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## An Integrated Retail Supply Chain Risk Management Framework: A System Thinking Approach

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# **An Integrated Retail Supply Chain Risk Management Framework: A System Thinking Approach**

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**Dublin Institute of Technology**

College of Business

**Supervisor: Professor Amr Arisha**



## ABSTRACT

It is often taken for granted that the right products will be available to buy in retail outlets seven days a week, 52 weeks a year. Consumer perception is that of a simple service requirement, but the reality is a complex, time sensitive system - the retail supply chain (RSC). Due to short product life-cycles with uncertain supply and demand behaviour, the RSC faces many challenges and is very vulnerable to disruptions. In addition, external risk events such as *BREXIT*, extreme weather, the financial crisis, and terror attacks mean there is a need for effective RSC risk management (RSCRM) processes within organisations. Literature shows that although there is an increasing amount of research in RSCRM, it is highly theoretical with limited empirical evidence or applied methodologies. With an active enthusiasm coming from industry practitioners for RSCRM methodologies and support solutions, the RSCRM research community have acknowledged that the main issue for future research is not tools and techniques, but collaborative RSC system wide implementation.

The implementation of a cross-organisational initiative such as RSCRM is a very complex task that requires real-world frameworks for real-world practitioners. Therefore, this research study attempts to explore the business requirements for developing a three-stage integrated RSCRM framework that will encourage extended RSC collaboration. While focusing on the practitioner requirements of RSCRM projects and inspired by the laws of *Thermodynamics* and the philosophy of *System Thinking*, in stage one a conceptual reference model, *The P6 Coefficient*, was developed building on the formative work of supply chain excellence and business process management. *The P6 Coefficient* reference model has been intricately designed to bridge the theoretical gap between practitioner and researcher with the aim of ensuring practitioner confidence in partaking in a complex business process project. Stage two focused on a need for a standardised vocabulary, and through the *SCOR11* reference guide, acts as a calibration point for the integrated framework, ensuring easy transfer and application within supply chain industries. In their design, stages one and two are perfect complements to the final stage of the integrated framework, a risk assessment toolbox based on a *Hybrid Simulation Study* capable of monitoring the disruptive behaviour of a multi-echelon RSC from both a macro and micro level using the techniques of *System Dynamics* (SD) and *Discrete Event Simulation* (DES) modelling respectively.

Empirically validated through an embedded mixed methods case study, results of the integrated framework application are very encouraging. The first phase, the secondary exploratory study, gained valuable empirical evidence of the barriers to successfully implementing a complex business project and also validated using simulation as an effective risk assessment tool. Results showed certain high-risk order policy decisions could potentially reduce total costs (TC) by over 55% and reduce delivery times by 3 days. The use of the *P6 Coefficient* as the communication/consultation phase of the primary RSCRM case study was hugely influential on the success of the overall hybrid simulation study development and application, with significant increase in both practitioner and researcher confidence in running an RSCRM project. This was evident in the results of the hybrid model's macro and micro assessment of the RSC. SD results effectively monitored the behaviour of the RSC under important disruptive risks, showing delayed effects to promotions and knowledge loss resulted in a bullwhip effect pattern upstream with the FMCG manufacturer's TC increasing by as much as €50m. The DES analysis, focusing on the NDC function of the RSC also showed results of TC sensitivity to order behaviour from retailers, although an optimisation based risk treatment has reduced TC by 30%. Future research includes a global empirical validation of the *P6 Coefficient* and enhancement of the application of thermodynamic laws in business process management. The industry calibration capabilities of the integrated framework application of the integrated framework will also be extensively tested.

## DECLARATION

I certify that this thesis which I now submit for examination for the award of Doctor of Philosophy is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any other third level institution. The work reported on in this thesis conforms to the principles and requirements of the DIT's guidelines for ethics in research.

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Signature John Ceame Date 12/04/2018



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## ABBREVIATION LIST

ABM	Agent-Based Modelling
AC	Formative Case Study Company
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
<i>Am</i>	Asset Management Set
ANOVA	Analysis of Variance
B2B	Business-to-Business
B2C	Business-to-Consumer
BMI	Brand Marketing Investment
BOGOF	Buy One Get One Free
BPM	Business Process Management
BPMM	Business Process Maturity Model
BPMo	Business Process Modelling
BPO	Business Process Orientation
BPR	Business Process Reengineering
BSC	Balanced Scorecard
BWE	Bullwhip Effect
CCP	Critical Control Points
<i>Ci</i>	Continuous Improvement Set
CLD	Causal Loop Diagram
COSO	Committee of Sponsoring Organisations of the Treadway Commission
CPFR	Collaborative Planning Forecasting and Replenishment
CSO	Central Statistics Office
DC	Distribution Centre
DES	Discrete Event Simulation
DFD	Dataflow Diagrams
DMAIC	Define, Measure, Analyse, Improve, and Control
DOE	Design of Experiments
DS	Decision Support
DSS	Decision Support Systems
DTS	Deliver-to-Stock
ECR	Efficient Consumer Response
ERP	Enterprise Resource Planning
FGP	Factory Gate Pricing
FMCG	Fast Moving Consumer Goods
FMEA	Failure Mode Effect Analysis
FOQ	Forecasted Order Quantity
FQ	Forecast Quantity
FTF	Farm-to-Fork

HACCP	Hazard Analysis and Critical Control Points
HAZOP	Hazard and Operability Studies
HHM	Hierarchical Holographic Modelling
HRA	Human Reliability Analysis
IDEF	Integrated Definition for Function Modelling
<i>Is</i>	Information Systems Set
ISO	International Standards Organisation
JIT	Just-in-Time
KAS	Knowledge about Systems
KPI	Key Performance Indicator
LCC	Life Cycle Costing
LT	Lead-Time
MCDA	Multi-Criteria Decision Analysis
MTMM	Multitrait-Multimethod Matrix
NDC	National Distribution Centre
NPV	Net Present Value
OF	Order Frequency
OOS	Out-of-Shelf
OR	Operations Research
OSA	On-Shelf Availability
P&H	Plumping and Heating
PAIS	Process-Aware Information Systems
PO	Purchase Order
QR	Quick Response
RCM	Reliability Centred Maintenance
RFID	Radio-Frequency Identification
RM	Risk Management
RSC	Retail Supply Chain
RSCM	Retail Supply Chain Management
RSCRM	Retail Supply Chain Risk Management
RSM	Response Surface Methodology
S/N	Signal-to-Noise Ratio
SC	Supply Chain
SCC	Supply Chain Council
SCD	Supply Chain Disruption
SCM	Supply Chain Management
SCO	Supply Chain Orientation
SCOR11	Supply Chain Operations Reference Model version 11
SCRe	Supply Chain Resilience
SCRM	Supply Chain Risk Management
SCV	Supply Chain Vulnerability

SD	System Dynamics
SKU	Stock Keeping Unit
SS	Safety Stock
SSL	Safety Stock Level
SWIFT	Structured <<What If>>
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TC	Total Cost
TCO	Total Cost of Ownership
TOC	Theory of Constraints
TQ	Total Quality
TQM	Total Quality Management
TSS	Theory of Scenario Structuring
VAR	Value-at-Risk
VSM	Value Stream Mapping
VUCA	Volatile, Uncertain, Complex and Ambiguous
WERC	Warehousing Education and Research Council
WIP	Work in Process

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## LIST OF PUBLICATIONS

### Journal Articles

Tobail, A., **Crowe, J.**, & Arisha, A. (2016). *Interactive learning: developing an eSimulation portal framework*. The Irish Journal of Management, 35(1), 17-33. doi:10.1515/ijm-2016-0002

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Abo-Hamad, W., **Crowe, J.**, & Arisha, A. (2012). *Towards Leaner Healthcare Facility: Application of Simulation Modelling and Value Stream Mapping*. Paper presented at the Proceedings of the International Workshop on Innovative Simulation for Healthcare (I-WISH), Vienna, 2012.

**Crowe, J.**, & Arisha, A. (2012). *Increasing Value Generation Using a Hierarchical Simulation-Based SCOR Framework*. Paper presented at the ICOVACS 2012 International Conference on Value Chain Sustainability, Izmir, 2012.

**Crowe, J.**, & Arisha, A. (2013). *An Integrated Decision Support Framework For Assessing Food Supply Chain Risk Management Processes: A Food Retail Case Study*. Paper presented at the 20th European Operations Management Association (EurOMA) Conference, Dublin, 2013.

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### **Book Chapter**

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Tobail, A., **Crowe, J.** & Arisha, A., (2012). *Serious Gaming Learning : Supply Chain Multi-Agent Web-Based Simulation Game*. Poster presented at ICERI Conference, Madrid, 2012.

### **Newspaper Article**

**Crowe, J.** (2013, 9th March 2013). *Entire cast in horsmeat scandal must recognise role*. The Irish Examiner, p. 22. Retrieved from <http://www.irishexaminer.com/archives/2013/0309/business/entire-cast-in-horsemeat-scandal-must-recognise-role-224942.html>



### Chapter 1. Introduction

*“There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace.”*

— Aldo Leopold

#### 1.1 Overview

The discipline of supply chain management (SCM) arose from managers’ recognition that getting the balance between supply, demand and customer satisfaction is an extremely expensive process. Once seen as a necessary evil to manage an organisations pipeline costs, by the turn of the last century, decision makers realised that SCM was a source of competitive advantage and not only a cost driver (Snyder & Shen, 2011). The supply chain (SC) pervades every dimension of our lives. It is so intrinsic to our everyday activities that any potential risk of supply disruption or failure can have costly consequences. For decision makers, the “Holy Grail” in SCM is the effective and efficient understanding, mitigation and control of all uncertainties, constraints and risks within their SC network. This has given rise to the area of supply chain risk management (SCRM).

SCRM is a nascent decision making process emerging from the growing appreciation of SCM and its associated risks within industry and academia (Sodhi, Son, & Tang, 2012). However, when the business world thinks of risk, they are generally financial risks, and refer to areas such as insurance, investments, and hedge funds (Manuj & Mentzer, 2008). But since major disruptions to global supply, such as; the 9/11 terrorist attacks and Hurricane Katrina in the US; foot and mouth disease in the UK; the volcanic ash clouds over Iceland, the tsunami that hit Japan in 2011; or the global horsemeat scandal

uncovered in Ireland in 2013; SCRM has received ever-greater attention of research to study the impact of unexpected events on the SC performance (Crowe, 2013; Monahan, Laudicina, & Attis, 2003; R. D. Wilding, 2007; Wilson, 2007).

The dynamic nature of retail supply chains (RSC, for consistency, the remainder of this research study will refer to all supply chains as RSC) and their complexity make them vulnerable to many kinds of internal and external risk. RSC vulnerability has been heightened by the relentless drive for cost cutting initiatives and the implementation of lean techniques such as Just-in-Time delivery (JIT) and Six Sigma, which have left very little room for error in decision making processes and a requirement of a high level of RSC dynamics understanding.

### **1.2 Problem Definition**

Over the past decade, a common theme in many leading journal article abstracts and introductions, from operations research (OR) to keyhole surgery, is that of describing the article discipline as complex, or uncertain or full of ambiguous, turbulent challenges. In fact, this is such a frequent theme in describing one's surroundings that the US military coined the term *VUCA* to describe how the world would be like after the collapse of the Soviet Union at the beginning of the 1990's (Casey, 2014). *VUCA* stands for volatile, uncertain, complex and ambiguous, terms that OR professionals or heart surgeons can quite rightly take ownership of in their respective disciplines. But in reality the world has always been *VUCA*, and it is no more *VUCA* in 2017 than it has ever been (Martin, 2013). In fact, Martin highlights this further when he cites (Mintzberg, 1993), who often uses the following paraphrased quote in his Strategic Planning presentations before asking the audience to suggest where it came from;

*“We are living in the most complex and rapid-changing of times. The pace of technological innovation, like never before, is challenging the way we operate”.*

One would be forgiven to suggest that this quote is aligned with the many different leading journal articles of the past 10 years, maybe the *European Journal of Operational Research*, *The New England Journal of Medicine* or the *MIT Sloan Management Review*? In fact, it is from an 1868 issue of *Scientific American*, claiming that the pace of change driven by the new oil industry had added more complexity and innovation to humanity in less than fifty years than in the entire previous existence of the race (Mintzberg, 1993; *Scientific American*, 1868). It is in this facetious acceptance and ownership of uncertainty and complexity within an industry, including the RSC, that the problem this research faces can be defined, and in two distinct levels. Firstly, knowing the difference between saying your system is VUCA and understanding why it is; and secondly, having the knowledge, capabilities and structures in place to make accurate and effective risk management decisions within your VUCA system.

### **1.2.1 Problem 1 - The Accepting VUCA v's Understanding VUCA Paradigm**

Retail SCM (RSCM) has grown in importance at an exponential rate since the early 1990s, even though the approach was first introduced in early 1980 by Oliver and Webber, cited in (Jüttner, Christopher, & Baker, 2007). As a management philosophy, it is a very vast concept, with many interpretations and definitions and very easily falls under the umbrella of industries that claim ownership to a VUCA system. RSCM can be defined as the management of upstream (supplier) and downstream (customer) relationships in order to create enhanced value in the final market place at less cost to the

RSC as a whole (Christopher, 2010). Figure 1.1 illustrates very effectively the relationship between upstream and downstream partners; information (the order cycle) flows both directions, downstream is the flow of material to the end user, whereas upstream is the flow of capital to finance the chain. For this system to work and bring greater value to the end consumer and all other customers in the chain, each partner needs to commit to strategic RSC relationships (Hung, Kucherenko, Samsati, & Shah, 2004).

This is fundamentally where the problem lies. That is, a RSC organisation can suggest they are part of VUCA system, but they will never fully understand that system until they can appreciate the dynamics of the total cost of owning the system, and that sometimes trade-offs are needed for the greater good of the system as a whole (Barratt, 2004; Cavinato, 2004; Pillai & Min, 2010).

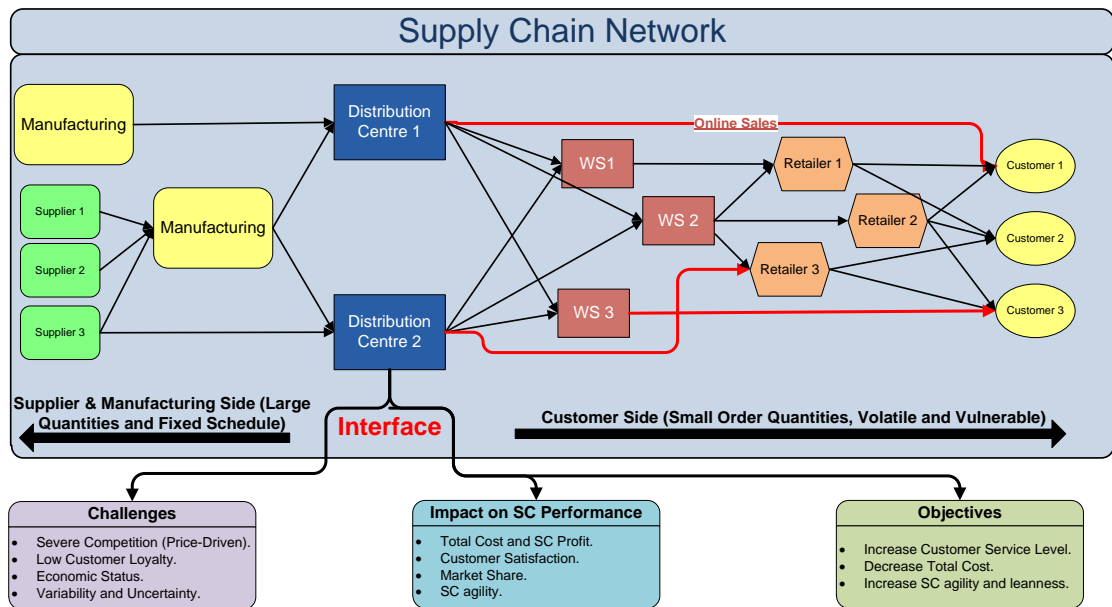


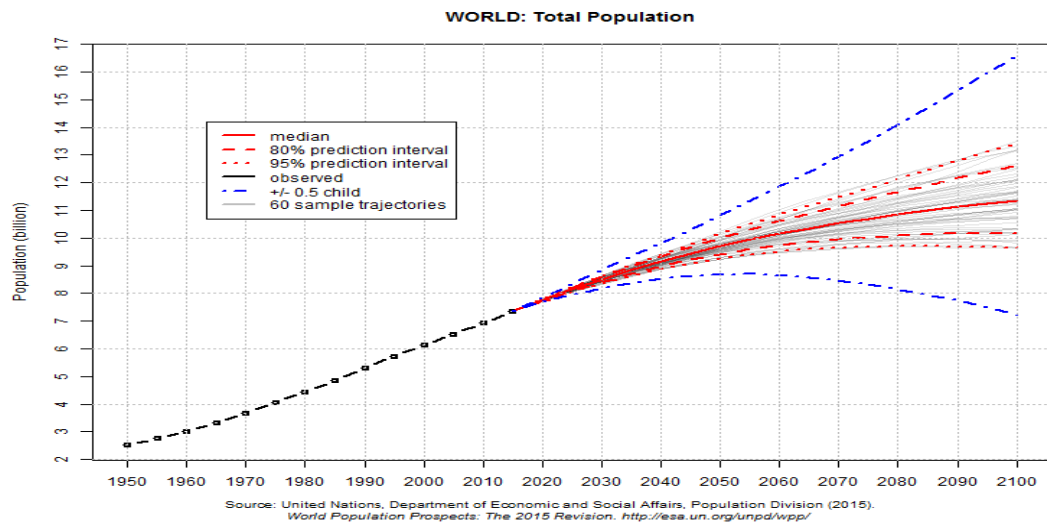
Figure 1.1 The Generic Retail Supply Chain

### **1.2.2 Problem 2 – Managing Risk in a VUCA System?**

At its macro level, an RSC is a sequential, continuous system as illustrated in Figure 1.1. But underneath this, at a more micro level, lies a more discrete, dynamic network, extending into a multitude of actors and nodes, multiple flows of items, information and finances; where each network node has its own customers' and suppliers' management strategies, demand arrival process and demand forecast methods, inventory control policies and items mixture (Longo & Mirabelli, 2008). As stated in Section 1.2.1, research has shown that understanding the magnitude of VUCA systems such as RSC's (and the relationships and partnerships needed to successfully operate them) is a concept many professional practitioners do not understand or fully appreciate (Barratt, 2004; Christopher, 1998; Spekman, Kamauff, & Myhr, 1998). This lack of understanding can lead to poor decision making processes, a key driver of risk within a RSC, with quite often disastrous consequences, especially in terms of order forecast accuracy and inventory levels, leading to "system chaos" (Hwarng & Xie, 2008). The problem for decision makers is in mitigating against decision making risks in a structured, analytical, robust manner, while considering the VUCA attributes of their system from both a strategic and operational perspective (Crowe & Arisha, 2013).

### **1.3 Research Motive**

According to the United Nations (2013), the world's population will have increased by 33% by 2050, from 7.2 billion, to a staggering 9.6 billion people (Figure 1.2). From a traditional economic perspective there are important consequences to this growth; the supply and demand equilibrium; and new market opportunities (2.4 billion of them) for retail organisations.



*Source: (UN Population Division, 2015)*

**Figure 1.2 World Population Prospects 2050**

### 1.3.1 The Year 2050 Dilemma

With population driven demand increasing by such a rate, the RSC not only has the concerns of on-shelf availability for an extra 2.4 billion consumers, but also the consideration of other resources. For example, from a grocery retail perspective this includes supply of water, agricultural land, livestock, and feed for livestock. The majority of population growth is expected to be in developing countries, Africa in particular, as economic prosperity grows (United Nations, 2013). The result of this is that demand for proteins such as livestock meat will increase, adding further supply strains on water, agri-food and land resources (Schneider et al., 2011; Wirsenius et al., 2010). Coupled with the competition from other industries for the same resources, including bio-fuels and bio-based non-foods (Koning et al., 2008), effective efficient decisions and management of resources is critical, with no room for error. Essentially, over the next 30 years, solutions are needed to double the world's availability of retail products, using the same capacity and resources as present levels, whilst decreasing the significant environmental harm

supply chains cause. Solutions to this problem, although very complex, are achievable. An example being the proposals of Foley et al. (2013), whose research centres on the constraints of finite global resources and the impact agricultural demands influenced by population growth have on them. An overview of this study can be explained in five steps.

**Table 1.1 Five Steps to Solving the 2050 Food Dilemma**

<b>Step</b>	<b>Description</b>	<b>Motive</b>
<b>1</b>	<b>Freeze Agriculture's Footprint</b>	We can no longer afford to increase food production through land expansion. Agriculture already accounts for 38.6% of the Earth's land area.
<b>2</b>	<b>Grow More on Farm's We've Got</b>	Attention to increasing yields on less productive farmlands - especially in Africa, Latin America, and Eastern Europe - where there are "yield gaps" between current production levels and those possible with improved farming practices.
<b>3</b>	<b>Use Resources More Efficiently</b>	Advances in both conventional and organic farming can give us more "crop per drop" from our water and nutrients.
<b>4</b>	<b>Shift Diets</b>	It would be far easier to feed 9B people by 2050 if more of the crops we grew ended up in human stomachs. Today only 55% of the world's crop calories feed people directly; the rest are fed to livestock (about 36%) or turned into biofuels and industrial products (roughly 9%).
<b>5</b>	<b>Reduce Waste</b>	An estimated 25% of the world's food calories and up to 50% of total food weight are lost or wasted before they can be consumed. In rich countries most of that waste occurs in homes, restaurants, or supermarkets. In poor countries food is often lost between the farmer and the market, due to unreliable storage and transportation.

*Source: Adapted from (J. Foley, 2014)*

### 1.3.2 Brand Ireland – Global Confidence in Ireland’s Supply Chains

The retail industry in Ireland, grocery retail in particular, is at the core of government strategic plans for growth during such extraordinary economic difficulties the country has faced since the global financial collapse of 2008. From “farm to fork” traceability to *an Bord Bia*’s current initiative, “Pathways for Growth” (Bord Bia, 2012), never has there been a more influential time for Ireland to become a world leader in the supply of sustainable, reliable and safe food products. To achieve this, global confidence and reliability in Irish food RSC’s are essential elements to overall competitiveness, and effective food retail SCRM (RSCRM) is an ideal strategic platform to gain such confidence.

Therefore, this research aims to utilise a system thinking, solution focused approach to the VUCA challenges RSC’s face and develop an integrated RSCRM framework that will assist in increasing the accuracy and efficiency of risk decision making processes within Irish RSC’s, from the source of raw material right through to the end consumer. It is intended that the framework can be expanded to be applied as a Decision Support (DS) tool within an organisation, as all DS tools in their very nature, mitigate the drivers of risk within a system.

### 1.4 Research Aim, Question and Objectives

The aim of this research study is to develop an integrated retail supply chain risk management framework that will increase practitioner understanding of complex business processes whilst encouraging the embracement of scientific methods and system thinking. The core challenges this research study faces are in addressing the complexity of supply chain systems and communicating sufficiently the applicability of system



modelling is in addressing it. Strong analytical tools such as mathematical programming, discrete event simulation (DES), system dynamics (SD) and optimisation; and business process reference models such as the Supply Chain Operations Reference (SCOR) model and ISO31000 are tried and trusted approaches to managing risk in complex business systems. Individually, such applications have been proven to increase cost efficiencies, improve risk assessment and give organisations a better understanding of their entire RSC network (Heckmann, Comes, & Nickel, 2015; Kevin, 2008; Purdy, 2010; Wilson, 2007).

