunity ranges from $30,850 to $296,035. An amount of $151,699 could be saved when a spoilage probability of 5% is used as input for the proposed models.

2.6.2.6 Product Allocation, Inventory Level and On-Time Delivery

Article /source: (González-Reséndiz et al.,2018)

Industry: Consumer Electronics Manufacturer

Case study description: A television manufacturing company in Mexico relies on two service providers to execute the logistics process in Mexico itself. The company's strategy is to allocate up to 30% of production to the logistics provider located in Tijuana for the distribution of FG to the retail customer located in Culiacan, Mexico; so, the remaining 70% is shipped to a distribution centre located in the city of Mexico to perform the FG distribution from that point to their other customers located in Guadalajara, Monterrey, Mexico City and Veracruz.

Problem and motivation of application OST: Define an optimal distribution cost for products shipped to wholesale customers located in different cities in Mexico from a manufacturing plant in Tijuana, Mexico while maximising the performance in Product Allocation (PA) for each distribution centre, finished good Inventory Level (IL) and On Time Deliveries (OTD).

Case objectives: Minimizing Total Logistics Cost = Inventory Carrying Cost + Response Time Cost + Lost Sales Cost (Min TLC = ICC + RTC + LSC). Simultaneously analyse the effect of the logistics cost improvement in case of increase the product allocation % in distribution centres.

Tools/methods used: Arena simulation and optimisation

Results obtained: Results describe that as much as the product allocation is increased for the DC located in Tijuana, the logistic cost is improved proportionally and can achieve a total logistics cost improvement of 5%, 10% and 15%. Also, distribution activity can be managed with fewer inventories without affecting customer delivery performance.

2.6.2.7 Inventory replenishment and holding cost

Article /source: (Avci & Selim, 2018)

Industry: Automotive Manufacturing

Case study description: A multi-national automotive supply chain system which consists of two suppliers, a manufacturer, and a customer. The manufacturer is a leading global automotive supplier. It receives materials from its suppliers located in Europe and assembles them to obtain a semi-finished product demanded by automobile manufacturers. The manufacturer has a safety stock level of 3.5 days for each material. Currently, the quantity flexibility limit of the suppliers for each material is 50%. Supplier delivery loss and delay risks are modelled by using past order data. This study aims to solve the Inventory Replenishment Problem with Premium freights (IRPPF) in convergent supply chains by considering both holding cost and supply chain risk.

Problem and motivation of application OST: In case of a stock-out or delay risk, last-minute emergency shipments called premium freight (PF) are requested. PF is a fast transportation service alternative offered by logistic service providers in case of an urgent delivery requirement. As PFs are generally transferred by airlines, they incur very high costs in a short time frame. Additionally, they cause bullwhip effects that adversely affect supply chain stability. To avoid from PFs is to hold extra safety stocks incur high material holding cost and keeping flexible suppliers are expensive.

Case objectives: Determine Demand forecast adjustment factor, safety stock, and supplier flexibility parameters that minimize total holding cost, inbound PF ratio and outbound PF ratio simultaneously.

Tools/methods used: multi-objective simulation-based optimisation approach convergent

Results obtained: Total holding cost and inbound PF ratio of the supply chain can be reduced to €124,389 and 0.0002, respectively. However, if the outbound PF ratio is reduced to zero, the total holding cost surges.

2.6.2.8 Disruption impact and recovery policies

Article /source: (Ivanov, 2019)

Industry: Non-perishable products production

Case study description: SC considered comprises four production plants and four regional distribution centres (DCs). In each of the four regions, there is a market, a plant, and a regional DC for a single aggregated product. The former SC manager of the company decided to close the production plant in Region #1 because of a decrease in demand in this region and high fixed costs. A couple of months after the plant closure, the DC in this region crashed due to construction quality problems. A huge amount of juice inventory was destroyed, and the disruption propagated into the markets. The new SC manager of this company is now responsible for reacting to this disruptive event.

Problem and motivation of application OST: The Impact of time-to-recovery and reconstruction of the DC will take about four months. The ripple effect deals with time-dependent settings which include dynamic inventory control, transportation control, sourcing control and production control policies

Case objectives: Execution of short-term and mid-term recovery policy to overcome the negative effects of disruption and ripple effect on the SC.

Tools/methods used: AnyLogistix / The simulations run over the optimisation results and include additional, time-dependant inventory, production, transportation, and sourcing control policies which are difficult to implement at the network optimisation level.

Results obtained: Compared SC performance in the disruption-free mode and the disrupted SC with and without contingency plans. Also analysed the impact of demand variability on SC performance in terms of profits, service levels, and lead time. Delayed and backlogged orders occur when there is no contingent recovery policy in place and when there is such a policy in place, but disruption tails still appear in the post-disruption period. The revival policy helps to improve service levels and reduce the impacts of the disruption tail in terms of delayed and backlogged orders in the post-recovery period.

2.6.2.9 Design a Reverse Supply Chain and minimize the disruption ripple effect

Article /source: (Özçelik et al.,2020)

Industry: Recycling household appliances

Case study description: A company disassembling household appliances and recycling activities the company are limited to the northern region of Turkey. There are 18 primary, four secondary collection centres, and two recycling centres. Over the last decades, it is observed that collection /city centres are highly affected by the ripple effect caused by heavy rainfall. With the strict legislation in Turkey regarding the recycling of WEEE (Waste Electrical and Electronic Equipment), the companies must design their network across the country. 1st stage: Products are collected in 18 possible primary collection centres, then 2nd Stage: transported to four different secondary collection centres and finally products are recovered in two different recycling centres. There are 200 available workers in the pool to be assigned to the operations.

Problem and motivation of application OST: Investigate the changes in the price of robustness (PR) concerning uncertainty parameters, while minimising the impact of the ripple effect of due to long-term disruption, and heavy rainfall in the potential landslide site.

Case objectives: Design the Reverse Supply Chain (RSC)

Tools / methods used: GAMS®/CPLEX optimisation

Results obtained: Based on the results, whilst the computationally tractable robust solutions are obtained; the price of robustness is higher than expected to protect the constraints against violation when the probability of constraint violation equals 0.01. Besides, it is quite interesting that the 2nd stage (Transport from 18 primary collection locations to 4 secondary Locations) of the RSC network is more affected by the ripple effect compared to the first stage in terms of the number of workers and vehicles.

2.6.2.10 Transport fleet mix, cost, and emission optimisation

Article /source: (Ravichandran et al.,2020)

Industry: Diary

Case study description: The supply chain of the company can be explained as; the milk is collected from various farmers of several villages and stored in the respective nearby bulk milk coolers (BMC). It is then transported to processing plants, (PP) wherein the milk is processed such as pasteurization and packing executed. From the processing plants, it is distributed to various distributors (D) associated with the supply chain and then traded with several retailers (R) to reach the customers (C) for sale. The transportation cost of light-duty vehicles is low, their minimal capacity will lead to more round trips, which will result in more CO2 emissions and fuel costs. On the contrary, for medium and large vehicles, the unloaded mass and fixed transportation costs are much higher, but there will be a significant reduction in the travel route which mainly influences the overall cost and CO2 emissions

Problem and motivation of application OST: Demonstrate the optimality of the type of truck that needs to be utilized while transporting the milk keeping into mind sustainable factors such as environmental and social factors.

Case objectives: Minimize the number of vehicles from the supplier to the end customer.

Tools/methods used: Software Arena®-based optimisation and simulation models

Results obtained: Optimized heterogeneous fleet supply chain model is more suitable, as it is more economically viable and environmentally friendly. The proposed simulation model can aid in the process of decision-making on problems related to logistics and supply chains in similar dairy units. Multiple scenarios with varying percentages of trucks to find the optimum number without losing any customers in the process were simulated. After performing the cost analysis and comparing the results, a difference of INR 33,962.656 (cost savings) was computed.

S.N.	Source	Industry	Application Domain	Objective
1	(Ding, Benyoucef, & Xie, 2005)	Textile	Supplier Selection	Redesign the supply chain by selecting the appropriate supplier(s) and transportation modes (While considering the cost of purchasing, Transportation, inventory, and penalties for missed orders).
2	(Carvalho et al.,2012)	Automotive	Inventory redundancy and transportation restructuring	Decision-making on keeping redundancy in stock (buffer stock) and flexibility in restructuring the existing transport in case of any disturbance occurs (While minimising Leadtime and total cost).
3	(Saif & Elhedhli, 2016)	Meat Processing	Plants and Distribution Centres consolidation	Restructure its supply chain that involves the consolidation of plants and distribution centres (DCs), aiming to achieve significant savings by minimizing the total cost - including capacity, transportation, and inventory costs - and the global warming impact.
4	(Sobottka et al.,2017)	Food Manufacturing	Facility optimal location and distribution network	Optimising the logistics to achieve the key indicators: costs (costs of production, logistics costs quality costs), network (lead-time, delivery service level), production site (site performance, infrastructure) and sustainability (CO2 Emissions, usage of renewable energy).
5	(Mejjaouli & Babiceanu, 2018)	Perishable Food	Transportation and Vehicle Routing	To optimize the overall cost by investigating the impact of stopping the transportation of presumed spoiled produce and of rerouting produce shipments at simulated checkpoints.
6	(González-Reséndiz et al.,2018)	Consumer Electronics Manufacturer	Product Allocation, Inventory Level and On-Time Delivery	Total Logistics Cost = Inventory Carrying Cost + Response Time Cost + Lost Sales Cost (Min TLC = ICC + RTC + LSC). Simultaneously analyse the effect of the logistics cost improvement in case of increase the product allocation % in distribution centres.
7	(Avci & Selim, 2018)	Automotive Manufacturing	Inventory replenishment and holding cost	Determine Demand forecast adjustment factor, safety stock, and supplier flexibility parameters that minimize total holding cost,

				inbound PF ratio and outbound PF ratio simultaneously
8	(Ivanov, 2019)	Disruption impact and recovery policies	Non-perishable products production	Execution of short-term and mid-term recovery policy to overcome the negative effects of disruption and ripple effect on the SC
9	(Özçelik et al.,2020)	Design Reverse Supply Chain and minimize the disruption ripple effect	Recycling household appliances	Design the Reverse Supply Chain (RSC) by Investigating the changes in the price of robustness (PR) concerning uncertainty parameters, while minimising the impact of the ripple effect due to long-term disruption, and heavy rainfall in the potential landslide site.
10	(Ravichandran et al.,2020)	Transport fleet mix, cost, and emission optimisation	Diary	Minimize the number of vehicles from the supplier to the end customer

Table 2. 4: A summary of real cases: successful application of OST

2.6.2 Review of exiting frameworks try injecting OST in SCM

<u>2.6.3.1 Embedding Simulation tools in business process finetuning</u>

The framework consists of five progressive stages: Foundation, Introduction, Infrastructure, Deployment, and Embedding (see Figure 2.26) Each stage of the proposed framework has its input and output elements. Input elements represent best practices; each stage is divided into three different dimensions namely, ‘people’, ‘technological’ and ‘organisational’. Under each dimension, there are guidelines to enable each company to achieve each best practice. Output elements represent the main objectives and outcomes which are interrelated with each of the following stages (Hughes & Perera, 2009).

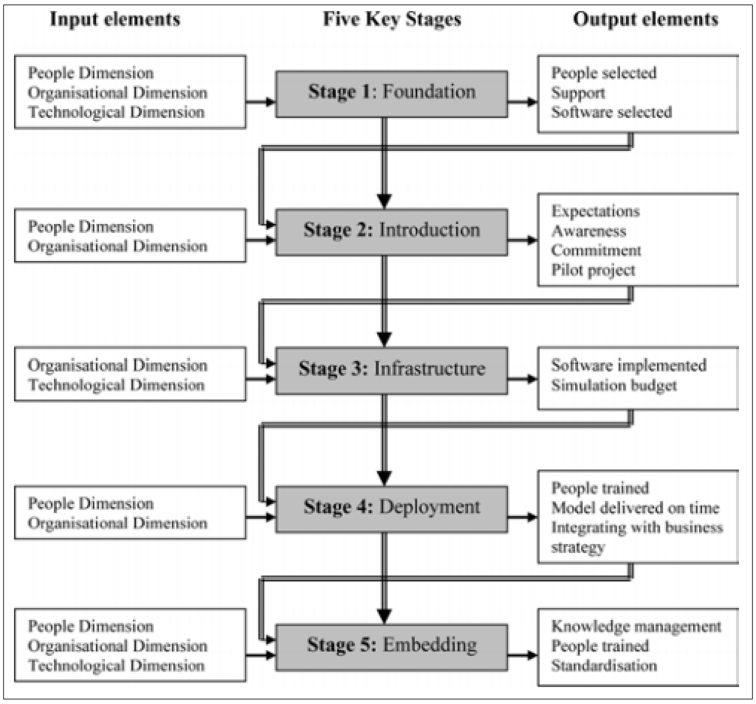


Figure 2. 26: Key stages in embedding simulation into business processes

Source: (Hughes & Perera, 2009)

<u>2.6.3.2 Simulation-Optimisation approach for Cold supply chain design and reducing the carbon footprint</u>

The solution approach combines the efficiency of optimisation methods with the accuracy of simulation methods. The model was developed for designing cold supply chains with environmental considerations and proposed a novel approach to solve it efficiently. The managerial insights drawn from these results enable the decision-makers to identify and target the primary cost and emissions drivers in their supply chain networks. Also, through these tests, the proposed approach is shown to be versatile and can be tailored to suit many real-life situations including different demand patterns, inventory policies, transportation modes, and operational constraints (Saif & Elhedhli, 2016).

<u>2.6.3.3 Embedding simulation into healthcare</u>

The main goal of the proposed SIMT (Simulation Thinking) implementation framework is to provide a practical and holistic framework that can enable health care managers and practitioners to understand how Simulation and modelling (S&M) can be successfully embedded in their organisations (see Figure 2.27). The author's approach to developing the implementation framework is to integrate the identified five SIMT components, the major activities, tools, and strategies for achieving each component and the best practices of the appropriate simulation methodologies within the framework (Hughes, 2010).

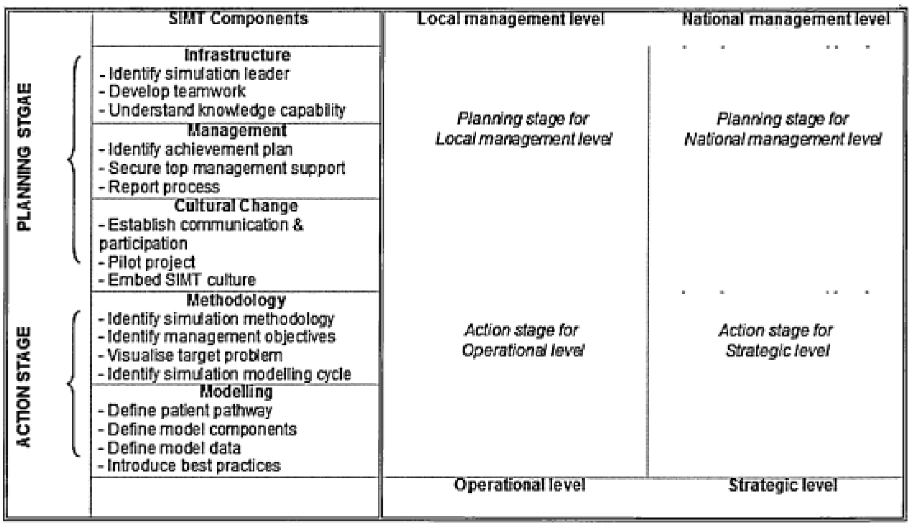


Figure 2. 27 SIMT frameworks to embed simulation and modelling in healthcare

Source: (Hughes, 2010)

2.6.3.4 Optimisation Framework for Improving Supply Chain Performance

According to Farsi et al., (2020) despite the existence of a range of frameworks for supply chain management in the literature, there is a lack of comprehensive framework looking at the service supply chain for bespoke service providers. To fill this research gap, an optimisation framework for improving supply chain performance using the DMAIC cycle (i.e., Define, Measure, Analyse, Improve, and Control) is developed in this paper. This framework is a step-by-step procedure to define areas of possible improvement, aligned with a set of tools and methods to act. Moreover, as part of the framework, an in-depth list of KPIs to evaluate the supply chain performance is identified (see Figure 2.28).

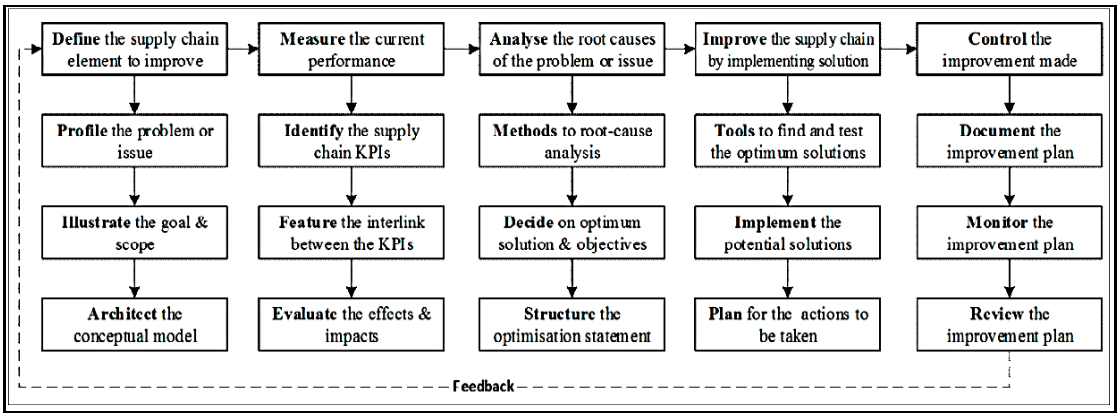


Figure 2. 28: Optimisation framework for supply chain performance improvement

Source: (Farsi et al., 2020)

2.6.3.5 SC Real-Time-Data combined with Simulation and Optimisation

The term Supply Chain Digital Twin (SCDT) is explained by Ivanov et al., (2019) a digital SC twin can support decision-making about the physical SC based on data. At each point in time, the digital twin mirrors the physical SC: the actual transportation, inventory, demand, and capacity data and can be used for planning and real-time control decisions. The combination of simulation, optimisation, and data analytics constitutes a full stack of technologies which can be used to create the SC digital twin – a model that always represents the state of the network in real-time (see Figure 2.29) For example, if there is a strike at an international logistics hub, this disruption can be spotted by a risk data monitoring tool and transmitted to the simulation model as a disruptive event. Then, simulation in the digital twin can help forecast possible disruption propagation and quantify its impact. In addition, simulation enables efficient testing of recovery policies and the adaptation of contingency plans – for example, alternative network topologies and backup routes can be reconsidered on-the-fly.

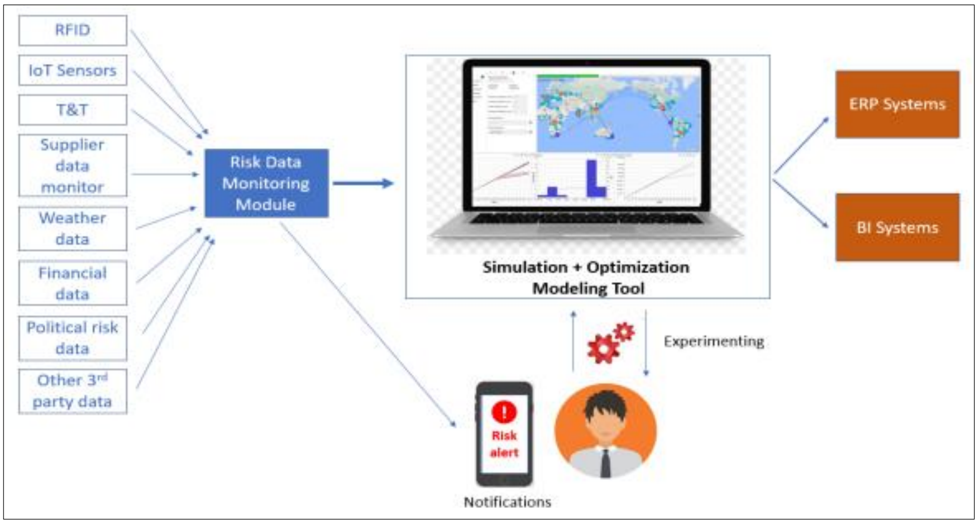


Figure 2. 29: SC Digital Twin & Simulation-Optimisation

Source: (Ivanov et al.,2019)

2.6.3.6 Application of Simulation-Optimisation in last-mile delivery of courier service

According to a detailed explanation given by Perboli et al., (2018) considering the revenues based on the number of deliveries and the penalties in case of not fulfilment, these problems impose pressure on the drivers of the traditional carrier company. On the contrary, the reduction of the number of parcels that the traditional carrier must deliver, combined with the optimisation of the routes and the reduction of vehicles on road, leads to a less and more balanced workload and the improvement of the working conditions. A new simulation–optimisation framework is proposed for building instances and assessing operational settings(see Figure 2.30) (1) Data fusion and operational context description: The first phase of the framework consists in describing both the problem studied and the operational context, which may consider different types of data sources (city network graph, vehicles and travel times, behavioural data, socio-demographical data and city constraints (e.g. limited traffic zones, specific restrictions for certain vehicles etc.) and problem objectives and constraints. (2) Scenario generation and simulation: Once both the problem and the operational context are well defined, a broad set of scenarios is generated by using a high-level scenario generator. (3) Optimisation: During this phase, each scenario is solved using a dedicated optimisation algorithm that we consider here as a black box. Provided that the solver outputs the KPIs required into consideration, the post-optimisation analysis is conducted. (4) Context modification: During this phase, some properties of the description are modified, leading to a new operational context to be analysed by reiterating through phases 2–4.

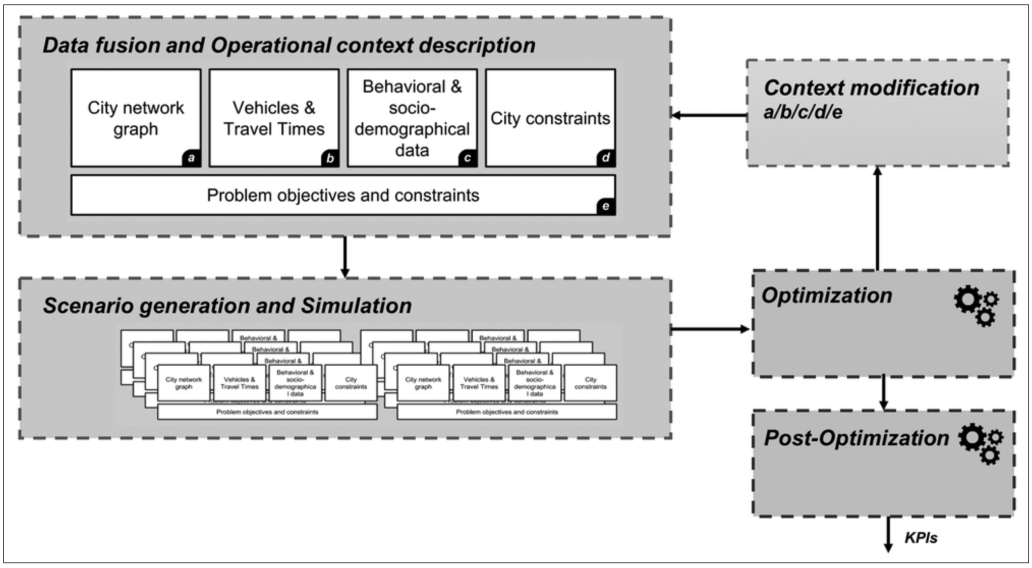


Figure 2. 30: Simulation-Optimisation Framework

Source: (Perboli et al.,2018)

<u>2.6.3.7 A decision-support system that combines a simulation, optimisation, and data analytics for SC Risk Analytics</u>

There is a good explanation which has given by Ivanov, Dolgui, & Sokolov, (2019) about the significance of having a sound Supply Chain Decision Support System (SCDSS) in business which can be enabled over optimisation and simulation. The decision-support system for SC risk analytics aims at proactive, resilient SC design in anticipation of disruptions and structural-parametrical adaptation in the case of disruptions. The decision-support system is based on a concept that combines simulation, optimisation, and data analytics. The Simulation-Optimisation part of the system is intended to provide proactive, resilient SC optimisation and simulation of SC dynamic behaviour in the event of possible disruptions or disruption scenarios. In addition, this supports reactive, predictive simulation of disruption impacts on SC performance and of recovery policies which are subsequently optimized in a prescriptive manner using an analytical model. The data analytics part of the system is applied to disruption identification in real-time using process feedback data, e.g., from sensors and RFID. In addition, this aims at the automated data input of disruption data into the reactive simulation model for recovery policy simulation and optimisation. Finally, data analytics is used as a data-driven learning system at the proactive stage, helping to generate adequate disruption scenarios for resilient SC design and planning (see Figure 2.31).

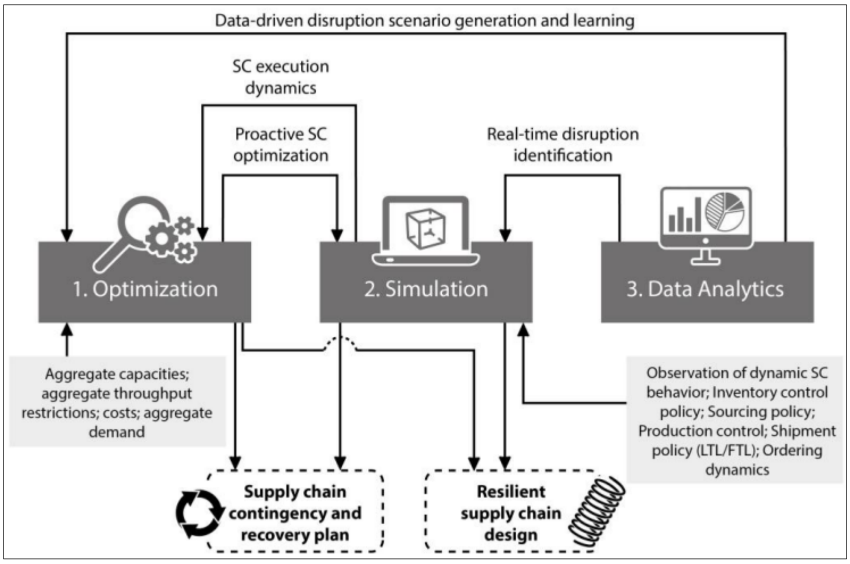


Figure 2. 31: A decision-support system that combines a simulation, optimisation, and data analytics for SC Risk Analytics

Source: (Ivanov, Dolgui, & Sokolov, 2019)

However, before analysing the benefits of the enabling technologies, we believe that a brief discussion about possible barriers to their adoption by companies is needed (Giusti et al.,2019).

2.7 The barriers to reaping the full potential of (OST) in SCM

The combination of simulation and optimisation, essentially unheard of in practice a decade ago, is much more accessible today, thanks in large part to the development of commercial optimisation software designed for use with existing simulation packages. Despite this growth, untapped applications abound (Boesel et al.,2001).

Although the potential is significant, the joint research in applying simulation-optimisation in SC applications is small. We highlighted this gap by a quick search of journal articles in the last decade has the phrase 'simulation optimisation for supply chain' either in their title, abstracts, or keywords by a selection of the main active publishers in the business, management, decision sciences, computer science, engineering, and mathematics. The number of papers published in applying simulation-optimisation for supply chain problems, from 2000 to 2009, is significantly less than those published in simulation-optimisation in general or supply chain management in general (Abo-Hamad & Arisha,2011).

The barriers which prevent using and reaping the full potential of (OST) in SCM have been captured under four main categories as Technology, Process, People, and Data (see Figure 2.32).

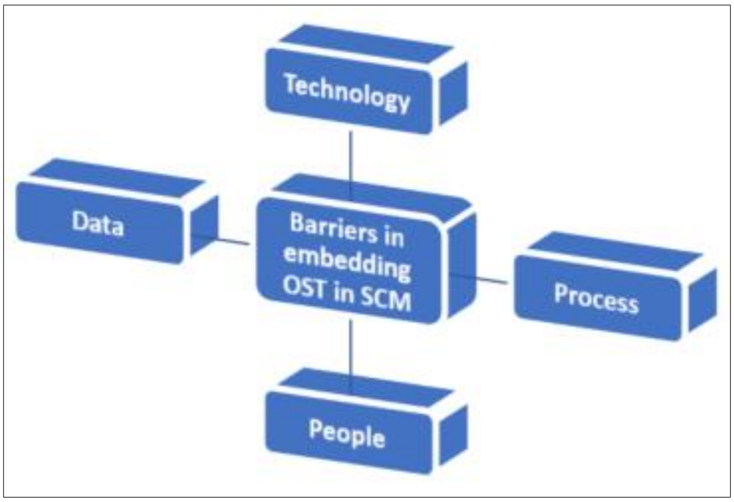


Figure 2. 32: Barriers to embedding OST in SCM

2.7.1.3 Barrier: Technology

While simulation models try to explain the relationships between input and output of complex systems, they do not provide the capability of finding the optimum set of decision variables in terms of the predefined objective function(s). This is the purpose of optimisation models, which allow decision makers to find the best possible alternatives while their impact on the system performance is evaluated using simulation models. Therefore, integrating simulation and optimisation, known as ‘simulation–optimisation’, into an SC framework provides decision makers with a comprehensive solution toolbox (Abo-Hamad & Arisha,2011).

A lack of a single methodology in developing simulation optimisation models has resulted in several optimisation methods, which are restricted to specific problems. Once more complex problems are considered, other optimisation methods should be developed. Therefore, there is a need to develop a new method that can deal with specific features of complex processes by using simulation models and applies to a wide range of such processes (Napalkova & Merkuryeva,2012).

The integration of existing models in simulation and modelling is an issue of two levels (1) Intermodal integration: The advances in integrating these models will have value in saving extra model building efforts; exchanging information between SC members; and reducing overall execution time (2) Model's legacy system integration: most developed simulation models are independent and standalone tools (AbuKhousa et al.,2014).

Discrete optimisation via simulation techniques has recently been developed to solve stochastic optimisation problems with discrete decision variables. The barriers that hinder the wide application of this approach are the long computation time required for simulation and the noise of performance evaluation using simulation under stochastic conditions (Lin & Chen, 2015).

Both Optimisation and Simulation models share similarities as well as some differences. The simulation model is preferred when the network structure of the logistics is pre-defined. The optimisation model is more effective to determine the optimal network structure. Since the actual transports were determined by the simulation model, it allows for the tracking of time-dependent parameters. In optimisation modelling, it is difficult to include the time-dependent effects because they are based on the annual flows (Zhang et al., 2016).

However, the models were limited in size and some instances had to be broken down because of the limited version used. While this approach provided the company with a low-cost option for planning and prediction compared to physical experimentation, there were several assumptions made, which not only presented challenges for validation and verification but also some level of doubt in management confidence to embrace the technology (Nyemba & Mbohwa, 2017).

2.7.1.2 Barrier: Process

A complex supply chain network will dramatically increase the level of difficulty in the model computation which may result in extremely large processor times for calculating the optimal result so efficient and effective solution methods should also be developed accordingly (Yu, Solvang, & Li, 2014).

Undoubtedly, one of the major challenges to be overcome by practitioners and researchers in the SCS field is the lack of research and methodologies that can facilitate and streamline the process of performance of Supply Chain Simulation (Oliveira et al., 2016)

From the sample of papers selected from the literature on modelling techniques, we observed that simulation is used by 14% of the papers, and the simulation-optimisation approach is relatively scarcely used for solving Supply Chain Network Design (SCND) under uncertainty problems (Salem & Haouari, 2017).

Supply chain structures are getting each time more complex and dynamic. Such transformation requires decision support tools able to consider these characteristics. While Industry 4.0 concepts bring technologies, which enable real-time data, decision support tools must be designed to incorporate dynamic and realistic behaviour (Pires et al.,2018).

The results showed a rising interest in scholars on Supply Chain Risk Management (SCRM). We identified a major gap in the lack of a systematic process to combine the SCRM phases, Performance Measurement Systems (PMS) and Simulation and Optimisation (S&O) perspective and better represent the diversity, dynamic, and complexity of SCs under risk effects. The SCND and portfolio optimisation approach was the risk mitigation strategy most applied by the authors. The integration and synchronization between simulation-Optimisation (S→O) and Optimisation-Simulation (O→S) are interesting approaches to managing SCR since this relationship maximizes the benefits of these methods (Oliveira et al.,2019).

2.7.1.1 Barrier: People

A lack of knowledge, skills, and time for the development of simulation models – decision makers involved in the upstream decision-making hierarchy seldom possess the time or required skills to build models and must, in many cases, rely on consultant firms or simulation experts, which would cause longer lead time and higher cost in a production system development process (Pehrsson, 2013).

Simulation and Modelling (S&M) requires users to be familiar with software and statistics knowledge. However, most SC managers and analysts are nonexpert S&M users. Thus, SM software should be easy to learn with an easy-to-use graphical user interface that helps users in problem definition, design of computer experiments, simulation runs, access ready information, and results from the analysis. Results should be presented in an understandable and interpretable format with the ability to transfer these results to be used in different reporting tools (AbuKhousa et al.,2014).

Risks, uncertainties, disruptions, and the stochastic nature of SC elements make Modelling & Simulation more challenging since SC has a dynamic and complex behaviour. Therefore, some challenges were identified such as, there is need for experts with in-depth knowledge of real SC; issues related to the coordination of efforts to model and simulate, especially in cases that require the integration of models; applying techniques that best fit the described problems, etc. (Oliveira et al., 2016).

A further key barrier to more widespread adoption of modelling is the current lack of capacity within health services. In addition, there needs to be a greater understanding of how and where modelling tools can support decision-making if policymakers are to become 'intelligent clients' and more aware of the benefits of adopting these techniques (Pitt et al.,2016).

Due to practical challenges (i.e., the inclusion of environmental and social aspects), many of the SC decisions can only be addressed using robust mathematical approaches. A good example of the above situation can be seen when supply chain planners (i.e., public planners and industrial practitioners) deal with facility location problems, one of the most difficult decisions of the SCND (Costa, Duarte, & Sarache, 2017).

Implementing a simulation and optimisation system is not a trivial task. Highly qualified personnel are required to configure those systems. We gathered the data manually for this case study, but the process should be automated in the future. The company needs to hire a consultant, but we believe they also need to build some expertise internally (Wery et al.,2018).

The lack of role identification is especially noticeable when it comes to the identification of participants in the simulation projects. Therefore, in most cases, it can be assumed that the projects are undertaken mainly by simulation experts. The lack of inclusion of companies' collective knowledge in simulation projects is one of the key issues in continuous improvement projects (Uriarte et al.,2020).

2.7.1.4 Barrier: Data

As highlighted by Perera & Liyanage, (2000) the rapid development and deployment of simulation models, however, are inhibited by factors such as inefficient data collection, lengthy model documentation, and poorly planned experimentation. A serious limitation among the above factors is inefficient data collection. Poor data availability was the major cause of the long data collection time (see Figure 2.33).

Major reasons	Rank
Poor data availability	1
High level model details	2
Difficulty in identifying available data sources	3
Complexity of the system under investigation	4
Lack of clear objectives	5
Limited facilities in simulation software to organise and manipulate input data	6
Wrong problem definitions	7

Ranking of the major pitfalls in input data collection

Figure 2. 33: Ranking of the major pitfalls in input data collection

Source: (Perera & Liyanage, 2000)

Producing credible simulation outputs within acceptable timescales is a key challenge. However, it appears that companies are failing to reap the full benefits of this powerful technology as the maintenance of simulation models has become very time-consuming, particularly due to the vast amounts of data to be handled (Skoogh, Perera, & Johansson, 2012). We want to emphasise the importance of collecting accurate data, which has been a major challenge in this work. With the required data, the proposed framework can be applied to a wide range of supply chains in the chemical and process industry. Moreover, the model can be used as a basis for further extensions such as multiperiod supply chain optimisation considering time-dependent demand and inventory constraints (Zhang et al., 2014).

Data collection is one of the most important issues related to improving the efficacy of a simulation model. A simulation model is only as accurate as the data used to calibrate it. Therefore, any difficulty in collecting reliable and complete data may lead to invalid simulation results (Guo et al.,2016). The different approaches and the lack of transparency on the data structure hamper the application of the simulation and optimisation models to other types of supply chains than the one for which they have been developed and constrain the exchange of the models among users (De Meyer et al.,2016).

In most current simulation optimisation applications, by contrast, data sets are collected over a long period and then used to estimate probability distribution models from which random variates are generated to drive the stochastic simulations. To reiterate, we argue that computational efficiency and data requirements are the two fundamental limitations that prevent simulation optimisation from being used in the control of complex stochastic systems (Xu et al., 2016). Since simulation model performance is based on the data used in the model, it is important to gather reliable and valid data before using the proposed approach. The most important limitation of the presented approach is collecting reliable and exact data to obtain acceptable results (Nasiri, et al., 2017).

The validation of models and methods becomes more difficult, being the results not directly compared with real or realistic settings. Even when some data sources become available, there is no standard way to mix data gathered from different sources and, from them, generate new instances for urban applications (Perboli et al.,2018). On uncertainty, its treatment is vital as several parameters characterizing Sustainable Supply Chain (SSC) are often subject to uncertainty and need to be modelled, ranging from product demand to products or raw materials prices and resource availability. Uncertainty on the available social and environmental data has been a field left unexplored, which represents a large limitation, as this data highly influences the decisions taken (Barbosa-Póvoa et al.,2018).