Although several of these techniques have been successfully integrated, especially DES with optimisation (Abo-Hamad & Arisha, 2011; Kamrani, Ayani, & Moradi, 2012) or SCOR (Persson, 2011), into DS frameworks, there is no literature available to suggest that the strengths of all techniques have been integrated into one working framework. Consequently, the primary question in this research project is:

***“Can an integrated supply chain risk management framework be developed for managing complex decision management processes in a retail supply chain from a practitioner perspective?”***

The primary research question can be divided into 4 further questions:

**RQ1:** How applicable are existing solution techniques in handling the dynamics and complexity within supply chain systems and how effective are they in mitigating risk?

**RQ2:** What are the correlations between system thinking and understanding supply chain risk?

**RQ3:** What requirements are involved in the design and development of an integrated risk management framework for complex RSC's?

**RQ4:** How useful is the developed framework to retail organisations and to what extent can it be applied in industry?

To address these questions, the overall hypothesis of this research project is:

***“The development of a system thinking based integrated framework that will increase practitioner engagement and understanding of retail supply chain risk management.”***

This main objective is then detailed further by breaking into four sub-objectives as follows:

**Objective 1** To gain an in-depth knowledge of the existing solution techniques to supply chain risk management.

**Objective 2a** To highlight the need for a system thinking approach to decision making to truly understand supply chain risk.

**Objective 2b** To explore the key risk categories and challenges from a RSC context.

**Objective 3a** To investigate requirements for developing a system-thinking based integrated SCRM framework.

**Objective 3b** To develop an integrated framework for managing SCRM processes.

**Objective 4a** To validate the framework.

**Objective 4b** To deliver accurate risk management solutions for RSC managers and executives.

**Table 1.2 Research Questions and Objectives**

<i><b>Research Question</b></i>	<i><b>Research Objective</b></i>
<b>1.</b> How applicable are existing solution techniques in handling the dynamics and complexity within supply chain systems and how effective are they in mitigating risk?	<b>1.</b> Gain an in-depth knowledge of the existing solution techniques to supply chain risk management.
<b>2.</b> What are the correlations between system thinking and understanding supply chain risk?	<b>2a</b> To highlight the need for a system thinking approach to decision making to truly understand supply chain risk. <b>2b</b> To explore the key risk categories and challenges from a RSC context.
<b>3.</b> What requirements are involved in the design and development of an integrated risk management framework for complex retail supply chains?	<b>3a</b> To investigate requirements for developing a system-thinking based integrated SCRM framework. <b>3b</b> To develop an integrated framework for managing SCRM processes.
<b>4.</b> How useful is the developed framework to retail organisations and to what extent can it be applied in industry?	<b>4a</b> To validate the framework. <b>4b</b> To deliver accurate risk management solutions for RSC managers and executives.

## 1.5 Thesis Layout

**Chapter 1.** Introduces the research project and its objectives and outlines the structure of the thesis.

**Chapter 2.** Presents an extensive literature review of the RSCM domain and risk management frameworks. System thinking based business process management is classified in a comprehensive taxonomy and the main approaches to risk management are identified.

**Chapter 3.** Describes the research methodology used in the research to address the research questions outlined in chapter 1. Based on the paradigmatic stance of the research, the mixed-method research design is discussed and justified for its ability to achieve the

research aims in an inclusive manner. The research plan composed of six distinct stages is detailed highlighting the aims, methods and techniques used in each stage.

**Chapter 4.** Using a formative case study, explores the feasibility of using particular RSCRM techniques within an organisation to manage risk. This is conducted using a qualitative and quantitative exploratory case study through a set of interviews with a number of senior managers within a market leading RSC Company. The findings of the study are presented and discussed in light of the academic literature and also to both review the scope of the research methods in use and literature reviewed.

**Chapter 5.** Demonstrates the development of the proposed integrated RSCRM framework, starting by the theoretical concepts underpinning the framework design. The framework structure, its individual components, and the interaction between them are then detailed, referring back to the underlying literature reviewed.

**Chapter 6.** Reports the results of the validation through an embedded mixed methods case study undertaken to examine the validity and applicability of the framework through 2 embedded units of analysis.

**Chapter 7.** Concludes the research by summarising its main findings and contributions along with its implications for both researchers and practitioners.

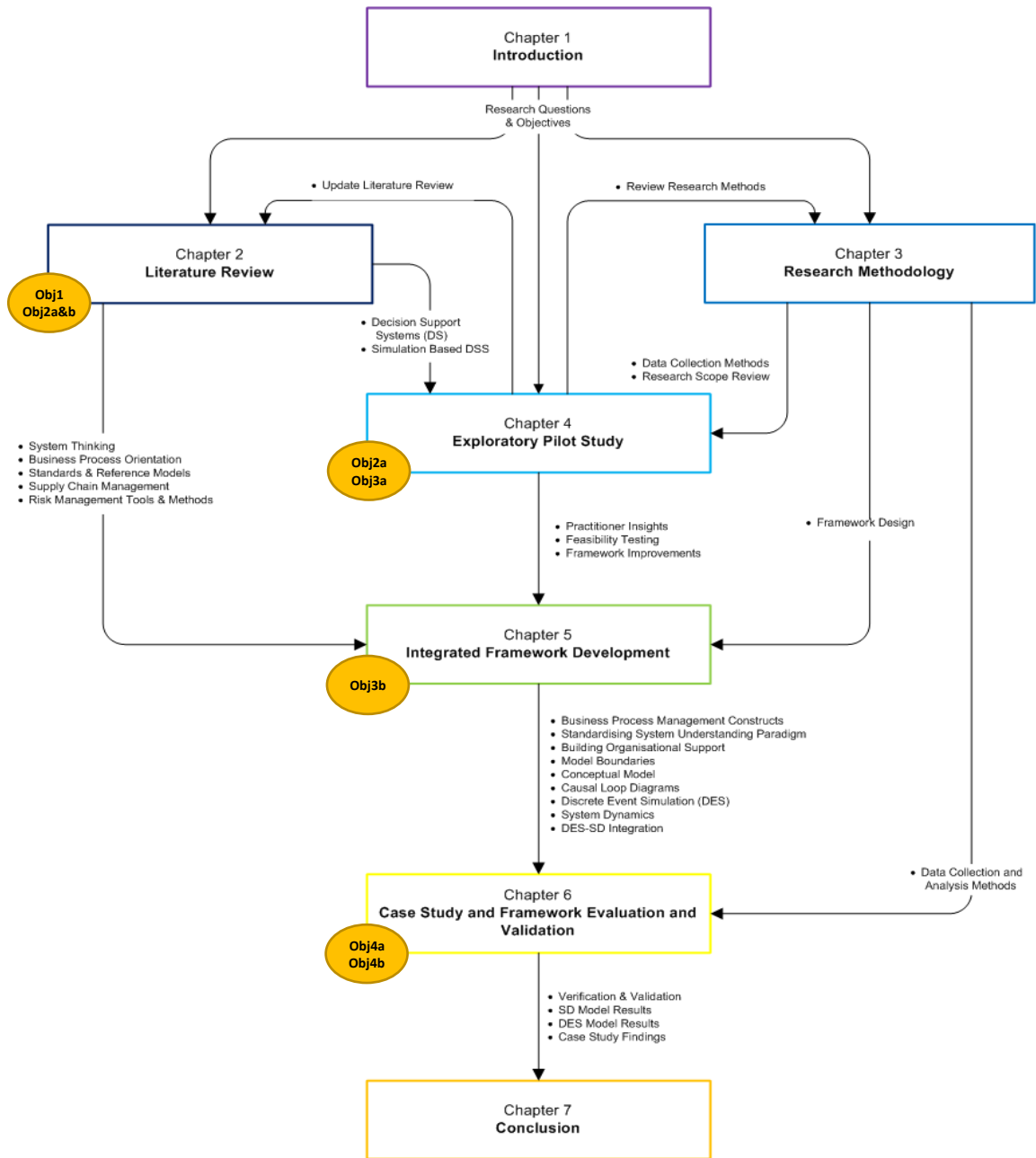


Figure 1.3 Thesis Layout

## Chapter 2. Literature Review

*“The story so far:*

*In the beginning the Universe was created.*

*This has made a lot of people very angry and been widely regarded as a bad move.”*

— Douglas Adams

### 2.1 Introduction

An underlying principle of RSCM is to establish control of the end-to-end process with the overall objective of creating an efficient, continuous flow of products (Christopher & Holweg, 2011), as well as information and capital (Christopher, 2010). The result of this process orientated control is sustaining competitiveness and customer service within the marketplace, whilst continuously improving performance at an optimal cost. As noted in Chapter 1, it has become an increasingly common practice for industry and academic professionals to open speeches and papers stating that the world is full of uncertain markets with demanding, globalised customers. If the realities of these claims were to come true, any disruptions or high risk events would have huge consequences to global supply networks that today’s organisations are built on (Martin Christopher & Holweg, 2011).

Complexity is a key managerial issue that RSCM needs to address, especially in terms of operational processes and manufacturing strategies (Caridi, Crippa, Perego, Sianesi, & Tumino, 2010). The complexity of most RSCs makes it difficult to understand how the actions and interactions of multi-tier RSC partners influence each other (Lambert &

Pohlen, 2001). Understanding RSC uncertainty and RSC visibility are essential in strategically measuring and understanding such influences.

### **2.1.1 Retail Supply Chain Uncertainty**

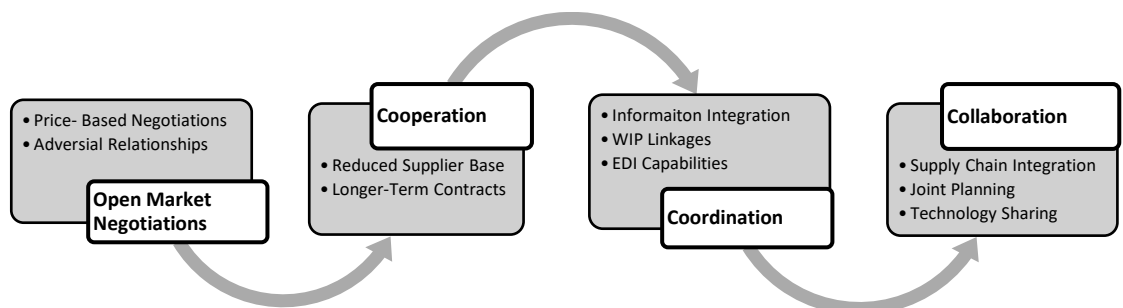
Uncertainty is a key issue known to impact the effectiveness of a RSC, most recognisably the uncertainty between supply and demand (Davis, 1993). Examples of uncertainty in the RSC process include; demand quantities, sales orders, delivery/arrival time, suppliers' lead time and defective rate of received products (Crowe, Mahfouz, Arisha, & Barrett, 2010). Dr. Andrew Grove, past president of Intel suggested that research into supply and demand at the company found that they were in equilibrium for just 35 minutes in 10 years (Huin, Luong, & Abhary, 2002; Towill, 1991; Wilding, 1998). The complexity triangle developed by (Wilding, 1998) is a framework that can explain such variances and uncertainty in the supply/demand relationship. The triangle explains that there are three interacting yet independent effects that cause the dynamic uncertain nature of RSC's. They are; deterministic chaos, parallel interactions and demand amplification. These effects are similar to the uncertainty in decision making situations described by (Van der Vorst & Beulens, 2002), primarily when the decision maker does not know definitively what to decide because of a lack of information, process knowledge, behavioural impact and controls. Visibility, through partnerships with key suppliers and customers may reduce uncertainty and risk within the RSC (Van der Vorst & Beulens, 2002).

### **2.1.2 RSC Visibility and Collaboration**

As noted, information and material flow, or the order cycle, plays a very important role in the effectiveness of RSCM, both upstream and downstream along the RSC. This order cycle is often referred to as pipeline time, and confidence in the RSC is weakened if the

pipeline is too long (Christopher & Lee, 2004). Visibility of material and information flow is associated with the length of the pipeline time, and the key to improved RSC visibility is shared information along the RSC (M Christopher & Lee, 2004). Collaboration along the entire RSC is needed to create a transparent, visible demand pattern that paces the entire RSC (Holweg, Disney, Holmström, & Småros, 2005).

Through collaborative links, stronger relationships will form within the RSC, that in turn will drive competitive advantage for the RSC partners (Spekman, Kamauff Jr, & Myhr, 1998). The days of poor co-operation, where suppliers are kept at arm's length, much like the traditional relationship outlined by Cousins (2002) are gone and a new wave of collaborating firms are being developed on high levels of; trust, commitment and information sharing (Spekman et al., 1998). The process of moving through the relationship process to collaboration is shown in Figure 2.1.



*Source: Adapted from (R. Spekman et al., 1998)*

**Figure 2.1 Transitions to Collaborative Partnerships**

RSCM is about the management of relationships across complex networks. Successful RSCs will be those that are governed by a constant search for win-win solutions based on, collaboration, mutuality and trust (M Christopher, 2005). There are four distinct relationship types outlined as being most effective for a win-win relationship (Cousins, 2002), depending on the level of strategic collaboration need; Traditional; Opportunistic



Behaviour; Strategic Collaboration; and Tactical Collaboration. As retailers grow and seek to enhance their collaborative activities and reduce costs, they search for the most appropriate management methods, tools and activities to enhance the flexibility of their RSCs. RSC flexibility is a critical dimension within today's business environment. Advances in technology, the globalisation of cultures and consumer tastes has resulted in the evolution of a worldwide fast moving consumer goods (FMCG) RSC system.

The FMCG RSC follows a business-to-consumer (B2C) order cycle as opposed to a business-to-customer, or business-to-business (B2B) relationship. For this reason, it is very sensitive to the fickleness of the end consumer, creating a sustained level of uncertainty. This is heightened in recent years by the increased pressures from retailers to reduce inventory levels, leaving the FMCG RSC more vulnerable to demand fluctuations (Manders, Caniëls, & Ghijzen, 2016). An attempt to increase resilience to such fluctuations has been the introduction of efficient consumer response (ECR) collaboration between RSC partners. ECR is a collaborative initiative between grocery FMCG suppliers and distributors for the benefit of the end consumer, with the understanding that RSC should be viewed more as a value chain (Zairi, 1998). In such a collaborative relationship, organisations need to understand and appreciate the macro and micro level challenges within their complex system, including decision making processes and associated risks and consequences. In an attempt to answer these complex system challenges through research questions 1 and 2 of this research study, the following literature view methodology and resulting literature classifications have been developed.

### 2.2 Literature Review Methodology

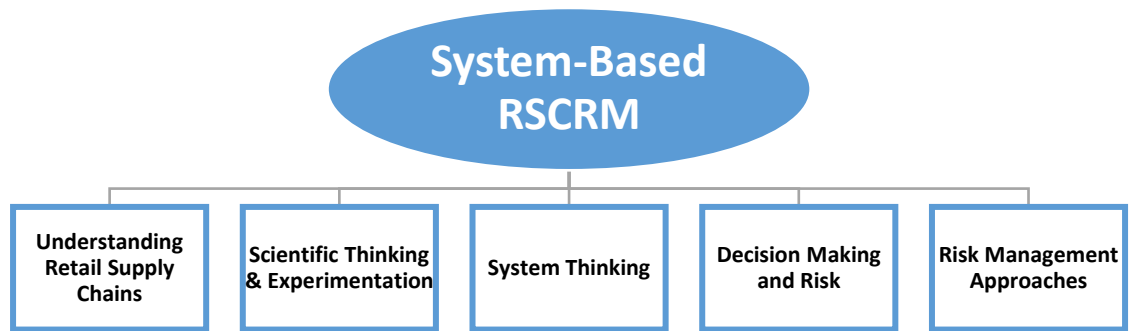
An effective literature review should create a firm foundation for advancing knowledge and facilitate theory development whilst closing areas where much research exists, whilst uncovering areas where research is needed (Webster & Watson, 2002). A comprehensive, systematic review of prior, relevant literature is an essential phase within this research study, covering a wide and multi-disciplined range of publications, with the following specific objectives:

- To explore the System Thinking landscape at large and identify its different research streams and applicability to RSCRM.
- To identify RSCRM research gaps in the current literature which require research efforts from a system thinking perspective.
- To thoroughly review previous research in RSCRM techniques and analyse the approaches and parameters that are used in existing models.

A concept-centric methodology of reviewing the literature was chosen over less effective methods such as chronological or author-centric approaches (Levy & Ellis, 2006). When selection criteria and review structure are based on the latter approaches, the researcher is at risk of “producing mind-numbing lists of citations and findings that resemble a phone book – impressive case, lots of numbers, but not much plot (p. 172)” (Bem, 1995). Acknowledging this, a research plan was devised to outline the concept-centric scope and methodology of the review and the publication selection criteria. The criteria for inclusion were English peer-reviewed journal and conference articles retrieved from electronic databases and through reference chasing (i.e. tracking references cited in collected papers)

and mostly published during the period of 2005 to present. This time period represents the most productive era of RSCRM research, but because RSCRM is still an emerging area, most publications in this area tend to come from different, more established areas and are not solely RSC specific (Sodhi et al., 2012). Older classic contributions, core textbooks, international standards and industry publications were included as well, while publications in other languages were criteria of exclusion.

In total, this research study has reviewed more than 1,100 publications, citing over 500, of which the majority were peer-reviewed journal articles. Publications were analysed by content and categorised into themes with the aim of constructing a taxonomy of system thinking and RM and RSCRM literature. A combination of deductive and inductive approaches were used to classify articles and although it was not based on a predefined classification like many RSCRM reviews (Jüttner, 2005; Tang & Nurmaya Musa, 2011), a systematic approach was followed, using wide-ranging and varied data to form a generalisation (Crilly, Jashapara, & Ferlie, 2010). As the review progressed, the researcher developed the boundaries of a taxonomic framework of system based RSCRM in which each paper was categorised under a certain theme according to its content. The taxonomy was iteratively refined until it reached its final form (Figure 2.2). RSCRM studies were classified into one of five categories: (1) The RSC (2) Scientific Thinking and Experimentation, (3) System Thinking, (4) Decision Making and Risk (5) Risk Management Approaches.



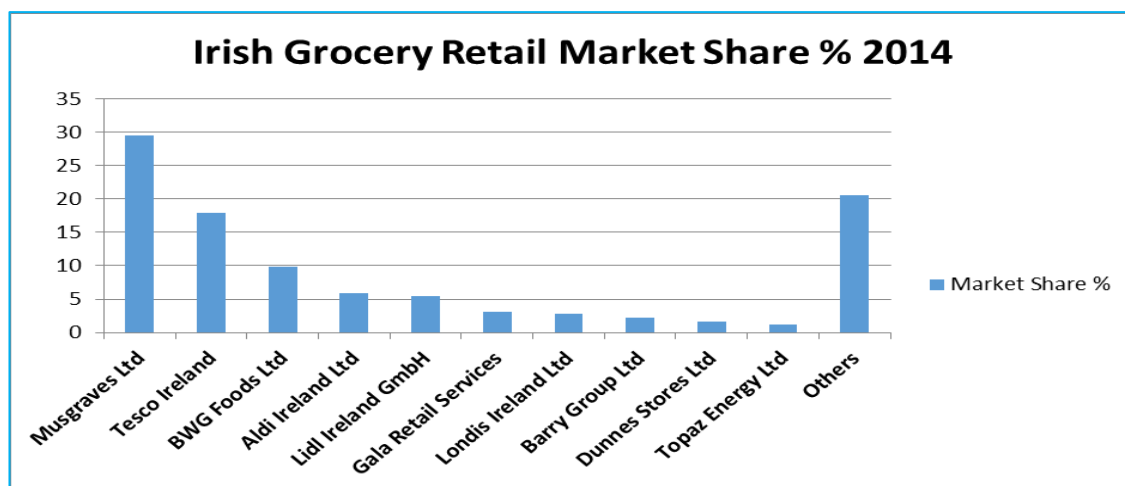
**Figure 2.2 The Proposed Classification of System Based SCRM Literature**

The following sections will in detail, discuss and review the contributions of each category outlined in Figure 2.2, with the ultimate objective of answering research questions 1 & 2 outlined in Table 1.2.

### **2.3 Retail – Irish Market**

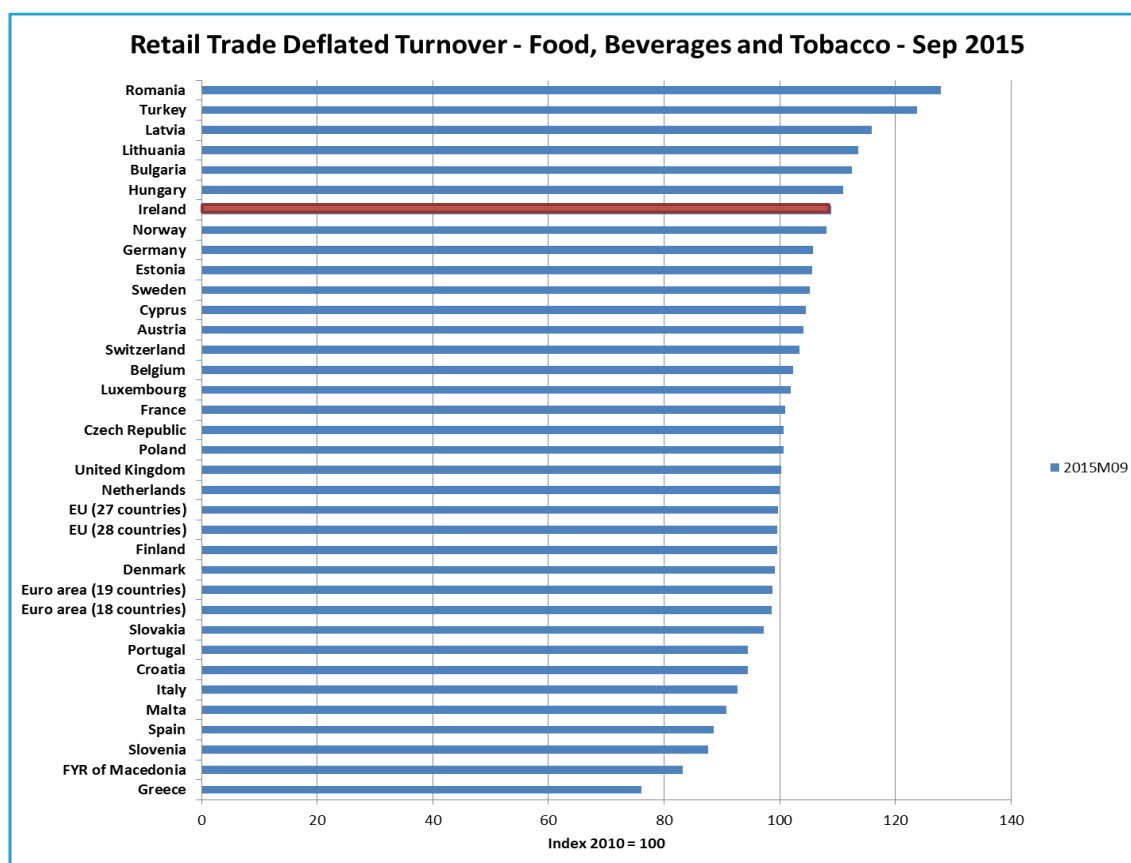
From a contextualisation perspective, it is important to understand the industry research is being applied to. In the case of this research study, this is the Irish grocery retail market. The sectors that make up Irelands retail market create a very strategic industry in relation to the overall success of the Irish economy. The retail sector alone employs just over 14.5% of the total workforce (CSO, 2014) and the entire sector was worth nearly €30 billion in sales to end consumers in 2014 alone, of which 50%, or €14.9 billion is made up of grocery retail (Euromonitor International, 2015b). Grocery Retail in Ireland is a very competitive market, where in 2014, the top 10 companies held 80% share of the market (Fig. 2.3), with the top 5 companies: Musgrave Group Plc. (29.5%), Tesco Plc. (17.9%), BWG Ltd (9%), Aldi Ireland Ltd (5.9%) and Lidl Ireland GmbH (5.5%) holding an incredible 69% share of the market (Euromonitor International, 2015a). Ireland also

has the strongest growth within Western Europe in terms of grocery retail turnover, growing 9% since 2010, as illustrated in Figure 2.4.



Source: Adapted from (Eurostat, 2015)

**Figure 2.3 Irish Grocery Retail Market Share % 2014**



Source: Adapted from (Eurostat, 2015)

**Figure 2.4 European Retail Trade Growth 2015**

### 2.3.1 Grocery Retail Challenges

There are many other barriers to sustaining growth within the Irish retail market (Table 2.1) other than aggressive competition between the top 10 retail chains. In a working research paper on financial risk and return in grocery RSCs, Corstjens et al. (2008) claim that the cost of switching retailers is becoming less and less evident with end consumers, where leading FMCG retail chains are struggling to turn retail power into superior value. Decreasing switching costs are also influencing the move away from the traditional retail chains to discounters. A leading market research company Mintel (2014) have stated that in Ireland, consumer opinions of discounters is improving and along with the disposable income burdens of the 2008 financial crisis, have permanently changed the dynamics of the retail grocery sector over the past decade. Price reduction pressures from consumers have resulted in the larger retail chains offering ongoing promotional discounts with all the cost risk being pushed upstream to the manufacturers and farmers as well as increasing demand uncertainty risk towards suppliers (Wang & Disney, 2016).

This along with rising operational costs, in particular logistics and fuel costs (Welborn, 2010) has increased tensions between RSC partners (Thomas, Esper, & Stank, 2010), making it a more challenging environment to operate within an ECR system. Downstream price reduction pressures has also increased RSC awareness to the very worrying practice of relabelling and counterfeit food products and the need for strong authenticity and security (Devaney, 2013). In face of such challenges and considering how important the grocery retail sector is to the Irish economy, the government have introduced certain initiatives to protect and grow the countries grocery retail market both nationally and internationally as already noted.

**Table 2.1 Retail Challenges**

<b>Retail Challenges</b>	<b>Authors</b>
• Low switching costs when choosing amongst retailers	(Corstjens, Maxwell, & Van der Heyden, 2007)
• Improving Opinions of Discounters	(Intel, 2014)
• Currency conversion and cross border competition	(Kim & Park, 2014)
• Decreasing demand during 2008 recession slow to recover	(Intel, 2014)
• Rising operational costs, including fuel and transport costs.	(Welborn, 2010)
• Pressure for price reductions and quick response has increased tension between RSC partners.	(Thomas et al., 2010)
• Demand uncertainty and forecast accuracy.	(Wang & Disney, 2016)
• Retail product authenticity and security.	(Devaney, 2013)

### 2.3.2 Pathways for Growth

Ireland's short and long-term challenges within the retail sector, as outlined in Table 2.1, can be perceived as potentially quite damaging, resulting in a diminished future for the sector within the economy. However, unlike most other developed countries in Europe, Ireland has a very valuable and scarce natural resource to combat these challenges; surplus land for agricultural expansion. Unfortunately, this opportunity has not been reflected with interest from the academic community, emphasis has primarily been with Ireland's other sustainable natural resource, renewable energy, including wind and tidal (Carton & Olabi, 2010; Connolly, Lund, Mathiesen, & Leahy, 2011; O'Rourke, Boyle, & Reynolds, 2010).

But, as introduced in Chapter 1, *an Bord Bia* (Irish Government Food Board) released an initiative in 2010 called "*Pathways for Growth*", as part of the longer term agri-foods industry strategic framework, "*Harvest 2020*" (Department of Agriculture, 2009), with the aim of marketing Ireland as the best place for countries to source food from. The

objective, developed by leading Harvard Business School Agri-Food experts, David E. Bell and Mary Shelman, was to turn Ireland's natural resources into high-value exports (Bell & Shelman, 2010). The initiative is split into four workstreams, described by *an Bord Bia* below in Table 2.2. They are; *Co-opetition* through mutual collaboration in the RSC; develop a *Brand Ireland* marketing campaign; encourage *Innovation and Entrepreneurship* initiatives, and increase the skill base and talent of workforce through *Education*. Although the Irish are not recognised internationally as country rich in culinary heritage, Ireland has always had a very respectful and close relationship with food and indeed, agriculture. Harvest 2020 and pathways to growth cement this claim. It is because of this that Ireland has a very good reputation globally with the supply of safe, quality food products.

**Table 2.2 Pathways to Growth Workstreams**

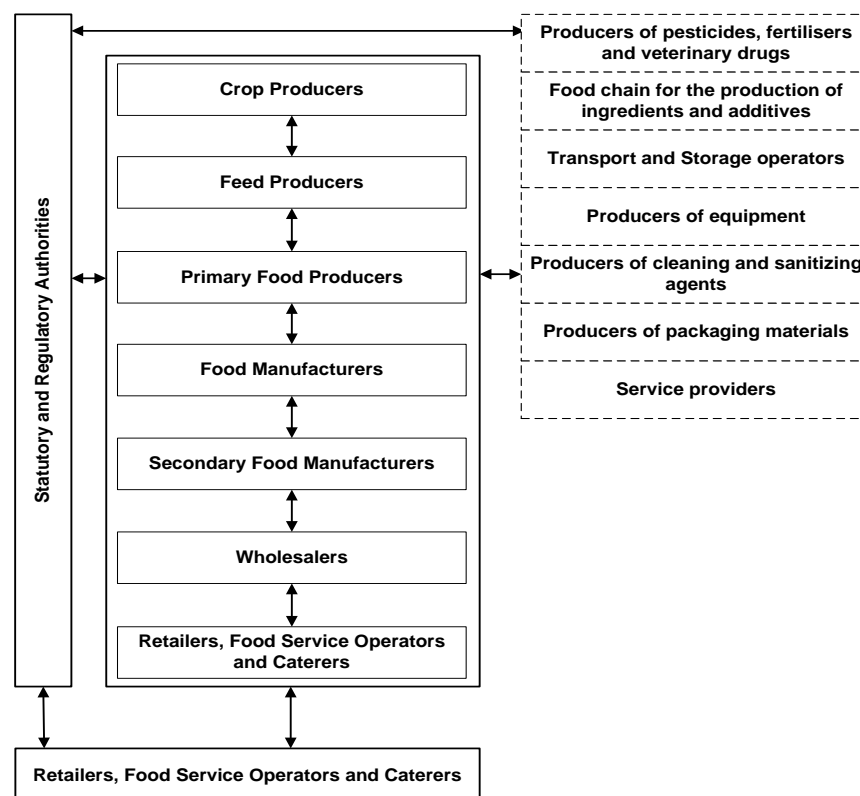
Workstream	Description
<b>Co-opetition</b>	Facilitating companies and value chains to identify areas of cooperation for mutual competitive advantage. This could include, for example, cost reduction, enhanced quality and technology standards or the combination of resources to supply large customers in distant markets.
<b>Brand Ireland</b>	The development of an umbrella brand or enhanced reputation for the industry which is both credible and distinctive and which embraces all aspects of Irish food and drink, assisting its differentiation and value growth in key markets.
<b>Innovation and Entrepreneurship</b>	Developing the industry's capacity to commercialise innovation through validated consumer and trade market insights resulting in fast and high level export growth. Creating a food business culture that is open to new ideas and embraces entrepreneurship.
<b>Education</b>	Supporting the ideal of the best talent being available to drive the ambition of the food and drink industry through highly effective, commercially oriented and market led learning, development programmes and placement schemes.

*Adapted from: (Bord Bia, 2012)*



### 2.3.3 The Grocery Retail Supply Chain

As noted in Section 1.1, risk within grocery RSCs have added complexities to consider than other RSCs including; food safety, short product life cycles, crop failure and disease, and complex network relationships to manage. Relationships, and more importantly, communication channels across RSC networks, including the “farm to fork” (FTF) network, are a critical catalyst in mitigating such risks (Li, Fan, Lee, & Cheng, 2015). The FTF network spans crop producers right through to retailers, caterers and the many other service providers that support the grocery RSC, including producers of pesticides, packaging, and a multitude of other service providers, (Figure 2.5). While the FTF process battles the complexities of grocery RSC relationships and common risks, environmental and societal challenges have also gained in significance (Lazarte & Tranchard, 2010).



Source: Adapted from (ISO, 2005a)

Figure 2.5 Communication Channels within the “Farm to Fork” RSC

Fundamental grocery RSC questions, which until recent times, were distant thoughts in the minds of society, especially in developed countries over the past 60 years, have now become more prevalent. Questions that are generating debate, as discussed by Li et al. (2014) include:

- Whether food can be supplied?
- Can food be distributed and consumed in a more sustainable way without compromising costs?
- How should standards be set and technologies be used to improve sustainable development?
- How to minimise food waste and reduce operating costs together?
- What will be the impacts of standards and technologies on the way food RSCs are operating? (D. Li et al., 2014)

As already explained, to contextualise the industry of application, it is important to the validation phase of this research study that the Irish grocery retail supply chain was explored. But because a core objective of this study is to develop a generic integrated framework that is applicable in any RSC, the challenges faced by all RSC's from a global perspective also need to be considered.

### **2.4 Understanding Global Retail Supply Chain Challenges**

It is often taken for granted that the right products will be available to buy in retail outlets 7 days a week, 52 weeks a year. A comprehensive understanding of RSC systems is required in order to control rapidly increasing operational costs, greater consumer product knowledge and decreasing brand loyalty, while fulfilling the growing demand for best-

in-class pre and post sales service levels and quality products. This means managers within RSC organisations, (such as wholesalers, retailers and logistics providers) have to recognise what are the types of systems and processes that affect decision making?; what are the operations within each sub-system?; what are the main bottlenecks and their causes?; which actions are efficient and which are not?; and what is the impact of changes and actions on the overall system performance? The supply chain council (SCC), a non-profit supply chain research group claim that there are 5 key challenges that every RSC organisation face, as shown in Table 2.3.

**Table 2.3 Top RSC Challenges**

<b>Top 5 RSC Challenges</b>	<b>Description</b>
1. Customer Service	Effective RSC management is all about delivering the right product in the right quantity and in the right condition with the right documentation to the right place at the right time at the right price.
2. Cost Control	RSC operating costs are under pressure today from rising freight prices, more global customers, technology upgrades, rising labour rates, expanding healthcare costs, new regulatory demands and rising commodity prices.
3. Planning & Risk Management	RSCs must periodically be assessed and redesigned in response to market changes, including new product launches, global sourcing, new acquisitions, credit availability, the need to protect intellectual property, and the ability to maintain asset and shipment security.
4. Relationship Management	Different organizations, even different departments within the same organization, can have different methods for measuring and communicating performance expectations and results.
5. Talent	As experienced RSC managers retire, and organizations scale up to meet growing demand in developing markets, talent acquisition, training, and development is becoming increasingly important.

*Adapted from (Supply Chain Council, 2013)*

From a retail perspective, according to a survey of RSC stakeholders by the Chartered Institute of Logistics and Transport (CILT) in 2009 (Fernie & Sparks, 2009), there are specific challenges confronting RSC's to achieve the ultimate goal of sustainable competitiveness. They include:

### **2.4.1 Increasing On-Shelf Availability and Replenishment**

On-shelf availability (OSA) of goods within a retail location is of critical importance to both retail and brand manufacturer organisations in the extended RSC because it adds competitiveness through enhanced consumer value, confidence to the brand, and shopper loyalty to the store, resulting in increased sales and profit (Berger, 2003). Equally, empirical research on non-shelf availability, or “out-of-shelf” (OOS) products has a very negative effect on consumer confidence and profit within the retail chain as a whole (Ettouzani, Yates, & Mena, 2012; Fernie & Grant, 2008; Pramataris & Miliotis, 2008). In a detailed empirical study, Gruen and Corsten (2003) claim that in the USA on average there is a 8.3% OOS rate within leading retail organisations.

It is well known that logistics activities are directly related to end consumer satisfaction within any RSC, (Christopher & Peck, 2003). OSA is such an important part of this as it is the “first moment of truth” for the entire RSC and its service levels (Ettouzani et al., 2012).

### **2.4.2 Promotions**

OSA and promotional activities are the new battle grounds of FMCG (Corsten & Gruen, 2003). They are unavoidably linked and the inaccuracies of either can have serious consequences to consumer satisfaction. Promotions are activities that stimulate consumer demand outside of the marketing channels of advertising, public relations and personal shopping (Gilbert, 2003; Tokar, Aloysius, Waller, & Williams, 2011). Demand for promotional activities is notably difficult to forecast accurately, resulting in a negative effect on OSA leading to increased OOS rates (McKinnon, Mendes, & Nababteh, 2007). It is quite evident from walking through any retail location, from grocery to apparel,

promotions are heavily invested in, and they work, but will only increase sales if the product is on the shelf for customers to purchase (Tokar et al., 2011).

The Bullwhip Effect (BWE), first coined in the 1990's by Procter & Gamble (P&G) to describe order variation and amplification between P&G and its suppliers (Wang & Disney, 2016); is a common promotion driven phenomenon that occurs when demand and consumption normally slows down for a period of time after a promotion. The concept is also known as the Forrester Effect, after Jay W. Forrester, who first uncovered it in his ground breaking book *Industrial Dynamics* in 1961, coining the effect as "Demand Amplification" (Forrester, 1961). BWE addresses the shift in a usually steady demand caused by promotions and other forecasting activities, resulting in enhanced demand fluctuation in upstream RSC's (Tanweer, Li, Duan, & Song, 2014).

### **2.4.3 Tracking & Radio-Frequency Identification (RFID)**

There have been many ambitious technological promises to improve RSC's over the past two decades, but very few have held out to their promise (Ferne & Sparks, 2009). Product tracking though RFID technologies has undoubtedly been the best-known promise to retail organisations. In general, RFID tags are only used in a small amount of a RSC's item ranges, primarily high items such as razor blades, apparel and cosmetics (Piramuthu, Wochner, & Grunow, 2014), with cost given as the biggest barrier to implementation (Zhou, 2009). From a grocery retail perspective, there have been many conceptual innovations in the use of RFID within the RSC, primarily in food safety, but there is little evidence of implementation. Although, its emphasis is increasing with recent studies, including sustainable supply if perishable foods to an increasing global population (Grunow & Piramuthu, 2013) and food safety and authenticity (M. Zhang & Li, 2012).

### 2.4.4 Factory Gate Pricing

A retail distribution practice, factory gate pricing (FGP), also known as ex-works ordering, was developed in 2001 to make transport operations within the larger retail chains more efficient with the result of reducing primary transport costs (Potter, Mason, & Lalwani, 2007). Since the introduction of central warehousing, or distribution centres (DC), traditionally, retail transport could be split into two levels; *Primary Distribution*: from the supplier to the retailer DC; and *Secondary Distribution*: from the retailer DC to the shops (le Blanc, Cruijssen, Fleuren, & de Koster, 2006). With FGP, the cost and management of primary distribution has been pushed onto the retailer, who basically takes ownership of the order at the “factory gates”. FGP needs close collaboration between retailers and brand manufacturers and is often classed as one of the prerequisites of collaborative planning forecasting and replenishment (CPFR) infrastructure (Davies, 2004).

### 2.4.5 Multi-Channel Retailing

Multi-channel retailing is where the same customer can visit the retailer via different channels to; obtain information online, make purchases offline, or contact customer service via telephone, with many retailers expanding their focus from selling products to engaging and empowering customers (Sorescu, Frambach, Singh, Rangaswamy, & Bridges, 2011). In some sectors such as travel agencies it has been seen as a disruptive innovation, but has had less impact in retailing (Verhoef, Kannan, & Inman, 2015).

Since the advent of smart phone technologies and the “internet of things”, multi-channel retailing has evolved into omni-channel retailing (Brynjolfsson, Hu, & Rahman, 2013; Verhoef et al., 2015).

### 2.4.6 Global Sourcing and Selling

The world is now a smaller place, advances in transport and communication infrastructures have resulted in the normal barriers of sourcing and selling such as geography being reduced (Christopher, 2010). Although, distance is still a reality within global sourcing and is the primary influence of replenishment lead times. However it is not the only factor that causes replenishment lead times to lengthen in global sourcing, there is also delays and variability caused by internal processes at both ends of the chain as well as the import/export procedures in between to be considered (Ferne & Sparks, 2009). This can lead to longer *RSC pipelines* with more work in process (WIP) inventories in them with consequent risks of obsolescence (Ferne & Sparks, 2009).

### 2.4.7 Localisation

The localisation of RSC's has been primarily driven by pressures to become more sustainable and reduce carbon emissions through reduced transport distances (Nicholson, Gómez, & Gao, 2011). Existing grocery RSC networks enable the consistent, yearlong supply of seasonal, relatively inexpensive grocery products and there is little empirical evidence to-date to understand the possible trade-offs between localisation and the overall cost to the RSC (King, Gómez, & DiGiacomo, 2010).

### 2.4.8 Postponement

Postponement is an agile process scheduling and design theory that can be applied when a mix of both standard and innovative components are involved in a production or service activity, see Table 2.4 (Vonderembse, Uppal, Huang, & Dismukes, 2006). An agile system encompasses four dimensions:

1. Enriching the customer.
2. Cooperating to enhance competitiveness.
3. Organizing to manage change and uncertainty.
4. Leveraging the impact of people and information.

(Goldman et al. (1991) cited in (Fernie & Sparks, 2009)

**Table 2.4 The RSC Classification Based on Product Type**

Product Lifecycle	Standard Products	Innovative Products	Hybrid Products
Introduction	Lean RSC	Agile RSC	Hybrid RSC
Growth		Hybrid/Lean RSC	
Maturity			
Decline			

More prevalent in industries with longer product life cycles and quick response (QR) requirements such as in the fashion and electronics industries, postponement requires extensive SC reengineering and is applied to a lesser extent in grocery RSC's (van Hoek, 1999).

#### **2.4.9 Planning Skills**

The availability of qualified, skilled people has been claimed to be the most important factor, even more than physical infrastructure and information structure to RSC competitiveness (van Hoek, Chatham, & Wilding, 2002). Competencies in planning are seen as a crucial requirement for RSC managers, both strategically and operationally, skills are required in project planning, technology integration into the planning process and measurement techniques (Prajogo & Sohal, 2013). How an organisation performs in



dealing with the other RSC challenges outlined in Section 2. 5 is an indicator of how skilled RSC decision makers are in planning their network (Fernie & Sparks, 2009).

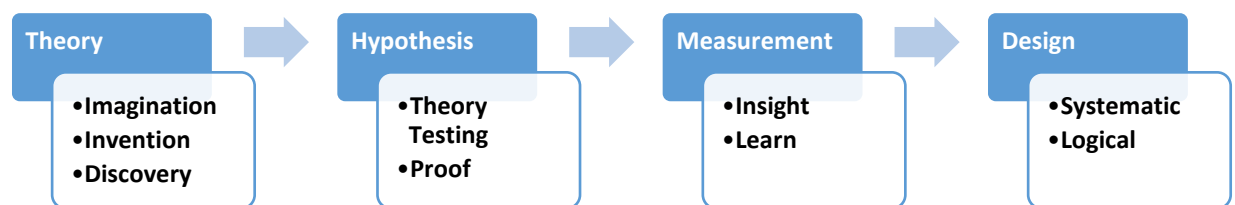
### **2.4.10 Return Management**

According to Guide et al. (2006), a necessary phase of a RSC is the recognition of customer product returns, with the processing of returns becoming a critical and extensive activity within a retail organisation. From a grocery retail perspective, the primary reason for returns is shelf-life constraints, as set by the European Parliament, reference regulation (EU) No. 1169/2011 on the provision of food information to consumers (EU, 2011). This regulation sets the strict rules on decision criteria for creating expiry dates including best-before and sell-by dates. Another reason for returns within grocery retail is due to the fragile nature of the product. Bernon et al. (2016) claims that risk lies in the fact that the principle handling characteristics of general FMCG merchandise and grocery products are very different and need separate standard operational procedures.

There are also recommended standards such as ISO22000:2005 for food safety management systems that require accurate traceability of all food returns, expiry dates and disposal records (ISO, 2005b), adding complexity to the return management process. Although there are opportunities for improvement initiatives, with the research of Amini et al. (2005) into reverse logistics network design claiming that effective returns structures will improve end-to-end transportation and information sharing; and reduce inventory, order processing and warehousing costs. An optimal return management network should comprise of four main management aspects; facility location, information systems, reverse/green SCM, and outsourcing.

## 2.5 Scientific Thinking and Experimentation

The world we live in is a very complex system. The word complex comes from the 14<sup>th</sup> century Latin expression *complexus* meaning “embracing or comprehending several elements” that are “plated together, interwoven” (Alhadeff-Jones, 2008), p.63). As explained in Chapter 1, many disciplines have certainly embraced the concept of multiple elements interconnected, but maybe do not comprehend fully the dynamic relationships between the elements of a system. One discipline that has fully comprehended the dynamics of system complexity is that of science. Whether calculating the temperature of the sun, destroying matter, or aging the universe itself, how have scientists achieved the level of understanding to make such things possible (Medawar, 2013)? The answer is through scientific method and experimentation. The foundations of the scientific method have been around for thousands of years and is commonly separated into four steps; theory, hypothesis, measurement and design (Patz, 1975).



Source: Adapted from (Patz, 1975)

**Figure 2.6 The Scientific Method – A Four Step Drill**

Kendal (2009) adds that in second level education, “we are taught that scientific knowledge is based upon a process of gathering observable, empirical, and measurable evidence and then using our powers of reasoning to make sense out of these data”. But

this skill seems to have not transferred to the workplace or third level education, outside of science or mathematical based disciplines (Mooney, 2016).

However, the paradigm of incorporating scientific thought and experimentation in business process management is not a new initiative. From Frederick Winslow Taylors advances in scientific management with his “time and motion studies” of the early 20<sup>th</sup> century (Taylor, 1914), Taguchi’s method for robust experimental design (Taguchi, 1987), to Deming’s Theories of Profound Knowledge (Deming, 2000), the physical sciences have been hugely influential in business management over the past century. The premise lies in the fact that scientific thought has in many ways strongly influenced the advancement of business theory (Overman, 1996). Chen (1999) argues that the use of “scientific theorems and their corollaries” may help managers to obtain a simpler, more structured approach to business management in what is a very dynamic world. In fact, by simply describing the basic principle of physical science, “The Newtonian Paradigm”, Dooley (1997) shows how relative such theorems are to any system. He states that; “The Newtonian world is understood via reductionism – the belief that systems are composed of independent elements and that one can completely understand the system by breaking it down to its smallest elements and describing how these elements interact”. Therefore the objective of “classical” or natural sciences is to find, even within a complex system, some underlying simpler level (Prigogine, 1987), from which a greater understanding of the complex system in a whole can be achieved.