New technologies are emerging every year in maritime logistics. These new technologies add a multitude of data sources on top of the Terminal Operating System (TOS). Thus, the question of how to effectively utilize this massive amount of data to improve port efficiency, capacity, safety, and profitability is an interesting one which can be explored (Zhou et al., 2018). Simulation models are very time-demanding in their building phase, especially for the data collection activity. The high cost and time required for data collection often result in useless simulation models, because they are not promptly aligned with the system changes (Lugaresi & Matta, 2018).

Another limitation concerns data collection. In this study, two months were spent on data collection without considering the increasing demand before or after holidays. To improve the situation, data regarding specific periods should be collected and investigated (Lee, Zhang, & Ng, 2019). The quality of model-based decision-making support strongly depends on the data, its completeness, fullness, validity, consistency, and timely availability. These requirements on data are of special importance in the supply chain (SC) risk management for predicting disruptions and reacting to them (Ivanov et al.,2019). Countless limitations may make it difficult to monitor risks, for example, some outcomes require a major organizational effort to collect data, analyse, and update the information on supply chain risk (Oliveira et al.,2019). Deciding on what data is required and knowing whether the system is accurately represented in the model's development data is a challenge. This problem is further compounded by a system where data availability is limited (Fisher et al., 2020).

NB:

There is a Cause-and-effect Diagram (CED) in Chapter 4 which reflects all the barriers captured here through reviewing this literature.

2.8 Research Gap

As for the future of simulation optimisation, there is certainly room for improvement. Currently, most of the published research on simulation optimisation focuses on a single aspect of simulation optimisation without considering the subject as a whole. For example, a great deal of research addresses the development and application of specific methods to optimize simulated systems (Boesel et el., 2001). However, a review of the literature indicated that there was little evidence to demonstrate simulation is being used extensively. Simulation is still used on a one-shot basis or as a stand-alone tool. Typically, it is used to address very specific problems in isolation (Hughes & Perera, 2009). New research efforts should be directed toward the creation of efficient methods that can improve the implementation of Modelling and Simulation (M&S) in real-world Supply Chains (SCs). This is the greatest challenge faced by companies in practice concerning M&S in SCs (Oliveira et al., 2016).

Due to the limited features of conventional mathematical modelling in the context of SC, the literature in this area is in the decline phase. The emergence of integrated mathematical modelling and Simulation-Optimisation (S-O) frameworks has been a response to this trend. According to the frequency analysis, S-O frameworks are transitioning from an emerging topic to a growing research area, while the integrated problems are likely to be saturated during the next few years (Pourhejazy & Kwon, 2016). Despite the availability and acknowledged potential, the practical application is still scarce, as both a literature review and practical experience in the field of planning projects in the manufacturing industry show. A major hurdle is a perceived difficulty of designing models and acquiring proper data as well as the scarcity of reference applications with significant shown benefits. (Sobottka et al.,2017).

To overcome the inconveniences and limitations of the analytic methods, simulation has been broadly used in modelling and evaluating a wide range of different strategies in SCM, as well as being a decision-making tool to improve supply chain performance. However, there is still room for gaining further insights into a wide variety of topics concerning operations and SCM analysis via what-if analysis (Cannella et al.,2017). It is necessary to strengthen the planning with the integration of models addressing the decisions on a strategic, operational, and tactical level as well as to provide easy-to-use optimisation tools for professionals (Scholz et al., 2018). A more interesting direction for future research would be to try to assess the impact of supply chain design decisions on the ongoing operational costs of the supply chain, based on the constraints these impose on the Master Planning and Production Planning decisions (Mönch, Uzsoy, & Fowler, 2018).

The model allows users to check the estimated input factors and their effect on output, showing how productivity and profitability can be improved and helping decision makers in production planning. The act of measuring performance provides information that aids intelligent decision-making and proper management, so the identification of other key performance indicators (i.e., profitability, revenue, on-time deliveries, customer response time and manufacturing lead time) should be considered in future research (Saad, Elsaghier, & Ezaga, 2018).

Many elements, such as market and weather conditions, competitor's plans, last-minute changes on the retail or supply side, promotions, or festivities, as well as intermittent demand behaviour, may have an impact on sales and considering their contribution to the forecasting process may represent promising future research directions (Dellino et al.,2018)

Sourcing, manufacturing, logistics, and sales data are distributed among very different systems, such as ERP, RFID, sensors, and Blockchain. Big Data Analytics integrates this data into information used by AI algorithms in the cyber-SC and managers in the physical SC. As such, a new generation of simulation and optimisation models is arising. The pervasive adoption of analytics and its integration with Operations Research shows that simulation and optimisation are key, not only in the modelling of physical SC systems but also in the modelling of cyber-SC systems and learning from them (Ivanov et al.,2019). Complexity in the supply chain can only help to smooth out the rippling effects of a disruption, which go largely beyond supply-demand unbalances and lead time fluctuations. To mitigate it better, the main company must act proactively with adequate resilience practices, which also connects to the importance of better visibility across multiple supply chain tiers (Birkie & Paolo, 2020).

Exploring the literature over the last two decades indicates the way of complexity and severity of SCs increased and the role of SC becomes an important element in business to consider. Therefore, only a proactive business that is capable in design, operating and enhancing its SC can bring resilience on board with clear visibility of its entire network which operates either on single or multiple shores.

Due to the uncertainty and the disruptions that occur while managing an SC, its propagation can bring a negative impact on the entire supply chain performance. As such it's proven that the tools like optimisation and simulation do a great job in planning, controlling, and preventing or mitigating these situations.

Optimisation and simulation are not a new topic and lots of work has been done by previous researchers. Thus, yet it’s reflected in most instances these OSTs are deployed for specific problems in isolation, have not been used widely and haven’t reaped the full benefits. Especially due to the barriers to application; (1) data limitations, (2) skills and knowledge, (3) resistance and inefficiencies in technology & infrastructure, and (5) inappropriate process flow of an application. Especially due to the scarcity of a robust process flow framework which can aid in embedding these OSTs in their business decision-making process. The research gap identified by reviewing the literature so far can be illustrated as follows (see Figure 2.34).

Figure 2. 34: Research gap

- To strengthen the evidence and highlight this gap much stronger a Survey Questionnaire and a few semi-structured Interviews with subject & industry experts were conducted. Data collection and final analysis are well presented in Chapter 4.
- All the barriers in OST identified here and the areas identified here are fully captured in a Cause-and-Effect diagram in chapter 4.

2.9 Conclusions

In the recent research space, there are simulation-optimisation frameworks which have been introduced but it seems there is no robust framework which provides a very structured approach as in whole. Thus, to provide a sound literature review at the very top of this chapter at currently what are the challenges faced by the users in terms of SC design, operations and re-design have been reviewed as an entry.

Then how significant it is the mechanism of model-based problem solving, the emergence of optimisation and simulation in SCM, application domains of optimisation and simulation models and how such complement each other for better decision making in enhancing overall supply chain performance was critically discussed while providing exiting frameworks and models which reflect a higher research impact to encourage the future academic research.

In the very latter part of this chapter, it's acknowledged that even though there is a good amount of research has been carried out, frameworks and models have been developed, there is a gap which significantly showcases how to tackle the existing barriers of application which prevents most users reaping the full potential out of this OST in SCM. So, in return, the full scope of barriers was briefly described in terms of how the different industries and their multifaceted level of decision-making are affected.

Then how significant it is to rectify such barriers before any investment of OST in any organization and how the novel framework can be deployed in such phase by either SCM professionals or researchers to achieve the highest performances have been discussed and can be provided in bullets forms as follows.

- The mechanism overcoming the existing barriers (challenges of application)
- Drives a smooth application process to embed these OSTs in their business decision-making process.
- Reap out the full potential of these tools and gain an optimal ROI against their OST investments.

Chapter 3

Research Methodology

3.1 Introduction

The purpose of this chapter is to illustrate the researcher's strategy in terms of how this research had been planned and conducted to achieve the final aim and objectives as pre-defined (see Figure 3.1). At the very beginning as an entry point under the research design and methodology, it briefly described the research problem formulation, university ethical consideration, pre-approval, and work plan as prerequisites which paved a solid foundation for this research to kickoff.

Then how the deductive approach and mixed methods have been deployed, multiple tools have been pre-tested and used in terms of data collection, analysis, and visualization have been described followed by a detailed justification of why those specific approaches, methods, tools, and participants have been selected to obtain the data during the study and present the results. During this explanation data sources, research population and sample consideration also have been described in detail.

Then as the most significant part, how the analyzed data which shed light on the existing research gap and act as the blueprint for the design and development of the Novel Framework proposed have been described.

Finally at the very latter part how strong the verification and validation of this research conducted internally and externally with Industry and Subject Matter Experts (SMEs) to bring in enhancements to the final framework has been illustrated before the final thesis submission, improvements, and publication have been described.

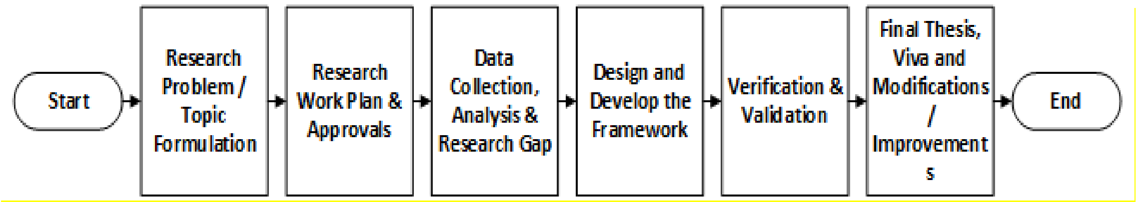


Figure 3. 1: Schematic representation of research methodology & process

3.2 Research Methodology and Design

According to Kothari (2004), research methodology is a way to systematically solve the research problem. In it, we study the various steps that are generally adopted by a researcher in studying his research problem along with the logic behind them. All the methods or techniques which are used by the researcher during studying his research problem are termed research methods.

3.2.1 Research Method and Approaches

Mixed Method:

Supply chain management phenomena are complex and dynamic. Thus, the application of mixed methods research would serve the advancement of the discipline as these approaches provide a richer understanding and more robust explanations of such phenomena (Flint et al.,2012).

To address the key objectives, due to the study area, nature of the data sources and data obtained, this research used both quantitative and qualitative approaches, methods, and tools to obtain and analyse the combination of primary and secondary data.

Deductive Approach:

Creswell and Plano Clark (2007) say that the deductive researcher "works from the 'top down, from a theory to hypotheses to data to add to or contradict the theory" (Soiferman, 2010). This research is based on well-known, and generally defined theories and the objective is trying to apply and resolve a specific phenomenon by collecting historical and empirical data (see Figure 3.2) In other words, from the general theory to resolve a specific phenomenon by proposing a novel framework while bringing improvements to the existing theory.

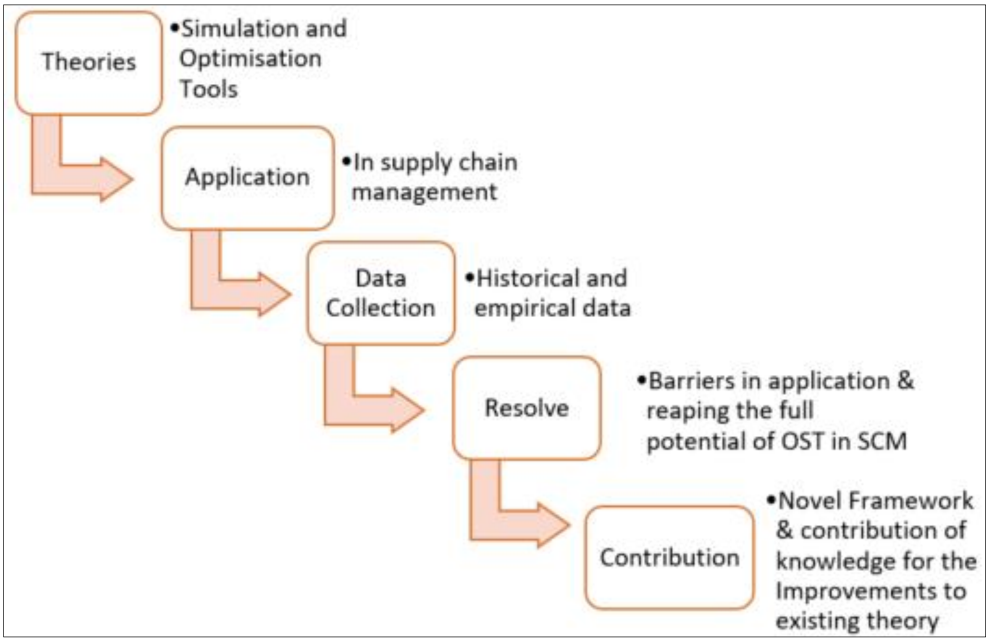


Figure 3. 2: Deductive approach of the research

Source: (Soiferman, 2010)- Only the template contains 5 steps

3.2.2 Research Design

The research design is intended to provide an appropriate framework for a study. A very significant decision in the research design process is the choice to be made regarding the research approach since it determines how relevant information for a study will be obtained; however, the research design process involves many interrelated decisions (Aaker et al.,2008). The strategy and processes executed by the researcher to achieve the objectives of this research are explained in this section (see Figure 3.3).

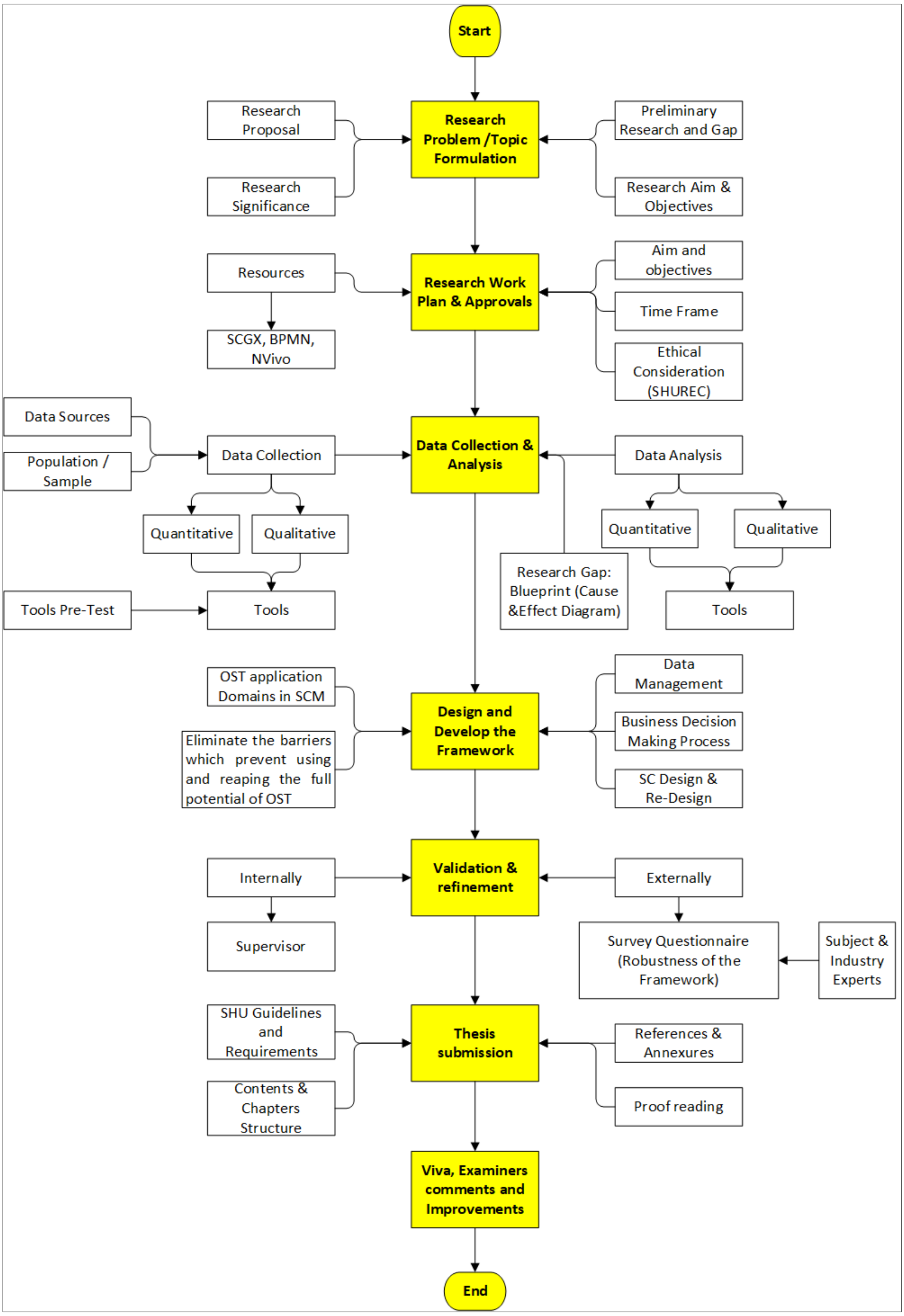


Figure 3. 3: Research design

3.3 Research Problem formulation, Plan and Approvals

The researcher's previous nature of work experience gained, throughout 5 years in the field of logistics and supply chain management in Contract Logistics and Consultancy (CLC) paved a solid foundation for this research. To formulate the research problem, preliminary research had to be conducted and the existing gap had to be justified. Therefore, the significance of the problem and area of study, the existing research gap, the research aim & objectives, and the novel knowledge of contribution has been well explained in the research proposal submitted.

Upon the acceptance of the research proposal, assigning the supervisor, research aim and objectives, time frame of the research project, resources allocation, and future work plan for the period of study were discussed and arranged. Then the ethical feasibility, general data protection regulations and the data repository of the research were approved by the University Research Ethics Committee (SHUREC).

3.4 Data Collection

3.4.1 Study Area and Population

The targeted research study area is the Optimisation and Simulation Tools (OST) in Supply Chain Management. To strengthen the data collection of previous research literature the targeted population is the professionals in the supply chain management who are the users of OST. So, they can be supply chain designers, managers, consultants, supply chain software providers, etc. When selecting the sample of 50 participants (SCM professionals), the researcher was able to capture the responses covering all three user categories as follows which provides a broader picture of the usage and the barriers that exist.

1. OST users (End users)
2. OST Consultants (Intermediate party)
3. OST Providers (Software vendors)

Especially the responses received from the software providers and consultants were also very helpful to identify the actual barriers the professionals in SCM face and what prevents them from using these tools up to the full potential and drawbacks of such.

3.4.2 Search strategy design and select the data sources

A well-designed search strategy is essential to the success of a sound literature review. As such, the strategy should be specific, unbiased, reproducible, and typically include subject headings along with a range of keywords or phrases which covers the scope of the research focus. During the research, the searches should be designed to capture as many studies as possible that meet the focussed criteria ultimately answering the defined research questions.

As such, assuring the quality and integrity of the research by locating previous/ relevant searches, Identifying the relevant databases, developing the search terms, and evaluating and modifying the searches are very important areas which should be taken into consideration. Conduct a preliminary set of scoping searches in various databases to test out the search terms (keywords and subject headings) and locate additional terms for the concepts are very important which leads to high-quality research ultimately. Such below listed were highly considered.

- Recommended key papers
- Papers by known authors in the field
- Results of preliminary searches from key databases
- Reviewing references and "cited by" articles lists for key papers
- Articles that have been published in reputed journals

Also, the key search terms which have been used with Boolean Logic and Truncation can be listed as follows to ensure capturing everything as much as possible without losing anything valuable.

Boolean Logic Strategy (BLS) deployed and its effect:

- AND: Narrows searches and used to join dissimilar terms
- OR – Broadens searches, used to join similar terms
- NOT- removes results containing specified keywords

How Search Terms have been deployed along with the BLS:

- Supply chain management
- “Supply chain design” OR “Redesign”
- Supply chain “optimisation” OR “optimisation”
- Supply chain “optimisation” AND “simulation”
- Supply chain “optimisation” OR “simulation”
- “Optimisation” OR “Simulation” NOT Information Technology

The peer-reviewed articles referred by the researcher were published in reputed journals (see Table 3.1) and the databases were able to access through google scholar and the university library gateway by using the university login subscription.

International Journal of Logistics Research and Applications
Journal of Business logistics
International Journal of Logistics Management
International Journal of Operations & Production Management
International Journal of Simulation
Journal of industrial and management optimisation
Journal of Manufacturing Technology Management
International Journal of Supply Chain Management
International Journal of Physical Distribution & Logistics Management.
International Journal of Supply Chain and Operations Resilience
International Journal of Simulation and Process Modelling

Table 3. 1: List of journals used for the research

To strengthen the data captured through literature, the researcher had to deploy multiple methods to obtain the data. For an instance, the literature related to the barriers that prevent using Optimisation and Simulation Tools in SCM is a bit limited. Therefore, in addition to the literature review, a Survey Questionnaire and a few Semi-Structured interviews were conducted.

3.4.3 Participants of Survey Questionnaire and Interviews

Initial participants were identified based on their experience with the industry, job titles and willingness to participate. As the research study progressed, when the need for understanding certain aspects of the emerging theory rose, participants that could provide further details on emerging questions were purposefully selected.

The interview participants have varying job titles in terms of their business and decision making, including vice president of supply chain strategy, director of supply chain strategy, director of global supply chain strategy, director of operations, director of supply chain integration, Director of distribution services, Supply Chain Consultants, Manager of supply chain solutions and Manager of warehousing & distribution. Most of the participants had senior-level managerial experience with other firms (and industries) before taking on their current jobs. Some are long-time employees of their current companies and were able to provide a historical perspective of their firm and their decision-making responsibilities. Also, the researcher was able to cover diverse verticals of logistics and supply chain sectors like automotive, healthcare, beverage, perishable, agriculture, oil & gas, consumer electronics, 3PL & 4PL, defence, ports & shipping, etc.

3.4.4 Quantitative Tools and Methods

A Survey Questionnaire:

This questionnaire design consists of 4 distinct sections but is interconnected to each. The main purpose of the data collected from sections 1-3 is to quantify the existing usage of OST in SCM. Therefore, out of the population, ‘’SCM subjects and industry experts’’ obtaining a sample of 50 completed responses was the target of the researcher (see Appendix)

Survey Questionnaire Techniques:

Before distributing the survey, a few trials were conducted to determine the average time to complete the full survey. A very compressed introduction and the purpose of the survey have been given while creating trust in participants by guaranteeing the confidentiality of the personal details they intend to provide. The ‘’Respondent’s Information’’ was designed to determine the weight of the response participants provided and obtain broader insights into the data capture even though this field was kept ‘’optional’’ to keep the participants stress-free and move on with the questionnaire if they do not want to provide such.

This survey questionnaire was conducted both in person and online. The engagement of the participants towards the questionnaire is increased by letting them provide their answers simply by a ‘✓ ’’. The survey Questionnaire (Sections 1-3) covered the existing usage (Quantitative) in the main application domains of OST in SCM (see Appendix 1).

3.4.5 Qualitative Tools and Methods

The literature review including a few real case studies, Survey Questionnaire, and a few Semi-Structured Interviews (see Appendix 2) were carried out to obtain subject & industry experts’ opinions which provided further qualitative aspect data wanted.

Literature Review:

By reviewing the recent literature, the researcher was able to find the existing challenges in SCM, the emergence of OST in SCM, real business cases which has successfully implemented OST in SCM and yet the existing research gap. Due to the nature of the research problem, (Identify the current barriers which prevent using and reaping the full potential of OST in SCM) researcher tried to stick to most of the literature reviewed which falls under recent 5 years (2016-2021) but due to the limited content found, the period of the study had to extend (2010-2021).

Survey Questionnaire:

As stated above, by distributing the Survey Questionnaire, qualitative data was also captured. This was very helpful to further strengthen the data obtained from the literature review since the content obtained from the previous literature was a bit limited. Section 4 of the Survey Questionnaire is designed to capture the qualitative data.

Semi-Structured Interviews:

According to Leicester and Lovell (1997), the aim of the interview, as with any qualitative research data collection tool, is to explore the 'insider perspective'. To capture, in the participants, own words, their thoughts, perceptions, feelings and experiences. However, the structured interviews, while possibly asking open questions and generating some qualitative data (words), tend to rely on a rigid, unchanging format and are most commonly a tool for surveys and thus should be viewed as a quantitative data collection tool. The term 'unstructured' can also provoke debate. Mason (2002) argues that no research interview can be entirely devoid of structure, even if that structure is the use of a single open question to prompt thought and discussion. Taylor, (2005) highlights that most qualitative research interviews will, and therefore, be semi/lightly structured, loosely structured, or in-depth in format and aim.

Interview Techniques:

To carry out this type of interview without any complications, good confidence is a must between the researcher (Interviewer) and the participants (Interviewees). Thus, a certain level of knowledge in the research topic area is mandatory, before constructing the Interview Template. In turn, this was strengthened by reviewing the extant literature, the conferences attended, and the supervisor's constant advice.

During the interviews' the researcher started asking the question as structured in the interview template. As the interviews progressed, broad questions were followed by more focused and direct questions. This type of interview enabled the researcher to improvise follow-up questions based on the participant's responses and go in-depth in the area of focus as the interview flows.

To ensure that all aspects of the research study were explored and adequately understood by the interviewer, during and at the end of each interview, the key points of the discussions were summarized, and participants were asked to add anything that was missed during the interviews. This provided the interviewee time for reflection after the interviews and an opportunity to express additional insights about the subject matter.

According to (Creswell, 2007; Krueger & Casey, 2009; Merriam, 2009; Rubin & Rubin, 2012) unlike an ordinary conversation, however, the purpose of an interview is to gain further information relative to the study at hand. You can preserve the conversational and inquiry goals of the research act by including four types of questions: (1) introductory questions, (2) transition questions, (3) key questions, and (4) closing questions (Castillo-Montoya, 2016).

The Semi-Structured Interview Protocol shown below (see Table 3.2) was constructed with the aid of the above-stated guidelines (type of the Question & Explanation of Type of Question) proposed by (Castillo-Montoya, 2016).

Type of the Question	Explanation of type of the Question	Purpose	Interview Question
Introductory Questions	Questions that are relatively neutral eliciting general and nonintrusive information and that are not threatening.	To initiate the interview by creating a conversational platform.	**Q1:** As of the present, what do you think about the Optimisation and Simulation Tools (OST) in the context of Supply Chain Management (SCM)?
Transition Questions	Questions that link the introductory questions to the key questions to be asked.	Pushing the conversation from general to more specific as per the research focus.	**Q2:** What do you think about the awareness, skills and knowledge, process of deployment and the usage of OST among the SCM professionals at present?
Key Questions	Questions that are most related to the research	To capture the areas: Application	**Q3:** What are the potential application domains of OST in SCM? (i.e., Supply Chain

	questions and purpose of the study.	domains of OST in SCM, barriers of application and their magnitude.	Design, Operation, Re-Design/Enhancement) **Q4:** What are the barriers which prevent using or reaping the full potential out of these OSTs in SCM? (i.e., People, Process, Technology, Data) **Q5:** Among what you mentioned previously, may I please ask you to rank the barriers according to their significance and reasoning why? This can be most to least or vice-versa.
Closing Questions	Questions that are easy to answer and provide an opportunity for closure.	To capture the overall recommendation for the development of the framework	**Q6:** What do you think about at present the requirement or significance for a Robust Framework that the OST users can use as a reference in terms of SC Design, Operation & Re-Design? **Q7:** Do you have any other concerns, recommendations, or anything to be added on top of what we have discussed?

Table 3. 2: Semi-Structured Interview Protocol

Source: (Castillo-Montoya, 2016) – The interview questions have been updated over the original protocol.

3.4.6 Tools Pre-Test

Pre-test the questionnaire and revise, if necessary, the final stage, is the use of a questionnaire in a small pilot study to ascertain how well the questionnaire works. Pretesting an instrument is necessary because, as Backstrom and Hursch (1963) have pointed out, "No amount of intellectual exercise can substitute for testing an instrument designed to communicate with ordinary people'' (Hunt, Sparkman Jr, & Wilcox, 1982).

Once the Survey Questionnaire and the Sem-Structured Interview Protocol were designed, the reliability and validity of the content were checked internally by the research supervisor and externally by a few industry experts (Supply Chain Design and Simulation software providers and consultants). Following the feedback both internally and externally, a few minor changes were made to the originally designed content. To assume the average time of completion few trials were conducted for both Survey Questionnaire and Interview.

3.5 Data Analysis

3.5.1 Quantitative Data

The quantitative data collected from the Survey Questionnaire from 50 participants (Respondents) were analyzed using Microsoft Excel Spreadsheet according to their usage of OST in application domains. For an instance, a partial snapshot of the spreadsheet (see Figure 3.4) is presented below, and it reflects that the 50th Respondent use OST in all application areas in both Network Design and Inventory Design. Then the 3rd Respondent use OST in 2 out of 3 application areas in Network Design but in all application areas in Inventory Design. So, whatever the observations marked as "x" count towards the use of OST and else count as Not-In-Use.

Therefore, when it comes to analysis, vertically it provides the respondent-wise usage in individual application areas then in the specific sub-domains, key domains and finally the overall usage of OST of that specific respondent. Correspondingly horizontally it provides the cumulative usage of all 50 respondents in every individual application area, sub-domains, and key domains. The results will be briefly explained and presented in Bar charts in chapter 4.

			Respondent									
Supply Chain Design		**OST Application Domain / Area**	1	2	3	4	5	6	...	48	49	50
	Network Design	Right "size" (No. of) facilities in your supply chain	x	x	x			x		x	x	x
		Right "sites" (Locations) of your supply chain network	x	x			x	x				x
		Right Service Levels		x	x	x		x	x			x
			2	3	2	1	1	3	1	1	1	3
	Inventory Design	Right inventory levels (SKU-wise)	x	x	x		x	x				x
		Right inventory placements (i.e., Inventory at different locations)	x	x	x		x	x			x	x
		Appropriate Inventory policies		x	x	x		x	x	x		x
			2	3	3	1	2	3	1	1	1	3

Figure 3. 4: Survey questionnaire data analysis technique (partial snapshot)

3.5.2 Qualitative Data

This was one of the concerns suggested internal examiner over the viva examination conducted in mid of the research. Necessary software requirement NVivo 12® and support provided by the university to carry out a solid qualitative data analysis and visualization over 50 participants and 5 respondents (Interview questionnaire)

<u>Data collection methods and techniques:</u>

Literature review, Real case studies in existing literature, Survey questionnaires, Semi-Structured interviews, Symposiums, and conferences (helped immensely to make a good network of industry and subject experts who contributed to these throughout the research).

<u>Data Analysis tool:</u>

NVivo 12.6® is a qualitative data analysis which has been used to collect, organise, analyse, and visualise unstructured or semi-structured data during this research. With NVivo, it was quite easy to upload a range of file formats, organize demographic data, code sources, capture ideas, run queries and visualize project items.

Results visualisation:

(1) File-Case- Classification Project Map

(2) Survey Questionnaire Project map

(3) Interview Project map

(4) Survey Questionnaire Matrix Coding Query

(5) Interview Matrix Coding Query

3.6 Process of identifying the Research Gap

This is a most important piece of an outcome derived from the combination of both the literature gap identified in Chapter 2 and both survey questionnaire and Interview results analyzed in Chapter 4. The results and conclusion of Chapter 4 strengthen the literature gap identified in Chapter 2 (see Figure 3.5). This is the blueprint for the success of the main objective of this research ''Design and Development of the Framework''.

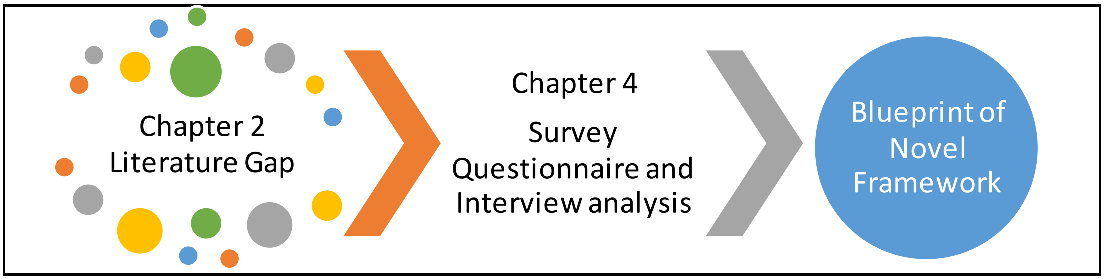


Figure 3. 5: The blueprint derived by literature gap, survey, and interview result

3.7 Design and development of the framework

The proposed framework and its process illustration have been presented in detail in Chapter 5 by using a few software and tools.

Design the Framework

Business Process Modelling Notation (BPMN) Stencil and Process Flow Diagrams (PFD) in MS Visio® v2016.16 software.

Modelling database tables their Terminology and Relational Integrity

Crow's Foot Database Notation in MS Visio® v2016.16 software.

To illustrate how significant, it is to be geared with a solid knowledge of these terms when constructing your relational database and modelling with sensible logic. Also, this is very useful when there is not much data in hand and starting from scratch by performing data assumptions and fulfilling the data requirement in modelling. When using any OST and populating the data there will be multifaceted dimensional data categories, tables, and fields so assurance of relational integrity among them by knowing how these data logically mapped over Primary and Foreign Key assignment is another area to be concerned. (Detailed explanation has been given in Chapter 5-Process 3: constructing & enriching the modelling database-MDB).

3.8 Validation and refinement

3.8.1 Verification and Validation of the Framework

This is where to showcase how robust the solution proposed before any submission. The validation process was carried out and necessary refinements have been executed as recognized over the validation output results. The validation strategy contains two techniques as follows.

1st Internally: Conducted a demonstration of the entire framework to the supervisor and modifications have been carried out over feedback. This filtered and rectified the inefficiencies which existed before sending it to the external validation.

2nd Externally: Conducted a Psychometric Scale survey questionnaire which is enclosed with the design of the framework and process explanation. Validation output is taken into consideration as further refinement to enhance the robustness of the framework.

3.8.2 Final submission and improvements

Final submission of the Thesis will be submitted to the University Research Degree Committee followed by a defence of the These through which further improvements can be imposed to the Proposed ‘‘OSTiSCM’’ before publication.

3.9 Conclusion

Before conducting any form of research, gearing up with a sound research methodology is mandatory. That provides a solid foundation through a research design which is the road map to the research objectives in finding solutions to the research questions formed. Since this research has been followed, adhered to the methodology and the process defined firmly, it was very easy to achieve the research objectives without any hesitations.

From the step of preliminary research gap identification, research problem formulation, university ethical consideration and obtaining necessary pre-approvals have fulfilled all the prerequisites as required. Then how the justification of deploying a deductive approach and mixed methods, selecting the study area, population and sample have been discussed.

The significance and justification of why particular tools are used in terms of data collection, analysis and visualization and pre-testing of such tools have been described in detail. Then how the search strategy development took place in terms of referring to the databases, deploying the Boolean Logic and Search Terms and data sources, articles, and journals referred to have been described.

Once the search strategy is in place, what data will be collected, the research gap will be identified and blueprint for the novel framework will be derived, and the way the framework is getting designed and developed have been discussed.

In the latter part of this chapter, it is well described how significant it is to deploy a strong verification and validation process which will leverage to achieve the research’s outcomes immensely through necessary enhancements, and modifications which can be brought in by a targeted set of industry and academic experts have been explained followed by the process of how final thesis and modification submission will be done before publication.

Chapter 4

Survey Questionnaire & Interviews Analysis

4.1 Introduction

This chapter is fully dedicated to illustrating how data capturing and analysis are performed throughout both survey questionnaires and interviews. Then on which basis conclude to demarcate the scope of design and development of the framework. Then the research outcome captured in the literature review in terms of exiting barriers has been merged with the qualitative results analyzed here and produced a strong Cause-and-Effect Diagram which is the primary objective. The same will be used as the 'Blueprint' in the designing and development of the framework.

4.2 Survey Questionnaire

4.2.1 Quantitative Data

In any survey, it's very normal that we cannot obtain completed responses from all the copies of the Survey Questionnaire that we distribute among the participants. In this case researcher's targeted sample size for the analysis is 50 completed responses.

The Survey Questionnaires were distributed in person at International Supply chain conferences, symposiums, and software providers' training forums where the researcher was able to make a strong network of subject and industry experts. These events were explicitly designed for SCM professionals who currently use and intend to use OST and I had to obtain prior approval from the officials/organisers of the events by sending my survey and questionnaire. Then they revealed their current and pipeline clientele who I should be targeted during the vent in distributing my materials for a better output.

The detail of the events I have attended, the online survey conducted, and the responses collected via email which led to obtaining the complete set of responses can be given in a summary table below (see Table 4.1).

- Llamcon EMEA Annual Supply Chain Conference – Amsterdam and United Kingdom (2017-2019)
- AnyLogistics Simulation conference – United Kingdom (2019)
- Llamsoft Training Centre Conference for SCM Professionals (2019)
- Llamasoft International Simulation Virtual conference (2021)
- Coupa Software EMEA virtual conference (2021)
- Survey Questionnaire – Online Survey Monkey platform (2017-2019)

Tool	Method	Distributed	Completed Responses
Survey Questionnaire	International Conference	65	37
	Online Survey	20	10
	Email	5	3
Total		90	50

Table 4. 1: Survey questionnaire sample size and methods in responses capturing

4.2.2 Observations Structures

The structure of the observations captured in terms of the main three application domains of OST (Tier 1) and under them the secondary and tertiary application domains/areas (Tier 2 & 3) can be illustrated as follows (see Figure 4.1). These are the application areas captured through the survey questionnaire (see Figure 4.2). The total number of observations against the sample of 50 respondents is 1000.