### 2.5.1 The Laws of Thermodynamics

Why are departmental barriers put across business processes? Why are organisations designed around functions rather than processes? It can be argued that organisations do not design themselves in this structure on purpose, but that it simply happens naturally as organisations evolve (Hammer & Champy, 2009). This theory is appealing from a scientific method point-of-view because it seems to be consistent with the general principle that all systems, including organisations, eventually will move towards a state of disorder, or higher entropy (Kock Jr & McQueen, 1996). Entropy is a fundamental law within thermodynamics, the laws of energy and mass conversion.

The laws of energy conversion and mass conversion are fundamental to all sciences, but from a business process point-of-view, the central correlation these physical science laws have is that of complexity and system understanding and the precursor of many knowledge-about-system (KAS) theories. Klein (1983) quotes Einstein as once stating about the laws of thermodynamics, that:

*“Thermodynamics is the only physical theory of general contents of which I am convinced of that it will never be changed with respect to the appliance of the basic fundamental concept...” (Klein, 1983).*

Thermodynamics is the branch of physics that deals with the conservation of the quantity and change of energy (i.e. energy doing work) in a system. A system is defined in terms of space and time, and is separated from its environment by system boundaries. System boundaries and reference systems are essential for the analysis of material and energy in thermodynamics. A system is referred to as isolated when neither energy nor matter cross

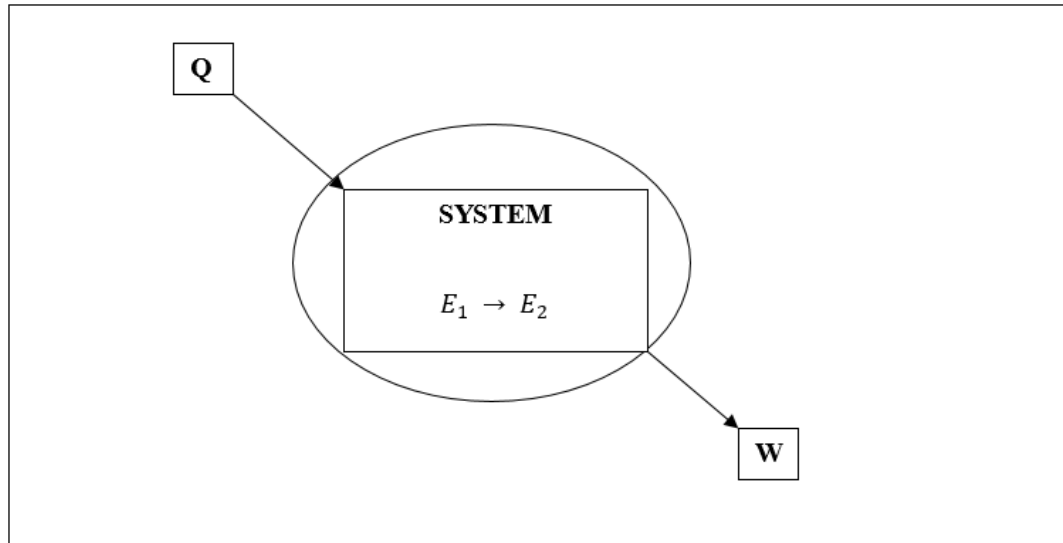
boundaries; it becomes closed if only energy crosses boundaries, and open when mass crosses boundaries. The core concepts of thermodynamics can be described by its first and second laws. The following introductions to the first two laws of thermodynamics and their adaptation from a business process perspective have been adapted from Chen's 1999 research study titled; *Business Process Management: A Thermodynamics Perspective* (Chen, 1999).

### 2.5.1.1 The First Law of Thermodynamics

The first law of thermodynamics states that energy is conserved for closed systems and for open systems at a steady state. In the physical universe, we are often concerned with the energy stored in a system and the energy in transit. While the absolute value of the stored energy cannot be measured, the value of its change can be measured by the transfer of heat and work by the following equation:

$$\Delta E = E_1 - E_2 = Q - W \quad (2.1)$$

Specifically, the amount of energy,  $Q$ , transferred to a closed system must be equal to the sum of the energy change (from  $E_1$  to  $E_2$ ) of the system,  $\Delta E$ , and the amount of energy transferred from the system by work,  $W$  for an open system of control volume at a steady state, the condition of the mass with the control volume does not vary with time. In such a case, the total rate at which the energy is transferred into the control volume equals the total rate at which energy is transferred out.



**Figure 2.7 The First Law of Thermodynamics**

In a business process, Figure 2.7 and equation 2.1 can be easily applied to input/output activity. For example, within a production process;  $Q$  would be a raw material or packaging input rate;  $E_1$  and  $E_2$  would represent the conversion activity, say an assembly line, and  $W$  the output or finished good. The difference between  $Q$  and  $W$  in turn would represent the waste/loss through the conversion process.

#### **2.5.1.2 The Second Law of Thermodynamics**

There are many alternative formulations of the second law. Perhaps the most commonly understood one is the Clausius statement given as; *it is impossible for any system to operate in such a way that the sole result would be an energy transfer by heat from a cooler to hotter body*. An important outcome of the second law is that the transformation of energy is always inefficient in the natural processes and will increase in entropy. Entropy is:

“a measure of the unavailability of a system’s energy to do work; in a closed system an increase in entropy is accompanied by a decrease in energy

availability... In a wider sense entropy can be interpreted as a measure of disorder; the higher the entropy the greater the disorder. As any real change to a closed system tends towards higher entropy, and therefore higher disorder, it follows that the entropy of the universe (if it can be considered a closed system) is increasing and its available energy is decreasing.” (Oxford Dictionary of Physics, 2015)

In other words it is a force that if not acted open by another force, an object will degrade or decay and from a business perspective can be associated with understanding waste (Fessenden, 2014) or information flow (Ruth, 2013) within a business process. From this perception, Table 2.5 represents a comparison between the parameters of the laws of thermodynamics and how they can be applied to a business process.

**Table 2.5 Parameters of the Business Process and Thermodynamics**

<b>Thermodynamics</b>	<b>Business Process</b>
Mass	A firm’s constituents, i.e. employees, machinery, facility, material.
Input Energy. (Q)	Input resources, i.e. material, money, manpower, & managerial efforts. ( $Q_{input}$ )
Work done by a System. (W)	System Output useful to Customer, i.e. Product & Service. ( $W_{useful}$ )
Change of Stored Energy. ( $\Delta E$ ) or <i>Enthalpy</i> .	Losses throughout the Process, e.g. Waiting time, defects, unnecessary report. ( $U_{loss}$ )
Thermal Efficiency of a Power Cycle. ( $\eta_t$ )	Efficiency of Business Process to Satisfy Customer. ( $\eta_b$ )
Temperature of Hot Reservoir ( $T_h$ )	System Capability, e.g. Technology, Leadership, Marketing, Proficiency. ( $C_s$ )
Temperature of Cold Reservoir ( $T_c$ )	Competitor/Environment Capability. ( $C_e$ )
<i>Entropy</i>	Extent of Disorder within the System

*Adapted from (W.-H. Chen, 1999)*

As noted, scientific methods encourage the fragmenting of complex problems into smaller, simpler pieces to solve and then put back together again. There are many merits

to this but it can also be seen as a futile exercise, as argued by Senge (2006), who cites famous Physicist David Bohm, who describes it similar to trying to reassemble a broken mirror to see a true reflection. Equally, scientific or analytical methods from a business management perspective, aim to separate variables to understand specific cause and effect relations, while another holistic approach called systems thinking considers a system's global behaviour and performance as a combined effect of all its variables and, most importantly, their mutual relationships (Conti, 2010).

### **2.6 System Thinking**

Just as scientific theories such as thermodynamics acknowledge the complexity of systems through reductionism; it is important to acknowledge that not all systems are complex. And more importantly, although not all systems are complex, all thinking is complex, and therefore, the actual process of thinking in a systematic way is very complex (Cabrera et al., 2008). Thinking is commonly defined as the process of reasoning or considering something (Oxford Dictionary, 2015). In business, this process is more commonly known as the decision making process, and from a systematic perspective, many academics; from Checkland's advances in "Systems Thinking and Practice" (Checkland, 1981, 1999), Deming's "Theories of Profound Knowledge" (Deming, 2000), to Senge's "The Fifth Discipline" (Senge, 2006), argue that it can only be achieved through what can be collectively categorised as KAS theology (Cabrera et al., 2008).

There is much disagreement in both academic and industry circles to what constitutes KAS or "system thinking". An ambiguous term, its origin can be dated as far back to Aristotle; some scholars describe it as synonymous with systems sciences (i.e., nonlinear dynamics, complexity, chaos), while others view it as a taxonomy of systems approaches



(Cabrera et al., 2008). Figure 2.8 highlights the vastness of such a taxonomy, encompassing both natural and social sciences throughout history, spanning everything from the use of binary numbers in ancient China to more recent developments in Complex Dynamical Systemics and cybernetics, and is categorised into 12 colour coded streams listed in Table 2.6 (Schwarz, 2001). Other studies that have acknowledged the vast dynamic diversity of system thinking include Midgley's evaluation of system thinking (Midgley, 2003, 2006) and François's work with cybernetic systems (François, 2004). The distinction between systems science and systems thinking was first made by Checkland (1981) in his claim that systems thinking is thinking in terms of systems rather than being about actual systems.

**Table 2.6 Streams of System Thinking**

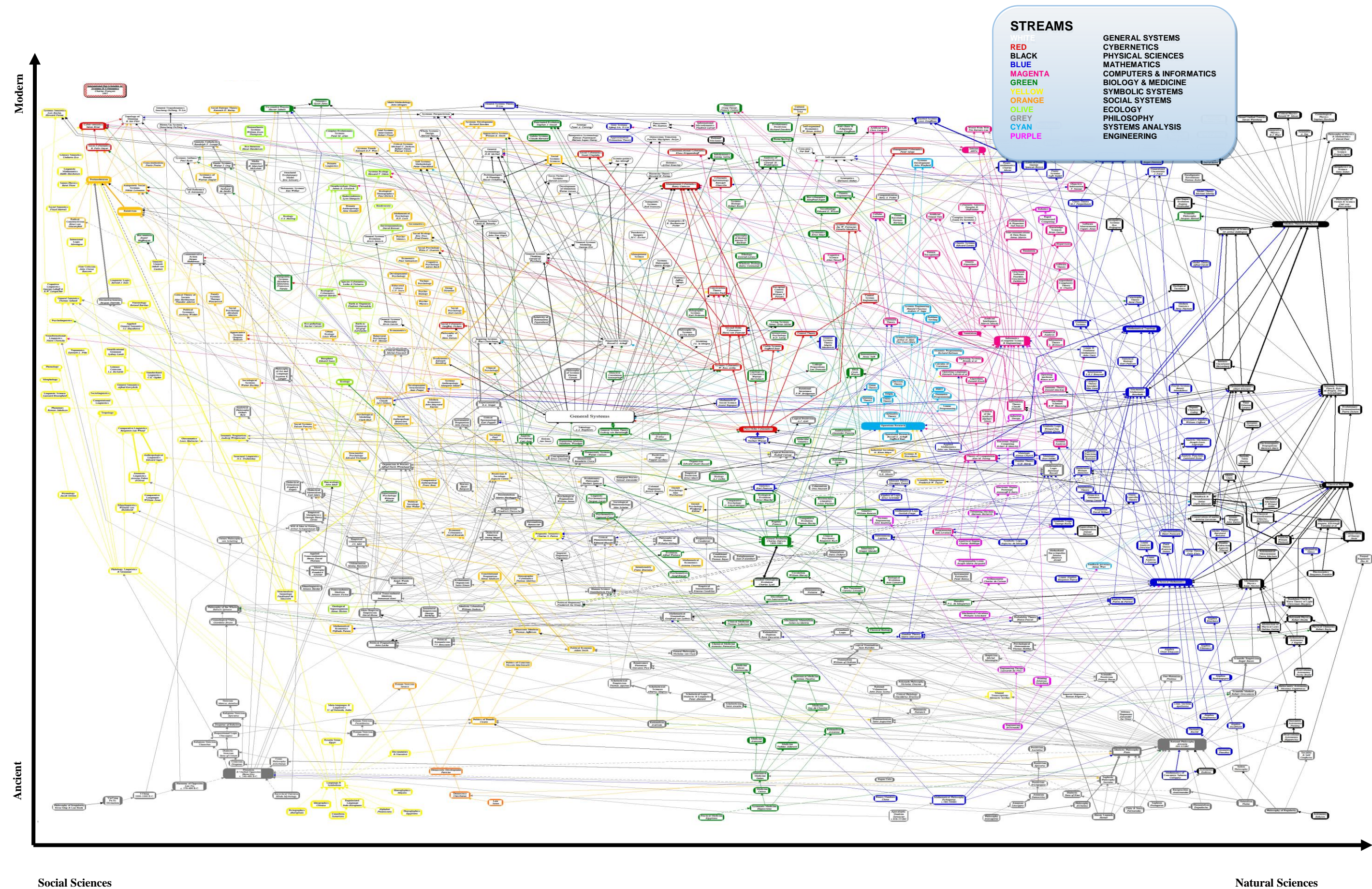
Colour	Stream
WHITE	GENERAL SYSTEMS
RED	CYBERNETICS
BLACK	PHYSICAL SCIENCES
BLUE	MATHEMATICS
MAGENTA	COMPUTERS & INFORMATICS
GREEN	BIOLOGY & MEDICINE
YELLOW	SYMBOLIC SYSTEMS
ORANGE	SOCIAL SYSTEMS
OLIVE	ECOLOGY
GREY	PHILOSOPHY
CYAN	SYSTEMS ANALYSIS
PURPLE	ENGINEERING

Others attributed with coining of this term is leading system dynamics expert Barry Richmond (Arnold & Wade, 2015), who introduced Forrester's (1958) ideology of system thinking based decision making to mainstream business application in a series of industry and academic publications during the late 1980's and early 1990's (Richmond, 1987, 1993, 1994). Richmond defines system thinking as "...the art and science of making reliable inferences about behaviour by developing an increasingly deep

understanding of underlying structure” (Richmond, 1994). Jackson (2006, 2010) adds that to understand any “problem situation” an understanding of how the complete system operates is needed, including the parts of the system and the connections between the parts. There are four recognised conditions to systems thinking within any system:

1. Any entity known as a system will contain sub-systems or, itself as a whole, be part of a wider system.
2. The system will only adapt if channels of communication are opened and process performances are actively measured.
3. If an option to adapt is taken, there needs to be several points of control within the system that can respond to shocks from internal and environmental failures.





Source: Adapted from (Schwarz, 2001)

Figure 2.8 Some Streams of Systems



4. There will need to be definable ‘emergent properties’ that can describe the particular system or systems of interest and objectives (Checkland, 2012).

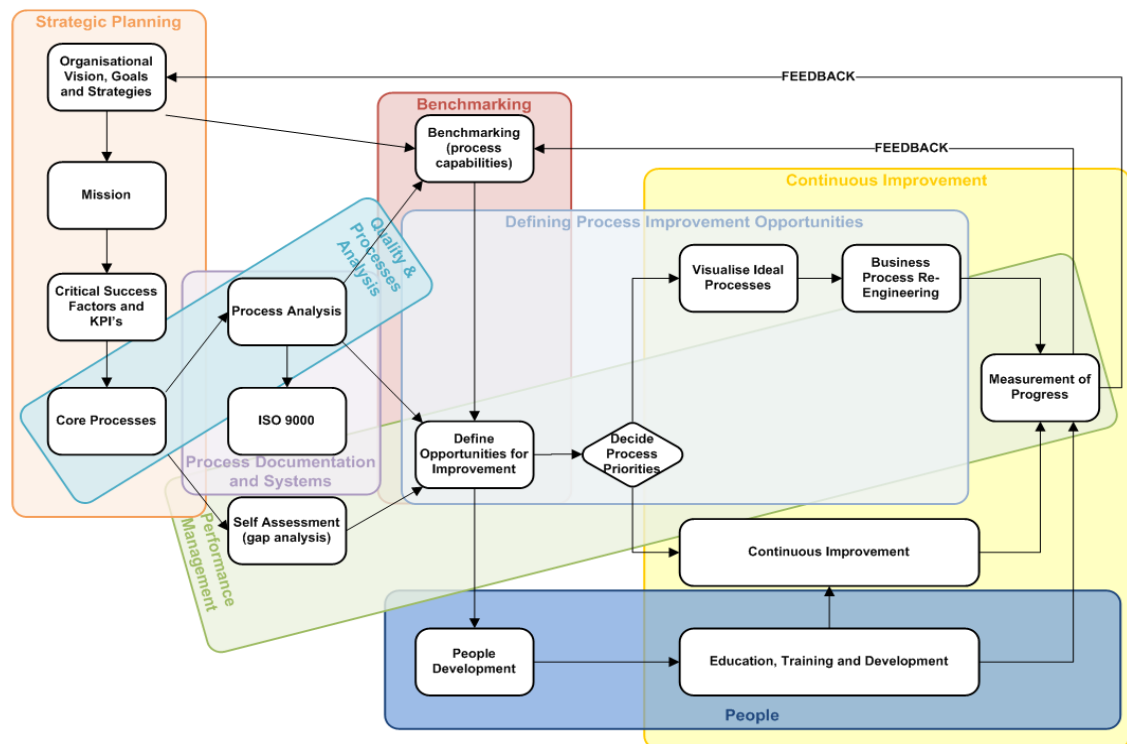
A system thinking perspective offers quite a unique viewpoint through “which assumptions about underlying perceived systems structures are continually found, challenged and, if necessary, changed”, similar to that of total quality management (TQM) (Jambekar, 2005).

### 2.6.1 Total Quality

Similar to system thinking and the VUCA world we live in, quality is not a new concept. Whether by ensuring food was safe to eat, or that sufficient shelter would protect against the environment and predators, throughout our existence, human beings have always been concerned with quality (Madu, 1998). The only difference in today’s world is that the volatile environment and predators have been replaced with unpredictable demand patterns and aggressive competitors respectively. Essentially the fundamental definition of quality remains constant, that is “*The standard of something as measured against other things of a similar kind; the degree of excellence of something...*” (Oxford, 2015). The discipline of total quality (TQ) emerged when it was acknowledged by academics and professionals that quality must not be viewed solely as a technical discipline, but rather as a management philosophy (James R. Evans & Lindsay, 2013) or indeed as a system thinking approach to management (Conti, 2010). To achieve this, organisations were encouraged to adopt the following TQ fundamental principles as outlined by (Oakland, 1999):

1. A focus on customers and stakeholders
2. Participation and teamwork by everyone in the organisation
3. A process focus supported by continuous improvement and learning

There have been proven positive correlation between TQ practices and RSC activities including performance management, supplier evaluation, inventory management, training and management leadership, process management and service/product design (Sharma & Modgil, 2015). The reasons behind why TQ practices can improve such a wide spread of activities within a function such as RSCM can clearly be seen in Figure 2.9. In this figure, the three fundamental TQ principles are developed further into key areas; strategic planning; quality & process analysis, benchmarking, performance measurement, continuous improvement and people, a truly system orientated approach to management. Another system thinking concept that emerged in the 1990's as a product of the TQ movement a decade earlier, is that of restructuring the business processes of a system (Aghdasi, Albadvi, & Ostadi, 2010).

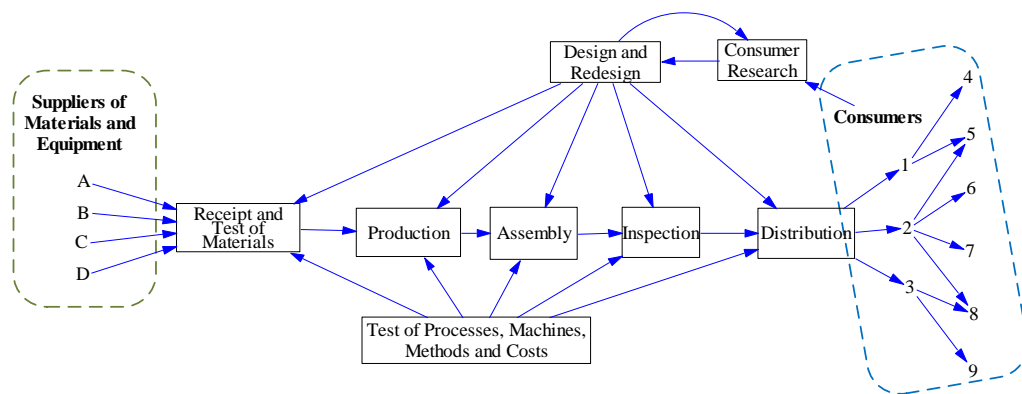


Source: Adapted from (Oakland, 1999)

**Figure 2.9 The Framework for Total Organisational Excellence**

### 2.6.2 Business Process Thinking

Many theorists within the discipline of management have cited Peter Drucker's (1999) forward-thinking 1954 statement "that marketing is not a specialised functional activity but rather "the whole business seen from the point of view of its final result, that is, from the customer's point of view" (Deshpande, 1999). It can be argued that this statement stems from the teachings of Deming et al. of the same decade, advancing TQ and system thinking philosophies. This was evident as early as 1950 when Deming introduced his production system flowchart (Deming, 2000), describing a business as a continuous process connected on one end by customers and on the other by the suppliers (Fig 2.10).



*Adapted from (Deming, 2000)*

**Figure 2.10 The Deming Business Process Flowchart**

Equally, the market orientation of this statement is in fact, in its very nature focusing on a system from a demand perspective, while acknowledging the system as a holistic process. The movement from market orientation to process orientation simply understands that having a system orientated view point is viewing from all directions within the process itself. More importantly, a process-orientated structure can also be defined as deemphasising the functional structure of business, (Davenport, 1993) cited in

(W. C. Johnson & McCormack, 2011; K. P. McCormack & Johnson, 2001), or business process reengineering (BPR).

BPR is the practice of reviewing and formalising the internal business processes of a system and evaluating their performance (Rinaldi, Montanari, & Bottani, 2015). It has been claimed that BPR can be used as the vehicle to influence and develop all decisions made at both strategic and tactical levels of a commercial organisation (Lynch, Mason, Beresford, & Found, 2012). Falling under the umbrella of business process management (BPM) techniques, BPR is one of its many acronyms (Van Der Aalst, Ter Hofstede, & Weske, 2003), another being BPO or business process orientation. BPO can be defined simply as a philosophy organisations can adapt to enhance their overall performance by adopting a “process view” of their system organisational structure (Lockamy & McCormack, 2004b), similar to Deming’s business process flowchart illustrated in Figure 2.10. BPO is the move from the vertical structure of the traditional hierarchical organisation to a more market orientated horizontal structure, or as McCormack (2001) explains from an employee’s perspective. That is, thinking in processes by having a mind-set that they report to the customer not to the hierarchy within the organisation. BPO is fundamentally process thinking, and there are four recognised categories that will assist organisations to transition into a BPO structure (Hammer, 1996; Hammer & Champy, 2009). They are:

1. Business Processes
2. Jobs and Structures
3. Management and Measurement Systems
4. Beliefs and Values

### 2.6.3 Supply Chain Orientation

As noted previously, SCM, in its current form, was first coined in the early 1990's. Like many other newer disciplines, it is a common theme for there to be ambiguity over definitions; the same is very true about SCM. Over the past 3 decades there has been an unresolved debate in defining the nature of SCM and other related topics (Esper, Clifford Defee, & Mentzer, 2010). There have been many accepted definitions in the literature (see Table 2.7), many overlapping and complementing each other. Whether conceptually defining SCM as customer, process, connectivity or systemically focused, there is one thing all have in common; such orientation ends with the end consumer and encompasses the entire system as a mutually dependant, collaborative entity (Omar, Davis-Sramek, Fugate, & Mentzer, 2012), with a mind-set of what can be described as supply chain orientation (SCO) (Hult, Ketchen Jr, Adams, & Mena, 2008), an extension of BPO.