Tier 1: (see Figure 4.1) below shows there are 3 Domains, and these are very high-level application domains SC Design, operation, and Enhancement / Redesign.

Then when you refer to both figures respectively (see Figure 4.1 & 2) how the Tier 1 Main domains have been divided into sub-domains when you move along vertically in Figure 4.2. likewise in Tier 3 as well.

There is a total of 20 application domains (9+5+6) and a total of 50 complete responses which provided a total of 1,000 Observations (20 Domains in each response * 50 Completed Responses) once all the responses were populated into a spreadsheet.

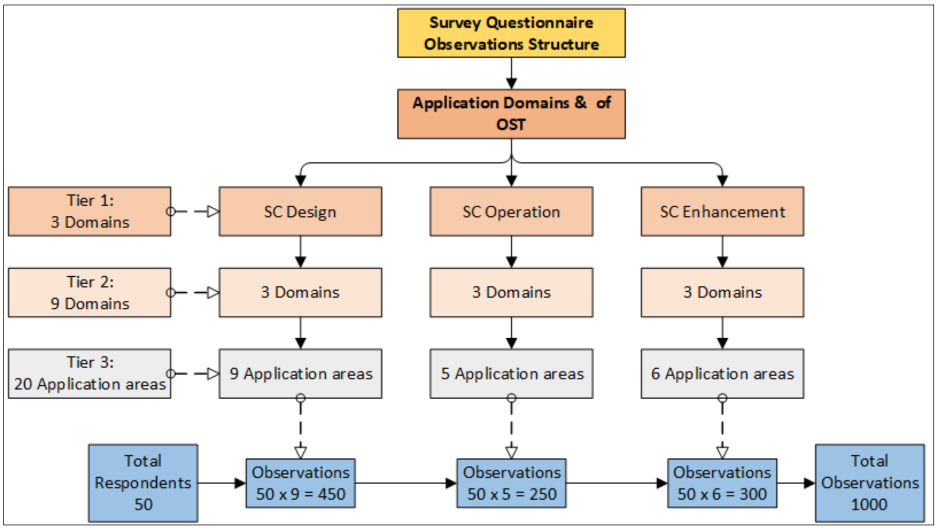


Figure 4. 1: Survey Questionnaire Respondent's Observations Structure

	Application Domains captured as pe the survey Questionnaire			Total
	Tier 1 (3 Domains)	Tier 2 (9 Domains)	Tier 3 (20 individual areas/domains)	20
Application Domain	**Supply Chain Design**	**Network Design**	Right No of Facilities	9
			Right Locations	
			Right Service Levels	
		Inventory Design	Right Inventory levels	
			Right Inventory at different locations	
			Right Inventory policies	
		Transport Design	Right Route	
			Right Mode	
			Right Fleet	
	Supply Chain Operation	**Operation Analysis**	Delivery / Order fulfilment	5
			DC/Hubs Utilization / Performance	
		Assets & Workforce Analysis	Assets Utilization / Performance	
			Work force Performance	
		Operati0nal Risk Analysis	Current & future level of Risk	
	Supply Chain Enhancement	**Performance beyond KPI's**	Delivery / Order fulfilment	6
			Sites / DC/ Warehouse performance	
		Mergers and acquisitions	Sites consolidation feasibility	
			Transport consolidation feasibility	
		Innovation & CSR	Increasing the level of Automation	
			Reducing the impact to the Environment	

Figure 4. 2 OST Application areas captured through the survey questionnaire

4.2.3 Results discussion:

As per the observation, and structure explained earlier, below three figures showcase the usage of 50 respondents over the corresponding application domains and each respondent-wise OST usage. The very first figure (see Figure 4.3) is an illustration of the usage over 9 sub-application domains under the 3 main application domains in Supply Chain Management (1) Design, (2) Operation and (3) Enhancement.

i.e., Network, inventory, and transport design are the three sub-application domains under the main application domain: SC Design.

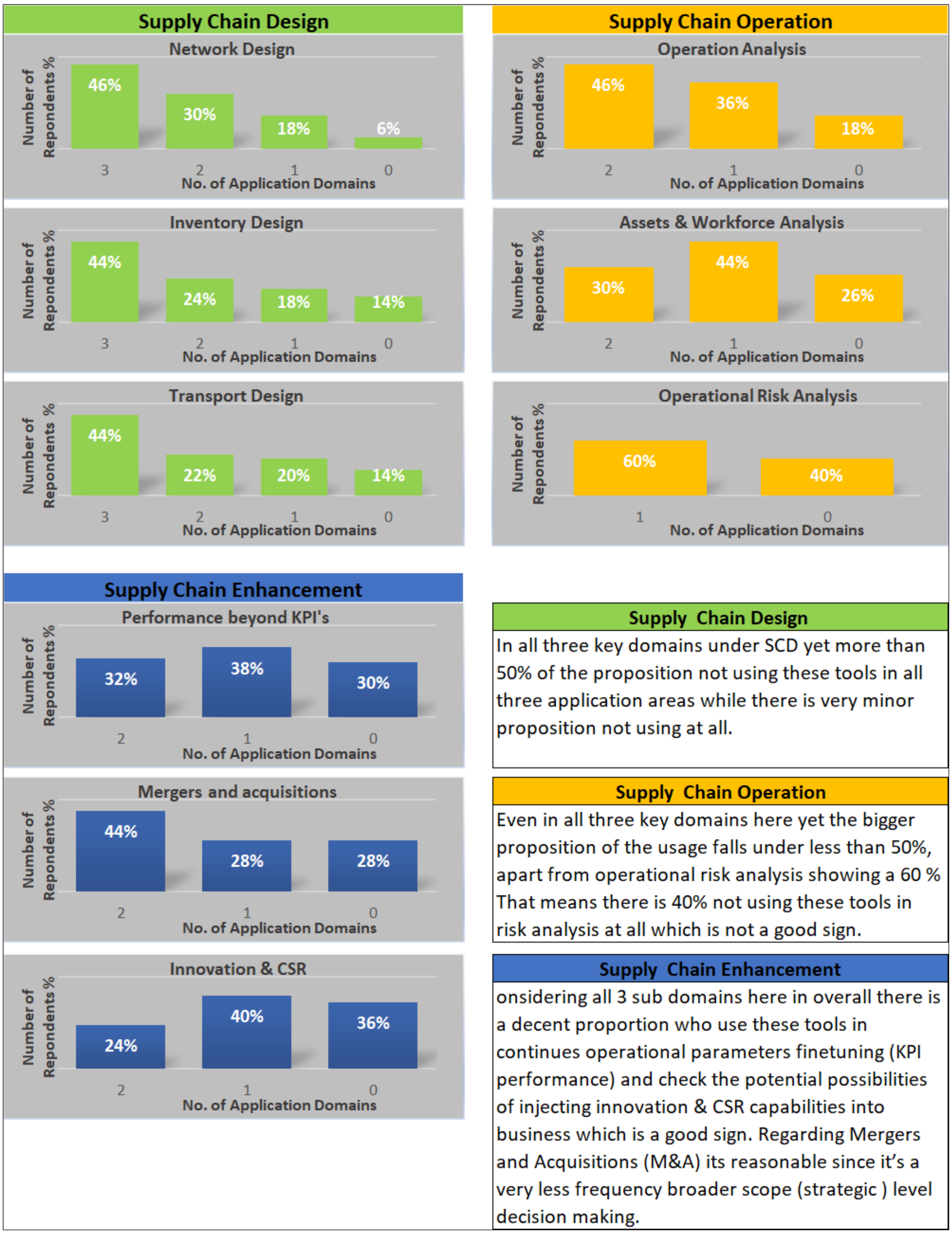
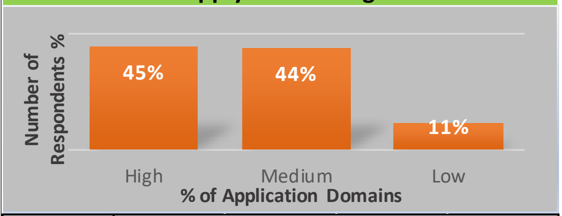


Figure 4. 3 SQ Results in the usage of OST over 9 Application domains in SCM

Note: During this analysis, it was well identified that a respondent can be a non-user in one application domain but a high or medium user in the other one or two domain(s).

The below figure (see Figure 4.4) is a summary obtained by scrutinizing the above which helped to derive the overall result of this analysis and shed light that yet there is only around 40% of users reap the maximum range of benefits out of these OSTs in their SCM pursuits.

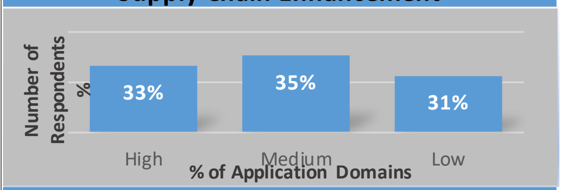
Supply Chain Design



Y axis	% Respondents out of 50	
X axis	High	The usage in application domains
	Medium	
	Low	

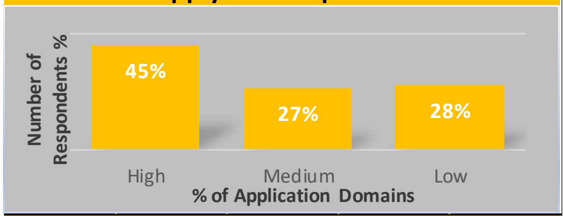
45% out of 50 respondents confirmed that their usage of OST stays at a higher level in Supply Chain Design but it seems yet there is a similar proposition who use these tools in a medium level usage while there is proposition which is closer to 11% can be reconised as the low level users.

Supply Chain Enhancement



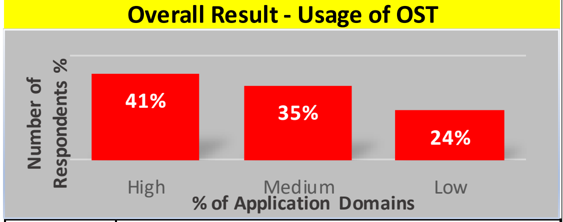
Due to the scope and the frequency of 3 application areas under the SC Enhancement, apart from "(1) Further Operational performance finetuning" the other two (2) Mergers & Acquisitions (Broader scope less frequency) and (3) Innovation & CSR (Broader scope medium frequency) the proportion of usage shows here are considerable but there is a hidden true value potential which these users can reap out by looking over some enhancements rather just focusing on only ad-hoc basis specific problems.

Supply Chain Operation



Likewise, in SCD even here its about 45% of proposition out of 50 respondents confirmed that that their usage of OST stays at a higher level in Supply Chain Operational experiments. But yet there is a bigger proposition which is almost closer to 30% which can be recognised as low level users and is not a good sign.

Overall Result - Usage of OST



Y axis	% Respondents out of 50	
X axis	High	The usage in application domains
	Medium	
	Low	

41% out of 50 users fall in the category of "high Usage"

Overall result concludes that we can recognise only a a proposition of less than 50% of users as the higher usage category who actually benefits a sound return against their investments. But unfortunately around 1/3 of users apply these as in medium level and 24% which is also a considerable proposition reflects as the low usage users which actually boost the motivation further over this research.

Figure 4. 4: SQ Results in the usage of OST over 3 Application domains and overall, in SCM

The below figure (see Figure 4.5) reflects the individual usage of OSTs of 50 respondents. Also, it's verified and validated that every user at least uses these OSTs up to some extent since the survey questionnaire is given for the selected sample of users who only use OSTs.

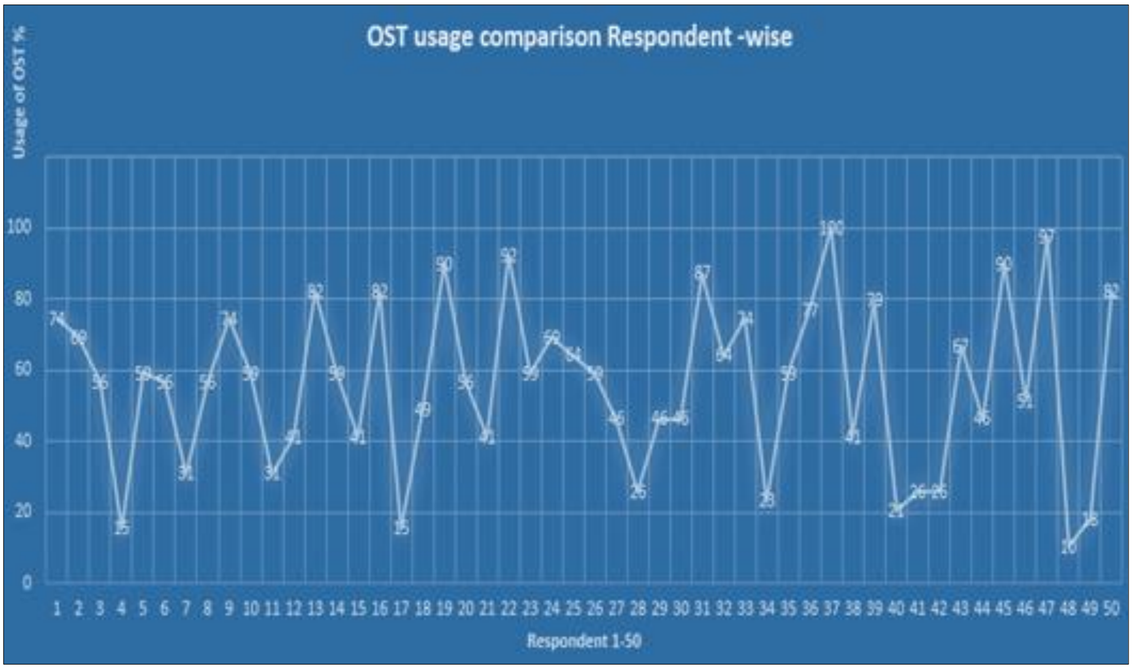


Figure 4. 5: Respondent-wise OST usage in SCM

4.2.4 Qualitative Data

Survey Questionnaire -Project map

All data were captured and reflected in the cause-and-effect diagram coded in NVivo as follows which can be shown as a project map (see Figure 4.6).

Question:

1. OST Usage and application domains (3 categories then 12 child nodes)
2. Barriers which prevent using or reaping the full potential (4 child nodes)
3. User flexibility of existing OST (3 child nodes)

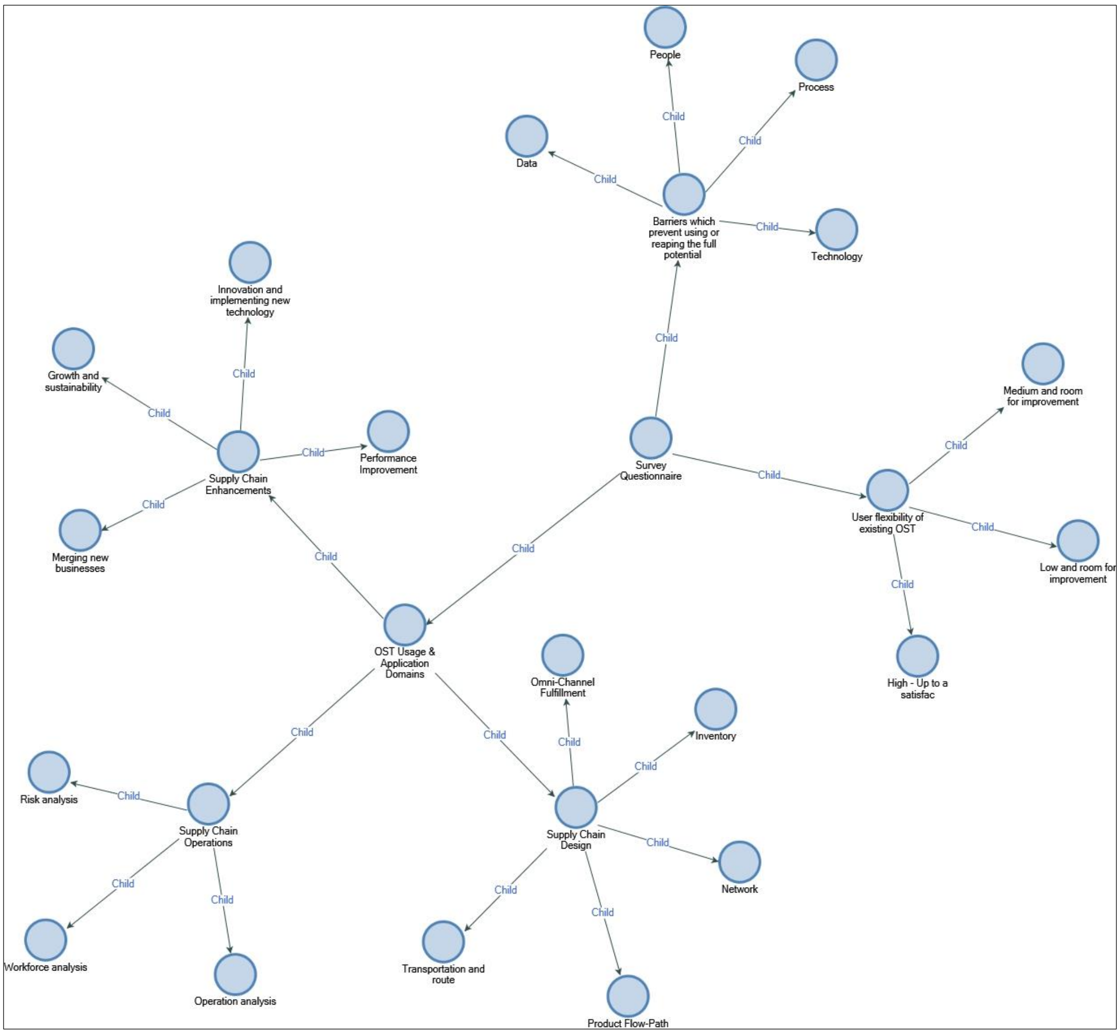


Figure 4. 6: Survey Questionnaire Project Map

4.2.5 Results Summary

Application of OST in SCND, Operation and Re-Design provides broader capabilities in getting the right supply chain design at first instance then finetuning the operational performance to bringing further enhancements while continuously seeking for the opportunities exist to shift the operational excellence to the next level even by a re-design if the experiments via OST provide better institutions. This type of OST maturity enables multifaceted savings for your business over time.

4.3 Interviews

4.3.1 Qualitative Data

5 semi-structured interviews were conducted with the subject and industry experts who were very supportive even during the peak COVID-19 pandemic situation. Then all the responses were uploaded into NVivo as explained earlier and the following outputs were obtained.

4.3.2 Results & Discussion

<u>File-Case- Classification - Project Map</u>

This project map (see Figure 4.7) shows the responses captured under the classification of 50 survey Respondents (50xSR) & 5 Interview Respondents (5xIR). All 55 respondent's data were captured in attributes of User category, Industry & Job Role under Case-Person.

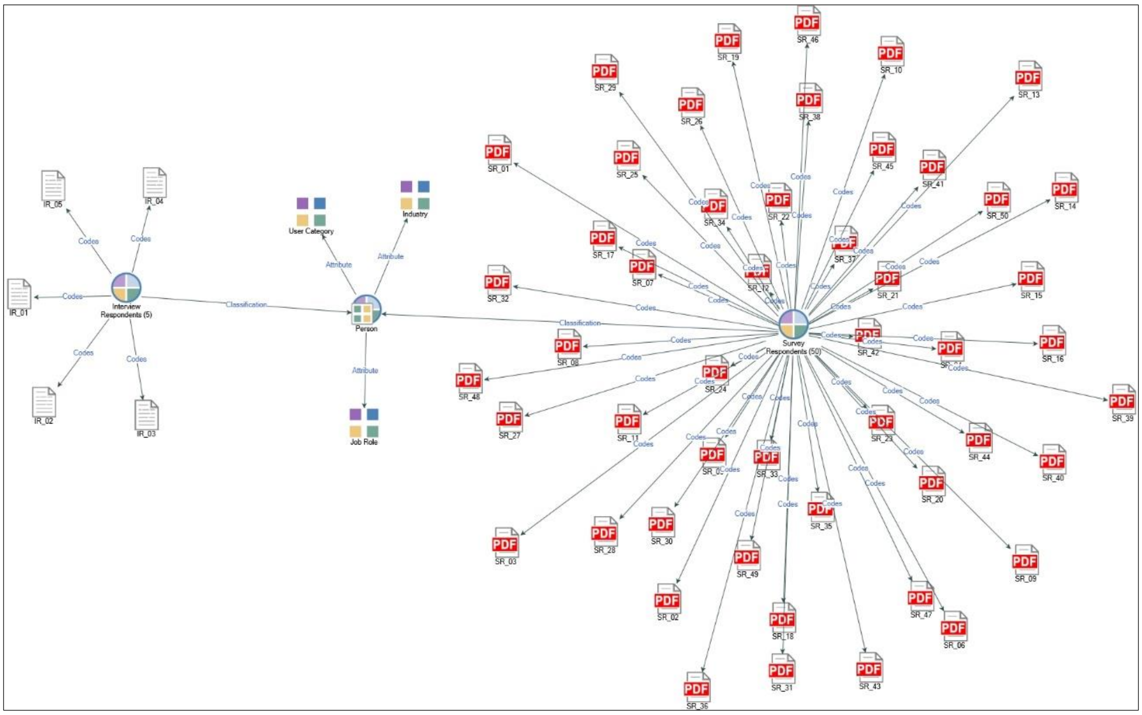


Figure 4. 7: File-Case-Classification Project Map

<u>Interviews – Main Project Map</u>

The way interviews have been carried out and the area covered through the questions have been coded in NVivo under three child nodes then which have been expanded further for 10 child nodes (see Figure 4.8).

<u>Questions:</u>

(1) Barriers which prevent using or reaping the full potential
(2) Current Usage and Awareness
(3) The Importance & requirement for a robust Framework to aid in the application of OST

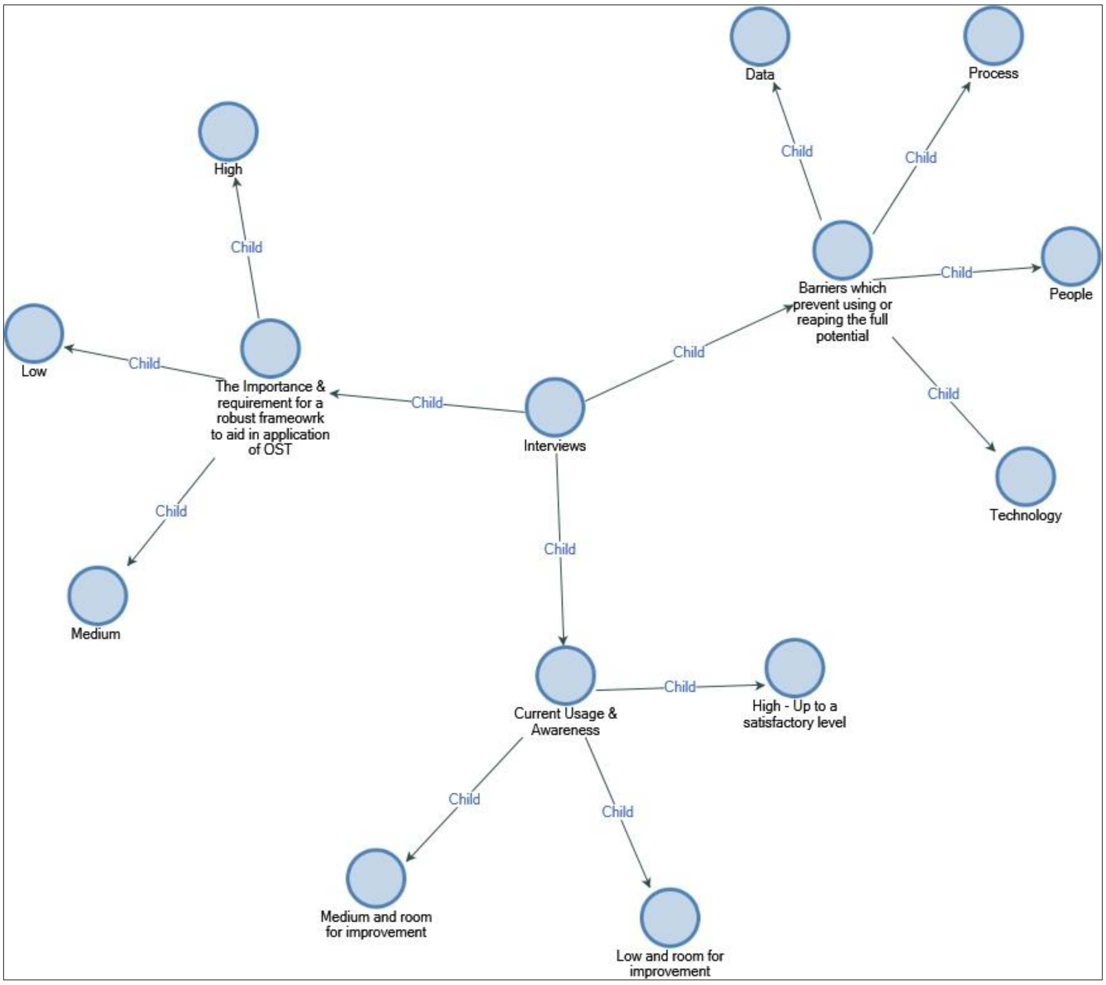


Figure 4. 8: Interviews-Main Project Map

Question Node: Barriers which prevent using or reaping the full potential

This project map (see Figure 4.9) shows 24 barriers (Codes) under 4 Child-Nodes (Technology, Process, People & Data) which is under the 1 Parent-Node (which prevents using or reaping the full potential of OST).

The references captured under these 24 barriers nodes as per the Primary and Secondary of the Cause-and-Effect Diagram (CED) under above mentioned 4 categories (Technology, Process, People and Data)

So that the connection between the analysis done through NVivo and CED.

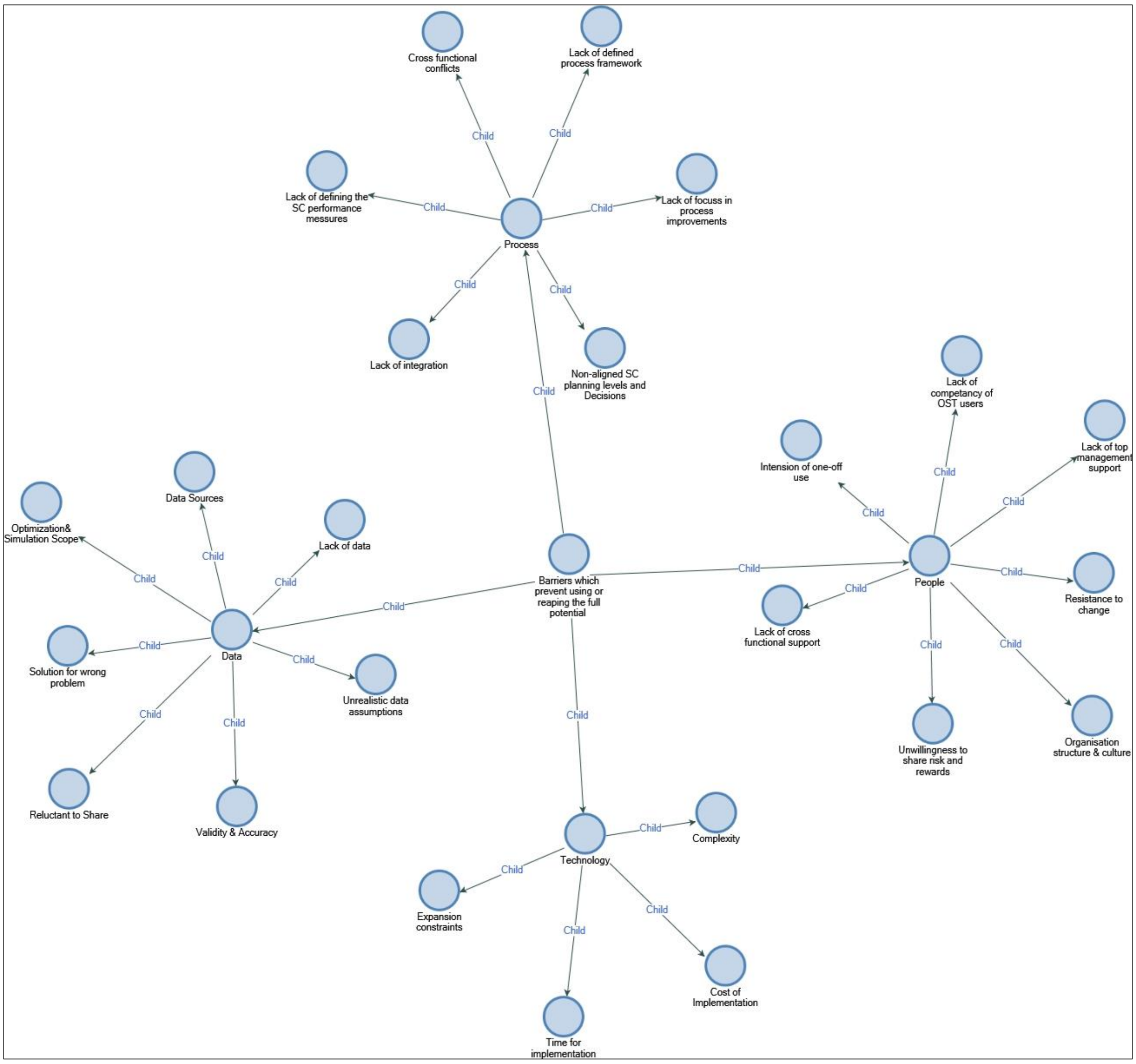


Figure 4. 9: Barriers which prevent using or reaping the full potential Project Map

4.3.3 Results Summary

To visualize the results over the coded references in NVivo one of the best ways is to run a Matrix Coding Query (MCQ) first and then generate the matrix table as per the criteria required (see Figure 4.10) then which can be converted as a chart for much better visualization (see Figure 4.11).

Matrix Coding Query -Table (Barriers which prevent using or reaping the full potential)

	Barrier in appllication & reaping full Potential of OST	A : Data	B : People	C : Process	D : Technology
A : Data	1 : Data Sources	5.71%			
	2 : Lack of data	49.52%			
	3 : Optimization& Simulation Scope	6.67%			
	4 : Reluctant to Share	5.71%			
	5 : Solution for wrong problem	4.76%			
	6 : Unrealistic data assumptions	14.29%			
	7 : Validity & Accuracy	13.33%			
B : People	8 : Intension of one-off use		2.86%		
	9 : Lack of competancy of OST users		59.18%		
	10 : Lack of cross functional support		7.76%		
	11 : Lack of top management support		22.45%		
	12 : Organisation structure & culture		2.04%		
	13 : Resistance to change		3.27%		
	14 : Unwillingness to share risk and rewards		2.45%		
C : Process	15 : Cross functional conflicts			1.43%	
	16 : Lack of defined process framework			76.43%	
	17 : Lack of defining the SC performance messures			2.14%	
	18 : Lack of focus in process improvements			8.57%	
	19 : Lack of integration			2.86%	
	20 : Non-aligned SC planning levels and Decisions			8.57%	
D : Technolog	21 : Complexity				27.83%
	22 : Cost of Implementation				44.35%
	23 : Expansion & Integration constraints				22.61%
	24 : Time for implementation				5.22%

Figure 4. 10: Matrix Coding Query -Table (Barriers which prevent using or reaping the full potential)

NB:

The significance of the results provided by this Matrix Coding Query triggered to insert below processes into the framework.

- Process 2: Leverage CSF: Technology, Process. People (TPP)
- Process 3: Construct & enrich the modelling database (MDB)

Matrix Coding Query – Bar Chart (Barriers which prevent using or reaping the full potential)

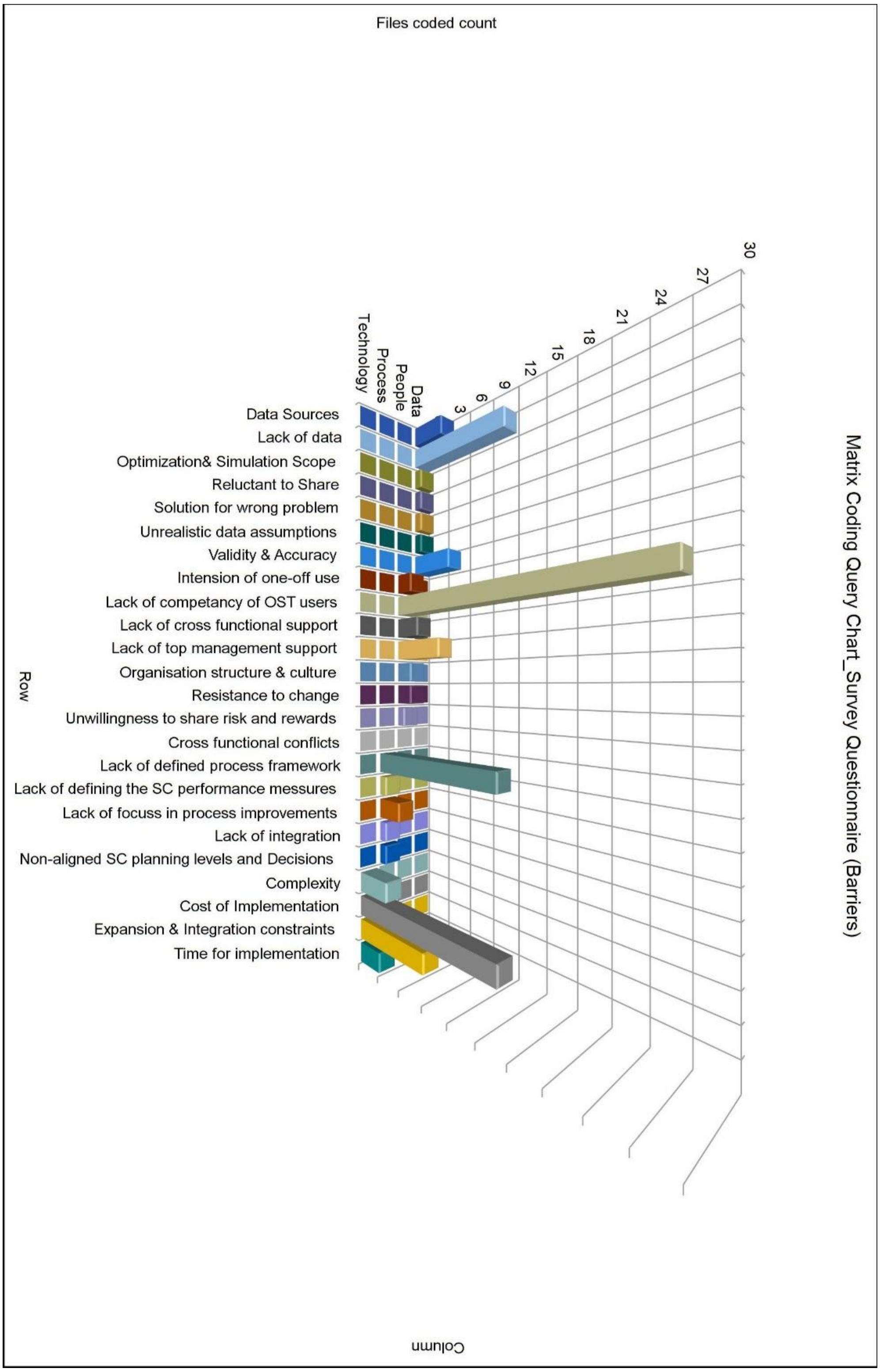


Figure 4. 11: Matrix Coding Query – Bar Chart (Barriers which prevent using or reaping the full potential)

4.4 Overall Summary and Conclusion

Based on the detailed analysis of both quantitative and qualitative data obtained; the potential application domains of OST in SCM and barriers which prevent using OST in SCM were identified. There were four distinct, but well-integrated barriers identified namely Technology, Process, People and Data. But out of all, it was well reflected that the Data Management in SC projects holds a substantial weight among the rest. So, the below-constructed CED (see Figure 4.12) will be the ‘’Blue-Print’’ for Chapter 5 which is the core element of this entire research ‘’Design & Development of the Framework’’.

4.4.1 Cause-and-Effect Diagram (CED)

As explained earlier in Chapter 2, this is the point of merging both (1) the initial research gap identified in Chapter 2 by Literature Review and (2) the overall results of the Survey and Interview Questionnaire. The research gap identified in Chapter 2 has been expanded with these results and can be well presented over a CED under 4 main categories (see Figure 4.12).

The major ground for identifying the 4 Primary (People, Process, Technology and Data), then Secondary and Tertiary causes is the data collected through survey questionnaires and interviews. A result of the way semi-structured interviews and the open-ended questionnaire were conducted helped immensely to go the extra mile and capture the expertise’s views and suggestions to produce a strong CED which reflects a better coverage of all possible causes which affect using and reaping the maximum potential out of the OSTs.

To get analysed and visualised the captured data systematically; NVivo® software had been deployed. All the possible causes were fed into NVivo as a structured Coding hierarchy (Primary and Secondary Causes as in 24 Codes) same as how CED reflects. The frequency in terms of how many times the same cause has been highlighted and discussed by the respondents/participants was captured as the number of references under each coding which was well explained at the beginning of the chapter.

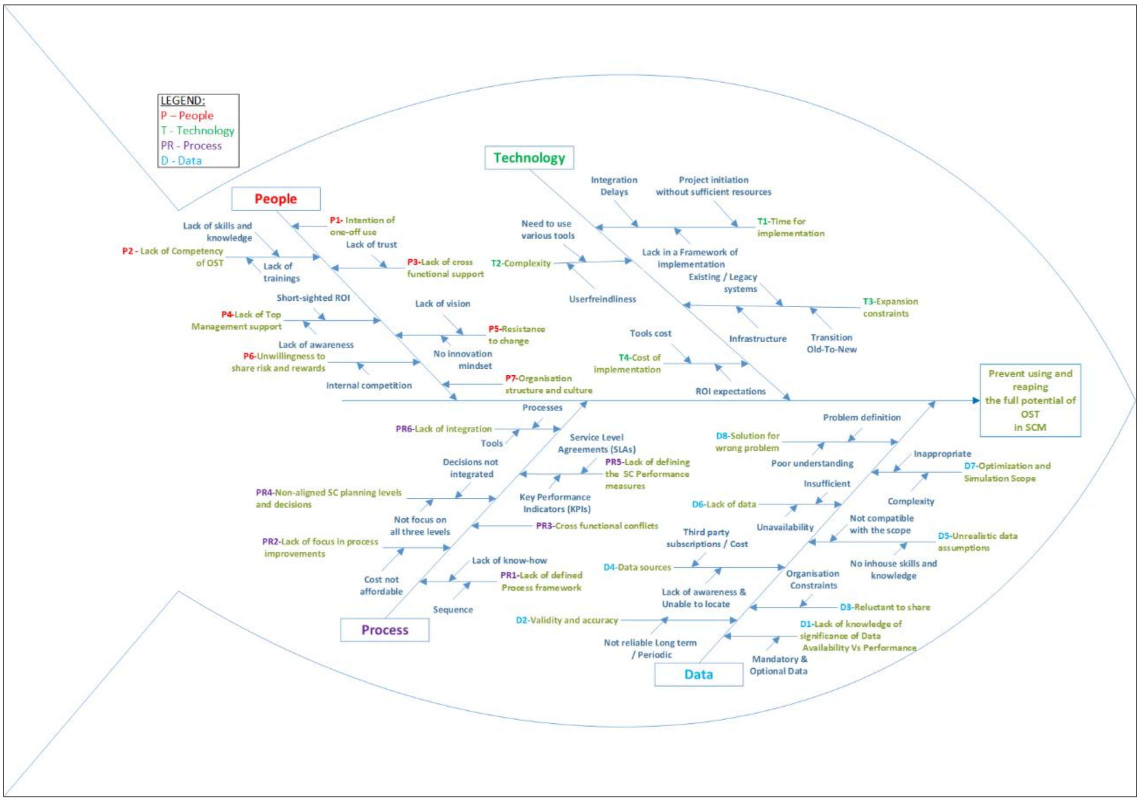


Figure 4. 12: Blueprint of OSTiSCM – Barriers in OST application captured as primary secondary and tertiary causes by a CED

Chapter 5

Design and Development of the Framework

5.1 Introduction

The barriers which prevent using and reaping the full potential of OST in SCM are well illustrated by a Causes & Effect Diagram in chapter 4. In that, it is well reflected that the community concerned in OST is required a well-structured approach to come across those barriers. This is the blueprint for designing and developing this Framework. All ''Primary and Secondary Causes'' (colour coded in CED) which ''Effect'' prevent using and reaping the full potential were successfully addressed by OSTiSCM (see Figures 5.1 & 5.2).

Therefore, the main objective/scope of this framework named ''OSTiSCM'' which is derived from ''Optimisation Simulation Tools in Supply Chain Management'' is to address those identified drawbacks, and inefficiencies and provide step-by-step guidance to transform the ''Business Strategy'' into a well-tested ''SCND Strategy''. In return, decision-makers can execute their decisions enterprise-wide successfully with full confidence over continuous experiments by using these tools to achieve operational excellence.

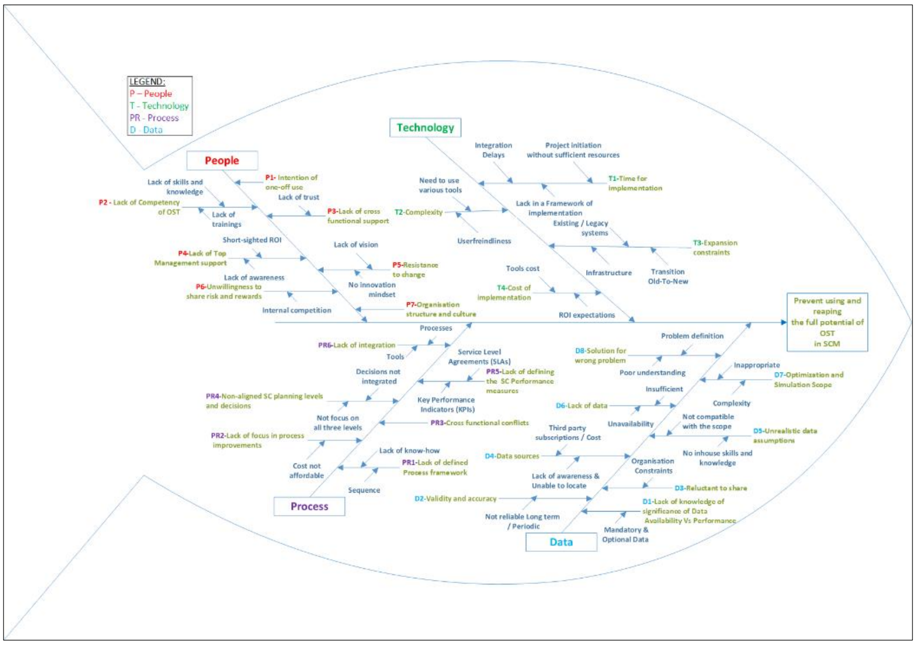


Figure 5. 1: Cause-and-Effect Diagram's relationship to Processes in OSTiSCM

There are four key columns below (See Figure 5.2) which explain the connection between the codes (4 colour coding) given in CED (see Figure 5.1) and how that paved a solid foundation to derive the key ten processes in the proposing Framework. Then how does that bring the novel contribution of knowledge to existing space in academia and application in industry and ultimately, what are the key milestones and outputs existing and intended users of OST can get achieved by deploying this Framework?

1. Barriers n OST: Captured by CED: -This column explains how the captured all causes have been filtered and selected based on what led to the form of that specific process.
2. OSTiSCM: - These are the ten Key distinct processes derived as a Framework which should be followed by the users to prevent the causes of that drawback using and reaping the full potential of OSTs.
3. Solution: Contribution to knowledge: - This is how this novel framework brings the novel contribution of knowledge to the existing space in both academia and industry.
4. OST/Output: - This explains what are the distinguish milestones and significant outputs users can be achieved during any deployment of OST by using this Novel Framework.

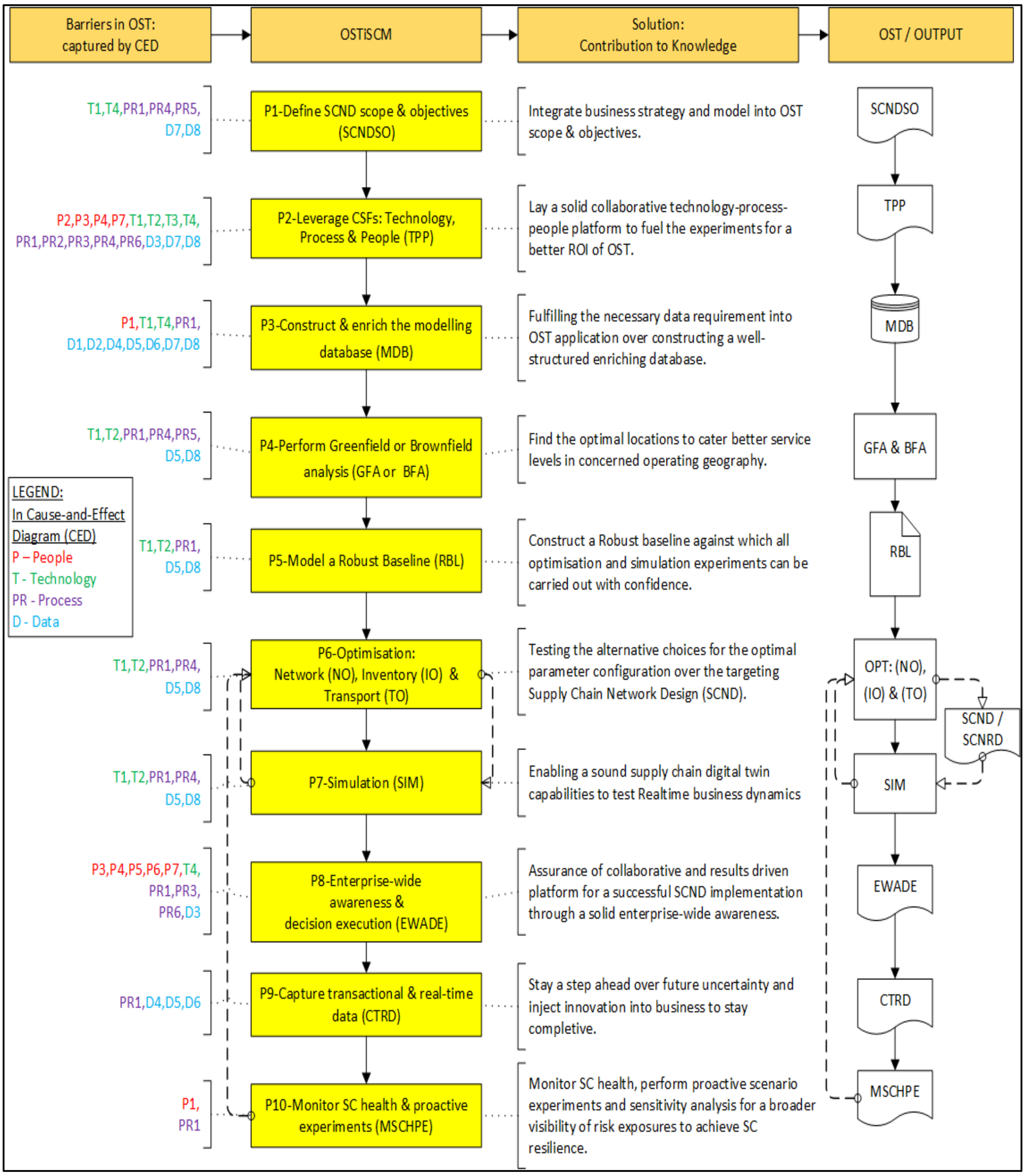


Figure 5. 2: Process in the Framework’s relationship to the CED

5.2 Building blocks

Since the requirement for a structured approach in the application of OST in SCM is well recognized, it's important to know the grounds which urged to design and development of Framework OSTiSCM. At the very aggregate level that can be illustrated as 4 key blocks on which the rest of the parts and criteria are taken into consideration over this OSTiSCM (see Figure 5.3).

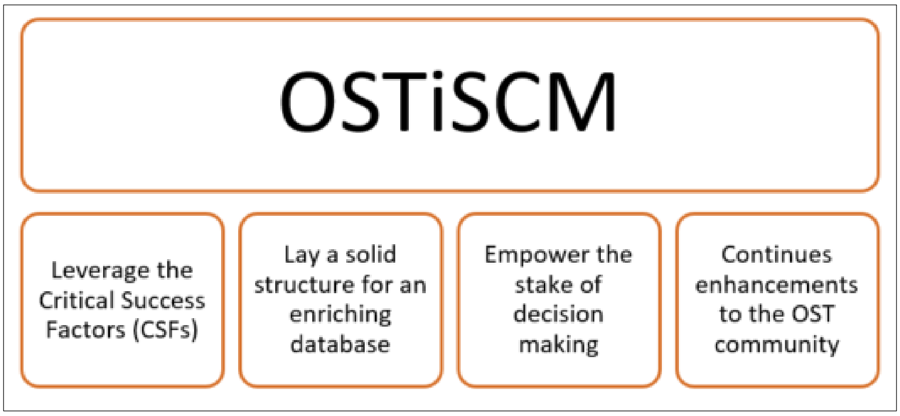


Figure 5. 3: Building blocks of OSTiSCM

5.2.1 Leverage the Critical Success Factors (CSFs)

A lot of inefficiencies and drawbacks which exist during OST application projects originated due to a lack of integration and cross-functional support among (1) Technology, (2) Process and (3) People''. Especially when a business seeks support during a very strategic level decision like SCND, which associates with a huge investment in terms of configuring the long-term business operating network that decision should be courteously supported. To provide such business intuitions to the decision makers through tools & technology that they use such as OST; should be well integrated with well-structured processes and skilled organisational resources. Then only the most important element ''Data'' can be input into OSTs and processed by skilled people for better outcomes. Therefore, its highly recognised that, these three CSFs should be well integrated and validated before any execution of the OST project which pave a smooth ready-to-operate platform with the data which will come on board at any time. By giving that priority this is the 2nd process in the framework which is fully pledged with a string of steps.

5.2.2 Lay a solid structure for an enriching database

The research (AnalyticsLearn, 2021) illustrates how significant the different type of data businesses associates with over time and the relationship among them spread across in complexity and value they hold (see Figure 5.4). As such if businesses have the capability of capturing that specific data into a well-structured database that will empower the amount of data that they have in hand at any point in time. When descriptive analytics reflects what has happened and predictive analytics is used to model and forecast what is likely to happen, prescriptive analytics strengthen the experiments over OST to hit the right choice among alternatives.

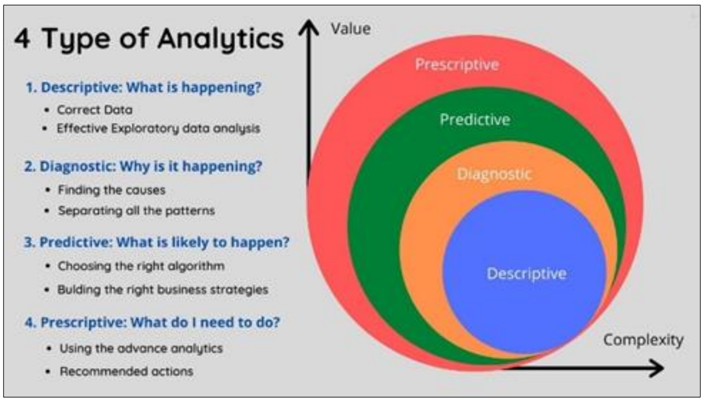


Figure 5. 4: Type of data and business decisions derived from 4 types of analytics (Source: AnalyticsLearn,2021)

Consequently, before capturing any data the scope of data which is required to start and operate the business which leads to achieving operational excellence should be well determined. Then the relationship among the different data categories, accessible sources, and acquisition from origin into a discrete workspace where data can be stored and manipulated should be well mapped and geared.

Just imagine if it’s a new business which is planning to operate in future but fully geared up with this type of platform, where they can start from scratch even with the data assumptions and enrich their database over time. In return that will strengthen them in using any tools such as OST to experiment as they move on. This is one of the objectives which is fully pledged within the framework which will help the businesses as in following.

- Gain the data management maturity through sound business intuitions fuelled by a structured DATA driven approach.
- Continuously enriching the database by capturing the data through the connected systems or devices (i.e., ERP, TMS, WMS, IoT) to strengthen the data analytics capabilities.
- The ability to inject strategic innovation into business proactively to stay competitive.

5 2.3 Empower the stake of decision making

Sometimes the decision makers in businesses gamble on their decisions due to the level of uncertainty and urgency they associate with the type of problem. So, the ones who stake the right choice are rewarded while the others will lead the business to an utter mess at some point. As such the consideration in SCND decision-making and the impact associated with the entire business objectives and goals is very significant. A multifaceted SC business case environment strongly entails a structured DATA driven Decision Making Approach. The true hidden causes behind most of the negative impact of decision-making can be listed as follows.

- When the problem is very complex, keep exploring for the best option unrealistically rather than simplifying it into smaller pieces.
  - i.e., Solution: Embed the full problem scope into OST aa Project which contains multiple Models as sub-objectives.
- No proper grounds are set to compare the alternative approaches precisely
  - i.e., Solution: Run multiple scenarios and perform comparisons through OST
- Failure to determine the appropriate calibre and the number of people must involve in decision-making.
  - i.e., Solution: Leverage the CSF- People before OST by defining the OST core and support staff structure
- Lack of enterprise-wide awareness and challenges involved in the execution of the decision
  - i.e., Solution: Leverage the CSF- People before OST project and strategy execution in a very democratised way, make everyone aware, get the full

cross-functional support and then which will help to perform an enterprise-wide awareness just before decision execution.

5.2.4 Continues enhancements to the OST community

Due to some negative impressions in the aspects of Time-Cost-Quality (TCQ) in most instances, businesses or individual users are still reluctant to apply these OSTs in their business decision-making process. This general idea is already well demonstrated and justified through a sound literature review and the results derived from survey questionnaires and interviews. For instance, the following situation can be described.

Data management is one of the very time-intensive processes in any OST deployment if the project is not geared with the appropriate prerequisites (Structure & Data). In any project, there will be time constraints imposed by the business leaders or stakeholders over any process. During the data acquisition, if the right data cannot be sourced or assumed that causes a huge drawback and allocated time limits will be crossed. Since that delay then propagates forth and the TIME allocated for actual experiments will be decreased or tightened up which will then restrict unlocking the true value potentials. Ultimately OST deployment may end up with unsatisfied decision makers due to the QUALITY of the results and that will generate a negative impression of their investments / COST on the OST. But the actual root cause of this negative impression is the lack of a structured approach to data management not any other problems with the tools / their investment.

Therefore, one of the main objectives of this framework (see Figure 5.5) is to transform that negativity, scariness, or lack of interest into a state of ‘’Confidence’’ which will stimulate them to use this as a guide to learn and unlock the true potential by continuous deployment. Likewise, this framework will help to spread the awareness of the benefits of these tools across the OST interested community (either business or academic) and enhance their domain knowledge continuously.

5.2.5 The Framework – OSTiSCM

Figure 5.5 presents the final version of the framework which now embodies three major changes suggested by the reviewers. Three major changes are (a) Improved presentation of the framework (b) short and clear headings for improved readability and (c) clear and concise instructions for the process.

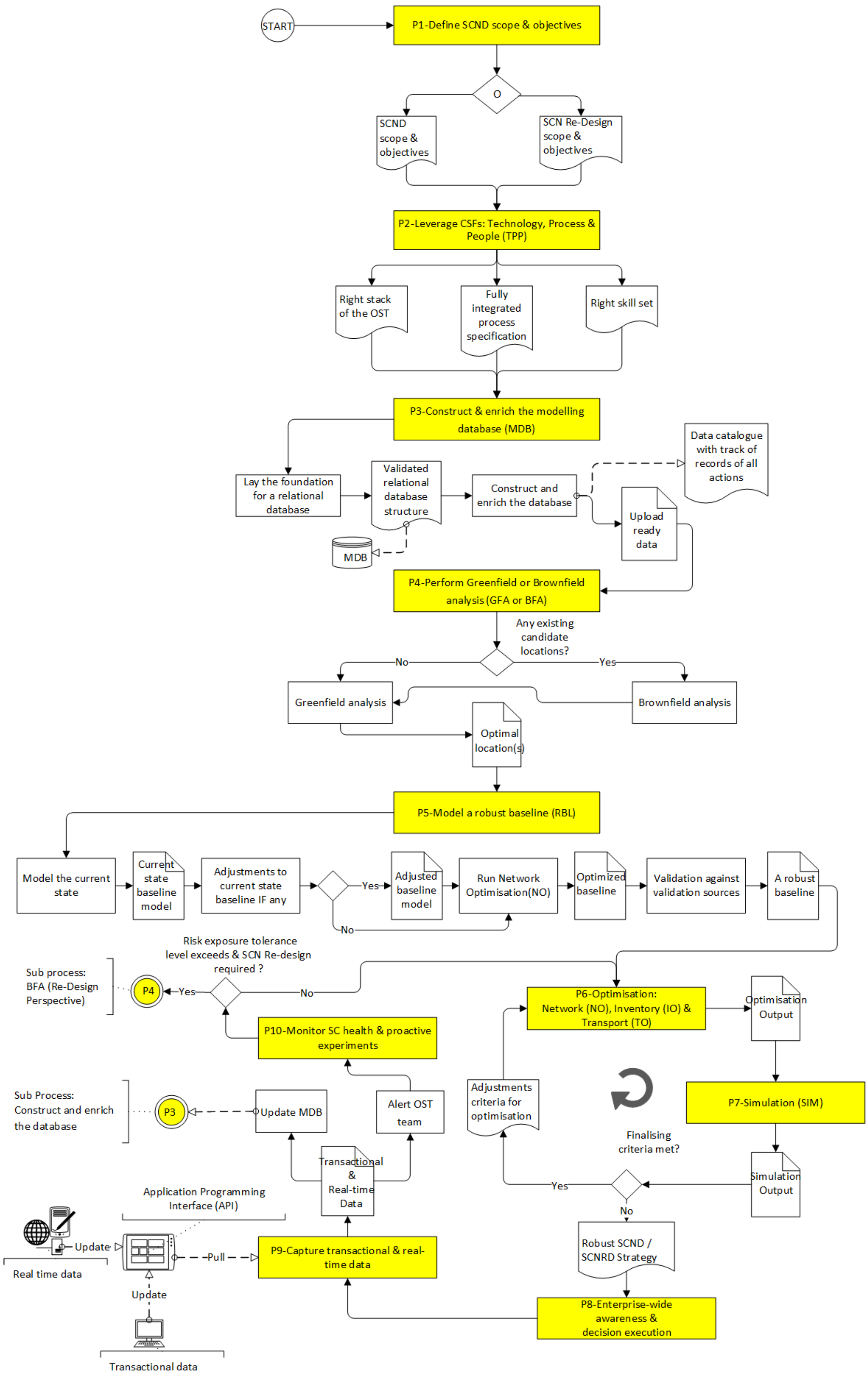


Figure 5. 5: Framework - OSTiSCM

5.3 Description

5.3.1 Define SCND scope & objectives

It's a kind of black swan if there is a simple solution straight away for any complex problem. Therefore, it's always better to disaggregate the complex problem into easy-to-understand, simple-to-solve smaller chunks. In an OST application project, it will be either for a SCND for a new business or SCN Re-Design for an existing business. The benefits of clear SCND scope and objectives are two folded (see Figure 5.6).

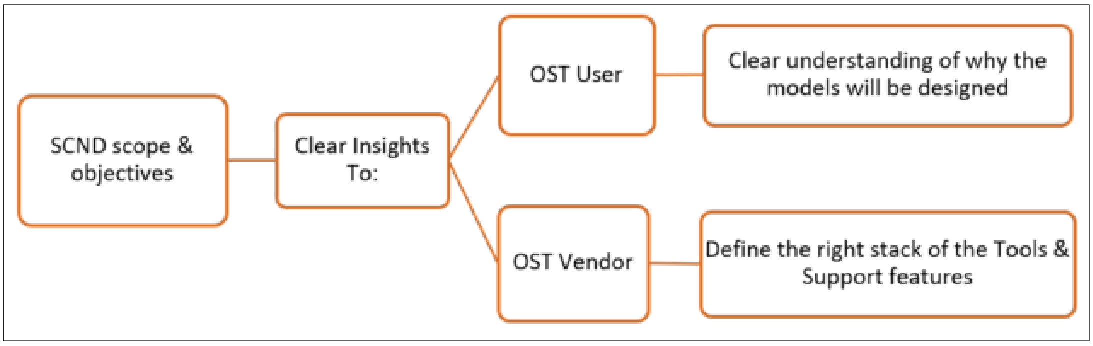


Figure 5. 6: Significance of SCND scope & objectives to the OST user & vendor

OST users must move forth with a clear understanding of why the models will be designed and it's a mandatory check since the results of the models/experiments provide good business intuition in all three levels of planning and decision making (Strategic, Tactical and Operational). Also, that provides a clear requirement specification to the OST Vendor (Software Provider) to bundle the right stack of tools, features and support that suites the business's short-mid-long term application scope. Based on the SCND scope it can be either a new design for a new business or a Re-design for an existing business (see Figure 5.7). Then the two tables are listed (see Table 5.1 & 5.2) to describe the process respectively either in New SCND or SCN Re-design.

5.3.1.1 The Process

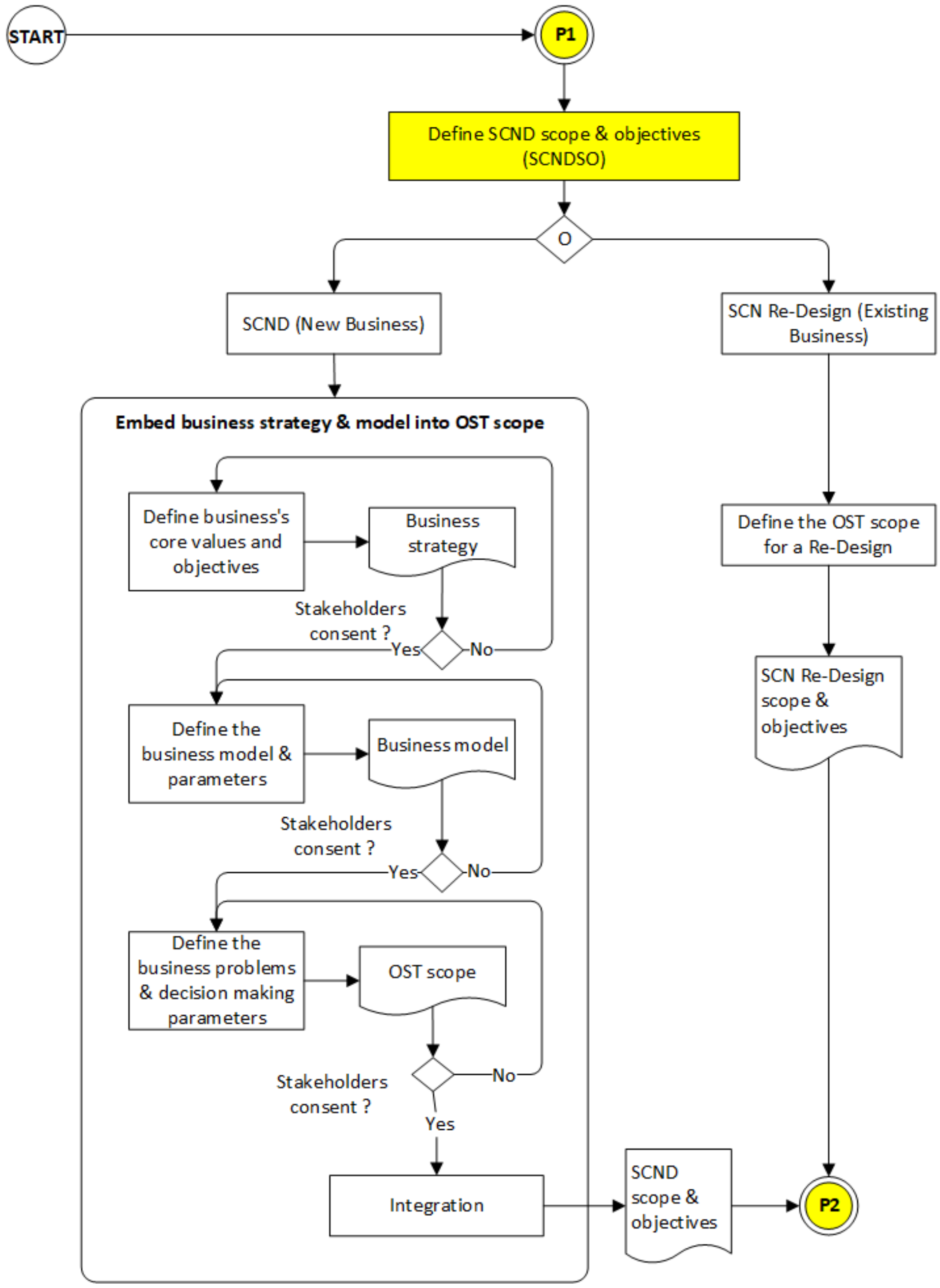


Figure 5. 7: Process - Define SCND scope and objectives

5.3.1.2 The description (SCND)

S.N.	Task	Description & criteria to determine	Deliverable
1	Sub Process: Embed business strategy & model into OST scope	All 3 key deliverables (1) Business strategy (2) Business model and (3) OST scope should be clearly defined and well-integrated.	N/A

2	Define the business's core values and objectives	• To drive any business strategy, the way business is geared with the supply chain strategy always matters.
		• Clear Projections/plans about the business's Financial Goals (Bottom line) and how Supply Chain strategy can help to achieve that must be defined clearly.
		    o Most of the ''line items'' in ''financial documents'' can be impacted by Supply Chain Network Design (SCND) Decisions. i.e., Cost of distribution as a % of the total cost of goods sold.
		    o Therefore, a clear idea about revenue and expense transactions (Projections/historical) is a must before any SCND strategy creation.
			Business strategy

<table>
<tr><td></td><td></td><td><u>Financial documents & line items:</u>

Profit & Loss Statement: Total Revenue, Cost of Goods Sold, Cost of distribution, Profit, etc.

Balance sheet: Assets as in Inventory, Facilities, Transportation, etc.

• Organisation future state alignment (Short-Mid-Long-Term planning)
• What Organisations do well (Competitive advantage: Strength, Opportunities)
• What Competitors do well (Barriers to Entry: Weaknesses, Threats)
• Business’s Unique Selling Proposition (USP): Specific geographical footprint, Single Product or mix, seasonality or throughout the year</td><td></td></tr>
<tr><td>3</td><td>Define the business model & parameters</td><td>• Business operating Geography (Market Segment)
• Supply Chain Network Nodes & Relationship (Including Reverse if Circular)
• Customer Nodes/ Footprint
• Demand Node / Footprint

Product: RM / FG flow through the network</td><td>Business model</td></tr>
</table>

		Unit of flow Mix (FTL, LTL, Pallet, Carton, package, assortment, unit) • Transportation Mode Mix	
4	Define the business problems & decision-making parameters	• A clear understanding of why the models will be designed (Foundation for breaking any complex problem into smaller chunks). As in experiment projects which contain multiple models. • Decision-making scope which spread across in Long-Med-Short Term time spans-Strategic, tactical & operational This provides good insights for the assessment (to both OST Users and Providers) when it comes to deciding the specification of the right stack of OST & features. **<u>Aggregation strategy:</u>** This is a very significant concern which should be defined and agreed upon among the stakeholders/ decision makers in the following aspects. **(1) Model reflection granularity:** • These can be Product(s), Geography, Facilities, Customers, Transportation,	OST scope

		Policies, Constraints, and Fleet. i.e. • Customer: Can be a Country, Port, City, Post-Code, 3PL WHS, etc. • Based on the demand % out of the total larger proportion of the demand nodes can be reflected as individual customers who hold a minor proposition that will be aggregated. • Product: As in individual or group as in weight-wise, pricewise, technology-wise, type-wise. **(2) Model results granularity:** • Always check the requirements from decision makers (i.e., CEO, CFO, CPO) in terms of visualisation of modelling outputs for their decision-making. • Aggregation strategies for entities enhance your ability to analyse trade-offs among decisions. **(3) Model Run-Time:** • Models aggregated to a higher level minimize the Run-Time and error fixing	

		time and in turn that timesaving can be used as an extra cushion for more scenario experiments/comparisons. (i.e., run at the very first instance) • Then review the aggregation later again after the first instance of running. If the model runs faster execute de-aggregation on required parameters based on which more granularity in results is required. • Decision maker's evaluation criteria & data format requirement (Conformity of model culture to satisfy the decision makers) • Define any periodic / seasonality nature associated with the business • Determine parameters such as Circuity factor for road transportation, road traffic concerns and transport asset speed according to the business operating geography. i.e., Simulation results over different geographical terrains: road speeds, circuity factor. This enables	

		us to get a deeper understanding of reality with supply chain dynamics and achieve operational excellence.	
5	Integration	All 3 deliverables should be properly integrated to produce a clear SCND scope & objectives.	SCND scope & objectives

Table 5. 1: Description - Define SCND Scope & objectives

5.3.1.3 SCN Re-design for an existing business

If the business operates at present and required a re-design in terms of finetuning the existing supply chain based on the desired state's scope this is the route for that. This step strongly connects with Brownfield Analysis (BFA) one of the Optimisation Tools used to see the potential facility locations during a re-structuring or expansion of an existing network configuration. BFA will be discussed in detail in Process-4. Before moving into very high-level causes for a Re-Design, getting a broader picture of multifaceted dimensions is worth it. For instance, if a business conducts a PESTLE analysis that may provide valuable business insights in those six dimensions how does any change in the concerned business operating geography affect relatively to the current business settings and in return what are the best causes of action business can take in short-mid-long-term periods. According to research by Business Documents UK Ltd. (2021) that multifaceted causes can be shown below (see Figure 5.8).

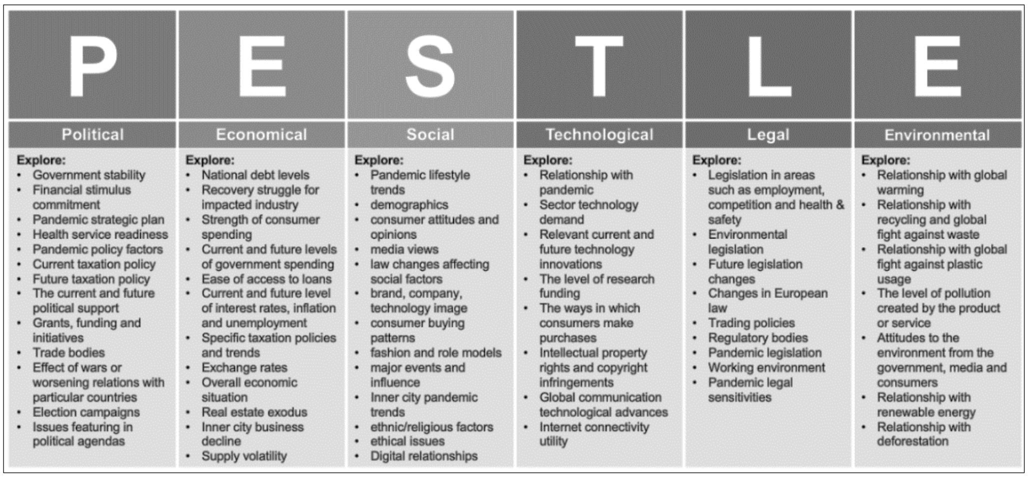


Figure 5. 8: SCN Re-design and connection with PESTLE Analysis

Source: (Business Documents.co.uk, 2021)

5.3.3.4 The description (SCNRD)

S.N.	Task	Description & criteria to determine	Deliverable
1	Define the OST scope for a Re-Design	<u>Facility Footprint:</u> Adding / Removing, Merging & Acquisition will change the SC's node's footprint (Sourcing, Production, Cross Dock, VAS, DC, WHS) or may be due to the following concerns. • Political or Legal (Boarder control. i.e., Brexit) • Economical (Country's debt level) • Environmental (CO_2 Emission by facilities / Production / Transportation fleet. i.e., ULEZ zones in London) • Changes to sourcing strategies (On-shore, offshore, far-shore. i.e., moving into low labour, production cost countries), closure or opening of new facilities • Demand Footprint	SCN Re-Design OST scope & objectives

		Adding / removing / merging new markets / business / facilities. - Identifying new markets or dropping non-profit markets – Changes of the Nodes of Demand Footprint - Some geographies you were not serving before but planning to serve in future will change the Distribution Footprint - Mergers and acquisitions are known as M&As to obtain a competitive advantage in the market by sharing resources and cost reduction for better service level improvements. • Distribution Footprint: - Mode of Transportation - Changing from fuel-powered to batter powered (electric) due to Environmental concerns and taxes or new rules imposed by the government. • Other Experiments (Policies, Logic, Period, Costing, Processes, Assets) - Seasonality, Product mix, Asset mix /MHEs inside 4 walls, operating hours, Capacity planning, etc.	

Table 5. 2: Description - SCN Re-design for an existing business

A hypothetical business case for starting a new business:

Before moving into the rest of the processes, let's go through a hypothetical business case which illustrates how strong the connection between steps, and deliverables of Phase-1 is and then the same as inputs into Phase-3: Construct the modelling database.

A company called RG Global established in the UK, came up with a new business Idea and their very high-level business model can be described as follows.

- Import Fans from Netherland to England and Distribution over an island-wide Retailer's network to cater for the seasonal demand during the British Summer which is forecasted for 2022.
- Import shipments will be 40' Full Truck Load (FTL /FCL), 400 units per container for £15 /Unit.
- Port of Origin will be Rotterdam seaport, Netherlands (NLRTM) where the Manufacturing Plant can be located in proximity and Port of Destination is Felixtowe seaport, England (GBFXT) where the Main Distribution Centre can be located in proximity.
- 2 sailing services are calling weekly basis NLRTM to GBFXT with an average Transit Time of 7 days
- Distribution will be done by Delivery Vans to the Island-wide Retailers located in Main Cities for £ 30/unit.