SCO is the recognition by SCM decision makers of the operational, tactical and strategic implications of managing the upstream and downstream flow of material, services, capital, and information across their suppliers and customers (Esper et al., 2010). Mentzer (2001) claims that there cannot be an efficient and effective SCM structure without a SCO mind-set from the core partners within the system.

**Table 2.7 Supply Chain Management Definitions**

<b>Author</b>	<b>Definition</b>	<b>Concept</b>
(Martin Christopher, 2010)	SCM can be defined as the management of upstream (suppliers) and downstream (customers) relationships in order to create enhanced value in the final market place at less cost to the supply chain as a whole.	Process & Customer Orientation
(Supply Chain Council, 2014)	The management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers.	Process Connectivity
(CSCMP, 2015)	Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement,	Process Flow



	conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.	
(Mentzer et al., 2001)	SCM is the systemic, strategic coordination of the traditional business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.	Systemic Process
(Chopra & Meindl, 2013)	Effective supply chain management involves the management of supply chain assets and product, information, and fund flows to maximize total supply chain surplus. A growth in supply chain surplus increases the size of the total pie, allowing contributing members of the supply chain to benefit.	Process Surplus

#### 2.6.4 Business Process Management

Management philosophies such as TQ, BPR and BPO are primary antecedents that have merged to form what is known as business process management (BPM). BPM is “an integrated system for managing end-to-end business processes (Hammer, 2015). It is a structured systematic approach in analysing, improving and controlling the management of processes with the aim of improving the quality of products and/or services (Elzinga, Horak, Lee, & Bruner, 1995). Chang (2006) states a similar product/service centric goal to BPM and adds a detailed list of principles and practices to full BPM compliancy, see Table 2.8. Chang’s principles and practices resonate of Deming’s contribution to TQ in a concerted effort to interlink, map, adhere and improve organisational processes.

**Table 2.8 Business Process Management Principles and Practices**

<b>Goal</b>	Improve products and services through structured approach to performance improvement that centres on systematic design and management of a company’s business processes.
<b>Principles</b>	<ol style="list-style-type: none"> <li>1. Business processes are organisational assets that are central to creating value for customers</li> <li>2. By measuring, monitoring, controlling, and analysing business processes, a company can deliver consistent value to customers and has the basis for process improvement</li> </ol>

	<ul style="list-style-type: none"><li>3. Business processes should be continuously improved</li><li>4. Information technology is an essential enabler for BPM</li></ul>
<b>Practices</b>	<ul style="list-style-type: none"><li>1. Strive for process-orientated organisational structure</li><li>2. Appoint process owners</li><li>3. Senior management needs to commit and drive BPM and execution of BPM process improvements should take a bottom-up approach</li><li>4. Put in place information technology systems to monitor, control, analyse, and improve processes</li><li>5. Work collaboratively with business partners on cross-organisational business processes</li><li>6. Continuously train the workforce and continuously improve business processes</li><li>7. Align employee bonuses and rewards to business process performance</li><li>8. Utilise both incremental (e.g., Six Sigma) and more radical (e.g., BPR) methodologies to implement process improvement</li></ul>

Complimenting Chang's principles, according to Rosemann and vom Brocke (2015), there are six core elements to BPM with close resemblance to the elements of the TQ system illustrated in Figure 2.9. These are strategic alignment; governance; methods; information technology (IT); people; and culture.

### **2.6.4.1 BPM Strategic Alignment**

Strategic alignment recognises business processes as enablers of strategic planning and, therefore, acknowledges the need to link them more closely to business strategies (Ndede-Amadi, 2004). Also known as strategic "synchronisation", business performance and competitive advanced is enhanced by the close link between organisational priorities and enterprise processes (Burlton, 2014).

### **2.6.4.2 BPM Governance**

BPM governance brings the necessary accountability and transparency of roles and responsibilities at all level levels of business processes, including daily operations, high level projects, specific BPM focused programmes, and macro level economic actions

needed to control market mechanisms (Niehaves, Plattfaut, & Becker, 2012). International standards and quality awards are closely linked to this BPM element.

### **2.6.4.3 BPM Methods**

Methods incorporates the core BPM tools and techniques, or toolbox, that support and enable competitive activities along the process lifecycle (vom Brocke & Rosemann, 2015). A BPM toolbox should include methods that facilitate process mapping, process modelling or analysis, as well as process improvement techniques (Dumas, La Rosa, Mendling, & Reijers, 2013) and include solutions such as Six Sigma (Yu & Zaheer, 2010) and supply chain operation reference (SCOR) model (P. Bolstorff & Rosenbaum, 2007; H. Zhou, Benton, Schilling, & Milligan, 2011).

### **2.6.4.4 BPM Information Technology**

IT solutions are of huge importance to BPM advances. The toolbox of process mapping, modelling and analysis, BPM developed IT systems increasingly manifest themselves into sophisticated, process-aware information systems (PAIS) or enterprise resource planning (ERP) systems (Millet, Schmitt, & Botta-Genoulaz, 2009; vom Brocke & Rosemann, 2015).

### **2.6.4.5 BPM People**

People are at the core of any BPM initiative (P. Bolstorff & Rosenbaum, 2007) and should be seen as the knowledge base that implement strategic-driven processes (Marjanovic & Freeze, 2012). The acquisition of knowledge through people learning and development programmes (Moore, Green, & Gallis, 2009) from a SCM perspective is of huge strategic importance and is crucial to efforts to create value in a unique, inimitable way (Hult, Ketchen, Cavusgil, & Calantone, 2006). Although from a BPM and system thinking

perspective, knowledge inimitability is in fact a barrier to overall synergies, cost efficiencies and competitiveness to the RSC as a whole (Shih, Hsu, Zhu, & Balasubramanian, 2012). Therefore, finding a balance between inimitable competitiveness and knowledge-sharing, collaborative synergies is the ultimate goal of BPM initiatives.

### **2.6.4.6 BPM Culture**

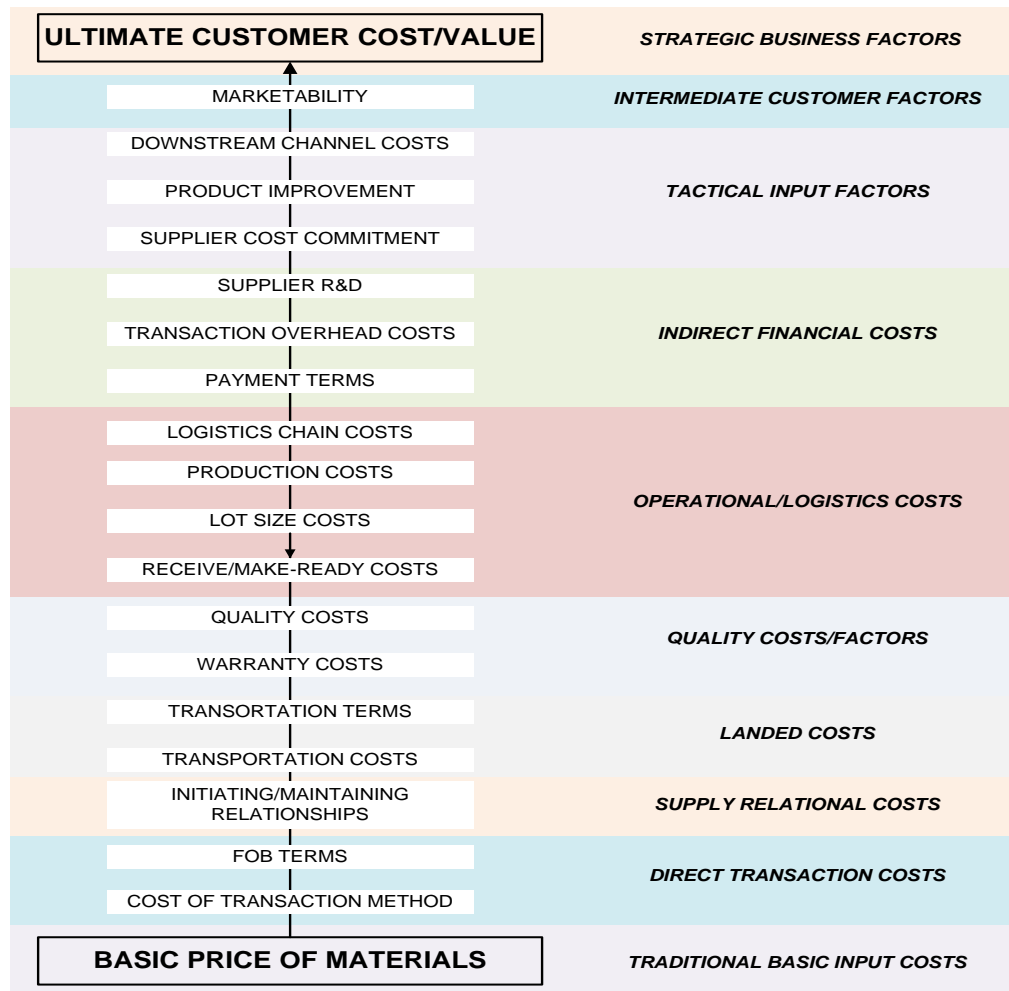
Closely linked to the BPM element “people”, culture is seen as probably the most influencing factor to BPM and also the most influenced factor to BPM initiatives (Hammer, 2015). Even though most culture references in BPM relate to the heavily researched and cited field of organisational culture, it is important to recognise national culture and work group culture as influential factors also (vom Brocke & Sinnl, 2011). BPM culture focuses on organisation cultural factors in relation to processes, such as; responsiveness to change; values and beliefs; and attitudes and behaviour (vom Brocke & Rosemann, 2015).

### **2.6.5 Total Cost of Ownership**

As introduced in Chapter 1 and Section 2.1, RSC uncertainty is at the centre of all SCM decision risks. Cavinato (2004) adds that anything that can reduce uncertainty will reduce costs within the RSC. In B2B markets, particularly those RSC relationships outlined in Table 2.7, transactions (material, capital and information flows) are becoming more sophisticated and the total cost of ownership (TCO) of such transactions can be a critical element in the success of RSC decision making (Christopher & Peck, 2003). TCO originated in the military strategic purchasing concept of “Life Cycle Costing” (LCC), which was created to ensure assets were appraised over their entire lifetime and not on

a short term, transaction or purchase price only (Ferrin & Plank, 2002; Woodward, 1997). Similarly, TCO is suggesting that supply decision makers should “adopt a long-term perspective, not a short-term, initial-price perspective, for the accurate valuation of buying situations” (Ferrin & Plank, 2002).

Not unlike SCO, TCO can be said to be an SCM integrating concept from the perspective of the flow of material, capital and information related to the purchase of a good or service and the costs associated with those transactions (Ellram & Siferd, 1993). And as the concept of a RSC is the ultimate extension of the distribution channel, TCO is a necessity as it concentrates on relational factors rather than transactional ones alone (Cavinato, 1992). Figure 2.11 captures the generic total cost elements of a RSC, including each firm within the system ending with the ultimate goal of customer value at an optimal cost.



*Adapted from: (Cavinato, 1992)*

**Figure 2.11 Total Cost/Value Hierarchy Model**

## 2.7 Risk – A Decision Making Perspective

The recently coined terms such as; decision support systems (DSS); risk mitigation or business analytics have one very important common denominator, that is the decision making process. Decision making from a business perspective is about creating events and opportunities that shape the future (Drummond, 1996). A decision needs to be made when an individual or a group faces a choice in which there is more than a single option. The range of possible outcomes may be minuscule, or they might be nearer to infinite and

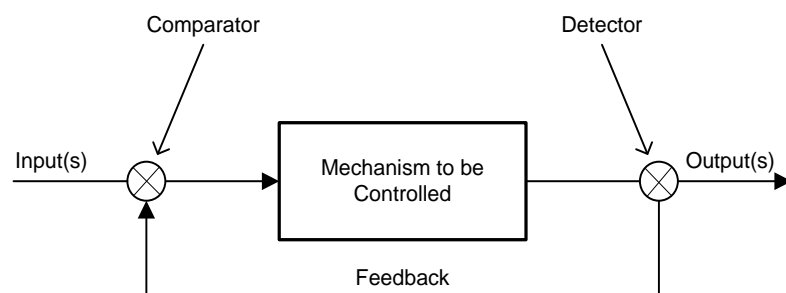
can be further complicated by being multiple or sequential decisions, each of which influence and affect subsequent options (Michael Pidd, 2009). Sequential decision making can be described as actions made by managers by making a series of decisions according to the system status as well as any personal or professional preferences to form a decision policy (X. Yang, Feng, Li, & Wang, 2001). Explicit models are useful tools in improving decision making in organizations, these can range from logical to mathematical models. Peter F. Drucker (1967) famously categorised the decision making process into the following sequential steps (Table 2.9), which have been cited and adapted through multiple disciplines since their publication in 1967.

**Table 2.9 Drucker’s Decision Making Sequential Steps**

Step	Description
1	Classifying the problem.
2	Defining the problem.
3	Specifying the answer to the problem.
4	Deciding what is “right”, rather than what is “acceptable”, in order to meet the boundary conditions.
5	Building into the decision the action to carry it out.
6	Testing the validity and effectiveness of the decision against the actual course of events.

It can be argued that this process in reality is the easy bit for decision makers. Pidd (2009) highlights that it is much harder to implement, manage and control the continued operation of the consequences of making decisions, and for the majority of organizations, is very time consuming, involving high levels of persuasion, arguments and consultation. This is complicated further by having to “battle” with other changes in the rest of the world that occur during this time and ensuring this does not affect your judgment.

An example of this would be results from a particular analytical model might make it clear to senior management of a retail chain in Ireland that it would be best to restructure their distribution system around one large centralized national distribution centre. The problem is that they currently operate several smaller regional depots. A transition to the single distribution centre would take time and many members of staff are likely to lose their jobs, meaning they are unlikely to cooperate with this transition. The implementation of this strategic decision is probably to be a volatile process, involving many meetings, consultations and arguments. This is not to say that the original model was a waste of time, just that it serves as a basis for control, against which progress can be measured (Michael Pidd, 2009). This can be described as a control system, as shown in Figure 2.12, and are based on the philosophy of feedback.



*Source: Adapted from (Michael Pidd, 2009)*

**Figure 2.12 A Feedback System**

In this system, the mechanism is controlled by the detection (Detector) of its performance, which is then fed back and compared (Comparator) with some target benchmark. This feedback can be conceptualized to represent any decision making process, from the detailed operational level, to more abstract strategic level. From a whole system perspective, a feedback system can be seen as a control point for the risk of making



decisions. Baird (1989) claims there are three outcomes to the level of knowledge available to a decision maker, they are: certainty; uncertainty and risk.

### 2.7.1 Risk and Control – The Philosophy of Risk

Risk, in simple terms, is something that has a tendency to happen in the future, with a possible loss or disadvantage (Jianxin, 2008). In the literature, no matter the discipline, risk can be identified as many different terms. Common synonyms include; uncertainty, turbulence, disruption, disaster, peril and hazard (Ghadge, Dani, Chester, & Kalawsky, 2013; Ghadge, Dani, & Kalawsky, 2012). For this reason and the purpose of consistency, this research relates all reference of the term “*Risk*” to the term given by the International Standards Organisation (ISO). The ISO in the standard ISO 31000 for risk management (RM) define risk as the “effect of uncertainty on objectives”, and “as the combination of the probability of an event and its consequences”, both positive and negative (ISO, 2009a). It is important to note that the ISO also incorporates both opportunities and threats to its definition. Therefore as risk arises because of uncertainty, and as organisations can never be sure of what will happen in the future, there is always risk (Waters, 2007). A quantitative definition (S. Kaplan, Haimes, & Garrick, 2001) for risk,  $R$ , is shown in equation (2.2):

$$\{ \langle S_i, L_i, X_i \rangle \}_c \quad (2.2)$$

where  $S_i$  is the  $i$ th “risk scenario”,  $L_i$  is the likelihood of that scenario, and  $X_i$  the resulting consequence, or “damage vector”. Subscript “ $c$ ” denotes that all possible scenarios of  $S_i$  should be considered. Dey and Ogunlana (2004) suggest that any goal an organisation sets, involves uncertainty and the success or failure will depend on how the company

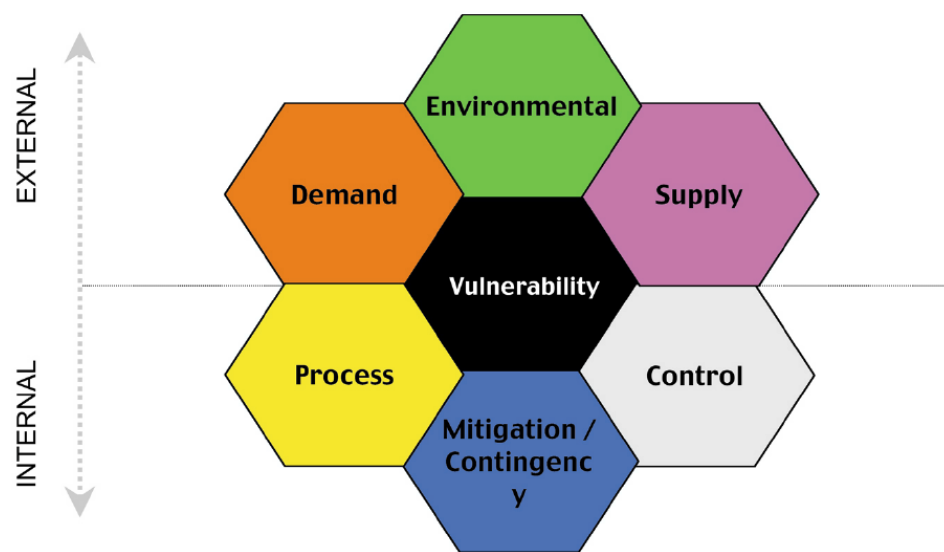
deals with it, or in terms of equation (2.2), limit the damage factor from the resulting consequences of their decisions.

### **2.7.2 Risk Categories**

As explained, in relation to decision making, risk is inherent in all activities. Logically, the number of risks that a system could be vulnerable to is in the thousands, therefore risks need to be grouped into manageable categories (Morgan, Florig, DeKay, & Fischbeck, 2000). There are generally six main areas of risk from a business perspective; strategic risks, operational risks, financial risks, compliance risks, people risks and technological risks (Sadgrove, 2015). Strategic risks are large scale exposure concentrations such as large counterparty, sector, geographical, and/or product risks (Calandro, 2015). Operational risks can be defined as the risk of loss resulting from inadequate or failed internal processes, people and systems or external events (Jarrow, 2008). Economic uncertainty about a company's assets and potential to sustain future profits is more commonly known as financial risk (Bartram, Brown, & Waller, 2015).

While compliance risk is closely associated with all other risks, financial and operational in particular, acknowledging the risks associated with non-compliance to tax authorities, health and safety regulations, and standards and certification bodies (Sadgrove, 2015). A more recent addition to the risk typology is that of people and technological risks. People can increase undermining of a system by knowledge gaps and/or errors in judgment resulting from inadequate skills and knowledge, exposing organisations to risk (Lehavi, 2015). Technological Risk is defined as "the likelihood of physical, social, and/or financial harm/detriment/loss as a consequence of a technology aggregated over its entire

lifecycle” (Renn & Benighaus, 2013). Business risks are very dynamic in nature, just like the VUCA system they are part of, but for all their diversity they can be split into two key sources; *Internal Risk*; and *External Risks* (Toma, Alexa, & Sarpe, 2011). There are many publications in relation to categorizing risk, (Aven & Renn, 2009; Manuj & Mentzer, 2008; Miller, 1992; R. D. Wilding, 2007; Woods, 2011), all centring on internal and external risk sources as illustrated in Figure 2.13.



Source: (Cranfield, 2003)

**Figure 2.13 External and Internal Vulnerability Drivers**

Internal risks are those drivers of risk that are focusing on processes within the organisation. From a system perspective, processes, control and mitigation/contingency plans are seen to be more tightly under the direction of the organization and are a less probable at being a source of vulnerability. Although it can be argued that internal risks such as process control can leave a system vulnerable due to the fact that they are natural amplifiers and absorbers of the effects of vulnerability on a system (Jüttner, 2005). While external risks are the drivers of risk that are more likely to be monitored by managers as

because they are outside of the organization they are perceived as unmanageable, such as uncertain demand, unreliable suppliers or disruption from a natural disaster (Cranfield, 2003). A detailed list of business risk categories with their associated drivers, from a RSC perspective can be seen in Table 2.10. The vulnerability drivers of Figure 2.13 have also been added to highlight the generic applicability of these categories.

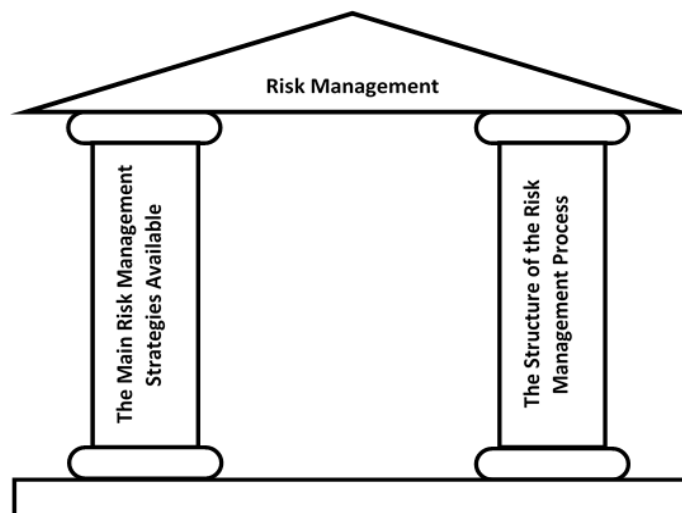
**Table 2.10 RSC Risks and Their Drivers**

<b>Category of Risk</b>	<b>Drivers of Risk</b>	<b>Vulnerability Driver</b>
Disruptions	<ul style="list-style-type: none"> <li>Natural Disaster</li> <li>Labour Dispute</li> <li>Supplier Bankruptcy</li> <li>War and Terrorism</li> <li>Dependency on a single source of supply as well as the capacity and responsiveness of alternative suppliers</li> </ul>	Demand Environmental Supply
Delays	<ul style="list-style-type: none"> <li>High capacity utilisation at supply source</li> <li>Inflexibility of supply source</li> <li>Poor quality or yield at supply source</li> <li>Excessive handling due to border crossings or to change transportation modes</li> </ul>	Supply Environmental
Systems	<ul style="list-style-type: none"> <li>Information infrastructure breakdown</li> <li>System integration or extensive systems networking</li> <li>Ecommerce</li> </ul>	Process Control Environmental
Forecast	<ul style="list-style-type: none"> <li>Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base</li> <li>“Bullwhip Effect” or information distortion due to sales promotions, incentives, lack of RSC visibility and exaggeration of demand in times of product shortage.</li> </ul>	Demand Process Control Mitigation/Contingency
Intellectual Property	<ul style="list-style-type: none"> <li>Vertical Integration of the RSC</li> <li>Global outsourcing and markets</li> </ul>	Environmental Mitigation/Contingency Control
Procurement	<ul style="list-style-type: none"> <li>Exchange rate risk</li> <li>Percentage of a key component or raw material procured from a single source</li> <li>Industrywide capacity utilisation</li> <li>Long-term versus short-term contracts</li> </ul>	Supply Process Environmental
Receivables	<ul style="list-style-type: none"> <li>Number of customers</li> <li>Financial strength of customers</li> </ul>	Demand
Inventory	<ul style="list-style-type: none"> <li>Rate of product obsolescence</li> <li>Inventory holding cost</li> <li>Product value</li> <li>Demand and supply uncertainty</li> </ul>	Control Process Mitigation/Contingency
Capacity	<ul style="list-style-type: none"> <li>Cost of capacity</li> <li>Capacity flexibility</li> </ul>	Process Control

*Source: Adapted from (Chopra & Sodhi, 2004)*

### 2.7.3 Risk Management

As noted in Section 2.8.1, risk should incorporate both opportunities (upside risks) and threats (downside risks). Therefore the management should be concerned with providing the necessary tools to control both the negative and positive impacts of risk (Woods, 2011). It is claimed that RM in organisations is related to the development of scientific instruments, methods and standards to address risk that have sustained organisations against the threat of disruptions (Popescu & Dascalu, 2011). Aven (2015) gives a comprehensive overview in the development of RM, stating that there are two well-established pillars of RM; firstly the main risk management strategies available; and secondly the structure of the risk management process.