Following is a sample output which can be derived after following the Process-1. Let's imagine the Optimisation and Simulation Project Team of RG Global has thoroughly followed Process 1 and resulted in something like the following (see Figure 5.9).

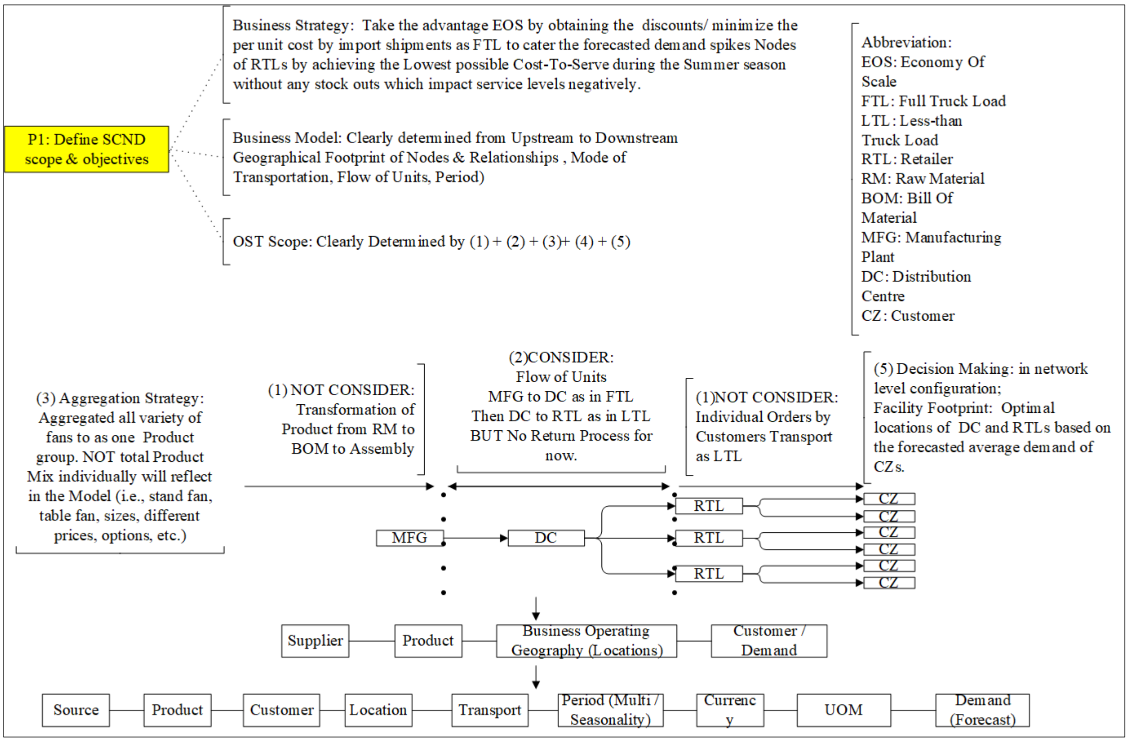


Figure 5. 9: Business model statement into SC's nodes & relationships

Once the (1) Business strategy, (2) Business model and (3) OST Scope are fully integrated and the OST user is crystal clear with why models will be designed (Aggregation strategies and Scale of Reflection in models are considered) and which business decisions must take (Note: For this example, only Strategic Level period is considered). The output will be a string of entries which reflects the SC network configuration which must consider during the OST application (set boundaries of OST application) and then in return provides a clear scope in the data required for future experiments.

5.3.2 Leverage CSFs: Technology, Process & People (TPP)

Once the Business Strategy is fully integrated with the ''New Business Model (For a New SC Design)'' OR ''Existing Business Model (For a SC Re-Design) into the OST scope and objectives, the platform where all future experiments will be tested is the Technology (OST). Such Technology should be fully integrated across all OST application-related Processes and the People who do all the experiments at the front-end (OST user: i.e., Skillset) and support from the backend (Stakeholders: i.e., Top management). In such to reap the true potential out of the Technology deployed and the Processes integrated the right People’s skillset and cross-functional support are mandatory. The detailed process can be shown as follows (see Figure 5.10).

5.3.2.1 The process (TPP)

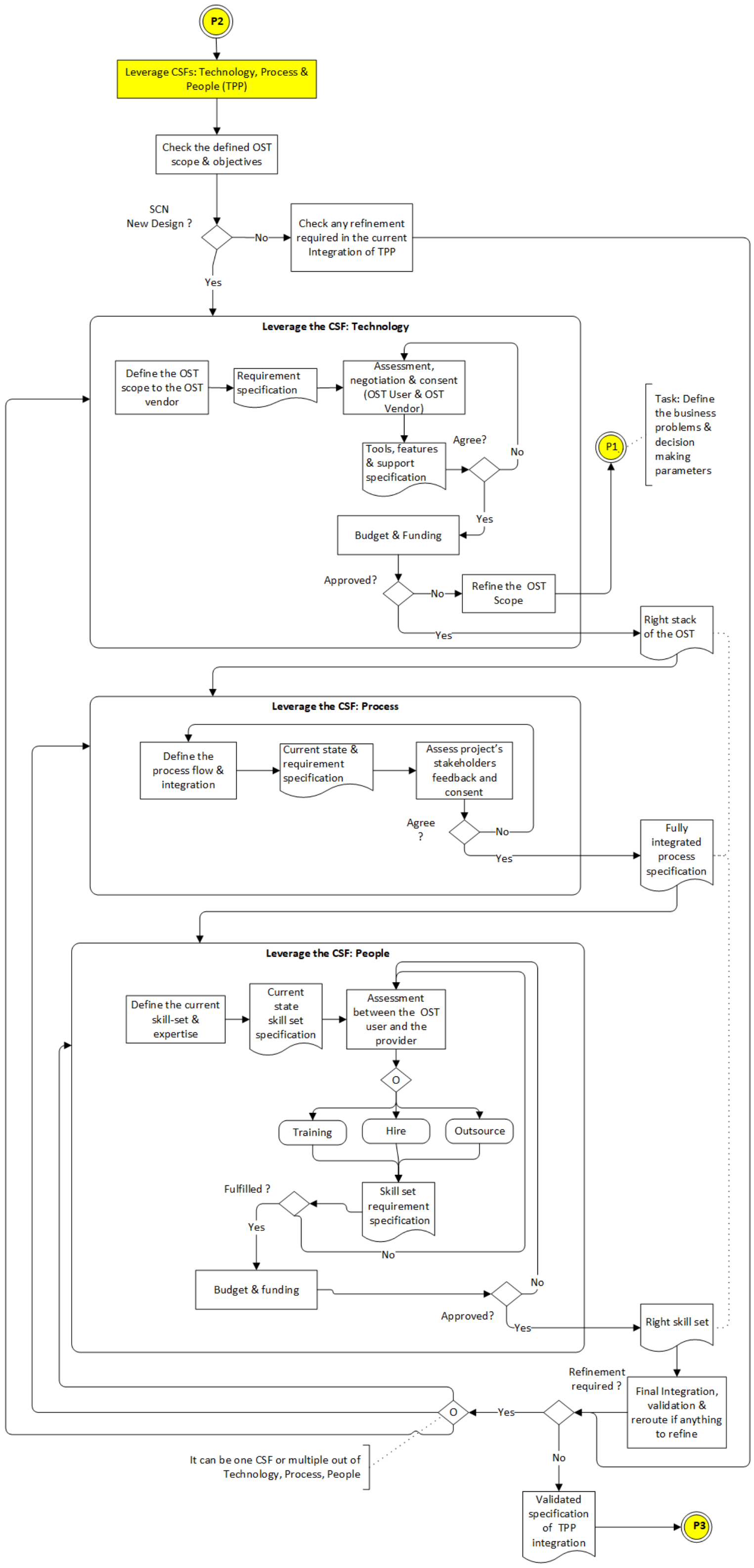


Figure 5. 10: Process - Leverage CSFs: Technology, Process & People

5.3.2.2 Leverage the CSF: Technology

It is very vital to gear up with the right stack of OST which will fuel to achieve the pre-defined OST scope and objectives. This will remove the majority of the drawbacks associated with the time for implementation, unwanted technology complexity bring-in, unnecessary investment & cost implications and unnecessary additional features which just stay in isolation with no value addition but may be affecting the model's runtime and space/storage constraints. Therefore, it's always better to inject the advice of OST vendors in bundling the right stack of tools since they are the best-in-class knowing what they offer. The table listed below (see Table 5.3) showcases the tasks, criteria to determine and deliverables that must obtain through this process.

5.3.2.3 The description (Technology)

S.N.	Task	Description & criteria to determine	Deliverable
1	Check the defined OST scope & objectives	If the scope is for new design all 3 Technology, Process and People (TPP) should be clearly define step by step and then integrated.	N/A
2	Check any refinement required in the current Integration of TPP	• If the scope is for a Re-design TPP already in place but it's important to check and validate if there any refinement requirement required. • Because redesign happens after a certain period when there might be some developed inefficiencies among TPP	IF validated: Validated specification of TPP Integration ELSE reroute.
3	Define the OST scope to the OST Vendor	With the OST Vendor: • Modelling limitations, Licencing duration,	Requirement Specification

		• Model Running Platforms (Local or Cloud), • Inclusive & Additional Cost for Subscriptions • Supporting Platforms i.e. Geo References / Location & Map Data, Distance/ Route Calculations, operating in cloud platform by multiple global users work on the same projects / models. • Supporting Data: Shipping, Parcel Delivery, Traffic, Weather, Terrain, Currency Exchange Rates, etc. • Connectivity capabilities / Limitations (Import & Export Data: From/ To & Format i.e., ERP, Data Analytics, BI Tools) • Avoid the barriers prevent Systems and Tools Integration & smooth Transition from Legacy systems (If Any)	
4	Assessment, Negotiation & Consent (OST User & OST Vendor)	Tools, Features and Support Specification by should be clearly understood by the OST user. • Any advanced capabilities required: (Connect with existing databases, systems, devices file or data formats, maximum number data rows in excel tec.) • This criterion is strongly connecting with once business	Tools, features & support specification

		starts operations and the way connect to the planned / existing data sources (any ERP system, remote devices, transport tracking systems, etc.) • Any additional features required: (maps, traffic data, shipment rates as supportive database connections to the more granular experiments) • Product support: The limitations / flexibility over any bugs fixing or any technology related assistance during the project., free product trainings, etc.	
5	Budget & funding	• From the finance end it can be approved or not approved • There may be no approval by finance department: constraints / exceeding the budget amount against OST.	IF approved: Right stack of the OST
6	Refine the OST Scope	• In such case refinement can be done in terms of reducing the scope of the OST considering the short-mid-long-term requirements. (Which will match the finance approved amount) • Then later additional features or support can be upgraded at an extra cost later.	Reroute to: Process 1-Define the Business Problems & decision-making parameters

Table 5. 3: Description - Leverage the CSF: Technology

5.3.2.4 Leverage the CSF: Process

Lack of process definition, awareness among stakeholders, resistance in the flow, cross-functional support and integration are the most highlighted drawbacks during the application of OST (As per the evidence provided in Chap.2-LR & Chap.4-Survey Questionnaire and Interviews results). Therefore, these should be well defined, integrated, followed, monitored, and rectified if any issues from the first instance of an application, and thereafter any experiment/business case consider. This provides a fully integrated, transparent, traceable, process-driven project management culture into OST application for a sustainable journey with a sound ROI in long run. The table listed below (see Table 5.4) showcases the tasks, criteria to determine and deliverables that must obtain through this process.

5.3.2.5 The description (Process)

S.N.	Task	Description & criteria to determine	Deliverable

1	Define the Process Flow & integration	• Bring in a clear scope, path, and cross functional support culture in project management perspectives: Define, Follow, Monitor, Finetune, Rectify, Terminate.
		• Tools/mechanism recommend: Work Breakdown Structure (WBS), Critical Path Analysis (CPA).
		  o Project Documentation
		  o Project Resources (Roles & Responsibilities)
		  o Milestones
		  o Project Schedule & Monitoring (i.e., Duration for Process: Data Acquisition & Manipulation,
			Current State & Requirement Specification

		Model Building & Results Visualisation, etc.) o Deliverables o Process flow (i.e., Determine the Data Management: Scoping, acquisition /sharing and Validation then Model Building, Results Visualization, decision making, etc.) o Access to Systems o Cross functional Support & Integration o Reporting /approval structure • Validation & refinement: o NOTE: Validation Sources and process must be clearly defined to prevent unnecessary delays in future phases. This is also very significant as well as the data requirement scope to build the models. o Sources / Systems / Reports must be identified and gathered in advance. o Validation must be done against the Current Business Model behaviour & Validation Sources o i.e., Validation Sources: Business Model & Processes Specification, Financial reports made based on Historical metrics / assumptions, etc.	

		• Decision execution and Enterprise-wide awareness.	
2	Assess Project's Stakeholders Feedback and Consent	• Remove the consequences cause by back & forth negotiation and obtain final consent. • Democratise the ideas and feedback of all the stakeholders • Embed a sustainable cross functional integration and support culture in long run	IF agreed: Fully Integrated Process Specification ELSE reroute.

Table 5. 4: Description - Leverage the CSF: Process

5.3.2.6 Leverage the CSF: People

Once the right stack of OST and properly integrated application process flow is in place the right skill set is the driver to take the next step forward by executing the defined OST scope successfully. Skill set in a broader picture defines the appropriate competency level required to perform a particular job or a series. As per the current drawbacks and the gap identified by the author; lack of awareness, competency, confidence, trust about the job specification and what are the deliverables to the project/team as a member is a burning point. OST provider is the best source of advice when it comes to defining the right skill set as they know the in & out of the tools. Therefore, identifying the current state of the skill set within your business setting, obtaining the necessary advice from the OST provider, filling the gap, and getting geared are very significant milestones. Then it's guaranteed that will leverage in unlocking a massive potion of true potential of these OSTs which are hidden due to these unnecessary barriers. The table listed below (see Table 5.5) showcases the tasks, criteria to determine and deliverables that must obtain through this process.

5.3.2.7 The description (People)

S.N.	Task	Description & criteria to determine	Deliverable
1	Define the Current Skillset and expertise	Competency level of the user: • Muddler must be a logical thinker who inject physical reality into the digital models. Also, must think out of the box and add some extra cushion in reflecting the business insights through decent model out puts to the decision makers. • Subject Matter Expertise (i.e., Data acquisition, cleansing, validation) • Previous Project Experience (i.e., the experience of similar business sector / vertical provides capabilities in rapid business case scenarios experiments and comparisons)	Current State Skill set Specification
2	Assessment between the OST User and the Provider	Any gaps of existing resources must be identified, and valuable suggestions can be obtained from OST provider (They are the best who knows the specific skillset required to operate the pre-configured / tailored tools & features) • Required level of Expertise: Benchmarking and trade-off analysis (Time, Cost, Quality)	Skill set Requirement specification

		• Based the on individual business setting, defined OST scope, defined systems & Process Structure, stack of the OST & features; OST provider can provide better insights for your decision in following options.
		  ○ Training for existing staff
		  ○ Hire additional staff
		  ○ Outsource (i.e., Support from Consultancy / Subject Matter Experts)	

3	Budget & funding:	• Its matter of expertise / skilled level and the budgetary constraints with finance department in terms of salaries. • The matter of skill level in terms of quick experiments and results for decision making. • By considering the Short-Mid-Long-term Cost-Benefit / Trade-off analysis at some point hire the hiring the best /skilled even at higher salaries enable the entire team of OST very efficient and effective. Also enabling domain knowledge transferring into the business in the longer run.	Right skill set
4	Final Integration, Validation & Reroute if anything to refine	• If identified any gaps in integration of all three CSFs TPP, reroute to the particular or multiple CSF leverage step(s)	Validated specification of TPP Integration

		• Refinement if any gaps in Integration • It can be one CSF or multiple out of Technology, Process and People.	

Table 5. 5: Description - Leverage the CSF: People

5.3.3 Construct the modelling database (MDB)

Once the Technology, Process and People are well integrated, then ‘’Data Management” is the most significant Process in any SC Design /Re-Design Project. Since the traditional approach, is very time and cost-intensive, the proposed Framework guide you through a well-structured approach to construct your database even the current business state and data availability is ‘’start from the scratch’’. According to Murphy & Perera (2001), data management is a requirement for the successful integration of all designing, planning, and decision-making issues. For continuous development towards the optimal solution in product and process refinement, all functions need to be able to respond directly to any changes necessary, leading to higher quality and productivity.

Concerning the constructed Cause-and-Effect Diagram in chapter 4 (see Figure 4.12) due to the unavailability or lack of data, not geared with a comprehensive self-constructed database, failing to identify the appropriate data sources or access is restricted; most of the projects are failing to succeed to the defined Optimisation & Simulations objectives. Thus, as the very first instance; paving a solid foundation to construct your Database is a key step which removes the majority of consequences encountered by OST users.

Before moving to the detailed steps as shown below (see Figure 5.11) followings are a few high-level burning points which triggered the author to determine the area to accomplish this process.

- Determine the Data Requirement scope according to the well-defined OST Scope & Objectives

- Lay a solid foundation for your Modelling Database (Database as a strategic asset with a strong long-term vision and not as a resource for specific problems in isolation as you move on)
- Identify and demarcate the Mandatory and Optional Data sets in Particular application domains and familiar with the trend/frequency of usage.
- Data blending (source, analyze, verify, cleanse, and validate) and making upload-ready data
- Enrich the Database over time with real-time data capturing and business case-wise experiments.

5.3.3.1 The process

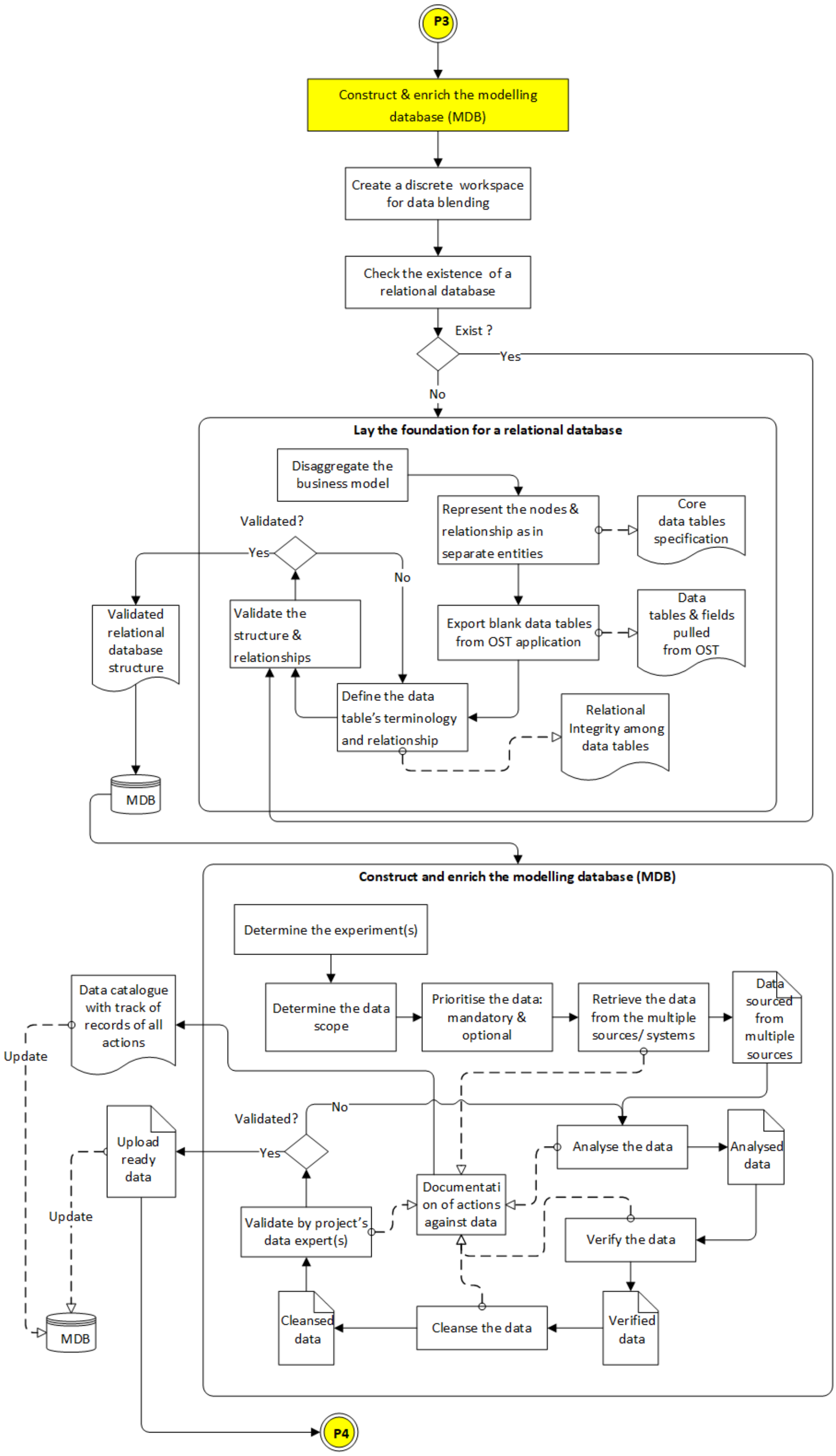


Figure 5. 11: Process – Construct the modelling database

5.3.3.2 Create a discrete workspace for data blending (DWDB)

Either way, whether it's a fresh start in the application of OST with no historical data at all or a redesign which is geared with some decent amount of data in hand; the amount of Data which must manage increases over time. Due to the scope and complexity in terms of multiple data sources, file formats, ownership, and the involvement of OST users with the sources the action must be taken against data may vary from business case to case. As such any actions must take against data during the steps; source, analysis, manipulation, validate must be underpinned with an assurance of no harm to the originality of the data. Therefore, keeping a separate workspace (see Figure 5.12) for Data Blending is a very significant precautionary method and all actions taken against data should be properly documented in detail, in case of tracing back to the original status of the data for any clarification in future such as following.

i.e.

- Due to any gaps/errors that come up during the final validation step of data before populating into OST
- Maybe after one year time due to a redesign process, during the validation/consent by stakeholders may need clarification on which base/grounds that specific data were assumed one year ago.

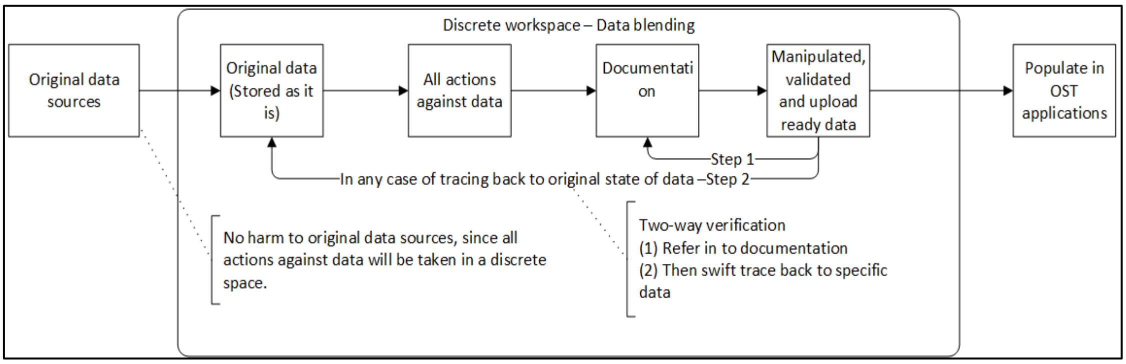


Figure 5. 12: Significance of a discrete workspace in data blending activities

After this step, there is a check gate to see any existence of a relational database with the project. For instance, if it's a re-design project OS team might have done the groundwork at the initial stages and is now fully geared with a solid foundation of a relational database.

In that case, after validation of relational integrity, it will route to the subprocess ‘’Construct and enrich the database’’

Before moving into detailed steps having a high-level picture about what are the possible data required to visualize any supply chain and do the experiments in an OST application is very important. As per the research outcomes, it’s identified that most data will fall under the following 8-key ‘’Categories’’ with corresponding ‘’Data Tables’’ (see Figure 5.13) which can be used to visualize any SC’s structure (physical elements) and their logical behaviour (relationships). Therefore, this can be proposed as a ‘’Base Template to construct the Modelling Database (MDB) for OST’’ and perform the relational integrity check which will be discussed next in detail. Then more granular you can capture the data in terms of ‘’Fields’’ under those ‘’Tables’’ (see Figure 5.14) that will fuel the OST user’s ability to bring more complexity into the experiments to fine-tune the SCN parameters to achieve operational excellence. Then the next figure after that (see Figure 5.15) shows how to disaggregate a business model to identify the entities in the network which will act like data tables when it comes to populating data. After that, the relational integrity between these data tables is a must to ensure the relationship and the uniqueness of any data field (no duplicates i.e., shipment ID) which is in a Data Table (see Figure 5.16).

	Data Category			
	1	2	3	4
	Structure (Physical elements)	**Transactions**	**Policies**	**General Measures**
Data Table	Product	Customer_Demand	Production_Policies	UOM
	Site_Facility	Site_Demand	Site Sourcing Policies	Currencies
	Site_Customer	Customer_Orders	Customer Sourcing Policies	Model Horizon
	Transport_Mode	Site_Orders	Transportation Policies	Operating Hours
	Transport_Asset	Demand Seasonality Factors	Inventory Policies	
	Work_Resource	Shipments	Return Policies	
	Work_Center	Production		
	Organization	Customer_Forecasts		
		Site_Forecasts		
		Retruns		

	Data Category			
	5	6	7	8
	Periods	**Additional Costings**	**Constraints**	**Processes**
Data Table	Period	Step Cost	Flow Constraints	Bills Of Material
	Products Multi-Period	Shipping Rates	Production Constraints	Sourcing Process
	Sites Multi-Period	Transport Asset Rate	Inventory Constraints	Production Process
	Site Sourcing Policies Multi-Period	Material Handling Equipment Ra	Site Constraints	Transportation Processes
	Production Policies Multi-Period	Human Resource Rate	Work Center Constraints	Inventory Processes
	Customer Sourcing Policies Multi-Peri	Parcel Rate	Production Process Constraints	Return Processes
	Inventory Policies Multi-Period	LTL Rate	Inventory Process Constraints	
	Transportation Policies Multi-Period	Taxes And Duties	Sourcing Process Constraints	
	Transportation Assets Multi-Period		Transportation Process Constraints	
	Work Centers Multi-Period		Return Process Constraints	
	Work Resources Multi-Period			

Figure 5. 13: Base template of constructing MDB for OST in SCND & Experiments

Structure (Physical Elements)	(Data Category)
Product	
Site_Facility	
Site_Customer	
Transport_Asset	
Work_Resource	
Work_Center	
Organization	
Transport_Mode	

(Data Table)

Transport_Asset					
Name	No Of Units	Fill Level (Weight)	Hourly Cost	Post Delivery Asset Return Location	CO2
Fixed Asset Cost	Type	Fill Level (Quantity)	Applicable Rate Type	Max Asset Search Distance To Site	CO2 Basis
Speed	Asset Weight	Fill Level (Volume)	Max Drive Time Before Break	Max Waiting Time At Location	Battery ID Electronic Vehicle
Transport Mode	Asset Volume		Fixed Break Time	Fixed Service Time	Shipping Route
Capacity (Quantity)			Max Distance Per Route	Fixed Load Time	Unit Selection Rule
Capacity (Weight)			Minimum Distance Per Route	Fixed Unload Time	Shift Pattern
Capacity (Volume)			Max Time Per Route	Variable Load Time	Asset Base Location
Organization Belong To			Max In-Transit Stops Per Route	Variable Unload Time	Asset While Idle Location
			Max Loading Stops	Variable Service Time Basis	
			Max Unloading Stops	Mx Distance from Last Drop To Home	

(Data Fields)

Data Fields are getting more granuar

Figure 5. 14: The way granularity of data fields increases over the experiments' complexity

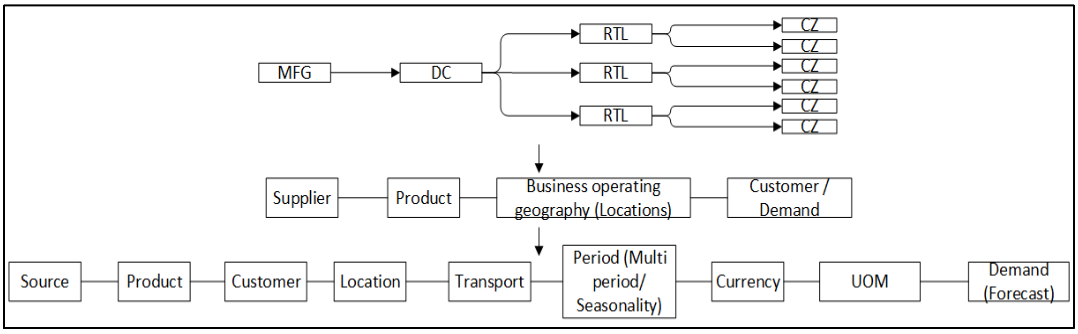


Figure 5. 15: Business model disaggregation into data tables in OST

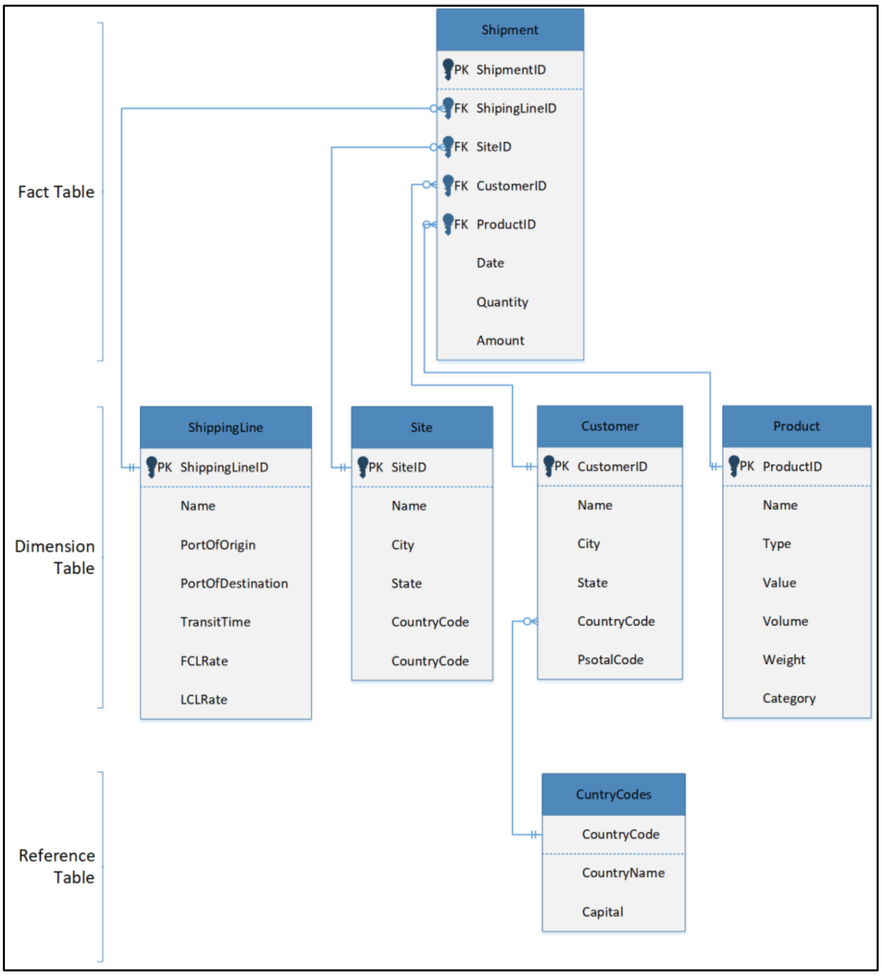


Figure 5. 16: Relational integrity among data tables in OST

(Above is an example of how shipment transactions (Fact table) assure their relational integrity among corresponding data tables (Dimension table) including any referential data (Reference tables). This is generally validated by the OST Data based on the Data Fields populate into the model as a collection of Entities and logical relationships.

5.3.3.3 Lay the foundation for a relational database (FRDB)

This sub-process contains a series of tasks (see Table 5.6) which guide you to lay a solid foundation to construct your relational database. Once the foundation is laid and validated; all future data management activities can be performed on it with full confidence. In turn, this will enable to construction of a sound database and enrich it over time with all transactional and live data captured from the systems and devices (i.e., ERP, IOT) which led to successful experiments in future.

‘’You can’t build a great building on a weak foundation – Quote by Gordon B. Hinckley’’

5.3.3.4 The description (FRDB)

S.N.	Task	Description / criteria to determine	Deliverable
1	Disaggregate the business model	• Disaggregate the business model's structure (physical elements) and their logical behavior (relationship) into data categories (see Table 5.15).	N/A
2	Represent the nodes & relationship as in separate entities	• Then under those categories identify the corresponding data tables (see Figure 5.13) and their relationship according to your business model.	Core data tables specification
3	Export empty data tables from OST application	• The objective here is reasonably map the potential data tables & fields according to the OST • Fastest and Easiest way to populate the data in a Single Workbook as in multiple work sheets (MS Excel: majority of OSTs enabled with this MS Excel file import & export capability).	Data tables & fields Pulled from OST (i.e., MS Excel file)
4	Define the data table's terminology and relationship	This step ensures the relational integrity between Data Tables. Primary key to Foreign Key assignment ensures there is no data violating the structure of the Database and this will be done between Fact & Dimension Tables (see Figure 5.16).	Relational Integrity among data Tables

		• Fact Tables: Main Transaction Table corresponding to specific business Process (i.e., Shipments, Orders, Sales, Productions, Returns)
		• Dimension Tables: Primary/ Master Tables and describes people or object integrated with the Fact Tables (i.e., Customer, Site, Product, Transport Asset, etc.)
		    • Site Master, Customer Master, Product Master, Transport Asset Master, etc.
		    • Reference Tables: Static Tables (i.e., Currency, UOM, Country /Ports / Postal Codes, etc.)
		    • Refer to the (see Figure 5.16) Identify Data Tables Terminology and Relationship
		    • Any Relational Database Notation can be used (i.e., Crow's Foot DB Notation – MS Visio, Entity Relationship Diagram (ERD),	

5	Validate the Structure & Relationships	Very significant Check Gate since this will be the foundation for all data management activities take place in future. • Data Populated Tables should be validated against the	Validated Relational Database Structure: Modelling

		Business operation behaviour & Validation Sources. • i.e., Business Model & Processes Specification, Financial & operational reports made based on historical metrics / assumptions, etc.) • Financial measures: Profit & Lost Statement, Balance Sheet, (i.e., Revenue, Cost of Goods Sold, Cost of Warehousing & Distribution, etc. • Operational measures: Inbound shipments, Outbound Shipments, Inventory snapshots., etc.	Database (MDB).

Table 5. 6: Description - Lay the foundation for a relational database

5.3.3.5 Construct and enrich the modelling database (MDB)

This is a very repetitive sub-process that contains a series of tasks (see Table 5.7) which strengthen the Modelling capabilities by enriching the amount of data available in hand over time. Once the business starts operating transactional & real-time data can be captured over time that will enrich this structured database progressively. As the business moves on and is well geared with new systems and technology (i.e., IOT) that will enable the business proactively to monitor the supply chain health alerts. Then in return, this data can be imposed into experiments and obtain good insights which help to set the necessary precautionary actions to bring resilience into business. Ultimately these benefits lead to making all stakeholders feel successful about the investment decisions that they have taken against these OSTs.

5.3.3.6 The description (MDB)

S.N.	Task	Description / criteria to determine	Deliverable

1	Determine the experiment	The business problems need to address, and the decisions need to take determine this.
		
		• Spread across in all three Planning levels
		    o Strategic- i.e., Greenfield / Brownfield Analysis
		    o Tactical-i.e., Transport fleet Planning
		    o Operational-i.e., Warehouse order picking process simulation
		• As the Problem move from static to dynamic (very aggregated to detailed level) the application of OST transform from optimisation to simulation.
		i.e., The discrete events in the supply chain and their logical association with the time, variability, and randomness.
			N/A

2	Determine the data scope	• It's matter of trade-offs between ''Aggregation Strategy'' and ''Level of granularity reflects in the model results for depth analysis and decision making''. In Such that spread across in following multifaceted dimensions such as (1) Product (2) Customer (3)	N/A

		Geography (4) Time (5) Policies (5) Constraints (6) Processes, etc. <u>Product:</u> Raw materials or finished goods in consideration? o Any Product Transformation in consideration (Raw material to Bill of Material to Finished Goods) <u>Customer:</u> o In which level as in Country /Port /City /exact post-Code, etc.? o Higher proportions of demand (Customer nodes) can be reflected as individual and customers who hold minor proposition will be aggregated. <u>Geography:</u> o How many suppliers / manufacturers /Dc's in scope? o Any specific region in scope (at present or future) <u>Time Period:</u> Granularity of Decision making: Weekly, Monthly, quarterly, annually? i.e., Any seasonality nature needs to be considered in the models?	

		• Model Reflection / Results Granularity required: ○ As per the requirement of decision makers (i.e., CEO, CFO, CPO) the visualisation of modelling outputs for decision making. Aggregation strategies enhance the ability to analyse trade-offs among decisions.	
3	Prioritise the data: mandatory & optional	Based on how granular you need the reflection in the models and results. When demarcate the mandatory and optional data requirement its very significant to consider what's the scope of the problem, the tool use, and the ability within that specific tool in terms of results generation. (i.e., how you set requirements of detailed output table results in which parameters prior to run any experiment. • i.e., Scenario wise detailed site to customer demand transactions as output table after running the experiment with Simulation tool, 5 repetitions / iterations under different frequencies imposed with probability distribution (to see how variability in demand impact over safety stock levels).	N/A

		• i.e., Run scenarios with different inventory policies in multi period (due to seasonality of demand) to analyse the sensitivity in terms which policy is the ideal in which period. • If the models built with mandatory data that is just fulfilling the minimum requirement of relational integrity among data in OST applications which is mandatory and checked by the application to solve / run the experiment without any error. • With more granular / optional data in hand you have the power to impose more logical constraints, randomness, and variability in to experiments for depth operational results and comparisons. Note: Under the data requirement of upcoming main process, below Tools and data required to run a decent experiment by them are provided. • Greenfield Analysis (GFA) or Brownfield Analysis (BFA) • Robust Baseline Modelling (RBM) • Network Optimisation (NO) • Inventory Optimisation (IO) • Transport Optimisation (TO) and • Simulation (SIM) (RBM is not a Tool it’s a key milestone/stage gate in SCND process)	

		NB: This is to provide an idea how the data getting more granular and different in terms of specific ‘’Data Fields’’ under that specific ‘’Data Table’’. Then that can be used as a base to shape your own data into OST. Some of Data field names may vary as per the business nature	
4	Retrieve the data from the multiple sources/ systems	• Understand and identify the best sources / systems for acquisition of required data (see Figure 5.17) • Retrieve and centralize the sourced data into the discrete workspace created.	Data sourced from multiple sources
5	Analyse the data	Data may retrieve from multiple sources / systems and may be with inconsistencies among this master data. Appropriate analyzing approach will fuel removing such inconsistencies (Removing the Noise of Data) • Completeness within the sources (Vertical Check) o Negative values, Duplicate Data, missing data, mismatch in data, Missing values, Misspellings, (i.e., One line item in Product Table field ‘’value’’ is blank) • Referential integrity among the sources (Horizontal Check):	Analysed Data

		- i.e., Are the ''Site names'' same across all the data? for an instance Sites Master data must match among the sources ''Shipments'' and ''Sales'' - Identify patterns and causes of incomplete or inconsistent data	
6	Verify the data	Find the reason for the issues identified in the Analyse step. - May be due to the data scoping issues that specific data / field not retrieved and its missing. - Inconsistency among sources. (i.e.in one source, Product name suffix are there and in other sources suffix are missing.) - The quarry logic issues: Shipments reflect the interfacility shipments as outbound shipments but not the actual outbound - Site to Customer. - The magnitude of the impact of the issue to the overall model scope should be considered: - Is it worth it taking the effort or is it possible to leave it by taking no further action?	Verified Data
7	Cleanse the data	Address data issues through remove, refill, and replace of Data. Then Formulate assumptions where data gaps cannot be easily resolved.	Cleansed Data

		<u>Remove:</u> • Very easy step but must ensure no vital data is removed • Understand why remove • Confirm that data out of the scope and does not add any value to solve the problem • Make a duplicate of this data just in case it becomes useful in later <u>Refill:</u> • When the current state of the date sourced is incomplete while sourcing again to fill the gaps <u>Replace:</u> • Fill the certain fields of the table accordance with the field in another rows • Correct the misspellings. i.e., prefix & suffix of data fields • Fil the blank fields of the data tables • But be careful not to duplicate anything in the same table. <u>Assumptions:</u> This is the general solution to rectify the issues relating to the missing data which may sometime be mandatory to full fill the scope. This must be executed due to following reasons • Data not existing	

<table>
<tr><td></td><td></td><td>
Sourcing data may cost or time intensive
Data sources are restricted or reluctant to share by the parties involved
i.e.,
May be its easy to assume (Product data of similar product in a market) and not required the exact data.
Assume Demand data of a same product / geography / seasonality (Period)
Assume transport speed based on a survey
</td><td></td></tr>
<tr><td>8</td><td>Validate by Project’s Data Expert</td><td>Once cleansing is done with the data should be validated with project’s experts in Data (Who’s skillset concerned in the Process 2: under CSF: People). very important stage gate before moving in to populate data into the any experiment. Optimisation (GFA/BFA/ Baseline) or
Summarize data sources for project stakeholder
Visualise data to stakeholders
Gain stakeholder viewpoints / feedback on accuracy of sources data / assumptions in terms of following,
Scope – Is the data within the Scope?
Values / Sums, correct?
</td><td>Upload ready

Data</td></tr>
</table>

		(i.e., Flow quantity, Transportation cost, Production quantity, inventory value) • Assumption have been made correctly.	
9	Documentation of actions against Data	All actions taken against data in S.N. 4 – 8 Tasks should be well documented. • Data Requirements – What data Mandatory / Optional under which Data Category, Table and Fields. • Track and Trace: the source, status, and traceability of all data collect. • Assumption made: Record of Assumptions carried out with base, dates, user, etc. • Data Relationships: visualise the relationship among Data categories, tables, fields. i.e., Entity Relationship Diagram (ERD) • Validation comments: Remarks by experts and stakeholders.	Data catalogue with track of records of all actions

Table 5. 7: Description - Construct and enrich the database

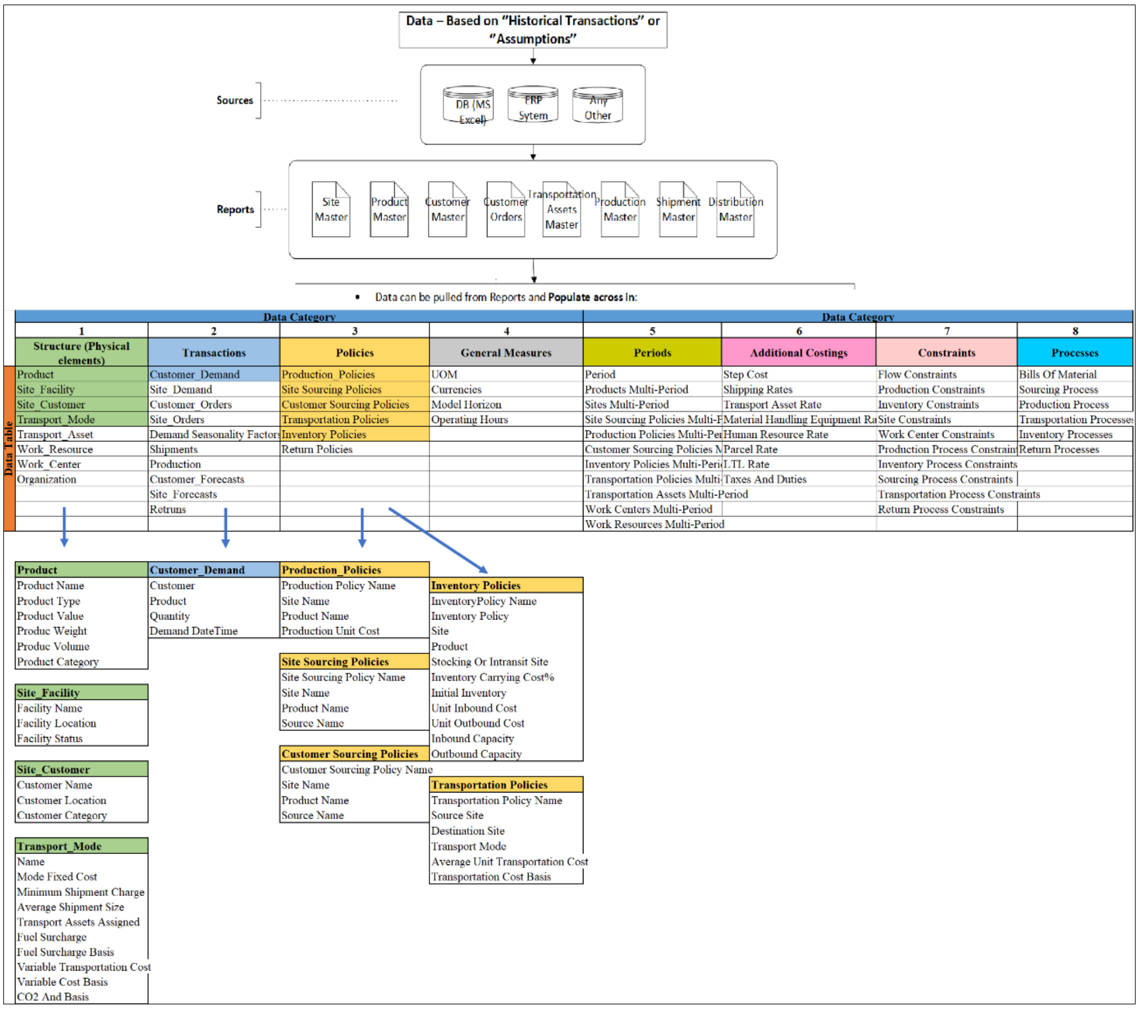


Figure 5. 17: Retrieve the data from the multiple sources/systems

5.3.4 Perform Greenfield / Brownfield Analysis (GFA / BFA)

Identifying the candidate locations for a supply chain network is a strategic decision generally known as Facility Location Problem (FLP). There are two routes based on the business's current state of decision making as in Greenfield Analysis (GFA) or Brownfield Analysis (BFA). GFA is for the experiment from scratch when there are no candidate locations known and BFA is when any candidate locations exist. The two key factors taken into consideration while selecting these candidates are Cost and Service Levels. In return, this provides the optimal count and locations of facilities for the concerned business operating geography.

Before moving into detailed steps, it's worth it to come up with a broader picture of how these two tools (analysis) create a strong foundation for the rest of the OSTs which will be discussed through the rest of the processes of this framework. As shown below (see Figure 5.18) top to bottom propagation of each area represents the magnitude of the forces that can impose on the OST application's solver/engine by the user during each experiment. Also, the figure illustrates (1) the flow and the connection of each experiment (2) how the data requirement increases (3) the time OST users must spend and (4) the way it increases the operational granularity reflection in the models and the results can obtain.

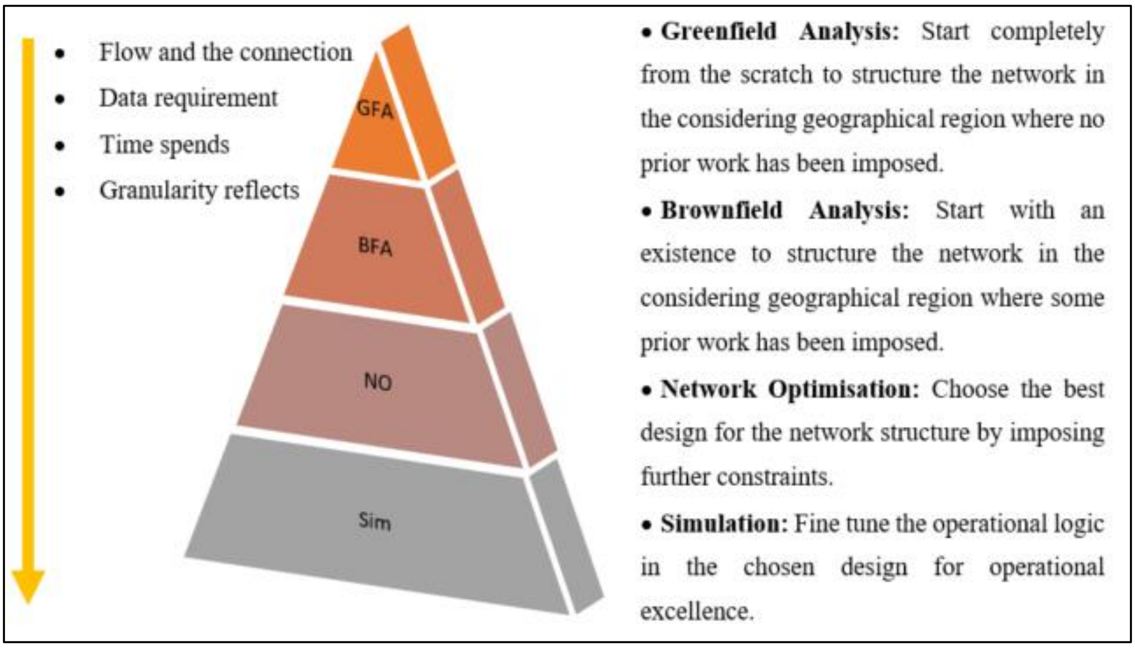


Figure 5. 18: Pyramid of experiments and its granularity using OST in SCM

The data requirement (see Figure 5.19), process (see Figure 5.20) and detailed description (see Table 5.8 & 5.9) can be illustrated as follows.

5.3.4.1 The data (GFA)

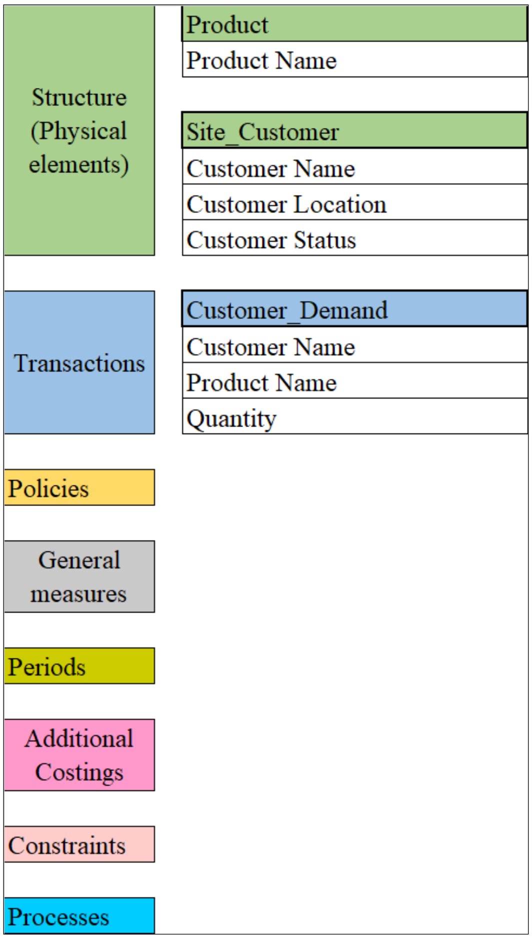


Figure 5. 19: The data requirement - GFA

5.3.4.2 The process (GFA & BFA)

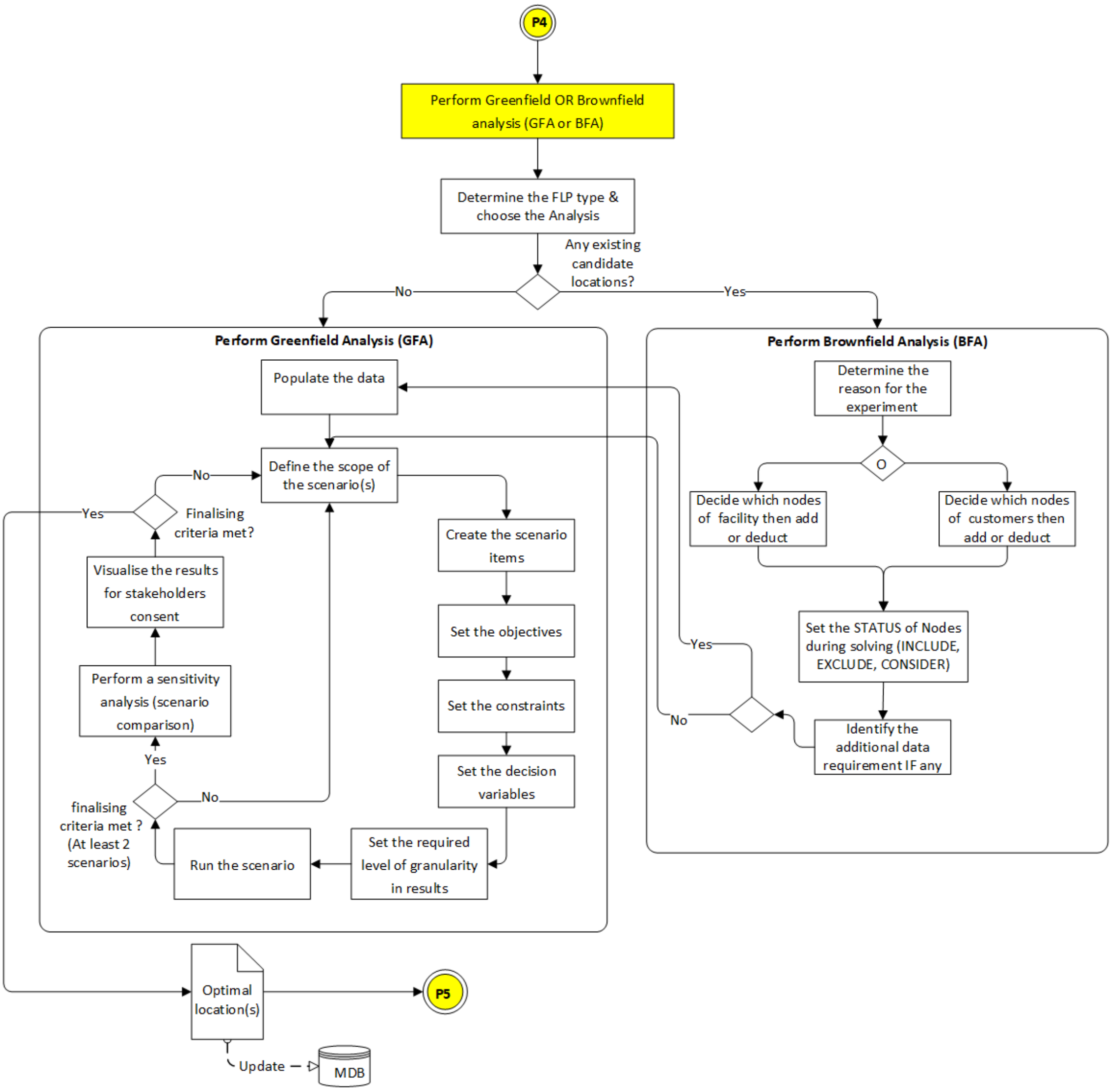


Figure 5. 20: Process – Perform Greenfield or Brownfield Analysis

5.3.4.3 The description (GFA)

S.N.	Task	Description & criteria to determine	Deliverable
1	Populate the data	The data taken into consideration here is very minimal such as: • Customer locations (Geocoded with latitude and longitude)	N/A

		• Products • Aggregated demand	
2	Define the scope of the scenario	• Determine how many scenarios are planned to run (at least should be two and more the better for sound sensitivity analysis) • Since GFA calculate only the direct distance from Sites (locations looking for) to customers (demand nodes) take into consideration the results of locations can be in a sea or on top of a mountain for an instance) • Therefore, please consider the experiment with roads	N/A
3	Set the objective	• Maximise profit / minimize cost	N/A
4	Set the constraints	• Number locations looking for • Any specific radius covers each location • Minimum number of customers/percentages should cover from targeting locations, or % of demand should cover • Any last mile service constraints	N/A
5	Set the decision variables	• It's always a trade-off analysis between Cost and service levels. (More DCs increase the service levels / quick deliveries but increase the transportation	N/A

		cost from the Manufacturing plant to multiple DCs • Cost (consider the transportation rates and minimise the total distance to travel) • Service levels (stay closer to the bigger proposition of the customer base / demand)	
6	Set the required level of granularity in results	• This is based on the aggregation strategy applied (i.e., How granular do you need to analyse the customer-wise flows from suggesting sites?) • Based on the detailed output level Model run time varies. • Recommended running with minimal detail at the first instance to avoid any infeasibility in results output. • Or based on the OST application's solver there may be inbuilt settings to opt-in to ignore any infeasible constraints imposed by the user) then the same can be viewed once the optimising run is completed, by viewing the infeasible / diagnose results.	N/A
7	Run the scenario	• At least two scenarios	N/A
8	Perform a sensitivity analysis	• Change the parameters which provide a sound sensitivity analysis to pick the right alternative/ combinations of an optimal number of sites and locations	N/A

	(scenario comparison)		
9	Visualise the results for stakeholders' consent	• It's always a matter of how powerful / depth analysis can be reflected in visualisations in a way of easy seeing the trade-offs between alternatives i.e., In terms of cost and service levels by using maps, charts, graphs, etc. to the decision-makers	Optimal location(s)

Table 5. 8: Description – Greenfield Analysis

5.3.4.4 The description (BFA)

S.N.	Task	Description & criteria to determine	Deliverable
1	Determine the reason for the experiment	• The main difference between this analysis and GFA there is the existence of constraints imposed in the network as in locations, customers and the flows and capacity between them. • Since it will be a change in the existing structure and flows that are false under the redesign scope. • This may be due to a (1) change in facilities (Closing, opening new, mergers and acquisitions, etc.) • (2) change in the nodes of the customers (i.e., leave any existing markets due to thin margins of profit, securing or placing	N/A

		a new product to a new market / geography, etc.) • Or both (1) & (2) together	
2	Decide which Nodes of the Facility then Add or Deduct	• Based on the reason (What's likely to happen or planning to execute) decide what to add or remove.	N/A
3	Decide which Nodes of Customers then Add or Deduct	• Based on the reason (What's likely to happen or planning to execute) decide what to add or remove.	N/A
4	Set the STATUS of Nodes during solving (INCLUDE, EXCLUDE, CONSIDER)	• It's about taking benefits of functionality available in the OST to keep the existing nodes (Facility or customers) as existing, but which should consider by the solver during solving. • Enabling to test multiple scenarios quickly	N/A
5	Identify the additional data requirement IF any	Note: Either YES or NO, from this task onwards same set of tasks described before in GFA (Table 5.8) must be followed. The reason behind this anyway the output will be optimal locations to serve the concerned set of customers.	N/A

6	Sub Process: <u>GFA</u>	If NO, Define the scope of the scenario(s) with existing data. IF YES, populate the new data • Only if any concern about adding any new nodes (facility or customers) or any significant changes in the existing value corresponding to your concerning reason for the change. As such there may be additional data required (New locations cost, new target customer nodes' historical demand / any increases in the forecast, any constraints to impose as in particular site should serve any specific customer in future, etc.)	Optimal Location(s)

Table 5. 9: Description – Brownfield Analysis

5.3.5 Model a robust baseline (RBL)

After application of optimisation at the very 1st instance through GFA or BFA the next 2nd instance is once the current state of the baseline is constructed; 'Run Optimisation' over it (see Figure 5.23). The baseline model replicates the current state of the supply chain (i.e., in this case, the network configuration parameters provided by GFA or BFA will be the base input to this process).

Once the baseline is modelled, it's very significant the validation of that against the validation sources such as financial statements (i.e., maybe a projected one for a new business) which describes the current behaviour and the values associated with the business. This is a very significant check gate before moving any step further since it confirms that what replicates in the OST is on the right path to get on with any future experiments on it. Otherwise, all future efforts will be in the drain if the base constructed is not the right benchmark to compare against future experiments.

''Computers aren't smart, just fast. Garbage in garbage out- Quote by Peter F. Hamilton''

5.3.5.1 Physical elements and behavioural relationships of a baseline

As the starting point, it's very important to know what mandatory data is required in OST to replicate the physical elements and the behavioural relationships of any supply chain. The following figure (see Figure 5.21) illustrates such which must be transformed as key data tables (see Figure 5.22) and then which must be populated into OST with the required mandatory data fields when modelling a robust baseline (see Table 5.10).

Note:

- In the following two figures, a Multi-Echelon Supply Chain Network (MESCN) is considered otherwise no requirement in site sourcing policies. If it's a Single Echelon Supply Chain Network (SESCN) only customer-facing sites are considered (if no inter sites relationships). The data category mentioned under ''General measures'' is related to model settings which are populated by OSTs. But here it is shown to show the mandatory requirement of the same to fulfil the relational integrity of data. (To ensure any multiple currencies then ratios basis, product flows in the network can be in different types of units, the specifically concerned time-period / no multi-period is concerned)

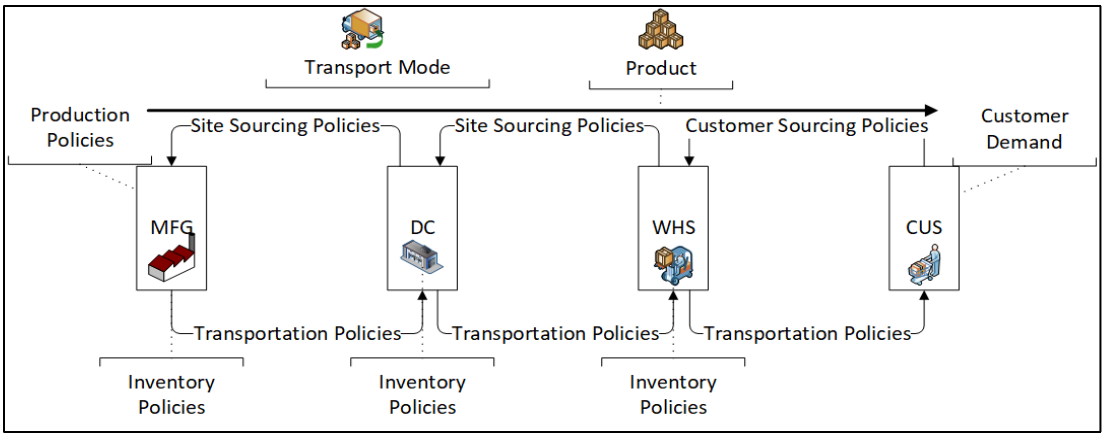


Figure 5. 21: Baseline modelling elements and logical behaviour in OST

5.3.5.2 The data

Structure (Physical elements)

Product
Product Name
Product Value
Product Weight
Product Volume
Product Price
Product Status

Site_Facility
Facility Name
Facility Location
Facility Status
Facility Type

Site_Customer
Customer Name
Customer Location
Customer Status

Transport_Mode
Name
Allowable Products

Transactions

Customer_Demand
Customer Name
Product Name
Quantity
Demand DateTime

Policies

Production_Policies
Production Policy Name
Site Name
Product Name
Production Unit Cost

Site Sourcing Policies
Site Sourcing Policy Name
Site Name
Product Name
Source Name

Customer Sourcing Policies
Customer Sourcing Policy Nam
Site Name
Product Name
Source Name

Transportation Policies
Transportation Policy Name
Source Site
Destination Site
Transport Mode Name
Average Unit Transportation Cost
Transportation Cost Basis

Inventory Policies
InventoryPolicy Name
Site
Product
Stocking Or Intransit Site
Inventory Carrying Cost%
InventoryPolicy
Initial Inventory
Unit Inbound Cost
Unit Outbound Cost
Inbound Capacity
Outbound Capacity

General measures

UOM
Type
Symbol
Name
Ratio Basis

Currencies
Name
Code
Symbol
Ratio Basis

Model Horizon
Model Start Date
Model Finish Date

Periods

Additional Costings

Constraints

Processes

Figure 5. 22: Data requirement to model a robust baseline

5.3.5.3 The process

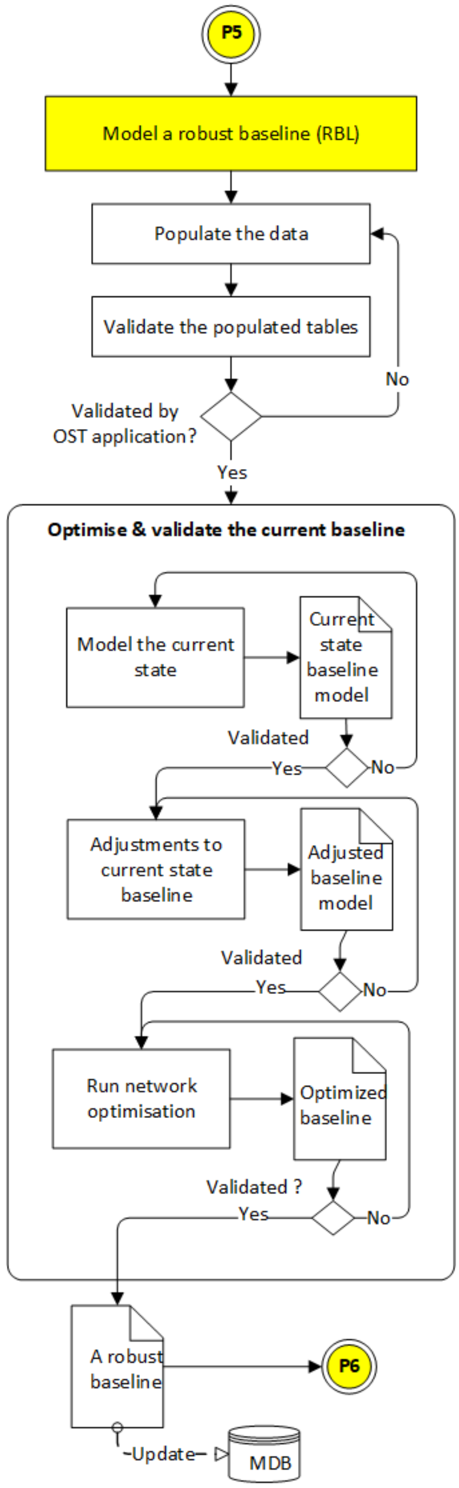


Figure 5. 23: Process – Model a robust baseline

5.3.5.4 The description

S.N.	Task	Description & criteria to determine	Deliverable
1	Populate the data into OST	• Reflets current state constraints and the behaviour of the Network as per the inputs by user based on assumptions or historical data. • Only consider populate the mandatory data requirement. Then over time or with any optional data in hand which falls under those data categories and tables can be populated. • Population of more granular data (Optional) will enhance the transparency to the user in terms of logical behaviour in the network towards more operational level.	N/A
2	Validate the populated tables	• This is an additional check perform by the OST application itself to ensure the relational integrity among unique data fields (Primary & foreign key mapping) to ensure the consistency and integrity of data populated among Tables. • This is the reason, and that assurance is reinforced by the framework: Process 3: Task 3-Export empty data tables from OST application. Task 4-Define the data table's terminology and relationship.	N/A

3	Model the current state	• Output should be validated against validation sources (Assumptions or recent financial and operational reports) • A simple representation of a map will clarify a high-level digital representation of the physical network.	Current state baseline
4	Adjustments to Current State Baseline	• Note: This is an optional task. • Based on the feedback of stakeholders during the validation some adjustments can be imposed into the model. • Also, if there any significant changes happened during the considered period of Model horizon that should be prorated and injected into the model. This is a scenario comparison which reflects the delta of that adjustments against the initial current baseline. (i.e., Emergency plant opening / closing or any unexpected fuel price increases, due to any product failure a region of demand / nodes of customers can be withdrawn)	Adjusted baseline model
5	Run network optimisation	• Remove existing inefficiencies in constraints based on assumptions or historical data input by user and force the solver to decide the optimal network structure. • Provide better insights and any inefficiencies removed by the solver during the transformation of the current baseline to optimised one.	Optimized baseline

6	Final validation	Optimised baseline should be validated against validation sources (Assumptions or recent financial and operational reports) • To make sure, the baseline what we are going use as the benchmark to further enhance, optimise, simulate in future is accurate to the data what has assumed / actually occurred (historical data). <u>For an instance reason behind validation:</u> • There may be incorrect data inputs, • Unrealistic assumptions, • Aggregation may be too high • Incorrectly imposed constraints (facility wise inbound & outbound, cost/ capacities, etc.) • Incorrect flows lead some incorrect results, • validation sources mismatch • Any mistake in the model structure by OST user // muddler.	A robust baseline

Table 5. 10: Description - Model a robust baseline

This is one of the very significant objectives (stage gate) of this ‘’Framework OSTiSCM’’ to fast-track the time spent by the current OST users in producing a robust baseline for their SCND objectives. With the traditional approach, OST users spend enormous time to accomplish this status due to lots of drawbacks and inefficiencies they associate during the deployment. But with the structured step-by-step approach proposed here provides the necessary guidance from scratch to come across all such barriers, especially with a strong structured enriching database with which they will get more benefit over time as capture more data when business starts operations.

5.3.6 Optimisation: Network, Inventory & Transportation

When the above process is completed the OST-user is fully geared with a robust baseline which replicates the current state of the supply chain in a digital experimental platform. Accomplishing this stage marks a significant milestone in any SCND project. Then the next process is populating more granular level data and performing Network Optimisation (NO), Inventory Optimisation (IO), Transport Optimisation (TO) (see Figure 5.31) and Simulation.

In each application, whether it is NO/ IO / TO / SIM the requirement of data to be populated into OST varies. The more complexity brings into the model based on the scale of the problem to be solved the granularity of the data requirement increases. Based on the current state of the business there may be not much granular data in hand until the business starts operating. But it is highly recommended that OST users can perform a sound assumption over these such data as this framework guides through (see Table 5.11) a few hypothetical data tables and fields in each application. Under this process, the suggested data can be illustrated in the following figures (see Figures 5.24 to 5.30).

Note: By following the framework a ‘’Baseline Model’’ is now already in the OST with the required data. Therefore, from this point onwards, the ‘’additional data’’ that we populate on top of that will be considered. As in what data can be useful in NO, IO, TO and SIM. Once you populated more granular level data as much as you can. But please note that should be done only as per the level of reflection in the models and the results outputs required for decision making, else do not populate unnecessary data which brings in unnecessary complexity to the model and it takes time during solving/running your models. The following set of figures illustrates the data which can populate when the application of NO Tool as per the first instance then with the rest of the Tools (IO, TO and SIM) respectively. Then it can be recognised that most of the data required for these three tools are already can be covered while application of the NO Tool.