*Source: Author (based on Aven 2015)*

**Figure 2.14 The Two Pillars of Risk Management**

#### 2.7.3.1 Risk Management Strategies

In general practice, there are four different alternative strategies to managing risks; 1. Avoid; 2. Reduce; 3. Transfer; and 4. Retain (Hubbard, 2009). Common methods for managing such strategies as outlined by Hubbard are:

- Expert Intuition
- An Expert Audit
- Simple Stratification Methods
- Weighted Scores
- Traditional Financial Analysis
- A Calculus of Methods
- Probabilistic Methods

Although Hubbards strategies are common within industry, it is important to note that “...management methods based on quantitative risk assessments, procedures of precaution or discursive approaches should always be preferred over pure intuition, public opinion or political pressure” (Klinke & Renn, 2001). Renn (2008) gives a more structured claim to what RM strategies are, claiming there are three major strategies used to manage risk; risk-informed, cautionary/precautionary, and discursive strategies. The risk informed strategy is closely aligned to Hubbard’s viewpoint, using risk assessment either to avoid, reduce, transfer or retain risk, while the cautionary/precautionary approaches risk by measuring how robust or resilient a system is to risk (Aven, 2015). The discursive strategy uses appropriate measures to build confidence and trustworthiness within the RM decision process and needs all parties involved to collaborate and collectively take responsibility for risks within their system (Klinke & Renn, 2001; Renn, 2008). In the majority of cases, an appropriate strategy should consider a combination of all three strategies (Aven, 2015) as requirements for all three approaches are needed when structuring the second pillar, the RM process.

### **2.7.3.2 Structuring the Risk Management Process**

In any network environment, the RM process essentially follows a similar structured approach (Hallikas, Karvonen, Pulkkinen, Virolainen, & Tuominen, 2004) and is broken down into phases, most likely in line with risks standards such as ISO 31000, which is the foundation of most RM citations (Aven, 2015; Hallikas et al., 2004; Meyer & Reniers, 2013; Purdy, 2010). These phases are:

- i. Establish the Context
- ii. Risk Identification
- iii. Risk Analysis
- iv. Risk Evaluation
- v. Risk Treatment

In complex business systems, such as the RSC, the interconnections within the system are dependent on each other; therefore it can be useful for system partners to share partially their RM processes and develop collaborative ways to manage system risks (Hallikas et al., 2004). Similar to system thinking philosophies such as TQ and BPO, this has given rise to the development of universal standards in RM that aid organisations in speaking the same RM language.

### **2.7.4 Risk Management Standards**

As noted, to achieve consistency and reliability in RM and its associated decision making processes, international standards have been developed with the objective of being able to be applied to all forms of risk. According to the ISO;

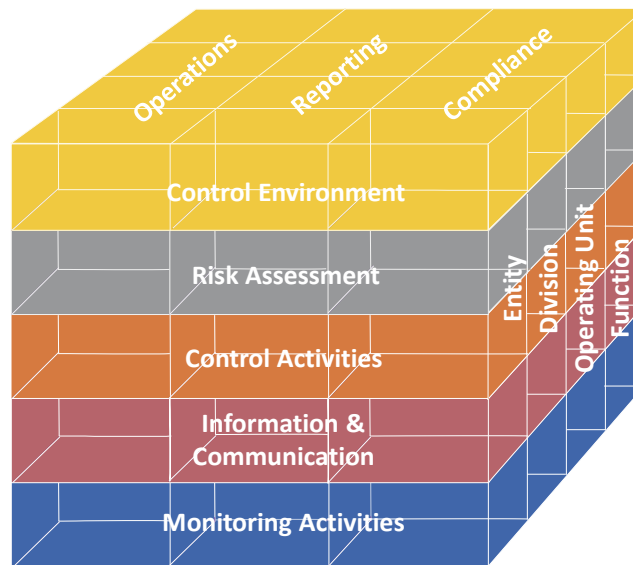
“International Standards make things work. They give world-class specifications for products, services and systems, to ensure quality, safety and efficiency. They are instrumental in facilitating international trade” (ISO, 2016).

### **2.7.4.1 Committee of Sponsoring Organisations of the Treadway Commission**

A well-known and published RM standard is that of the Committee of Sponsoring Organisations of the Treadway Commission (COSO). Which is a voluntary private sector initiative dedicated to improving organisational performance and governance through effective internal control, risk management, and fraud prevention (COSO, 2013). COSO:2013 has five core internal controls; the control environment, risk assessment, control activities, information and communication, and monitoring activities. These controls are spread across the organisational entity right through to individual functions, designed to provide reasonable assurance regarding the achievement of objectives relating to operations, reporting and compliance (McNally, 2013), as illustrated in the COSO Cube below (Figure 2.15).

Traditionally viewed as a financial and accounting audit/control framework, (Oprea, 2014; Vandervelde, Brazel, Jones, & Walker, 2012), there are claims that the framework is limited in terms of its application and acknowledgement of the wider system an organisation is part of, and the integration with RSC partners and associated technologies in particular (Janvrin, Payne, Byrnes, Schneider, & Curtis, 2012).





*Source: Adapted from (McNally, 2013)*

**Figure 2.15 The COSO Cube**





#### **2.7.4.2 Supply Chain Operations Reference Model**

The supply chain operations reference model (or as the most recent version is known - SCOR11) is often seen as the first cross-industry reference framework for integrated SCM (Stewart, 1997). The SCOR11 model gives organisations the ability to describe system process architecture in a way that makes sense to other partners within their system. It is especially useful for describing RSC processes that cut across multiple functions and organisations, providing a common language for managing such processes (Supply Chain Council, 2013). The reference model is divided into 4 hierarchical process levels (figure 2.16). Level 1 consists of six strategic RSC processes: Plan (P), Source (S), Make (M), Deliver (D), Return (R), and Enable (E). Level 2 describes core processes. Level 3 specifies the best operational practices of each process and Level 4 is specific activities to the organisation.

SCOR11 has been researched extensively in the literature with many publications across all functions of an organisation, highlighting its cross-functional, process orientated architecture. Whether its aligning strategic management processes of an organisation with extended RSC after sales strategies (Cavalieri, Gaiardelli, & Ierace, 2007); developing simulation decision support frameworks (Jin, Hongwei, Changrui, & Wei, 2006; Persson, 2011); assisting in the complex task of RSC network design (M. Rabe, Jaekel, & Weinaug, 2006); enhancing performance management (Lockamy & McCormack, 2004a) or even utilising SCOR11's People category to develop human resources (P. A. Bolstorff, 2002); the framework has shown its adaptability and popularity as a research topic over the past 20 years. And that is not including the many publications of SCOR11's primary use as an operations reference guide.

One RSC discipline that the SCOR11 is quite strong from a reference model perspective, but weaker in research publications is that of SCRM. Apart from recent research into mapping SCOR metrics and processes using Bayesian Network to manage risk (Abolghasemi, Khodakarami, & Tehranifard, 2015) and a theoretical analysis of the level of RM integration into SCOR10 (Rotaru, Wilkin, & Ceglowski, 2014), SCOR based SCRM publications are limited. This is a significant research gap, as SCRM (sE9 in SCOR coding) is an important sub-process of the strategic process Enable (E), see figure 2.17. Enable categorises all the processes associated with establishing, maintaining and monitoring information, relationships, resources, assets, business rules, compliance and contracts required to operate the RSC. According to the SCC, Enable processes support the realization and governance of the planning and execution processes of RSCs. They

interact with processes in other domains including finance, HR, IT, and facilities management processes (Supply Chain Council, 2014).

	Level		Examples	Comments
	#	Description		
Within scope of SCOR	1	 Process Types (Scope)	Plan, Source, Make, Deliver, Return and Enable	Level-1 defines scope and content of a supply chain. At level-1 the basis-of-competition performance targets for a supply chain are set.
	2	 Process Categories (Configuration)	Make-to-Stock, Make-to-Order, Engineer-to-Order, Defective Products, MRO Products, Excess Products	Level-2 defines the operations strategy. At level-2 the process capabilities for a supply chain are set. (Make-to-Stock, Make-to-Order)
	3	 Process Elements (Steps)	<ul style="list-style-type: none"> <li>Schedule Deliveries</li> <li>Receive Product</li> <li>Verify Product</li> <li>Transfer Product</li> <li>Authorize Payment</li> </ul>	Level-3 defines the configuration of individual processes. At level-3 the ability to execute is set. At level-3 the focus is on the right: <ul style="list-style-type: none"> <li>Processes</li> <li>Inputs and Outputs</li> <li>Process performance</li> <li>Practices</li> <li>Technology capabilities</li> <li>Skills of staff</li> </ul>
Not in scope	4	 Activities (Implementation)	Industry-, company-, location- and/or technology specific steps	Level-4 describes the activities performed within the supply chain. Companies implement industry-, company-, and/or location-specific processes and practices to achieve required performance

Source: (Supply Chain Council, 2014)

Figure 2.16 SCOR11 Hierarchical Process Levels

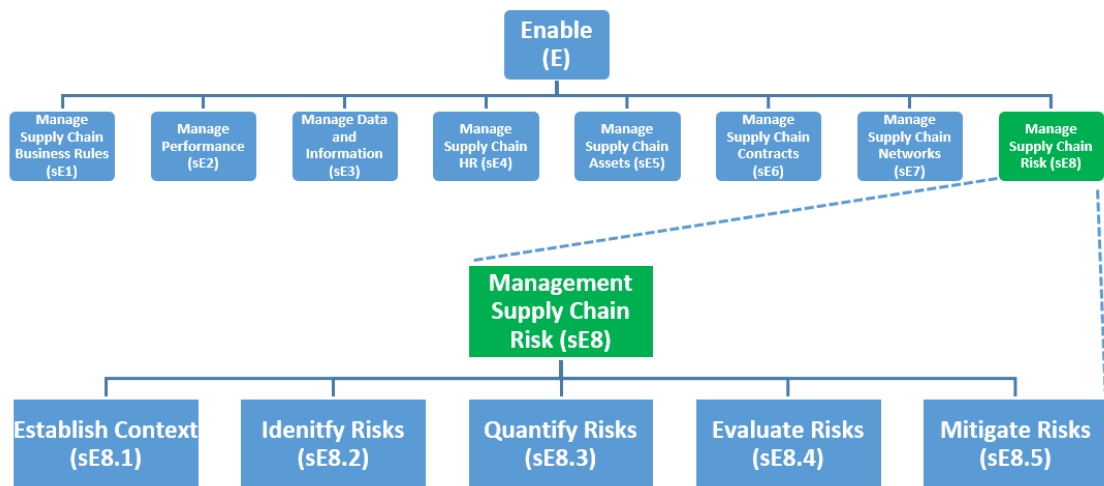


Figure 2.17 SCOR11 Enable (E) Process Hierarchy with RM sub-process

The SCOR11 level 2 process sE8 (manage RSC risk) and its level 3 subordinates, processes sE8.1 to sE8.5 are quite detailed reference models, highlighting what are the

best practices and metrics to use at each stage of a SCRM project. The entire sE8 SCRM process in SCOR11 has been developed directly from the ISO standard 31000:2009 for risk management.

Acknowledging that there are many official standards for RM, including AS/NZS 4360:2004, OCEG “Red Book” 2.0:2009, IRM/Alarm/AIRMIC:2002, or BS 3100:2008, along with many nationally adapted RM standards including the National Standards Authority of Ireland (NSAI) RM standards (NSAI, 2016), this research has focused on the most commonly used RM standard, ISO 31000:2009.

### **2.7.4.3 ISO 31000:2009 for Risk Management**

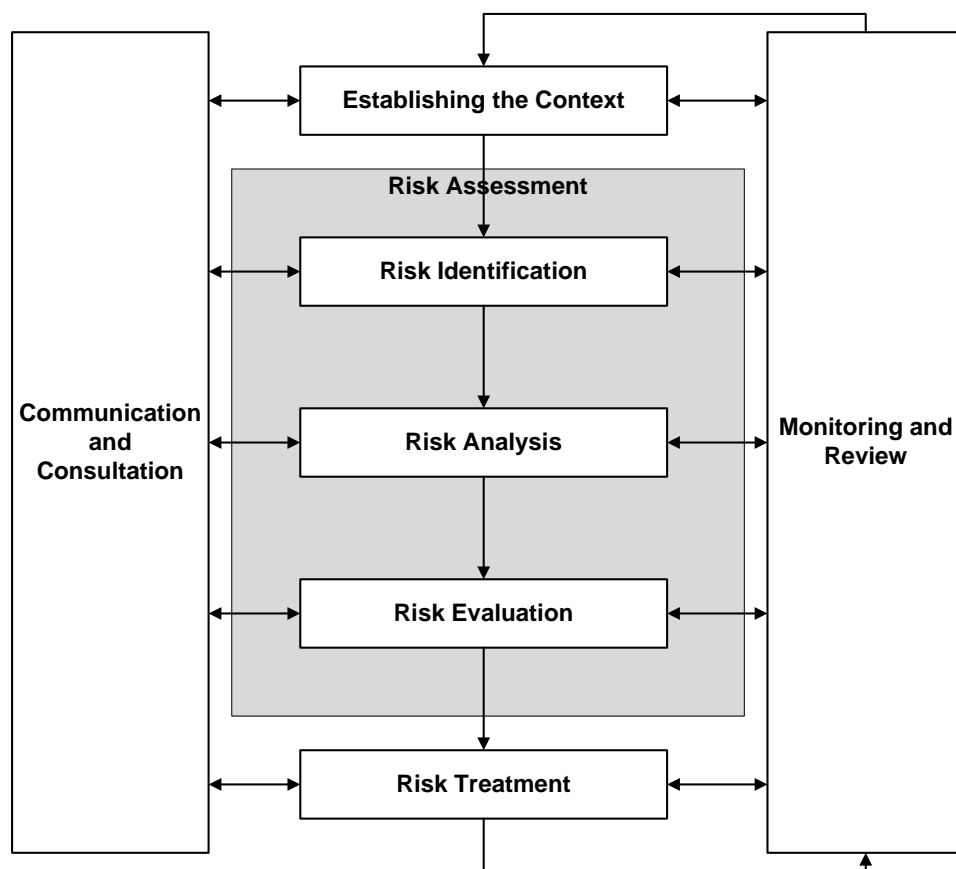
The objective of ISO’s standard 31000 was the creation of a robust, consistent and reliable approach to RM that would be applicable to all forms of risk. According to Purdy (2010), the standard would contain:

1. One vocabulary;
2. A set of performance criteria;
3. One, common overarching process identifying, analysing, evaluating and treating risks (see Figure 2.18);
4. Guidance on how that process should be integrated into the decision-making process of any organisation.

The following is a summary of the ISO’s descriptions of each of the ISO31000 RM processes based on ISO31010 standard for risk assessment techniques (ISO, 2010).

- **Communication and Consultation** - Successful RM is dependent on effective communication and consultation with stakeholders and will assist in; developing a

communication plan; defining the context appropriately; ensuring that the interests of stakeholders are understood and considered; bringing together different areas of expertise for identifying and analysing risk; ensuring that different views are appropriately considered in evaluating risks; ensuring that risks are adequately identified; securing endorsement and support for a treatment plan.



*Source: adapted from (ISO, 2009b)*

**Figure 2.18 The ISO31000 Risk Management Process**

- **Establish the Context** – Establishing the context defines the basic parameters for managing risk and sets the scope and criteria for the rest of the process. Establishing the context includes considering internal and external decision variables relevant to

the system as a whole, as well as the background to the particular risks being assessed.

- **Risk Assessment** - Risk assessment is the overall process of risk identification, risk analysis and risk evaluation. Risks can be assessed at an organisational level, at a departmental level, for projects, individual activities or specific risks. Different tools and techniques may be appropriate in different contexts. Risk assessment provides an understanding of risks, their causes, consequences and their probabilities.
- **Risk Treatment** – Having completed a risk assessment, risk treatment involves selecting and agreeing to one or more relevant options for changing the probability of occurrence, the effect of risks, or both, and implementing these options. This is followed by a cyclical process of reassessing the new level of risk, with a view to determining its tolerability against the criteria previously set, in order to decide whether further treatment is required.
- **Monitoring and Review** - As part of the RM process, risks and controls should be monitored and reviewed on a regular basis to verify that assumptions about risks remain valid; assumptions on which the risk assessment is based, including the external and internal context, remain valid; expected results are being achieved; results of risk assessment are in line with actual experience; risk assessment techniques are being properly applied; risk treatments are effective (ISO, 2010).

### 2.8 Understanding RSC Risk

RSC risk (SCR) is the probability of an unforeseen event disrupting the RSCs objective, which is the smooth flow of finished goods, component parts and raw materials through the system (Waters, 2011). Ho et al. (2015) classify SCR as the likelihood and impact of

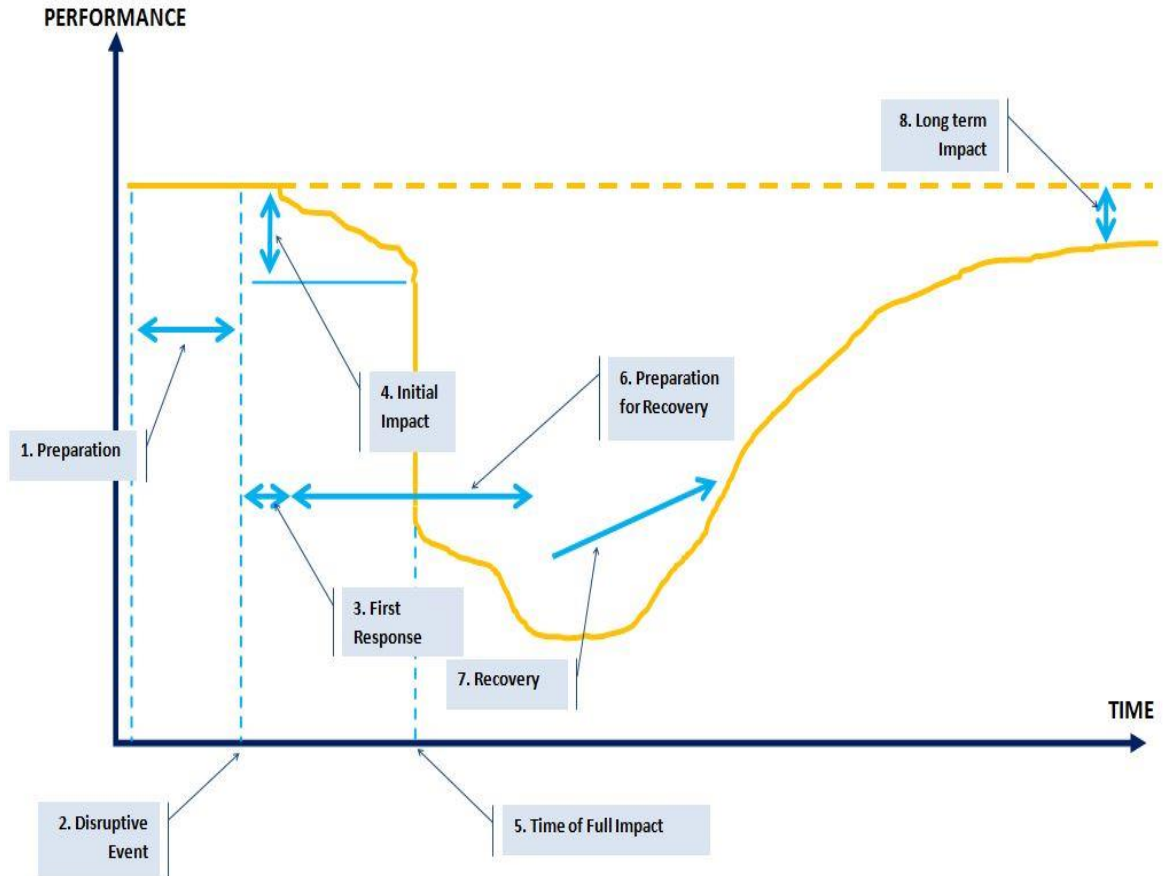
unexpected macro and/or micro level events or conditions that adversely influence any part of a RSC leading to operational, tactical, or strategic level disruptions. SCR “...consists of RSC characteristics which create vulnerability in the RSC; a trigger in the form of a RSC disruption (SCD) will reveal the negative consequences that result from RSC risk” (Monroe, Teets, & Martin, 2014). It can be argued that risk of SCD can be seen as an indicator of the health of a RSC and measure an organisations capability of matching supply and demand (Hendricks & Singhal, 2005).

### **2.8.1 Supply Chain Disruption**

RSC’s require the “capacity to anticipate, cope with, resist and recover from disruptions” (Friesz, Lee, & Lin, 2011). The “new normal” in modern business systems is that of global, multi-tiered, lean rSC’s that recent studies suggest, up to 80% of all companies are vulnerable to a major SCD (Yossi Sheffi, Vakil, & Griffin, 2012). Consequently, huge resources are invested by companies in gathering, analysing and assessing information to control potential SCD triggering events (Heckmann et al., 2015). SCD’s can occur at many levels, from localised disruptions such as a flood in a warehouse, to more globalised network failures such as a major natural disaster (Manners-Bell, 2014).

Apart from the obvious performance and monetary impact, SCD’s have the potential to severely damage the relationships between RSC partners and stakeholders (Hendricks & Singhal, 2005; Y. Sheffi & Rice, 2005). Consequently, managing SCR and SCD within an organisation is increasingly becoming just as important as controlling financial risk (Sodhi et al., 2012). As illustrated in Figure 2.19, most disruptions have a distinct, 8 stage

profile in terms of their effect on company performance (Y axis) over time (X axis) (Y. Sheffi & Rice, 2005).



Source: Adapted from (Y. Sheffi & Rice, 2005)

**Figure 2.19 Understanding the Disruption Profile**

Whether performance is measured by sales, production throughputs, TCO, profits or customer service, the behaviour of the SCD profile remains relatively the same. In fact, it is claimed that the goal of RSCRM is the design and implementation of a RSC system which can anticipate and successfully cope with disruptions (Friesz, 2011). Although complex, this should be very achievable, if the 8 Step SCD profile is fully understood and embedded into the RM strategies outlined in Section 2.8.3.