5.3.6.1 The data (NO)

Structure (Physical elements)

Product	Site_Facility	Site_Customer	Transport_Asset
Lead Time CostDayUnit	Organization	Organization	Name
Maximum Lead Time	Fixed Operating Cost	Transportation Region	Fixed Asset Cost
Shelf Life	Order Review Frequency	Sourcing Type	Speed
	CO2 Fixed Output	Tax Region	Organization Belong To
	Capacity/Fixed Cost Period		Transport Mode
	Tax Region		Capacity (Quantity)
	Fixed Startup Cost		Capacity (Weight)
	Fixed Closing Cost		Capacity (Volume)
	Throughput expansion		No Of Units
	Sourcing Type		Type
	Capital Investment Cost		Asset Weight
	Book Value		Asset Volume
	Depreciation Schedule		Fill Level (Weight)
	Minimum Capacity		Fill Level (Quantity)
	Maximum Capacity		Fill Level (Volume)
			Hourly Cost

Work_Resource	Work_Center	Organization	Transport_Mode
Name	Name	Name	Name
Site	Site	Address	Mode Fixed Cost
Type	Fixed Startup Cost	Fixed Startup Cost	Minimum Shipment Charge
Work Centre	Fixed Operating Cost	Fixed Operating Cost	Average Shipment Size
Units	Capacity/Fixed Cost Period		Transport Assets Assigned
Fixed Unit Cost	Capital Investment Cost		Fuel Surcharge
Shift Pattern	Fixed Closing Cost		Fuel Surcharge Basis
Hourly Cost	Minimum Capacity		Variable Transportation Cost
Maximum Capacity (Hours	Maximum Capacity		Variable Cost Basis
Capacity/Fixed Cost Period	Book Value		CO2 And Basis
Book Value	Depreciation Schedule		Allowable Products
Depreciation Schedule			

Transactions

Customer_Demand	Site_Demand	Customer_Orders	Site_Orders
Due DateTime	Site	Customer	Site
Demand Lead Time	Product	Product	Product
Occurrences	Quantity	Quantity	Quantity
Transport Mode	Demand DateTime	Order DateTime	Demand DateTime
Period	Due DateTime	Due DateTime	Due DateTime
Seasonality Name	Demand Lead Time	Demand Lead Time	Demand Lead Time
Minimum Demand Quantity	Occurrences	Transport Mode	Transport Mode
Demand Penalty Cost	Transport Mode	Minimum Order Quantity	
	Period	Order Penalty Cost	
	Seasonality Name		

Demand Seasonality Factor	Shipments	Production	Retruns
Name	Shipment ID	Site	Customer Name
Period	Source	Product	Destination Site
Seasonality Factor	Destination	Process	Organisation
	Product	Quantity	Period of Departure
	Quantity	Order DateTime	Period of Arrival
	Weight	Due DateTime	Product Name
	Volume	Production Lead Time	Recived Quantity
	Direct Shipping Cost		Retuned Quantity
	Mode		
	Occurrences		
	Shipment Strat Date		
	Shipment Due Date		
	Shipment Lead Time		
	Shipment Frequency		
	Service Level		

Figure 5. 24: The data suggestion for (NO) - I

Policies	Production_Policies	Transportation Policies	Inventory Policies
	Fixed Order Time	Product Name	Unit Storage Cost
	CO2	Specific Period	Minimum Shelf Time
	Minimum Order Quantity	Transport Time	Maximum Shelf Time
	Production Frequency	Distance	Safety Stock
	Production Unit Cost	Asset	Inventory Turns
	Process	Variable Transportation Cost	Maximum Inventory
	Quantity	Variable Cost Basis	Minimum Inventory
	Order Date	Fixed Shipment Cost	Unit Disposal Cost
		Product Class	
	Site Sourcing Policies	Duty Rate	Return Policies
	Guaranteed Lead Time	Minimum Charge	InventoryPolicy Name
	Minimum Order Quantity	CO2	Period
	Sourcing Unit Cost	Fixed Load Cost	Origin
	Maximum Sourcing Distanc	Fixed Load Time	Product
		Fixed Unload Cost	Destination
	Customer Sourcing Policies	Unit Unload Time	Return Policy
	Guaranteed Lead Time	Average Shipment Size	Unit Return Cost
	Minimum Order Quantity	Fuel Surcharge	Retrun Product Ratio
	Unit Sourcing Cost	Fuel Surcharge Basis	Return Minimum Qty
	Maximum Sourcing Distanc	CO2 Basis	Return Max Qty
		Applicable Period	

General measures	Operating Hours
	Facilty Name
	Opening Time
	Closing Time

Periods	Products Multi-Period	Sites Multi-Period	*All policies above also can be imposed in the mmodel with these "Data Fields"
	Period Name	Period Name	
	Product	Site	
			Period Name
			Policies Multi-Period
	Transportation Assets Multi	Work Centers Multi-Period	Work Resources Multi-Perio
	Period Name	Period Name	Period Name
	Transportation Assets Multi	Work Centers Multi-Period	Work Resources Multi-Perio

Figure 5. 25: The data suggestion (NO) - II

Additional Costings

Step Cost	Shipping Rates	Transport Asset Rate
Name	Name	Transport Asset ID
Type	Rate Source	Asset Type
Minimum Quantity	Freight Class	Origin
Cost	Source Country	Destination
Step Period	Source Postal Code	Fixed Cost
Step Throughput Basis	Destination Country	Reposition Distance Cost
	Destination Postal Code	Cost for Out of Route
	Step Period	Per Unit Cost
	Minimum Quantity	Unit Cost Basis
	Step Throughput Basis	In Transit Stop Cost
	Cost	Variable Rest Time Cost
		Fixed Rest Time Cost
		Minimum Cost
		Drive Time Cost
		Service Time Cost
		Wait Time Cost
		Break Time Cost

Material Handling Equipme	Human Resource Rate	Taxes And Duties
MHE ID	Human Resource ID	Name
Organization	Organization	Period
Site	Site	Origin
Work Centre Assigned	Work Centre Assigned	Destination
Transport Asset assigned	Transport Asset Assigned	Product
Capital Cost	MHE Assigned	Duty Rate Percentage
Depreciation Basis	Fixed Cost	Non Refundable Tax Base
Minimum Hours work Day	Varibale Cost Type	Non Refundable Tax Rate
Maximum Hours work Day	varibale Cost Basis	Refundable Tax Base
Minimum Hours Break Day	Minimum Hours work Day	Refundable Tax Rate
Maximum Hours Break Day	Maximum Hours work Day	
	Minimum Hours Break Day	
	Maximum Hours Break Day	

Figure 5. 26: The data suggestion (NO) - III

Constraints

Flow Constraints	Production Constraints	Inventory Constraints
Period	Period	Period
Source	Site	Site
Destination	Product	Product
Product	Constraint Type	Pre-Build Stock
Mode	Constraint Value	Safety Stock
Constraint Type	Constraint Period	Cycle Stock
Constraint Value		Constraint Type
Constraint Period		Constraint Value
		Constraint Period

Site Constraints	* All Processes below also can populated as Process Constraints with these	
Period		
Site		
Constraint Type	Period	
Constraint Value	Site/ Customer /Source	*As per the Process
Constraint Period	Product	
	Destination	*Source in Return
Work Center Constraints	Process	*Mode also in Trans.
Period	Work Center	*Process Step in Inven.
Work Center	Work Resource	
Site	Constraint Type	
Constraint Type	Constraint Value	
Constraint Value	Constraint Period	
Constraint Period		

Processes

Bills Of Material	Sourcing Process	Production Process
Name	Name	Name
Product	Source Site	Source Site
Type	Product	Product
Quantity	Destination Site	Work Center
Period	Work Center	Next Step Basis
Site	Next Step Basis	Fixed Process Cost
Process Assignment	Fixed Process Cost	Unit Process Cost
Asssignment Rule	Unit Process Cost	Fixed Process Time
Unit BOM Cost	Fixed Process Time	Unit Process Time
	Unit Process Time	Variable Cost Basis
	Variable Cost Basis	Variable Time Basis
	Variable Time Basis	Work Resource
	Work Resource	Period
	Period	Work Resource Time
	Work Resource Time	

Transportation Processes	Inventory Processes	Return Processes
Name	Name	Name
Source Site	Source Site	Source Site
Product	Product	Product
Destination Site	Work Center	Destination Site
Work Center	Next Step Basis	Work Center
Next Step Basis	Fixed Process Cost	Next Step Basis
Fixed Process Cost	Unit Process Cost	Fixed Process Cost
Unit Process Cost	Fixed Process Time	Unit Process Cost
Fixed Process Time	Unit Process Time	Fixed Process Time
Unit Process Time	Variable Cost Basis	Unit Process Time
Variable Cost Basis	Variable Time Basis	Variable Cost Basis
Variable Time Basis	Work Resource	Variable Time Basis
Work Resource	Period	Work Resource
Period	Work Resource Time	Period
Work Resource Time		Work Resource Time

Figure 5. 27: The data suggestion (NO) - IV

5.3.6.2 The data (IO)

Structure (Physical elements)

Product
Product Type
Start Date
End Date

Transactions

Customer_Forecasts	Site_Forecasts
Period	Period
Customer	Site
Product	Product
Order Date	Order Date
Quantity	Quantity

Policies

Production_Policies	Transportation Policies	Inventory Policies
Fixed Order Cost	Unit Load Time	Review Period
	Fixed Unload Time	Minimum Safety Stock
Site Sourcing Policies	Minimum Replenishment Quant	Maximum Safety Stock
Fixed Order Cost	Minimum Service Time	Minimum Service Time
Source Lead Time	Maximum Service Time	Maximum Service Time

Customer Sourcing Policies
Fixed Order Cost
Source Lead Time

General measures

Periods

Additional Costings

Constraints

Processes

Figure 5. 28: The data requirement (IO)

5.3.6.3 The data (TO)

Structure (Physical elements)

Site_Facility	Transport_Asset
Time Zone	Applicable Rate Type
Asset Lookup Distance	Max Drive Time Before Break
Fixed Service Time	Fixed Break Time
Fixed Load Time	Max Distance Per Route
Fixed Unload Time	Minimum Distance Per Route
Variable Load Time	Max Time Per Route
Variable Unload Time	Max In-Transit Stops Per Route
Variable Service Basis	Max Loading Stops
Number of Dock Doors	Max Unloading Stops
Dock Door Reset Time	Post Delivery Asset Return Location
	Max Asset Search Distance To Site
Site_Customer	Max Waiting Time At Location
Time Zone	Fixed Service Time
Asset Lookup Distance	Fixed Load Time
Fixed Service Time	Fixed Unload Time
Fixed Load Time	Variable Load Time
Fixed Unload Time	Variable Unload Time
Variable Load Time	Variable Service Time Basis
Variable Unload Time	Mx Distance from Last Drop To Hom
Variable Service Basis	CO2
Number of Dock Doors	CO2 Basis
Dock Door Reset Time	Battery ID Electronic Vehicle

Transactions

Shipments
Fixed Service Time
Fixed Service Time Load
Fixed Service Time Unload
Variable Service Time Load
Variable Service Time Unload
Variable Service Time Basis

Policies

General measures

Periods

Figure 5. 29: The data requirement (TO) - I

	Parcel Rate	LTL Rate
Additional Costings	Carrier Name	Carrier Name
	Origin	Origin
	Destination	Destination
	Product	Product
	Fixed Cost	Fixed Cost
	Variable Cost Basis	Variable Cost Basis
	Discount Rate	Discount Rate
	Minimum Charge	Minimum Charge
	Transit Time	Transit Time
	Minimum Quantity	Minimum Quantity
	Maximum Quantity	Maximum Quantity
	Minimum Weight	Minimum Weight
	Maximum Weight	Maximum Weight
		Minimum Volume
		Maximum Volume
Constraints		
Processes		

Figure 5. 30: The data requirement (TO) - II

5.3.6.4 The process

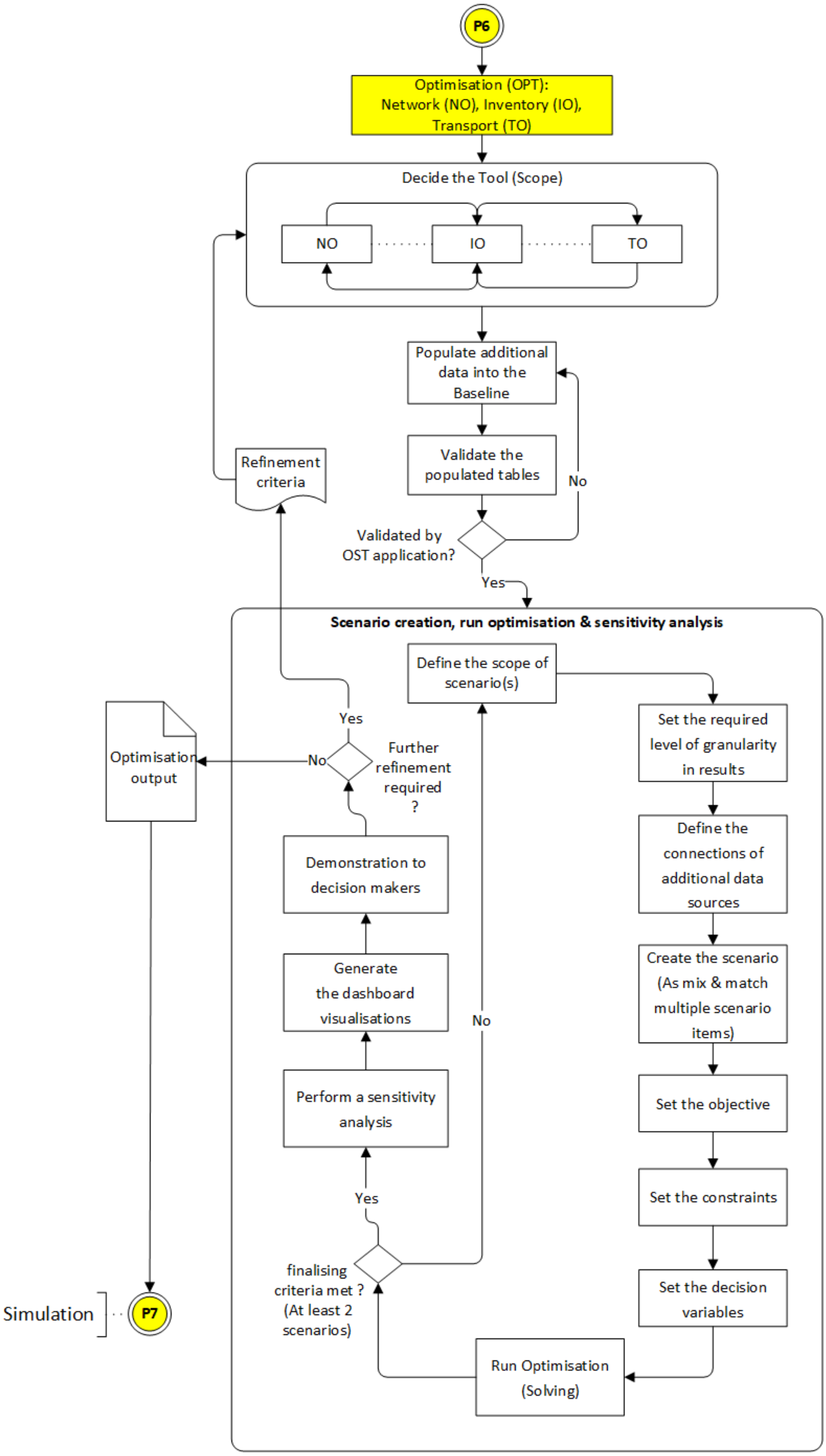


Figure 5. 31: Process – Optimisation: Network, Inventory & Transportation

5.3.6.5 The description

S.N.	Task	Description & criteria to determine	Deliverable
1	Decide the Tool (scope)	• What problems going to be solved? • Using the Tools: NO, IO, TO and their scope.	N/A
2	Populate additional data into the Baseline	• Based on the problem scope that determine the data requirement (this determines by in which data fields/variables you need the results output and how granular you need it) • Please bring in the required necessary level of complexity (right data granularity / characteristics into the model) otherwise do not populate that data and do not build those characteristics.	N/A
3	Validate the populated tables	• This is an additional check perform by the OST application itself to ensure the relational integrity among unique data fields (Primary & foreign key mapping) to ensure the consistency and integrity of data populated among Tables. • This is the reason, and that assurance is reinforced by the framework: Process 3: Task 3-Export empty data tables from OST application. Task 4-Define the data table's terminology and relationship.	N/A

4	Define the scope of scenario(s)	• Be price when naming the Scenario (Which will help later to identify and pick quickly, i.e., use prefix, suffix, or coding. i.e., Consolidate DC SHF_MAN to DC BIR)	N/A
5	Set the required level of granularity in results	• Groups-When create groups its static with the elements grouped for. (Site groups, Transport asset group, etc.) • Filters (Not static sets or groups): dynamic i.e., as change anything in the primary table or source that will be picked up automatically by the filters/ i.e., no requirement to change anything in scenario items if any • Any specific individual elements for comparison? (This strongly connect with results visualisation) i.e., if group formed, results granularity less but models run quicker (Product group, site group, etc.)	N/A
6	Define the connections of additional data sources	• i.e., Any transportation rates files connection which will be subject to change. • Then easy to change the values in that specific source rather do any changes in the model every times as the source value subject to change.	N/A
7	Create the scenario (As mix & match multiple scenario items)	• Scenario feature / tool allows you to identify the trade-offs among alternate scenarios for a network design	N/A

		• Set scenario items in multiple purpose using in other scenarios (Save time and easy to mix and match the scenarios) • Please provide a sensible / easy to identifiable name. which tells precisely what type of change that scenario item does. • Once scenario items created it's very easy apply any change among scenarios by mix and match the specific scenario items to make one single scenario (Easy and quick). i.e., Scenario Item (SI) SI 1: EXCLUDE DC_1 SI 2: EXCLUDE DC_4 SI 3: INCLUDE DC_6 Scenario 1 = SI 1+ SI 3 Scenario 6 = SI 2 + SI 1	
8	Set the objective	• This the objective of the optimisation which is used to compare the alternatives. (i.e., profit, cost)	N/A
9	Set the constraints	• The limitations want to add into the existing configuration /model (as per this framework's journey, the robust baseline model exists now in the OST)	N/A
10	Set the decision variables	• This where to impose the variables which explains options / combinations to test and on which you can take the decisions by changing that certain	N/A

		variable. (Different factory, Transport mode, etc.)	
11	Run Optimisation (Solving)	• Run NO and select the scenario to solve • At least 2 scenarios should be run for a better sensitivity analysis	N/A
12	Perform a sensitivity analysis	• Review the output results and set the comparison strategies • This shows the change in the target variables (objective) based on the change in other input variables (objective, constraints, and decision variables)	
13	Generate the dashboard visualisations	• Fulfilling the visualisation requirement as per the decision makers choice. • Scenario Comparison can be strongly visualised as in maps, grapes, schematic, etc. • As a collection on dashboard.	N/A
14	Demonstration to decision makers	• Provide a snapshot on how their financial objectives are changing over different alternatives. • If they need to see more alternatives and results comparison, then must generate more scenarios to fulfil such.	Optimisation output

Table 5. 11: Description – Optimisation: Network, Inventory & Transportation

5.3.7 Simulation (SIM)

Through the cycle of Optimisation-Simulation (OPTSIM) when it comes to SIM, there are few more granular level data (see Figure 5.32) additional to what is already populated through NO, IO and TO. Then the data under the suggested data fields can be populated and run the SIM (see Figure 5.33) which will provide an enormous number of detailed outputs (transactional, time series & queue statistics). In that case by application of SIM the user will be capable to see how the current defined SCN configuration behaves over real business dynamics since the user can bring the variability into the models by defining concerned parameters (network, inventory, transport, etc.) as per the concerned scope (see Table 5.12) (demand, safety stock estimation, stock replenishment, lead time, pickers order picking movement, forklift operating movement, unloading cargo, etc.).

Users can change these concerning parameters in the current process's logic and simulate with multiple replications to see how performance fluctuates. If any risk/inefficiencies are identified from the statistics given by simulation results then the user can go back to the Optimisation model and fine-tune the concerned parameters (Objective, Constraints as per the decision variables) and run Optimisation (Solving).

Therefore, this optimisation and simulation cycle can continue until the business decision-makers are satisfied with the final SCND output which provides full confidence towards a final decision execution.

5.3.7.1 The data

Structure (Physical elements)

Site_Facility	Site_Customer	Transport_Asset
Operating Schedule	Operating Schedule	Shipping Route
Queue process Basis		Unit Selection Rule
Order Review Policy	**Work_Center**	Shift Pattern
	Max Queue Capacity	Asset Base Location
Work_Resource	Queue Selection Rule	Asset While Idle Location
Work Asssign Queue Basi	Shift Pattern	

Transactions

Customer_Demand	Site_Demand	Customer_Orders	Site_Orders
Demand Frequency	Demand Frequency	Cancel Basis	Cancel Basis
Cancel Basis	Cancel Basis	Priority Basis	Priority Basis
	Priority Basis		

Shipments	Production	Customer_Forecasts	Site_Forecasts
Tracking ID	Occurrences	Forecast Name	Forecast Name
Priority Basis	Production Frequency	Type	Type
Cancel Basis	Priority Basis		

Policies

Production_Policies	Customer Sourcing Policie	Transportation Policies	Inventory Policies
Unit Production Time	Fixed Order Time	Load Resource	Reorder Point
Due Date	Unit Sourcing Time	Unload Resource	Reorder/Order Up To Qty
Occurrences	Back Order Basis	Unit Load Cost	Fixed Inbound Shipment Cost
Production Frequency		Unit Unload Cost	Fixed Outbound Shipment Cos
Priority Basis	**Site Sourcing Policies**	Shipment Frequency	Forecast Name
Tracking ID	Fixed Order Time	Cancel Basis	Order Partial Fullfill eligibility
	Unit Sourcing Time	Priority Basis	
	Back Order Basis	Tracking ID	

General measures

Periods

Additional Costings

Constraints

Processes

Sourcing Process	Production Process	Transportation Processes
Changeover Time	Changeover Time	Changeover Time
Minimum Quantity	Minimum Quantity	Minimum Quantity
Maximum Quantity	Maximum Quantity	Maximum Quantity

Inventory Processes	Return Processes
Changeover Time	Changeover Time
Minimum Quantity	Minimum Quantity
Maximum Quantity	Maximum Quantity

Figure 5. 32: The data requirement (SIM)

5.3.7.2 The process

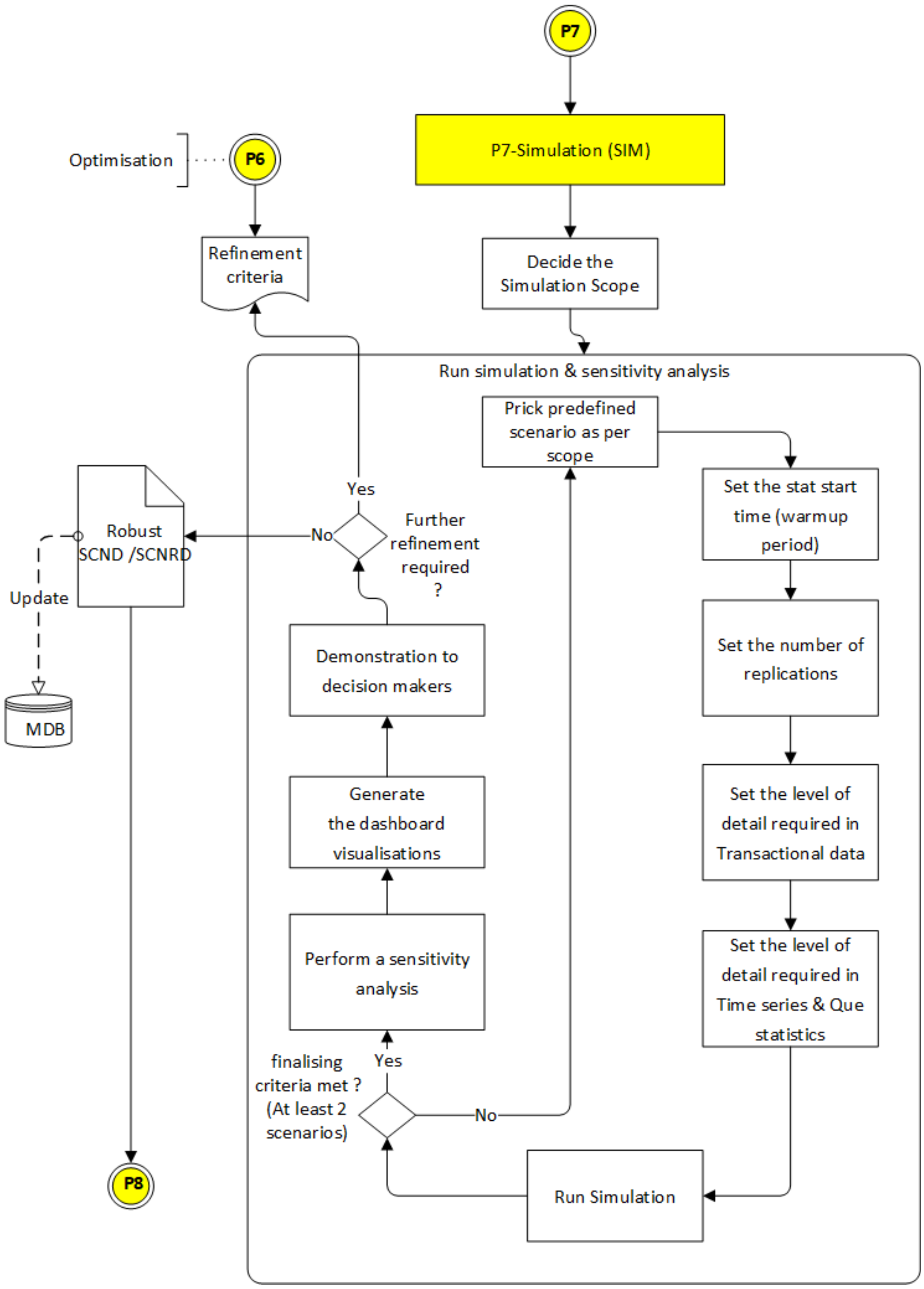


Figure 5. 33: Process – Simulation

5.3.7.3 The description

S.N.	Task	Description & criteria to determine	Deliverable
1	Decide the Simulation Scope	• Problem scope determines this. • The data you need as results output and how granular /detailed you need it • This brings in the necessary level of complexity into the model (data granularity / the level of the output statistics).	N/A
2	Prick predefined scenario as per scope	• Scenarios must be picked as per the scope of the simulation. • Pick the right scenario to run from the set of predefined scenarios.	N/A
3	Set the stat start time (warmup period)	• For an instance if the model horizon is set as 01/01/2021 to 31/12/2021. You can set the stat start time on a later date. Its matter from which date you need stats of simulation run (this provides a warmup period for simulation)	N/A
4	Set the number of replications	• Please stick to what only you want otherwise simulation runs over time unnecessarily. • This must be determined over the precision required in the output. • If the concern is only for a rough estimate a smaller number of replications can suggest (i.e., 3-5)	N/A

		• Otherwise for greater precision more replications.	
5	Set the level of detail required in Transactional data	• Transactional Data (i.e., demand, production, mileage, shipment, production process, etc.)	N/A
6	Set the level of detail required in Time series & Que statistics	• Time series related statistics (i.e., inventory, inventory volume, backorder units, re-order point, transportations asset, odder cycle, work centres etc. • Que related statistics (i.e., site orders, site back orders, site outbound shipments, etc.)	N/A
7	Run Simulation	• Suggestion: remove the animations for a quick 1st instance simulation run to get an idea about the time it takes. • Then take it as a bench march and you can judge even for more replications later or try with animation if required (if feature is activated or / enable when you decide the stack of the tools: Process 2-Technology).	N/A
8	Perform a sensitivity analysis	• Review the output results and set the comparison strategies. • This shows the change in the target variable / objective based on the change in other input variables. (Objective, constraints, and decision variables)	N/A

9	Generate the dashboard visualisations	• Fulfilling the visualisation requirement as per the decision makers choice: Scenario Comparison can be strongly visualised as in maps, grapes, Schematic, etc. • As a collection on dashboard.	N/A
10	Demonstration to decision makers	• Provide a snapshot on how their financial objective are changing over different alternatives.	SCND / SCNRD Strategy

Table 5. 12: Description - Simulation

NB:

In a conclusion over applying these Tools: NO, IO, TO, SIM and looking at the data, if the user can embed the NO Tool at the very first instance in a robust approach with a solid amount of data suggested (Not all the suggested data required based on your scope, specific data fields/ parameters link to the problem trying to solve), then the rest of Tools will be automatically embedded within the journey of OST deployment with enormous capabilities in the concerned area of Optimisation or Simulation.

5.3.8 Enterprise-wide awareness & decision execution (EWA)

Once the SCND or SCNRD model is created that should be converted into a detailed specification which will be the blueprint for the decision execution. In that nature, collaboration and support over cross-functional processes and individual performance are very vital. Therefore, a sound enterprise-wide awareness before execution (see Figure 5.34) of any decision is mandatory. Also, the assurance of a necessary platform to capture the feedback for rectifying any conflicts, and inefficiencies then rewarding against any recognized performances will shift the businesses to the next level of operational excellence. The criteria concerned here can be briefly described as follows (see Table 5.13).

5.3.8.1 The process

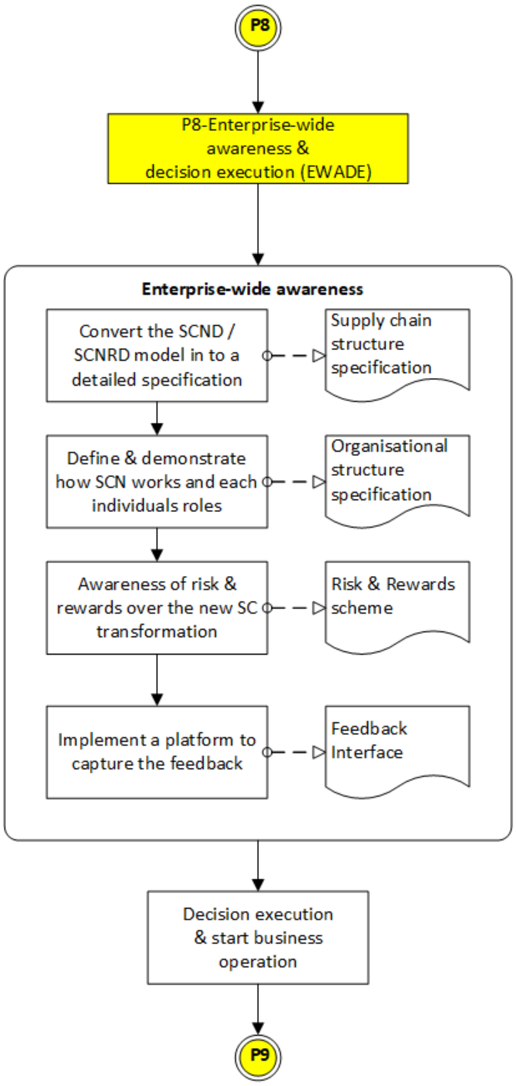


Figure 5. 34: Process - Enterprise-wide awareness & decision execution

5.3.8.2 The description

S.N.	Task	Description & criteria to determine	Deliverable
1	Convert the SCND / SCNRD model into a detailed specification	• Provide awareness on how supply chain structure works in terms of geography, the entities, assets, processes, and their relationships.	Supply chain structure specification
2	Define & demonstrate how SCN works and everyone's contribution	• Provide awareness on how organizational structure has been formed, individual's roles and contribution towards the business operation & objectives. • The importance of everyone's support and performance for better cross-functional integration.	Organisational structure specification
3	Awareness of risk & rewards over the SCN strategy	• The significance of the returns to the business over the investment of time, effort, and cost is associated with the new strategy. • Awareness of recognition in performance and rewards they can get in return • Awareness of the risk associated with any resistance to changing or supporting the new strategy execution.	Risk & Rewards scheme
4	Implement a platform to capture the feedback	• This helps the business to find how the SCN strategy works practically and get the full awareness of the feedback from all levels of staff.	Feedback Interface

		• Awareness of how important it is to stay ahead always with an innovation mindset for continues improvements • Awareness on how important everyone's continues feedback over the new strategy execution or any conflicts and the top managements support over that. • Awareness on how important and helpful the way can bring in their new ideas in to business operations which can be tested over these new OST and implement for enhanced performance.	
5	Decision execution & Start business operation	• Finally, this is where all the effort taken so far come into action. i.e., this is the date relates to OST experiments: models' horizon start date, Simulation stats start date	N/A

Table 5. 13: Description - Enterprise-wide awareness & decision execution

5.3.9 Capture transactional & real-time data

Once the business starts operation it's all about monitoring, controlling and further finetuning the SCN configuration and performance. So, capturing necessary transactional and real-time data (see Figure 5.35) through whatever systems or devices are in place and well connected to the OST Team is very important. How robust capturing and storing the data and using them for further experiments over OST (see Table 5.14) is always a crucial concern which in return strengthens the capabilities by enriching the amount of necessary data available in the Modelling Database (MDB).

5.3.9.1 The process

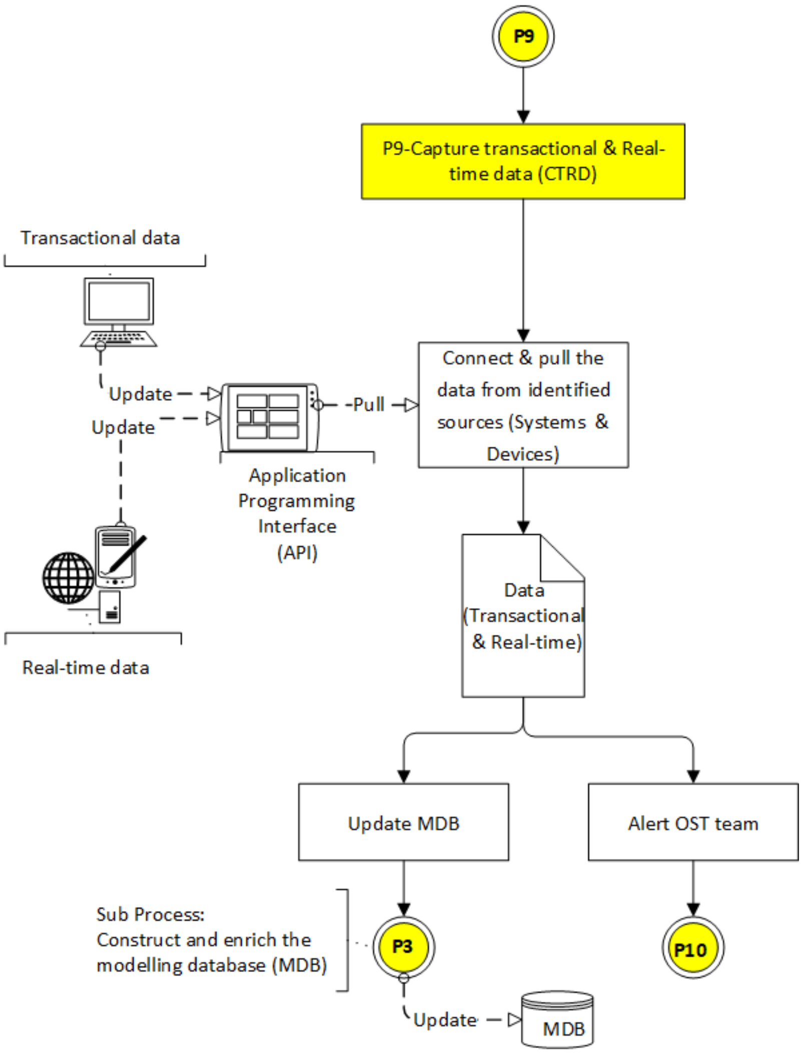


Figure 5. 35: Process - Capture transactional & Real-time data

5.3.9.2 The description

S.N.	Task	Description & criteria to determine	Deliverable
1	Connect & pull the data from identified sources	• The requirement and concerned criteria here (systems, devices, file types, connections, etc.) have been defined and integrated in the Process 2-	Data (Transactional & Real-time)

	(Systems & Devices)	Leverage CSFs: Technology, Process & People (TPP). • There are mainly two types of data based on the status (1) Transactional and (2) Real-time. <u>Transactional Data</u> i.e., for an instance through an ERP system or any other planning systems, etc. • Customer Order Management System (demand variability, forecasting, etc.) • WMS (safety stock level fluctuations & inventory snapshots, prebuild stock, in transit stock, etc.) • TMS (transport cost variances, asset utilization, speed data, etc. CO2 emission levels, etc.) • Shipment Management System (to customer and inter-site flows • <u>Real-Time Data</u> i.e., for an instance through IOT devices, or any remote sensors, RFID tags, etc. • Sales representatives Entries for future sales (good indication to set the capacities, supply & demand balancing) • Weather data • Road traffic data (i.e., for transport re-routing) • Disruption data (i.e., port congestions) • Rates (i.e., in case of premier freights)	

		There might an interface in the business such as an Application Programming Interface (API) to synchronise and connect all this data capture from multiple sources and Business Intelligence (BI) tools as well to do the data analytics and powerful visualizations.	
2	Update MDB	Route to: Process 3 - Sub Process: Construct and enrich the modelling database (MDB)	N/A
3	Alert OST team	Route to: Process 10 - Sub Process: Construct and enrich the modelling database (MDB)	N/A

Table 5. 14: Description - Capture transactional & Real-time data

5.3.10 Monitor SC health & proactive experiments

To reap the full potential out of these OSTs, keep monitoring the SC health alerts, analyze the captured data, and proactively react with the necessary precautionary experiments is very crucial. This way it provides broader visibility about the current risk exposure of the supply chain network. Based on the pre-defined risk exposure tolerance level in the business it will route to either SCNRD (Re-design) over BFA or general experiments over IO, TO and SIM. This is how it starts the Optimisation and Simulation cycle again and again for a continuous experiments culture in OST deployment to achieve SC resilience. The figure below explains the process (see Figure 5.36) followed by the description table of the same (see Table 5.15).

5.3.10.1 The process

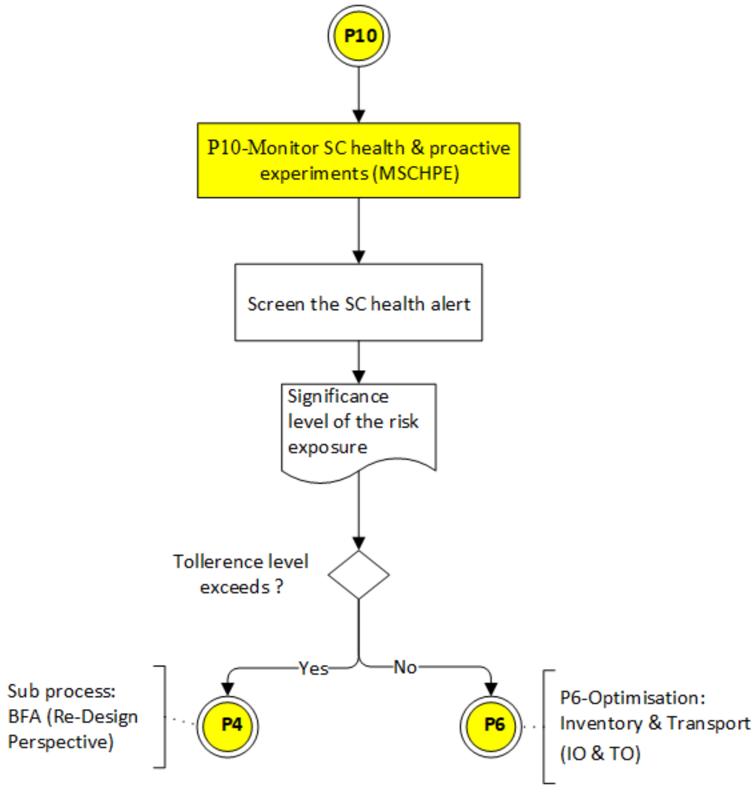


Figure 5. 36: Process - Monitor SC health & proactive experiments

5.3.10.2 The description

S.N.	Task	Description & criteria to determine	Deliverable
1	Screen the SC health alert	• According to the process based on the tolerance level of risk exposure that will route to either Process 4: BFA or Process 6: NO: IO, TO and SIM. Defining the risk exposure tolerance level and deciding the basic criteria is dependent on the business and its operational nature. • Business strategic level decision makers must predefine on which basis/level of	The significance level of the risk exposure

		significance of the SC health alert must have to route for SCNRD (re-design) • Since this may be very costly and time-consuming, demarcating what are the major-medium-minor causes and which decisions to be executed are very important. • In general, a high-level SCNRD will be performed due to any significant strategic to upper tactical network level causes. This is where BFA perform (already explained in the Process 4.	

Table 5. 15: Description - Monitor SC health for practice

5.4 Conclusions

The optimisation is ideal when you consider the experiments at network level configuration and flows. But for the operational level of rationality, variability, and randomness; simulation provides numerous capabilities during the experiments in a very transparent environment to see how the operational dynamics impact the supply chain over time and achieve operational excellence. Therefore, a hybrid application is the best approach which complements each other and should be applied as an optimisation and simulation cycle which is the primary objective of the proposed. To enable such an approach (1) the stack of technology & features, (2) process and cross-functional support, (3) the right amount of skillset and especially (4) the right amount of data must be fully geared with the defined business's strategy which will intuit clear scope and objectives for OST application and decision making. Since this framework is a complete guide in such and raises the awareness of the full potential of OST that will stimulate domain interested community to apply these more frequently which will enhance and shift their knowledge to the next level.

Chapter 6

Validation and refinements

6.1 Need for validation

Once the framework is fully designed and developed to check its robustness, the validation process was vital. Especially due to the limitations and difficulty of finding a real business or entrepreneur who is willing to apply this in their business decision-making process.

The main objective of this external validation process was to obtain the subject and industry experts' opinions in terms of the overall clarity and the way Framework provides clear instructions to the OST users as proposed. Then this was a concern and advised by the examiner during one of the internal viva examinations. The concerns were recognized over responses; necessary refinements have been carried out successfully.

That was very helpful in finding a few areas where some gaps were identified, then performing the necessary modifications and proposing the framework much stronger over the submission. Then definitely this will be very helpful over the viva examination too.

6.2 Validation strategy

6.2.1 Survey questionnaire (Psychometric scale)

The survey constructed was pre-tested with the supervisor to estimate the time roughly how long it will take during the validation. Then based on the recognized criteria, some modifications to the survey were carried out. The survey consists mainly of two sections as follows.

1. Validation of overall clarity of the framework
2. The precision of instructions provides by the framework

The validation process has been carried out in two ways as follows.

- 1st Internally: Conducted a demonstration of the entire framework to the supervisor and modifications have been carried out over the feedback. This filtered and rectified the inefficiencies which existed before sending it to the external validation.

- 2nd Externally: Conducted a Psychometric Scale survey questionnaire over 5 subject and industry experts. Followings were sent along with the survey to provide a quick and easy reference for their validation and obtain better output.

  (1) A brief explanation of the Framework which contains below

    a. Exiting key barriers in the application of OST in SCM and how the Framework has addressed those and embedded the capability to overcome such (see Figure 6.1).

    b. How framework processes guide through step by step to reach the key milestones in OST application and obtain the specific deliverables at the end of each process (see Figure 6.2).

  (2) The full-scale framework

  (3) 10 key Processes and their descriptions

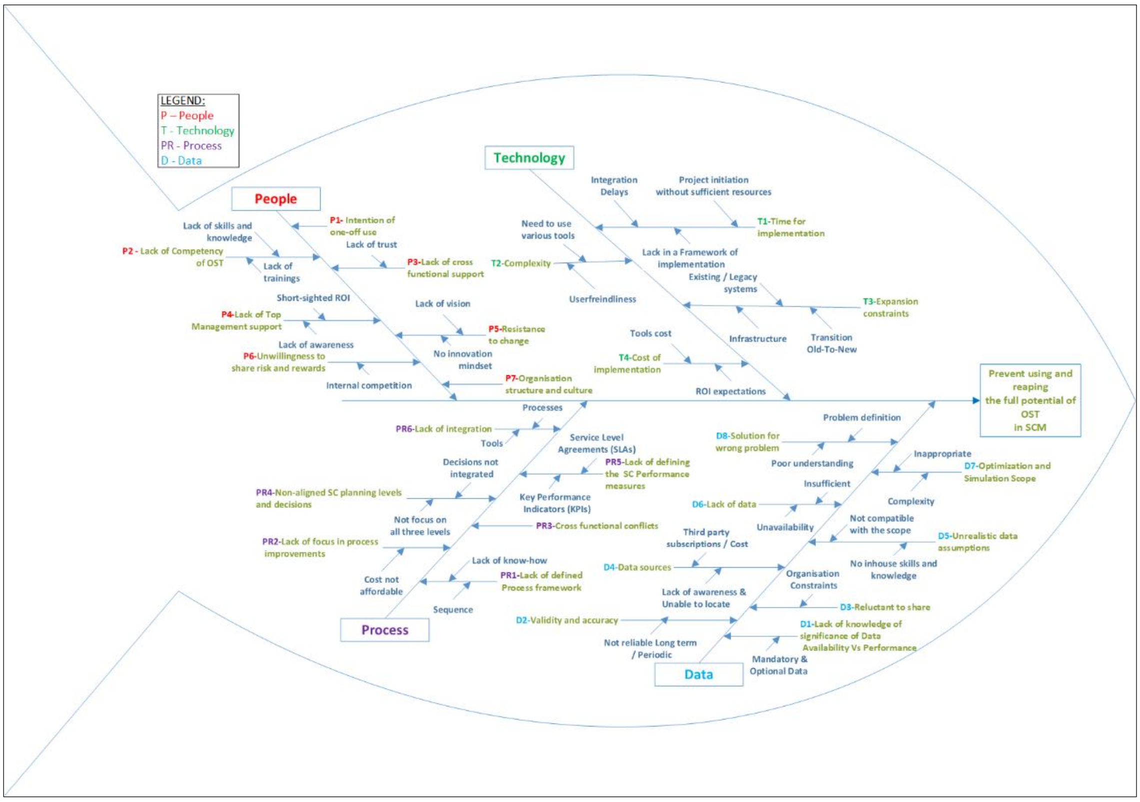


Figure 6. 1: Validation Strategy – Coded CED to show the relationship to OSTiSCM

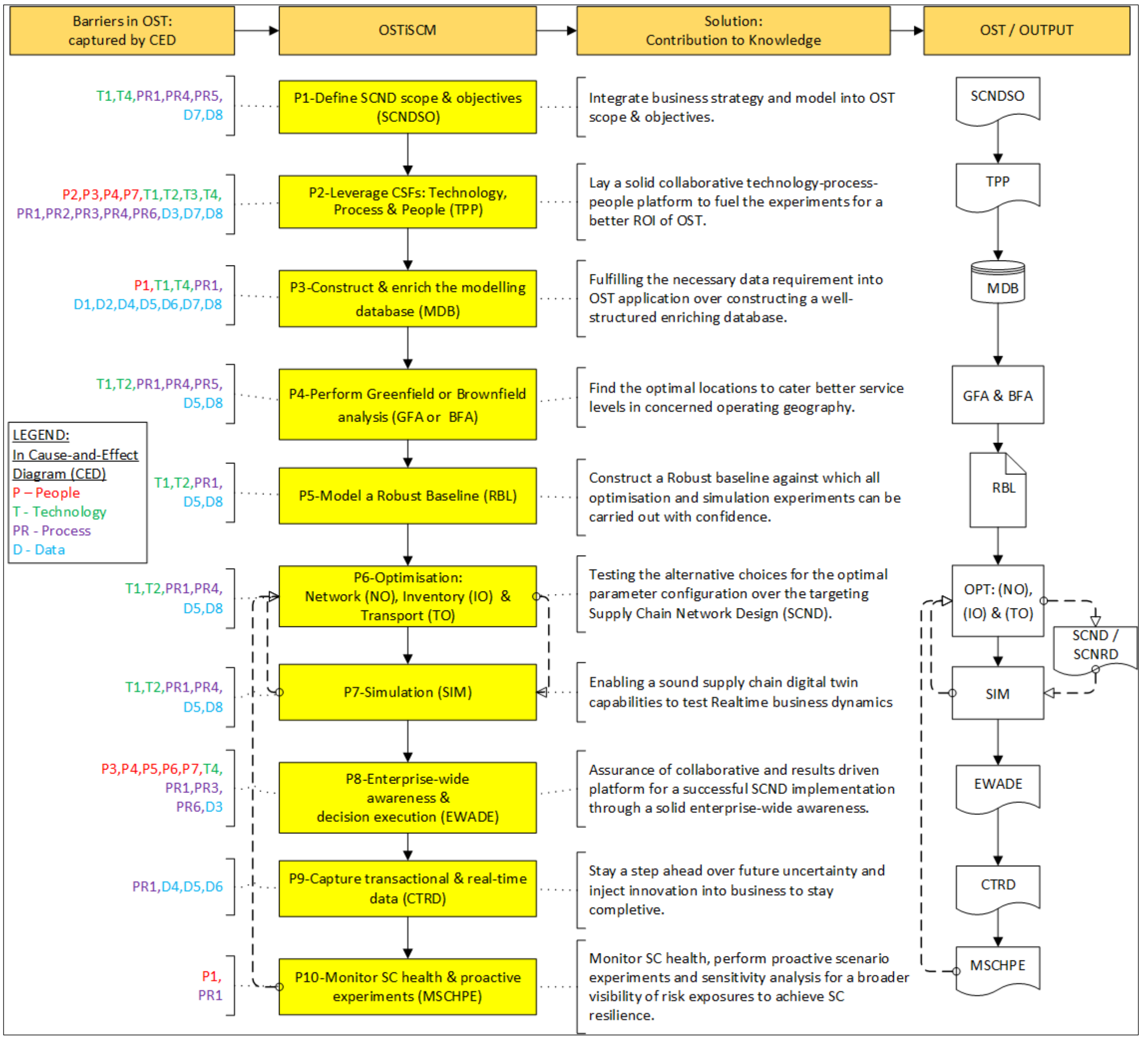


Figure 6. 2: Validation Strategy – Particular Process in OSTiSCM addresses the coded barriers in CED

6.3 Validation outcomes

6.3.1 Responses

The captured responses were analyzed, and result visualization was performed by using MS Excel® (see Figures 6.3 to 6.8).

<u>Analysis method</u>

RESPONSES

SN	OVERALL CLARITY OF THE FRAMEWORK	OVERALL CLARITY				
		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	The overall structure of the proposed framework is logical and systematic	3	2	0	0	0
2	The framework has been presented in a concise manner	2	2	1	0	0
3	Overall presentation is clear	3	2	0	0	0
4	Processes have been appropriately labelled	4	1	0	0	0
5	Connections between sub-processes and main processes are clear	4	1	0	0	0
6	Tasks provide clear instructions	3	2	0	0	0
7	Flow is unambiguous	4	1	0	0	0
		23	11	1	0	0

SN	Validator 1					Validator 2					Validator 3					Validator 4					Validator 5				
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	1					1					1						1					1			
2		1				1						1					1						1		
3	1						1				1					1						1			
4	1					1					1					1						1			
5		1				1					1					1					1				
6	1					1						1				1						1			
7	1					1					1						1				1				

SN	PROVIDE CLEAR INSTRUCTIONS	OVERALL CLARITY				
		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	Integrate business strategy and model into the OST scope & objectives.	3	2	0	0	0
2	Lay a solid technology-process-people platform to stimulate the experiments	2	2	1	0	0
3	Fulfil the necessary data requirement into OST application over a well-structured database.	3	2	0	0	0
4	Find the optimal locations to produce better service levels	4	1	0	0	0
5	Construct a Robust baseline against which all optimisation and simulation experiments can be carried out.	3	2	0	0	0
6	Testing the alternative choices for the optimal parameter configuration over the targeting Supply Chain Network Design (SCND).	2	2	1	0	0
7	Enabling a sound supply chain digital twin capabilities to test Realtime business dynamics	3	2	0	0	0
8	Assurance of collaborative and results driven platform through the solid enterprise-wide awareness for a successful SCND implementation.	4	1	0	0	0
9	Stay a step ahead over future uncertainty and inject innovation into business to stay competitive.	2	2	1	0	0
10	Monitor SC health, perform proactive experiments and sensitivity analysis to achieve SC resilience.	2	3	0	0	0
		51	30	4	0	0

SN	Validator 1					Validator 2					Validator 3					Validator 4					Validator 5				
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	1						1				1						1				1				
2	1					1						1						1				1			
3	1					1						1					1				1				
4	1					1					1						1				1				
5	1					1						1					1				1				
6		1				1						1				1							1		
7	1						1				1					1						1			
8	1					1					1						1				1				
9	1					1							1				1					1			
10		1				1						1					1				1				

Figure 6. 3: Capturing the validation responses

ANALYSIS

SN	OVERALL CLARITY OF THE FRAMEWORK	OVERALL CLARITY				
		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	The overall structure of the proposed framework is logical and systematic	60	40	0	0	0
2	The framework has been presented in a concise manner	40	40	20	0	0
3	Overall presentation is clear	60	40	0	0	0
4	Processes have been appropriately labelled	80	20	0	0	0
5	Connections between sub-processes and main processes are clear	80	20	0	0	0
6	Tasks provide clear instructions	60	40	0	0	0
7	Flow is unambiguous	80	20	0	0	0

SN	PROVIDE CLEAR INSTRUCTIONS	INSTRUCTION-WISE				
		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	Integrate business strategy and model into the OST scope & objectives.	60	40	0	0	0
2	Lay a solid technology-process-people platform to stimulate the experiments	40	40	20	0	0
3	Fulfil the necessary data requirement into OST application over a well-structured database.	60	40	0	0	0
4	Find the optimal locations to produce better service levels	80	20	0	0	0
5	Construct a Robust baseline against which all optimisation and simulation experiments can be carried out.	60	40	0	0	0
6	Testing the alternative choices for the optimal parameter configuration over the targeting Supply Chain Network Design (SCND).	40	40	20	0	0
7	Enabling a sound supply chain digital twin capabilities to test Realtime business dynamics	60	40	0	0	0
8	Assurance of collaborative and results driven platform through the solid enterprise-wide awareness for a successful SCND implementation.	80	20	0	0	0
9	Stay a step ahead over future uncertainty and inject innovation into business to stay competitive.	40	40	20	0	0
10	Monitor SC health, perform proactive experiments and sensitivity analysis to achieve SC resilience.	40	60	0	0	0

Figure 6. 4: Analysing the validation responses

6.3.2 Results visualization and discussion

<u>Overall Clarity</u>

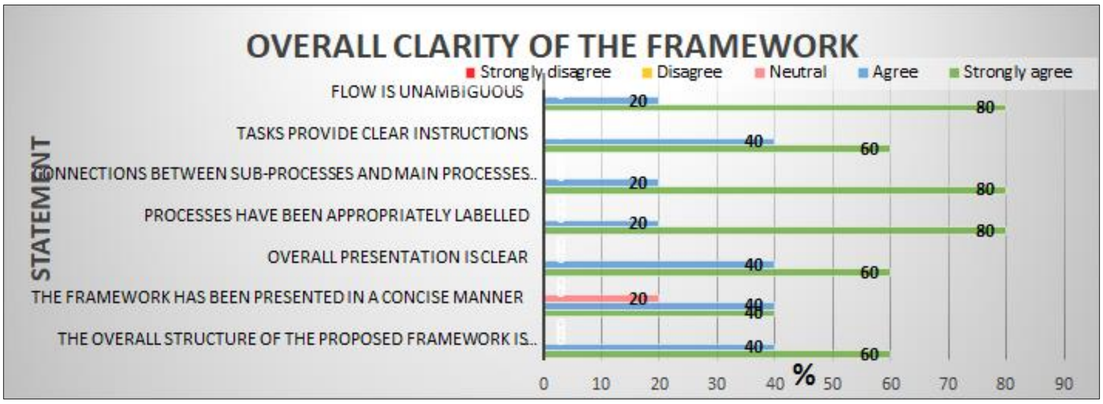


Figure 6. 5: Validation results – Overall clarity of the Framework: Statement-wise

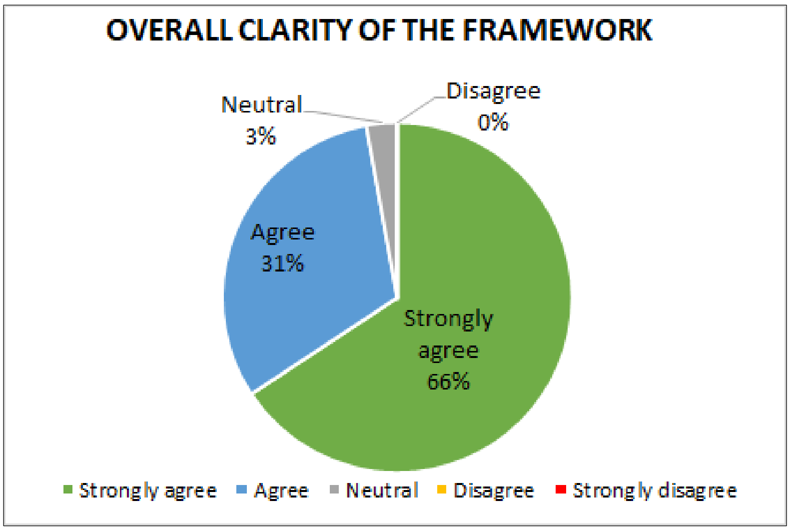


Figure 6. 6: Validation results - Overall clarity of the Framework

It's a good indication that 2/3 of a proposition strongly agrees with the overall clarity of the framework. There is another almost closer to 1/3 proposition that confirmed that they can stand as ''Agree'' which is also a good sign but provided some suggestions on where to consider for the refinements. Then there is a very minor proposition which is that 3% falls under ''Neutral'' but taken this seriously into consideration to do some refinements in terms of the presentation of the framework. No one stood by ''Disagree'' which indicated a very good sign in terms of the overall clarity.

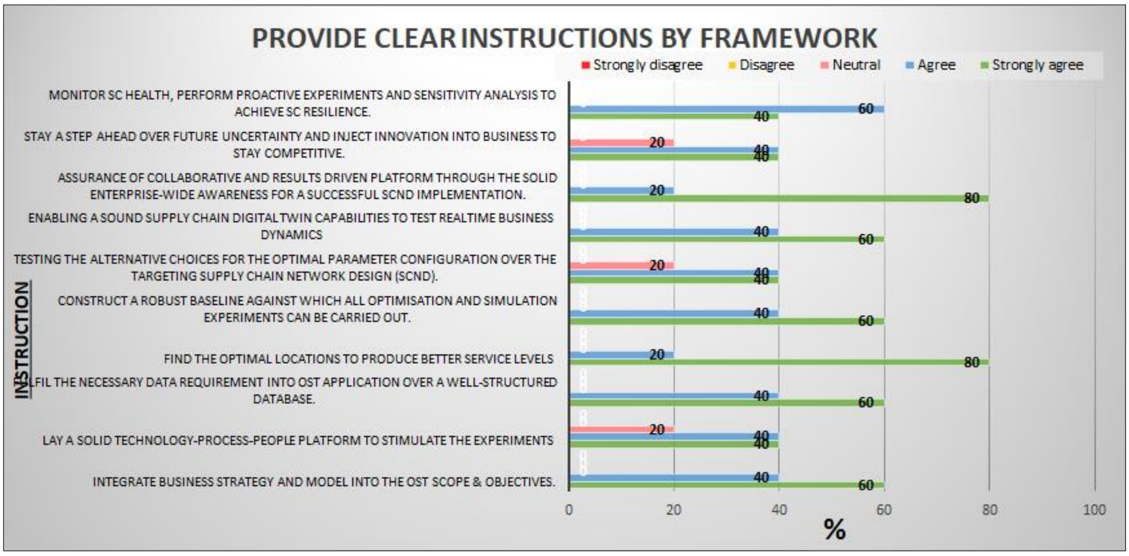


Figure 6. 7: Validation results – Clear instructions provided by the framework: Instruction-wise

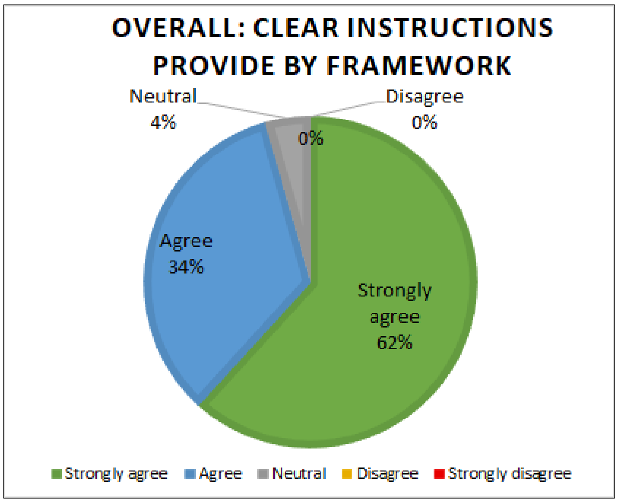


Figure 6. 8: Validation results - Overall Clear instructions provided by the Framework

It's a good indication that a bigger proposition which is more than 60% ''Strongly Agree'' in terms of clear instructions provided by the Framework. There is another 1/3 proposition confirmed that they can stand as ''Agree'' which is also a good sign but provided some suggestions on where to consider for the refinements. In which area of instructions especially the tasks of the processes and their descriptions in the framework could have been done much better. Then there is a very minor proposition which is 4% falls under ''Neutral'' but takes this seriously into consideration to do some refinements in the framework. No one stood by ''Disagree'' which indicated a very good sign in terms of the overall instruction provided by the framework.

6.4 Refinements

Based on the above results the refinements which have been carried out can be described briefly in two ways. Before taking any modifications against the Baseline Framework (Pre-Validation) all points were discussed in detail in the supervisor's presence.

6.4.1 Overall clarity:

1. Presentation in a concise manner: Improvements were done by further squishing the processes' tasks, and abstracting the length of their labels to bring a more concise manner into the framework (higher priority was given to this one since there was a 20% response as ''Neutral''
2. Further screening of all the processes which contain sub-process has been carried out some sub-processes were renamed to provide collective / aggregated ideas by the main Process.
3. Some tasks in the process were amended to provide clear instructions

6.4.2 Instructions provided by Framework:

These three Processes were highly concerned with refinements since responses have been provided as ''Neutral'' in providing instructions.

- P2-Leverage CSFs: Technology, Process & People (TPP)
    - Few tasks were amended and able to provide much more detailed instructions and highlight the significance of this process.
- P6-Optimisation: Network (NO), Inventory (IO) & Transport (TO)
    - Suggested some extra data fields in data tables under the Data requirement subheading to provide a clear idea about how OST users can bring in a decent complexity to their models by gearing up with more granular ''Data Fields'' into their Modelling Database (MDB). This is the reason more data fields were suggested over the NO before moving into very specifically like inventory transport and their simulation. In this survey responses provided a big contribution
- P9-Capture transactional & real-time data (CTRD)
    - There were some minor modifications done in this process as well in terms of data sources/types and how these can be connected through an API

(Application Programming Interface) and then passed alert to the OST team.

6.5 Conclusions

The validation process and results provided broader intuitions in how the framework could have been finetuned further in terms of the overall clarity and the precision of the instructions provided. All the possible refinements were executed successfully unless any limitations associated with such have been described in chapter 7 under limitations and recommendations for the future. Since it was not that difficult to embed the recognised modifications to the Baseline Framework (Pre-Validation Framework) that justified the framework has been constructed with a solid foundation/approach. Therefore, it reflects that the proposed framework is fully capable and supportive of any future developments which take OSTiSCM to the next level. In such as an improvement of the usefulness and simplification bring in some automation into it is desirable.

Chapter 7

Conclusions

The first section of this chapter illustrates the summary of the research findings and how that contributes to the existing domain knowledge as novel value addition. In the second part how the depth of the research went in, the personal experience gained by using OST and yet the limitation that exists within the research study is explained. Then finally, the recommendations on how future work can be derived by bringing enhancements to this novel framework are described.

7.1 Summary of findings and contribution to knowledge

Application of OST ad hoc basis just in specific problems in isolation is not the right path to reap the full potential return out the investment of time and cost over these tools. It is well-recognised that previous research works in OST have focused on the development of frameworks which aim to improve some areas rather than taking the whole process of the deployment cycle into account which factually helps to embed these tools into any business and decision-making process. If businesses can embed these tools in the cycle which is well integrated from the business strategy point of view until a solid enterprise-wide awareness to execute that well-experimented SCND or SCNRD strategy over OST that's the best path to reach the deployment maturity.

The business strategy should be well reflected within the OST scope and objectives. Then in return, it will provide a clear requirement specification of the right stack of OS Tools, features and support which is mandatory, and the business must gear up throughout the OST experiments.

Once the business is well geared with the right OST package then it's all about a well-integrated process to follow, the skill set of the user and assurance of the mandatory data in hand before execution of the project.

Then the well-scoped experiments done over a such platform provide a robust SCND strategy which will produce the best network configuration and parameters for the concerned business operating geography.

As such since this framework, OSTiSCM is moulded with that robustness which provides a solid knowledge contribution to the OST community (either industry or academia) who can use this as a guide to achieving a state-of-the-art SCND to nourish a sound operational excellence in the application of OST. Therefore, the new knowledge distribution can be grasped through this framework by existing businesses, entrepreneurs, researchers or even students in a very multifaceted nature which can be illustrated in bullet points as follows. The research was very successive from the point of contribution to knowledge since all listed areas have been fully captured over 10 Processes within the proposed OSTiSCM.

Process in OSTiSCM	Area of knowledge
1	Integrate business strategy and model into OST scope & objectives.
2	Lay a solid collaborative technology-process-people platform to fuel the experiments for a better ROI of OST.
3	Fulfilling the necessary data requirement into OST application over constructing a well-structured enriching database.
4	Find the optimal locations to cater to better service levels in the concerned operating geography.
5	Construct a Robust baseline against which all optimisation and simulation experiments can be carried out with confidence.
6	Testing the choices for the optimal parameter configuration over the targeting Supply Chain Network Design (SCND).
7	Enabling a sound supply chain digital twin capabilities to test real-time business dynamics
8	Assurance of collaborative and results-driven platform for a successful SCND implementation through a solid enterprise-wide awareness.

9	Stay a step ahead over future uncertainty and inject innovation into business to stay completive.
10	Monitor SC health and perform proactive scenario experiments and sensitivity analysis for broader visibility of risk exposures to achieve SC resilience.

7.2 Limitations

At the very initial stage of the research, the scope to design and develop this framework is purely triggered by the identified gap in the existing research context. Then as moved on, the local and international conferences, symposiums, and seminars attended through the university, helped to pave a superb platform to build some interesting connections among industrial and other academic personnel.

In return, these connections helped by contributing to the survey questionnaire, interviews and then even with the final validation process of the framework. On top of that, the hands-on experience obtained by working on hypothetical model building provided very pragmatic insights where this framework can help in both business's perspective and future research context.

But it is very limited and not straight forwards to convince a business or entrepreneur to apply this proposed in their business decision-making process.

Thus, it can be recognized that the primary achievement of this research is provisioning the novel idea of the structured approach for the future enhancement of academic space. Also, for the community of entrepreneurs who are willing to execute their novel business, ideas into reality but need a solid framework to test and quantify their supply chain strategy before any investment.

7.3 Recommendations for future work

Process & content refinement:

During the validation process, the outcomes of the results provided some good intuition regarding the amount of process and content that exists in the proposed framework. The suggestions were about checking the possibility of reducing the amount of the stepwise process and squishing the content into it. Suggestions were taken into consideration up to some extent and able to merge a few processes and content.

But injecting a higher level of rationalization into some areas during that stage was limited. So, it's highly recommended to bring those improvements/alterations into the framework in future developments. But significantly, any modifications taken into consideration do not eliminate any vital steps and content within the current framework which may affect the robustness negatively.

Development of an automated guide:

This framework act as a complete step-by-step guide with instructions yet in a graphical format (paper-based) which the user must follow manually. So, businesses or users may be fascinated by automated instructions rather than manual ones. In such a case, if the proposed framework can be transformed into an automated Graphical User Interface (GUI) as an application that will be very attractive and can embed more automated features in it with which users can fast track the process.

For instance, if it's a mobile application, users can simply select the current state of the business and scope of OST over their decision-making requirement from just a simple dropdown which will route them to the next step. The user can simply rate/define the current strength within the business in terms of Technology, Process and People (skill level) and the application will provide a well-customized stack of OS Tools, features, and support with the required skill set.

Then the same can be applied in terms of data requirements and so on. So, its highly recommended a transformation of this manual framework into a novel automated one which will provide further enhancements in fast-tracking the user's process in decision making and preventing any errors which can cause following manually (i.e., missing any step's significant consideration/ suggestions under any subprocess).

Business operation-centric customization over data granularity

This proposal is not specifically targeted at any precise goods or service provisioning industry. But the robustness embedded in it provides the capability and adaptability in application in any operational environment. Fulfilling the data requirement into OST business operations and their characteristics wise always varies and is very challenging. This was another concern acknowledged over the validation outcomes.

Therefore, it's highly recommended for the OST community who are fascinated to go more granular operational finetuning in any precise product or service to reach a state-of-the-art SCND, this can be adapted as per such scope. For an instance, any future developments targeting 3PL service providers who are into business in provisioning just space (distribution centre or warehousing facilities) their scope of the business is limited to inside 4 walls operation. So, the data requirement is bounded to those operational assets and logic that interact with each other.

Therefore, any future development can bring into the proposal by remoulding the way businesses can ''construct and enrich the modelling database'' as per their operational characteristics' data granularity and business logic.

Any further development over a new research outcome raises a sound awareness in both academia and industry. Also, that stimulates the targeting community in the frequent application of the same in either industry or academic space. As the author witnesses, more success stories and enhancements which can be built upon this novel robust framework will be very inspiring and motivational to take the OSTiSCM to the next level.

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Appendix 1: Survey Questionnaire

Survey Questionnaire

Use of Optimization & Simulation Tools in Supply Chain Management

Introduction

Researcher: Ranjika Gunathilaka	Research Supervisor: Prof. Terrence Perera
Research Degree: PhD	Framework for embedding Optimisation & Simulation Tools in Supply Chain Management

Purpose of the survey

I am a PhD candidate at the Sheffield Hallam University, United Kingdom. It seems that most companies use Optimization and Simulation Tools (OST) to address specific problems in isolation. These tools are hardly embedded in design, operations, and enhancement of supply chains. Therefore, the proposed research aim is to design and develop a framework to embed this Tools in Supply Chain Management. This survey aims to collect information on where OST have been used in supply chain management context and what the existing barriers over the deployment of these Tools.

As the subject / industry experts, I highly appreciate you taking not more than 10 minutes of your time to complete this survey which will be very supportive towards my research.

Confidentiality of data collected

The personal identifiable information collects here will be removed and described as anonymous when it comes to publication. In addition to this, please note that all data is handled here in accordance with the SHUREC (Sheffield Hallam University Research Ethics Committee) standards and regulations during the entire life cycle of survey.

Respondent's information (OPTIONAL)	
Company Name	
Type of the Industry	
Qualifications / if any	
Job Role / Description	
Length in this role /industry	
Contact / Email Address	

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Have you ever used simulation / optimization tools or their applications to determine?

Please mark your responses for all items in the table below by putting a " ✓ "

SECTION 1 - Supply Chain Design	
Network	
Right "size" of your supply chain network (Size: No. of facilities)	
Right "sites" of your supply chain network (Sites: Locations)	
Right service levels	
Inventory	
Right inventory levels	
Right inventory placements (i.e., Inventory at different locations)	
Appropriate Inventory policies	
Transportation and route	
Optimal mode of transportation for the supply chain (Mode)	
Optimal level of transportation assets (Fleet)	
The most efficient routings (Route)	

SECTION 2 - Supply Chain Operation	
Operation analysis	
DC / hubs / warehouse performance and maximize the utilization	
Delivery performance and customer satisfaction / order fulfilment	
Workforce analysis	
Asset's utilization / performance	
Right amount of workforce	
Risk analysis (Disruptions and Resilience)	
The level of risk in supply chain (Current / Future)	

SECTION 3 - Supply Chain Enhancement	
Performance Improvement beyond KPI's	
Delivery / Order fulfilment	
Sites / DC/ Warehouse performance	
Mergers and Acquisitions	
Feasibility of sites consolidation (Structure)	
Feasibility of transport consolidation (Distribution)	
Innovation and cooperate & Social Responsibility	
Reducing the work force and maximize the use of automation	
Environmental sustainability (Analyse / optimise the impact on the environment)	

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SECTION
• What are the barriers do you see in implementing of simulation / optimization tools in companies?
• Do you find the existing simulation / optimization tools are flexible as per the today's business needs?

Thank you for completing this survey and contributing to my research with your honest opinions and thoughtful suggestions.

Appendix 2: Semi-structured Interview Questionnaire

Interview Questionnaire

Use of Optimization & Simulation Tools in Supply Chain Management

Introduction

Researcher: Ranjika Gunathilaka	Research Supervisor: Prof. Terrence Perera
Research Degree: PhD	Framework for embedding Optimisation and Simulation Tools in Supply Chain Management

Purpose of the survey

I am a PhD candidate at the Sheffield Hallam University, United Kingdom. As a part of my research, I further investigate where and how the Optimization and Simulation Tools (OST) have been deployed in Supply Chain Management (SCM) in any industry in terms of (1) Application Domains/Areas (i.e., Supply Chain Transport Optimisation), (2) The Usage of the Tools and (3) The Barriers which prevent using or reaping the full benefits out of these tools. It seems that most users use OST in SCM to address specific problems in isolation and these tools are hardly embedded in the Design, Operations and Enhancement of supply chains life cycle. Therefore, the proposed research's aim is to design and develop a framework to embed these OST in SCM and decision-making processes.

I highly appreciate if you could take some of your valuable time to complete this survey questionnaire which will be very supportive and strengthen the development of my novel framework which will be useful as a reference for all the users of OST in SCM.

Confidentiality of data collected

The personal identifiable information collects here will be removed and described as anonymous when it comes to publication. In addition to this, please note that all data is handled here in accordance with the SHUREC (Sheffield Hallam University Research Ethics Committee) standards and regulations during the entire life cycle of survey.

Respondent's information	
Name / Company	
Type of the Industry	
Job Role	
Contact / Email Address	

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If your opinions / statements can be a bit descriptive, that would be very helpful for a depth analysis and contribute immensely for a successful development of a novel framework.

Q1: As at present, what do you think about the Optimization and Simulation Tools (OST) in the context of Supply Chain Management (SCM)?

Q2: What do you think about the awareness, skills and knowledge, process of deployment and the usage of OST among the SCM professionals at present?

Q3: What are the potential application domains of OST in SCM? (i.e., Supply Chain Design, Operation, Re-Design/Enhancement)

Q4: What are the barriers which prevent using or reaping the full potential out of these OST in SCM? (i.e., People, Process, Technology, Data)

Q5: Among what you listed (In the answers of Q4) may I ask you to rank the barriers from most to least and reasoning why?

Q6: What do you think about the requirement and significance at present for a Robust Framework which OST users can use as a Reference in terms of SC Design, Operation & Re-Design?

Thank you for completing this survey and contributing to my research with your honest opinions and thoughtful suggestions.

Appendix 3: Validation Survey Questionnaire

Survey Questionnaire

Validation of the proposed Framework ‘‘OSTiSCM’’

(Optimisation and Simulation Tools in Supply Chain Management)

Introduction

Researcher: Ranjika Gunathilaka	Research Supervisor: Prof. Terrence Perera
Research Degree: PhD	Research Title: Framework for embedding Optimisation and Simulation Tools in Supply Chain Management

Purpose of the survey

I am a PhD candidate at the Sheffield Hallam University, United Kingdom. My research was focused on design and develop a framework to embed Optimisation and Simulation Tools (OST) in Supply Chain Management (SCM). It seems most of the businesses yet use these tools for specific problems in isolation rather use them in their entire cycle of business decision making process in the context of SCM. Thus, the proposed framework ‘‘OSTiSCM can be used by them as a complete guide to embed these Tools in their business decision making process to achieve the operational excellence and supply chain resilience.

As the subject / industry experts if you could please take some of your valuable time to validate this framework by completing the attached psychometric scale survey that will be very supportive and strengthen the necessary refinements to be done prior to it goes for the final submission.

The appendices enclosed herewith illustrates the full framework can listed as follows.

1. A brief explanation about the Framework (Existing barrier and how OSTiSCM have addressed them)
2. The full-scale Framework
3. 10 key Processes and their descriptions

Confidentiality of data collected

The personal identifiable information collects here will be removed and described as anonymous when it comes to publication. In addition to this, please note that all data is handled here in accordance with the SHUREC (Sheffield Hallam University Research Ethics Committee) standards and regulations during the entire life cycle of survey.

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Respondent's information

Name / Company	
Industry	
Job Role	

Please mark rating by putting a 'X'

	OVERALL CLARITY OF THE FRAMEWORK	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	The overall structure of the proposed framework is logical and systematic					
2	The framework has been presented in a concise manner					
3	Overall presentation is clear					
4	Processes have been appropriately labelled					
5	Connections between sub-processes and main processes are clear					
6	Tasks provide clear instructions					
7	Flow is unambiguous					

	FRAMEWORK PROVIDE CLEAR INSTRUCTIONS TO:	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	Integrate business strategy and model into the OST scope & objectives.					
2	Lay a solid technology-process-people platform to stimulate the experiments					
3	Fulfil the necessary data requirement into OST application over well-structured database.					
4	Find the optimal locations to produce better service levels					
5	Construct a Robust baseline against which all optimisation and simulation experiments can be carried out.					
6	Testing the alternative choices for the optimal parameter configuration over the targeting Supply Chain Network Design (SCND).					
7	Enabling a sound supply chain digital twin capabilities to test Realtime business dynamics					
8	Assurance of collaborative and results driven platform through the solid enterprise-wide awareness for a successful SCND implementation.					
9	Stay a step ahead over future uncertainty and inject innovation into business to stay competitive.					
10	Monitor SC health, perform proactive experiments and sensitivity analysis to achieve SC resilience.					

Thank you for completing this survey and contributing to my research with your honest opinion.

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--The End--