**Table 2.11 The 8 Step SCD Profile**

<b>Step</b>	<b>Description</b>	<b>Example</b>
1. Preparation	Using warning signals to prepare for a disruption and limit its impact.	Deteriorating Union Negotiations.
2. The Disruptive Event	The actual moment a disruptive event occurs.	A brand manufacturers Global ERP system crashes with no quick resolution.
3. First Response	Control the situation, protect the system and prevent further damage.	A serial product recall.
4. Initial Impact	The initial effect of the event, which can be immediate or have a time delay.	The delivery of goods from a brand manufacturer to a wholesaler is delayed by 5 days due to bad weather and ferry closures at Christmas time.
5. Full Impact	Whether immediate or delayed, once full impact is felt, performance reduces exponentially.	A manufacturer factory fire increase OOS rates on shelves.
6. Recovery Preparations	Qualifying alternative suppliers and resources. Should occur in parallel to first response and even beforehand if warnings are given.	Direct shipments to an alternative port due to increasing fears of a port strike.
7. Recovery	Objective is to get back to normal operational levels.	Use of overtime and supplier/customer resources to increase production utilisation.
8. Long-Term Impact	It takes time to recover from a major disruption. If customer relationships are damaged, service levels may never recover to post event levels.	Offer compensation or promotions for a delayed or cancelled order.

## 2.9 Supply Chain Risk Management (SCRM) Techniques

Managing SCR is difficult because individual risks are often interconnected. As a result, actions that mitigate one risk can end up exacerbating another (Chopra & Sodhi, 2004). Due to the increasing complexity and interdependence of modern RSC's, the type and nature of uncertainty or the impact of any action have become hard or even impossible to predict (Helbing & Lammer, 2008).

Executing equation 2 from Section 2.8.1, in a RSC system is a very difficult task. The number of risk scenarios is vast; likelihood is full of uncertainty and variability, with damage factors ranging from insignificant to catastrophic, or from a traffic jam to an earthquake. Add to the “risk mix” pressures for cost reductions due to recession, increased

implementation of lean techniques to reduce waste, supply risk vulnerabilities in RSC's have increased in likelihood. Tang and Nurmaya Musa (2011) note that although lean has smoothed operations in all RSC's, they have created problems if unexpected events happen. Every RSC faces risks that threaten its ability to operate efficiently. According to Aven and Renn risk has two prevailing characteristics, uncertainty and severity of the consequences of an activity (Aven & Renn, 2009).

SCRM, like SCM itself, is a very broad topic, with many important sub-categories including SCD, supply chain vulnerability (SCV) and supply chain resilience (SCRe). It is directly because of SCRM's relationship with its popular, research heavy sub-categories, that some literature highlights that there is ambiguity with the actual definition of SCRM, (Diehl & Spinler, 2013; Ho et al., 2015; Monroe et al., 2014; Sodhi et al., 2012). An often cited definition in the literature is that of Jüttner et al. (2003) p.203), which states that SCRM is "the identification and management of risks for the RSC, through a coordinated approach amongst RSC members, to reduce RSC vulnerability as a whole". Norrmand and Jansson (2004) have a more singular perspective to SCRM stating it is the collaboration of SC partners to deal with uncertainty and risk caused by logistics related activities. As Table 2.12 highlights, more recent literature including (Thun & Hoenig, 2011) and (Ho et al., 2015) give a more holistic system orientated definition of SCRM including macro/micro and strategic/operational perspectives, more aligned to the system thinking theme of this research study.

The literature offers a significant number of SCRM publications, many empirical studies and conceptual frameworks. Aligning SCOR11's adaptation of ISO31000 RM methods (see Figures 2.18 and 2.19), the following six phases to SCRM have been identified; (1)

Establish Context, (2) Identify Risk Events, (3) Quantify Risks, (4) Evaluate Risks, (5) Mitigate Risks, (6) Monitor and Review.

**Table 2.12 A Chronology of SCRM Definitions**

Authors	Definition of SCRM	Scope
Jüttner et al. (2003)	The identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole.	Identification and management processes
Giunipero and Eltantawy (2003)	The focus of supply chain risk management (SCRM) is to understand, and try to avoid, the devastating ripple effects that disasters or even minor business disruptions can have in a supply chain.	Supply risk management
Normand and Jansson (2004)	To collaborate with partners in a supply chain apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics, related activities or resources.	Generic SCRM Processes
Tang (2006)	The management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity.	Generic SCRM Processes
Goh et al. (2007)	The identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole.	Identification and management processes
Thun and Hoenig (2011)	Characterised by a cross-company orientation aiming at the identification and reduction of risks not only at the company level, but rather focusing on the entire supply chain.	Identification and mitigation processes
Waters (2011)	Supply chain risk management (SCRM) is the process of systematically identifying, analysing and dealing with risks to supply chains.	Generic SCRM Processes
Ho et al. (2015)	An inter-organisational collaborative endeavour utilising quantitative and qualitative risk management methodologies to identify, evaluate, mitigate <sup>9</sup> and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain.	Generic SCRM Processes

*Adapted from: (Ho et al., 2015)*

### 2.9.1 Establish Context

According to the SCOR 11 model, this is the process of defining and documenting the objectives and scope of managing risk (Supply Chain Council, 2014). This includes both internal and external relationships and parameters that influence the RSC's ability to achieve risk assessment objectives, establish risk criteria, and determine risk assessment programmes (ISO, 2010).

### 2.9.1.1 Problem Definition

Problem Definition is a term commonly used for the establish context phase of mathematical, BPM and simulation projects. This technique can be split into two steps; problem formulation; and the setting of objectives and overall project plan (Banks, 1998).

It can be argued that problem definition is the most important step in any project and is where a team establishes the central issues and scope of the project (Musselman, 1998).

The author also introduces a logical flow to the problem formulation process:

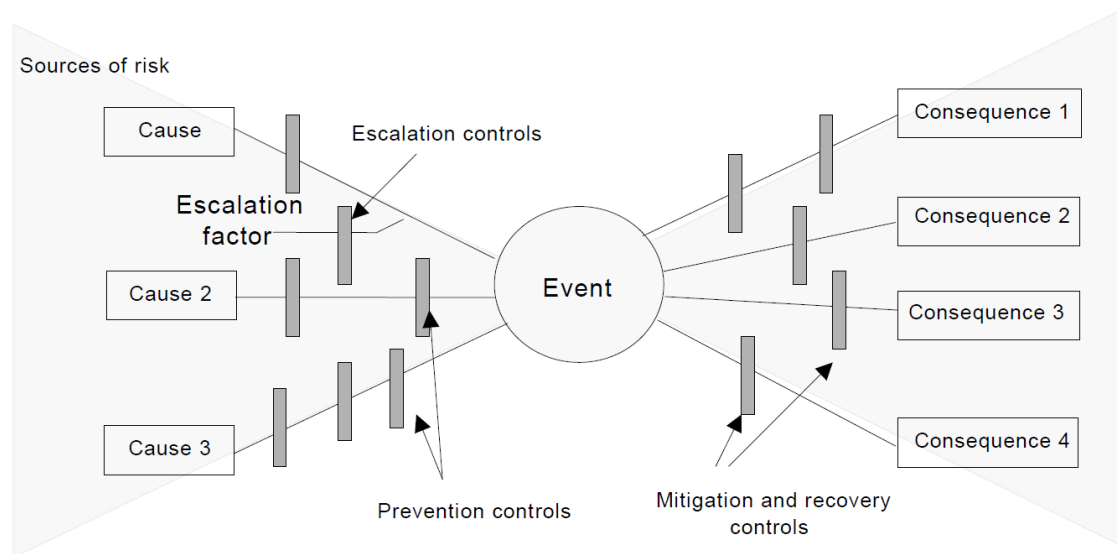
1. Start off on the right foot
2. Work on the right problem
3. Manage expectations
4. Question skilfully
5. Listen without judgement
6. Communicate openly
7. Predict the solution

Understanding the scope and complexity of a problem is also essential to knowing what level of sophistication is needed in developing a solution, where if applied effectively, sometimes more simpler modelling and analytical techniques such as closed form equations are more suited than more expensive techniques such as simulation (Norman & Banks, 1998).

Although very important to the success of BPM and other modelling techniques, the problem definition phase of modelling projects is not extensively discussed in the literature (Mashayekhi & Ghili, 2012), with no major contribution within the SCRM field.

### 2.9.1.2 Bowtie Analysis

According to ISO 31000, the Bowtie Analysis is a simple diagrammatic way of describing and analysing the pathways of a risk from hazards to outcomes and reviewing controls. It can be considered a double sided cause and effect decision tree, or a combination of the logic of a fault tree analysing the cause of an event, represented by the knot of a bowtie (see Figure 2.20), and an event tree analysing the consequences (ISO, 2010).



*Source: adapted from (Aqlan & Lam, 2015)*

**Figure 2.20 A Bowtie Diagram of RSC Risks**

Bowtie diagrams are a good exercise in establishing, scoping and formulating SCRM strategies (Y. C. Yang, 2011) and is seen as the “de facto” diagram to use in any RM project and can establish an overall summary of the risk process (Iacob & Apostolou). Apart from establishing and mapping the scope of a SCRM project, bowties are also effectively used in risk analysis (Garbolino, Chery, & Guarnieri, 2016), in particular, analysing SCRM probability and impact (Aqlan & Lam, 2015). However, some authors

suggest that the bowties are most effective after the modelling phase of a RM project (Andrews & Moss, 2002) and not the establishing context phase.

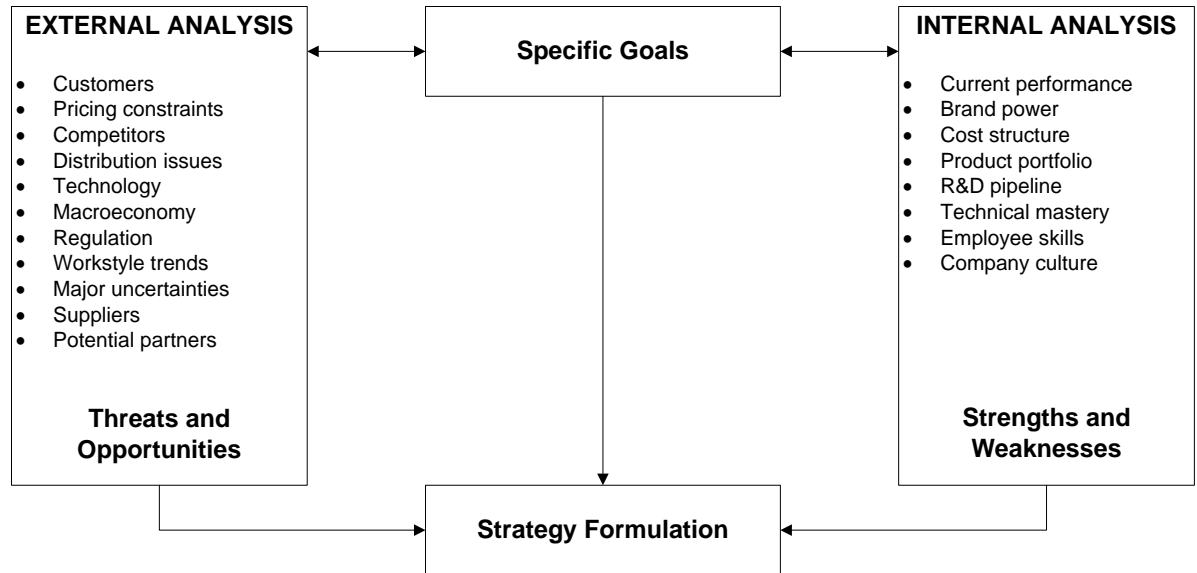
### 2.9.1.3 SWOT Analysis

A common technique in establishing alignment between a projects objectives and an organisation overall business strategy is the SWOT Analysis. The strategic SCRM choices available to an organisation emerge from the process of looking outside and inside the organisation (Figure 2.21), similar to how an organisation may determine its strategic goals (Harvard Business, 2005). This analysis goes by the acronym SWOT: or Strengths, Weaknesses, Opportunities, and Threats.

- **Strengths** are capabilities that enable an organisation or business unit to perform well – capabilities that need to be leveraged.
- **Weaknesses** are characteristics that prohibit your company or unit from performing well and need to be addressed.
- **Opportunities** are trends, forces, events, and ideas that your company or unit can capitalise on.
- **Threats** are possible events or force outside of your control that your company or unit needs to plan or decide how to mitigate.

From a RSC perspective, SWOT's are beneficial to overall strategy formulation based on the understanding of system strengths, weaknesses, opportunities and threats (Rauch, 2007), and has been quite successful, when integrated with fuzzy logic to develop supplier selection (Amin, Razmi, & Zhang, 2011) and SCM planning frameworks (Bas, 2013). But there is no empirical evidence of its application or conceptualisation within the

SCRM field in the literature. The static, subjective and intuitive nature of the SWOT analysis may be one reason it has not been used often with the SCM domain (Agarwal, Grassl, & Pahl, 2012).



*Source: Adapted from (Harvard Business, 2005)*

**Figure 2.21 External and Internal Analysis - SWOT**

### 2.9.2 Identify Risk Events

As noted in Section 2.8, most real systems are exposed to thousands of potential risk events. Over the past three decades, the identification, filtering and ranking of such risks has been a challenge for both decision makers and the RM community as a whole (Haimes, Kaplan, & Lambert, 2002). There are many qualitative and quantitative techniques, varying in sophistication, that have been developed to identify risks within a system.

### **2.9.2.1 Brainstorming**

Brainstorming has been a default technique for creative problem solving since its invention by Alex Osborne over 60 years ago (Gobble, 2014). From a RM perspective, brainstorming is a group discussion technique used in risk-related planning processes, including risk identification, risk assessment and modification programmes (Hammersley, 2011). Although not actively published within SCRM literature, brainstorming sessions have been very successful within finance, specifically fraud identification and risk assessment, as discussed in detail by (W. Chen, Khalifa, & Trotman, 2015). Even if not identified as a specific step in the SCRM process, brainstorming occurs naturally within establishing context and risk identification steps of SCRM, therefore justifies consideration. In addition, a 2005 survey and focus group study of SCM decision makers; it was found that over 83% of organisations use brainstorming sessions at some stage during the risk assessment process (Jüttner, 2005).

### **2.9.2.2 Structured and Semi-Structured Interviews**

Structured interviews use a fixed set of questions which are asked in a predetermined order to all respondents and may offer the interviewee a fixed range of answers (Bryman, 2012). They are also mostly closed questionnaires and are used to collect mostly quantitative data from respondents. Unstructured interviews, in contrast, are similar to informal discussions and do not have standardised questions. The interviewers may alter the questions between interviews and allow respondents to express themselves freely in relation to the topic under study (Healey & Rawlinson, 1994). Semi-structured interviews fall between both ends of the spectrum as they have a predetermined set of questions, however, they allow a high degree of flexibility to ask new questions or discard existing ones, and allow new ideas to emerge during the discussion (Greener, 2008). Moreover,



the sequence of questions may also vary depending on the flow of the discussion. Semi-structured interviews were used by (Elzarka, 2013) to identify potential disruptions and impact of such disruptions to Egypt's SC's after the 2011 revolution. Davarzani et al. (2015) successfully used semi-structured interviews as a primary data collection method for risk identification and assessment of economic and political risks on automobile SC's.

### **2.9.2.3 Delphi Method**

The Delphi Method can be used to establish communication between geographically dispersed experts that allows the systematic and methodological analysis of a complex problem (Collis & Hussey, 2009), such as risk identification. This is achieved through the careful selection of and distribution of sequential questionnaires and summarised information to the chosen experts for feedback. Similar to focus groups, it is widely used as a forecasting technique, but unlike focus groups, the Delphi method generates decisions from a structured group without the risk of peer pressure, which can be present in a focus group environment (Lindqvist & Nordänger, 2007). An excellent example of the Delphi methods applicability to risk identification is in the research of Wentholt et al. (2010) who effectively identified potential food borne risks to the food RSC by carefully selecting experts to answer a set amount of structured questions. In a European wide study, experts in SCM IT infrastructure were contacted using the Delphi method to identify and analyse the impact and risk of full enterprise resource planning (ERP) to SCM (Akkermans, Bogerd, Yücesan, & van Wassenhove, 2003). When developing a Delphi-based SCRM identification and assessment framework, (Markmann, Darkow, & von der Gracht, 2013) give a comprehensive chronological listing of the Delphi Methods

contribution to risk analysis over the past 5 decades. The authors also outline the structure of this data collection method, as illustrated in figure 2.22.



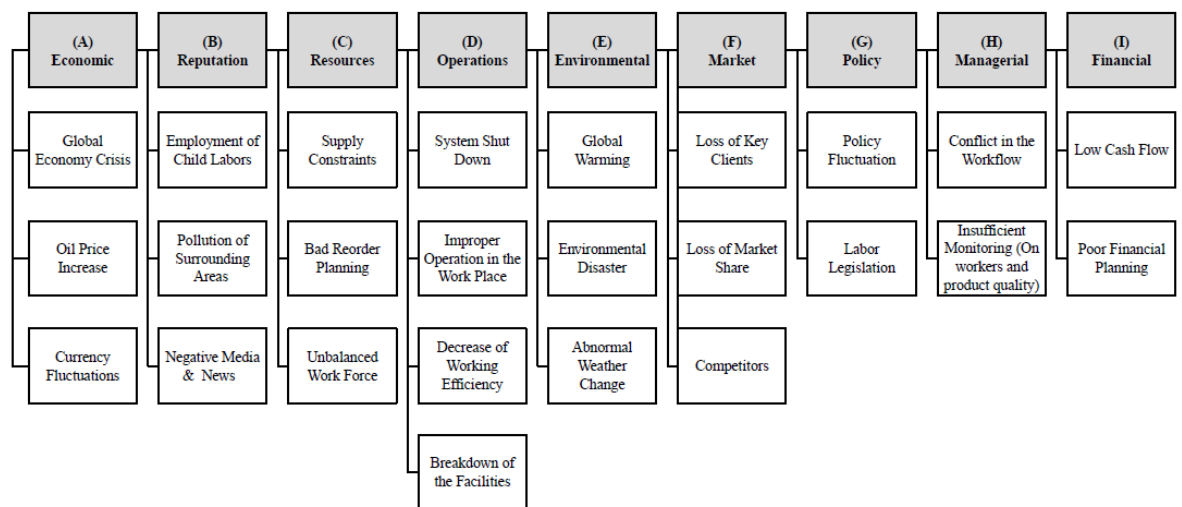
**Figure 2.22 Structure of the Delphi Method Process**

### **2.9.2.4 Hierarchical Holographic Modelling (HHM)**

Most systems from an organisational, process and technological perspective are hierarchal in nature, as a result the RM of such systems is driven by this hierarchical reality and must be responsive to it (Haimes, 2009). This includes identifying risks within the system and its sub-systems, as well as their relationship or influence on each other. The distribution of risks between subsystems for example, can often play a dominant role in the allocation of resources and costs (S. Kaplan et al., 2001). A form of Theory of Scenario Structuring (TSS), a modelling technique called Hierarchical Holographic Modelling (HHM), first introduced in 1981 by Yacov Haimes (1981), is a particular diagram approach useful for the analysis of systems with multiple, interacting ( and perhaps overlapping) subsystems such as a regional transportation or global RSC systems. The different columns in the diagram reflect different “perspectives” on the overall system, as illustrated in Figure 2.23 (Haimes, 2009). HHM can be seen as a general method for identifying the set of risk scenarios in a system. It has been particularly successful in large, complex RM projects such as transportation infrastructure, military planning (Dombroski, Haimes, Lambert, Schlusel, & Sulcoski, 2002; Haimes et al.,

2002; J. H. Lambert, Haimes, Li, Schooff, & Tulsiani, 2001) and textile manufacturing SC's (Lai & Lau, 2012).

The philosophy of HHM is “that the process of identifying the risk scenarios for a system of any kind should begin by laying out a diagram that represents the “success,” or “as planned,” scenario of the system” (Haimes et al., 2002). Each subset is a result of such successes, noting the success can have a negative or positive impact, just like a risk event.



Source: (Lai & Lau, 2012)

**Figure 2.23 A HHM Diagram identifying risks to textile industry**

### 2.9.2.5 Network Prioritisation for Risk Identification

According to the SCOR11 model, network prioritisation for risk identification is the process of prioritising parts of a SC for risk analysis based on the overall risk potential in each portion of the system. Prioritisation is typically based on the criticality of the component (material, capital or information) flowing through a portion of the direct SC of an organisation (Supply Chain Council, 2014). Focusing on potential SCD's, it is the process of identifying, collecting and documenting all potential risk events that may

impact the organisation from meeting its strategic objectives. This includes identification of sources of risks, identification and discovery of risk events. Normally integrated with other identification and data collection techniques, this process generates a comprehensive list of all risks that may disrupt the SC, including information which processes in the RSC will be directly and indirectly impacted by the occurrence of the risk event.

### **2.9.2.6 Hazard Analysis and Critical Control Points (HACCP)**

Hazard analysis and critical control point (HACCP) is a systematic, proactive, and preventive system for assuring quality, in systems, processes, product and services. HACCP provides a structure for identifying hazards and putting controls in place at all relevant parts of a process to protect against the hazards and to maintain the quality assurance and safety of a product or service. HACCP aims to ensure that risks are minimized by controls throughout the process rather than through inspection of the end product (ISO, 2010). The introduction of robust quality protocols such as HACCP has the potential of improving employee training standards and understanding, and also improves overall RSC financial performance (Jraisat & Sawalha, 2013). Closely aligned with ISO 22000:2005, the international standard for safe food management, according to the Food Safety Authority of Ireland (FSAI), HACCP is a systematic approach to identifying and controlling hazards (i.e. microbiological, chemical or physical) in the supply, conversion and distribution of food products for human consumption (FSAI, 2015). Unsurprisingly, HACCP is a popular topic within food industry publications, (Celaya et al., 2007; Fotopoulos, Kafetzopoulos, & Gotzamani, 2011) and although clearly strategically and operationally linked to RSC's, surprisingly, there is no significant evidence of HACCP's

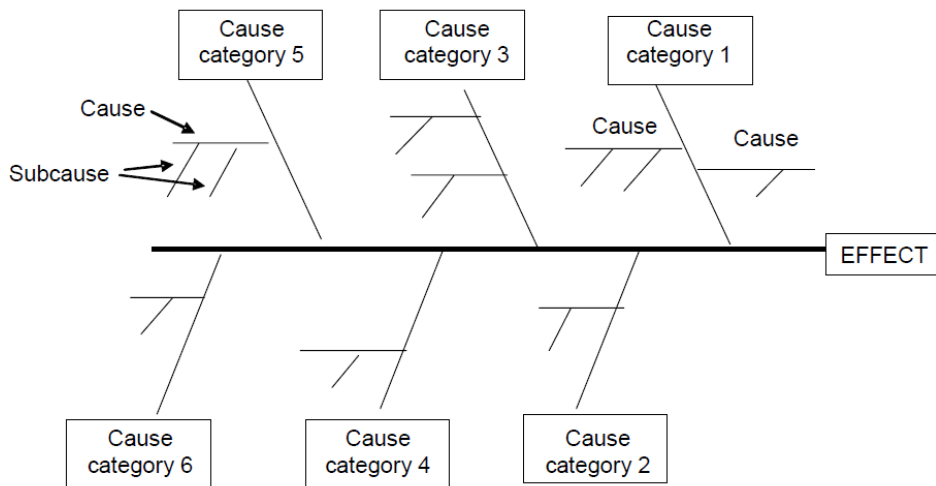
contribution to RSC performance or risk mitigation in the literature. HACCP's seven cores principles are:

1. Identify the hazards
2. Determine the critical control points (CCPs)
3. Establish critical limit(s)
4. Establish a system to monitor control of the CCP
5. Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control
6. Establish procedures for verification to confirm the HACCP system is working effectively
7. Establish documentation concerning all procedures and records appropriate to these principles and their application

### **2.9.2.7 Cause-and-Effect Analysis**

Cause and Effect Analysis, also known as fishbone or Ishikawa diagrams, like HHM, is a risk identification graphical technique that is normally used in parallel with brainstorming sessions. Cause-and-effect diagrams are useful in assisting RM project teams to generate ideas for risk causes and, in turn, to serve as a basis to plan for potential solutions (James R. Evans & Lindsay, 2016). This technique provides a means for RM teams to focus on the identification of a list of risk input variables that could affect key process output variables (Breyfogle III, 2003). When creating a cause-and-effect diagram, it is recommended to consider six categories or risk causes that can contribute to a characteristic response/effect and are commonly grouped as; materials; machine; method; personnel; measurement; and environment (Breyfogle III, 2003), as illustrated in Figure

2.24. Although, they are easy to use, it has been claimed that cause-and-effect diagrams do not provide a dynamic foundation for further analysis, such as relative importance of individual causes of a problem, and hence are not common in SCRM literature. Therefore, these diagrams are more often used for deterministic problems in a very specific domain (Ahmed, Kayis, & Amornsawadwatana, 2007), and from a SCM perspective normally centre on quality improvement initiatives using Six Sigma methodologies (Knowles, Whicker, Femat, & Canales, 2005).



*Source: (ISO, 2010)*

**Figure 2.24 An example of an Ishikawa or Fishbone Diagram**

### 2.9.3 Quantify Risks

According to the ISO (2009b) quantifying risks, or risk analysis, involves developing an understanding of the risk within a system. Risk analysis provides decision makers with input variables to risk evaluation techniques and to decide on the best risk mitigation strategy. Risk analysis can also provide an input into making decisions where choices must be made that may involve many different types and levels of risk (ISO, 2009b). Risk

analysis involves consideration of the sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur. Factors that affect consequences and likelihood need to be identified. Risk is analysed by determining consequences and their likelihood, and other attributes of the risk. Decisions makers need to understand that a risk event can have multiple consequences and can affect multiple objectives (ISO, 2009b). Within SCRM, there have been many Risk Analysis techniques in the literature.

### **2.9.3.1 Hazard and Operability Studies (HAZOP)**

Also effective in the risk identification phase of SCRM projects (Adhitya, Srinivasan, & Karimi, 2009), hazard and operability studies (HAZOP) is a general process of the identification of risk (or hazard) and the assessment of the possible deviations from the expected or intended performance because of such risks (ISO, 2010). HAZOP studies are normally best suited to the manufacturing-based nodes of a RSC where safety of products is critical and risks of hazardous contamination are high (Hopkin, 2012). A qualitative approach, HAZOP is a critical enquiry into the operation of a system, mainly from a hazard point-of-view (Dickson, 2003). Dickson adds that in any HAZOP study the decision maker should be concerned with four main questions:

1. What is the intention of the part examined?
2. What are the deviations from the declared intention?
3. What are the causes of the deviations?
4. What are the consequences of the deviations?

HAZOP systematically examines how each part of a system, process or procedure will respond to changes in key parameters by using suitable guidewords (ISO, 2010), as shown in Table 2.13.

**Table 2.13 Hazard and Operability - Guidewords**

<b>Guidewords</b>	<b>Meanings</b>	<b>Comments</b>
<b>No or Not</b>	This is the complete negation of the intention	No part of the intention is achieved, i.e. there is no flow or heat or no pressure. Nothing else happens; there is simply no part of the intention achieved.
<b>More or Less</b>	There is an increase or a decrease in the quantity of the property	There could be more flow than was the intention or less flow. In the same way there could be more heat or less pressure, etc.
<b>As well as</b>	There is a qualitative increase in the property	The design intentions are achieved but an additional activity occurs, e.g. water gets into the system and flows into petrol tank of a vehicle.
<b>Part of</b>	There is a qualitative decrease in the property	Only some of the intention is achieved and some is not. This is not a quantitative decrease that would be less than but is a decrease in the quality of the property.
<b>Reverse</b>	The logical opposite of the intention	An example of this could be where the flow is reversed or instead of boiling a liquid it is frozen.
<b>Other than</b>	The complete substitution of the intention	No part of the original intention is achieved and something entirely different takes place. For example some other liquid may be put in the tank and then flow down the pipe to the vehicle.

*Adapted from: (Dickson, 2003)*

HAZOP studies have been successfully utilised in SCRM to identify and assess potential risks. The risk events of a primary transport system of a oil SC were successfully identified and assessed using HAZOP by (Cigolini & Rossi, 2010). An oil refinery direct SC is also studied using HAZOP by (Adhitya et al., 2009), where the authors suggest the technique is effective as a standard approach to hazardous SC risk assessment. Mitkowski and Zenka-Podlaszewska (2014) use the technique as a SCRM tool for organisations who use the complex and expensive information system infrastructure Collaborative Planning Forecasting and Replenishment (CPFR).

### **2.9.3.2 Environmental Risk Assessment**

Environmental risk assessment (ERA), also known as a toxicity assessment, is used to assess risks to plants, animals and humans as a result of exposure to hazards such as micro-organisms, other species or chemicals. The ERA process is consistent with other

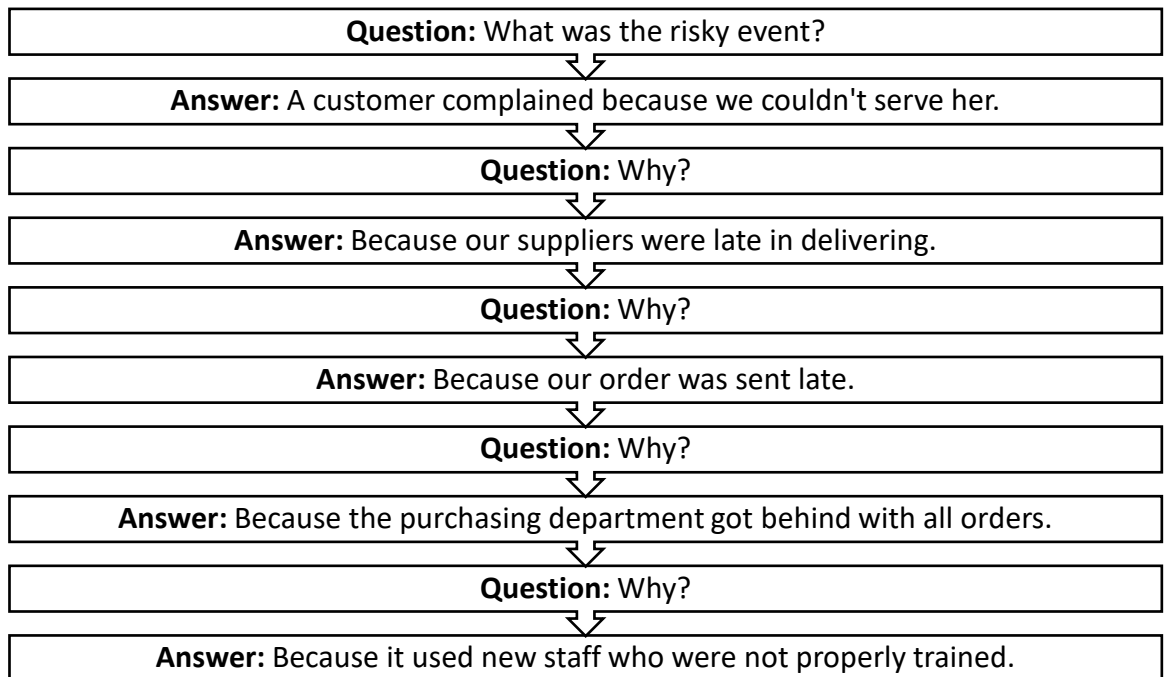


RM modelling techniques; (1) Problem Formulation, (2) Hazard Identification, (3) Hazard Analysis, (4) Exposure Analysis, and (5) Risk Characteristics.

Although not a business orientated technique, aspects of the assessment method, such as pathway analysis, which explores the different routes by which a target might be exposed to a source of risk, can be adapted and used across many different risk areas, outside human health and the environment, and is useful in identifying treatments to mitigate risk (ISO, 2010). For example, Wu, Hasan, and Chen's (2014) work on Proteomics, a term used for the data analysis of the interplay between proteins, protein complexes, signalling pathways and network nodes bears close resemblance to the complex and dynamic nature of a global RSC network. The author's development of a multi-scale pathway analysis also has potential to be transferred to a SCRM structure, as can be seen in Soni and Kodali's (2016) use of interpretive structural modelling pathway technique to improve SCM excellence in the manufacturing industry. Other ERA solutions to measure uncertainty (Darbra, Eljarrat, & Barceló, 2008) and sustainability (K. Zhang, Pei, & Lin, 2010) in environmental systems have also potential to be adapted and applied within the SCRM.

### **2.9.3.3 Root Cause Analysis**

A method of risk assessment that normally is used after a risk event has occurred, root cause analysis is often seen as the easiest way of identifying future risk, by repeatedly asking questions about the cause of the past risk event and find the likelihood that it will reoccur (Waters, 2011). Waters adds that it is also known as the "Five Whys" method, an example of which is shown in Figure 2.25.



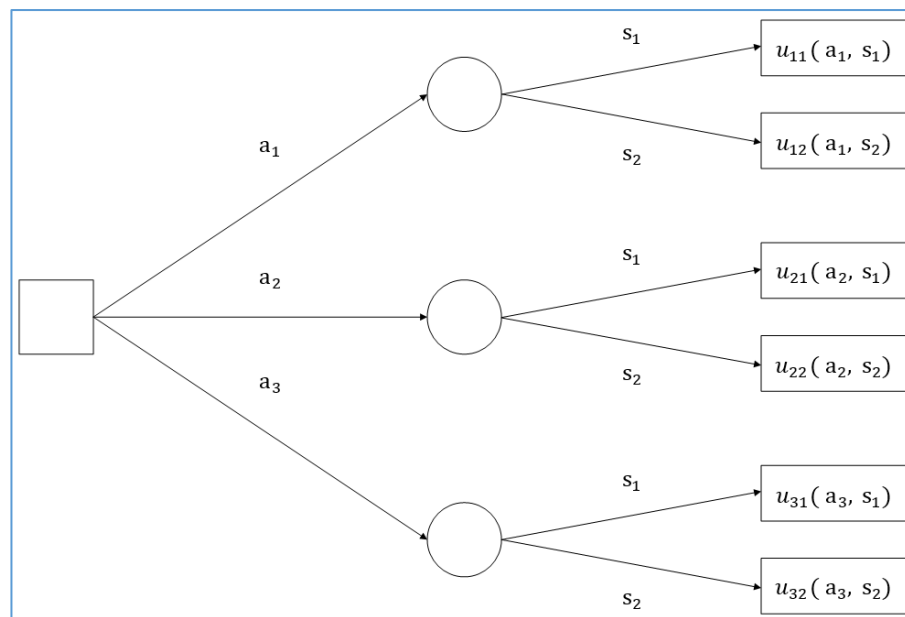
**Figure 2.25 Example of “Five Whys” Root Cause Analysis Session**

This method is often embedded into the DMAIC methodology of Six Sigma projects in SC companies, and is noted as the best way to find the true cause of risks or problems in a process (Kumar & Schmitz, 2011). Tomlinson (2015) adds that answering the “five why” questions is most effective when the business process the incident occurs in is split into three elements; the employee, the equipment, and the environment. It is also a useful tool in analysing the risk cause and sub causes identified in a fishbone diagram (Figure 2.21) (P. Bolstorff & Rosenbaum, 2007). Chappell and Peck (2006) note that using a qualitative approach such as the “five whys” encourages SCRM modellers to be more in contact with elements of the business processes at risk, or “walk the route”. The authors found that this “hands on” approach can uncover unforeseen detail that data collection alone would not provide, such as two different warehouses with high risk event incident,

identified by information system codes, were in fact the same warehouse with duplicate codes from a legacy system.

#### 2.9.3.4 Decision Tree Analysis

Since the 1960's, one of the most commonly used tools for risk-based decision making has been the decision tree (Raiffa, 1968). The popularity of the decision tree stems from its reliance on an integrative approach of a graphical component that descriptive yet easy to understand and an analytic component that builds on Bayes' theorem (Haimes, 2009). Haimes adds that there are 3 main components to a basic decision tree as illustrated in Figure 2.26.



**Figure 2.26 Generic Decision Tree**

They are:

1. **Decision node** - Decision nodes are designated by a square. Branches emanating from a decision node represent the various decisions (actions) to be investigated. It is

conventional to designate each alternative choice by a letter, e.g., “a”, and identify each branch with that decision choice (i.e.,  $a_1$ ,  $a_2$ , and ,  $a_n$  ...).

2. **Chance node** - Chance nodes are designated by a circle. Branches emanating from a chance node represent the various states of nature (i.e.,  $s_1$ ,  $s_2$ , and ,  $s_n$  ...) with their associated probabilities.
3. **Consequences** - The value of the consequences (outcomes) (e.g., cost, benefit, or risk) is written at the end of each branch.

### 2.9.3.5 Human Reliability Analysis

Human error refers to human capacity to incorrectly perform tasks under certain conditions, for a given time or at a given time; and perform additional tasks that can affect human-machine system in terms of safety, quality, productivity and work rates (Shappell & Wiegmann, 1997). Human reliability analysis (HRA) is a technique for assessing this tendency to fail, known as the human factor and dates back to the 1960's (Baziuk, Jorge Nunez Mc, Calvo, & Rivera, 2015). HRA can be split into two categories; first and second generations. First generation HRA centres on binary methods with a simple success/fail outcome with little consideration for cognitive actions and more emphasis on error quantification. Whilst second generation HRA, a more recent addition, considers cognitive and organisational behaviour and focuses on error causes not error frequency (Cacciabue, 2000).

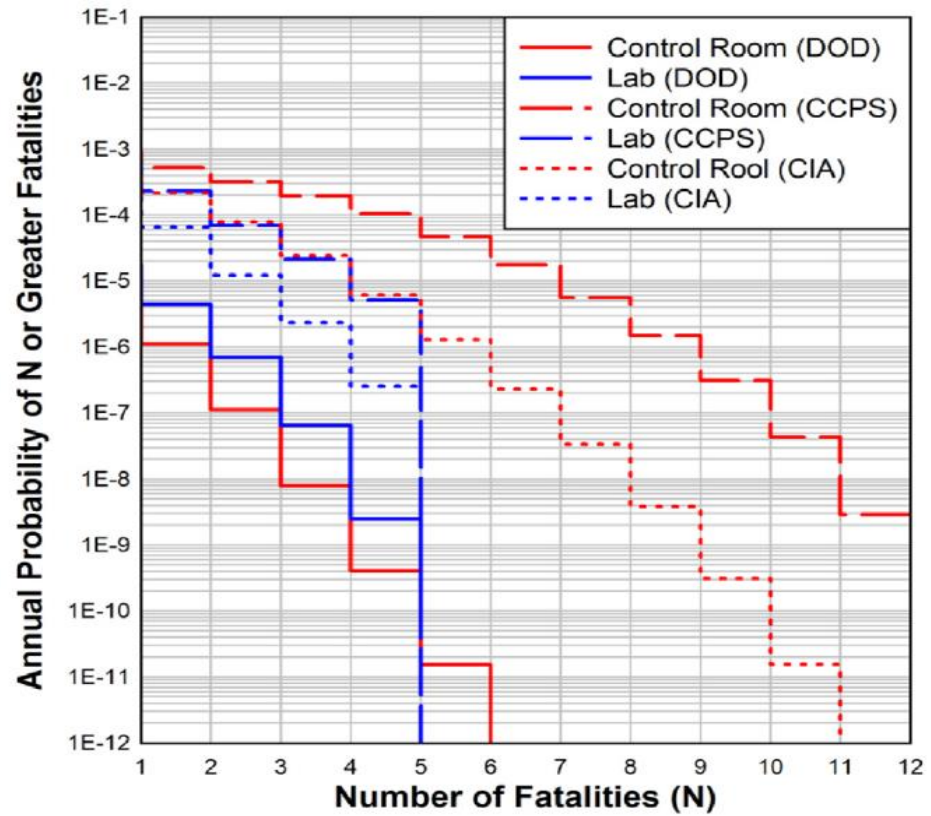
The risk of human error is high in all complex business systems (French, Bedford, Pollard, & Soane, 2011) and there is a huge diversity of HRA techniques available. Research in HRA is strong in system with high probability and impact of human error, including the aviation industry, chemical manufacturing and clinical risk management (Boring,

Hendrickson, Forester, Tran, & Lois, 2010; French et al., 2011). Although RSC reliability is a common research topic at present, there is no evidence or direct link to HRA in the literature.

### **2.9.3.6 FN Curves**

FN curves are a graphical representation of the probability of events causing a specified level of harm to a specified system, and most often refer to the frequency of a given number of casualties occurring (ISO, 2010). FN curves show the cumulative frequency (F) at which N members of the population that will be affected. High values of N that may occur with a high frequency F, are of significant interest to a system (such as a RSC) because they may have unacceptable, hazardous or costly consequences. They are used frequently to compare external risks such as societal, political and environmental (A. W. Evans & Verlander, 1997; Prem et al., 2010) and their impact. Specifically in low probability, but high fatality impact areas such as chemical plant explosions (Fig 2.27) and natural disasters (Marx & Werts, 2014).

From a RSC perspective, FN curves use as a risk assessment technique is still heavily weighted toward the distribution of hazardous and chemical materials (Z. Yang, Bonsall, Wall, & Wang, 2005) and busy marine shipping channels (Mullai & Paulsson, 2011). These applications have potential to be used in RSC's where human fatalities follow a similar pattern when high impact hazardous contaminants occur.



Source: (Marx & Werts, 2014)

**Figure 2.27 FN-Curve comparison of event-fatality relationship**

### 2.9.3.7 Risk Indices

Traditionally used in financial risk analysis to measure bank, organisation or even country wide performance using risk metrics and similar to most index techniques, a risk index is a semi-quantitative scoring approach using ordinal scales. The use of risk indices are typically the final phase of a risk analysis methodology, consolidating the scores and metrics of other SCRM assessment techniques (Samvedi, Jain, & Chan, 2012).

The use of risk indices in SCRM commonly centres on the resilience of respective RSCs from a global perspective, and normally grouped by economic regions or by country (Burnson, 2015). Quantifying what risks a country presents to the supply has been very effectively collated into an index rating by commercial property insurer FM Global and

is called the FM Global Resilience Index (Burnson, 2015). The index has three core resilience factors; economic factor; risk quality factor; and RSC factor, an each factor has 3 corresponding drivers as outlined in table 2.14 (FM Global, 2016b).

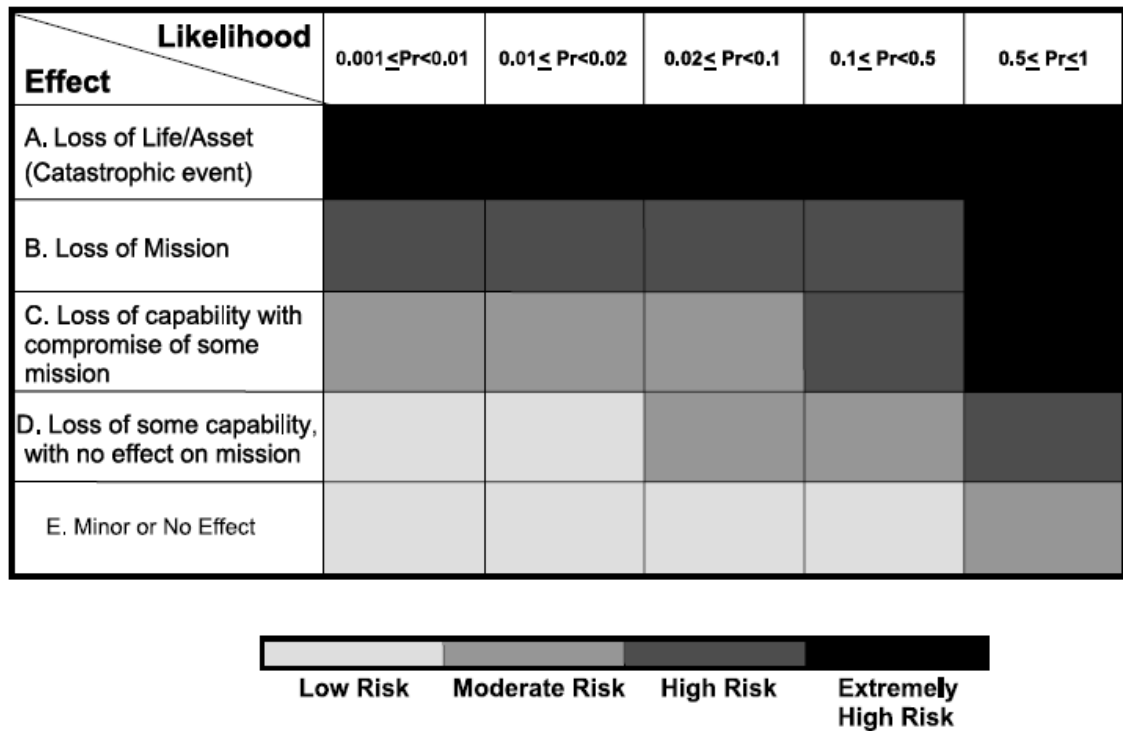
**Table 2.14 FM Global Resilience Index Factor and Drivers**

<b>Economic Factor</b>	<b>Risk Quality Factor</b>	<b>Supply Chain Factor</b>
GDP Per Capita Driver	Exposure to Natural Hazard Driver	Control of Corruption Driver
Political Risk Driver	Quality of Natural Hazard Risk Management Driver	Infrastructure Driver
Oil Intensity Driver	Quality of Fire Risk Management Driver	Local Supplier Quality Driver

In 2016, Ireland ranked number 3 in the world for overall resilience, behind Norway and Switzerland, number 7 for economic factors; number 1 for risk quality factors; and number 25 for supply chain factors (FM Global, 2016a).

### **2.9.3.8 Consequence/Probability or Risk Matrix**

Also known as risk maps, consequence and probability matrices can be produced in many formats with a basic style of plotting the likelihood of an event against the consequence or impact should the event occur (Hopkin, 2012). A common version of this matrix technique is the ordinal version developed by the US Department of Defense for military logistics and operations, cited in (Moriarty & Roland, 1990). According to Haimen, Kaplan, and Lambert (2002), the likelihoods and consequences are combined, creating the concept of “severity.” The mapping is achieved by first dividing the likelihood of a source of risk into at least five discrete ranges. Similarly, the consequence scale also is divided into four or five ranges. The two scales are placed in matrix formation, assigning relative levels of risk severity to each cell of the risk matrix, see figure 2.28.



Source: (Haimes et al., 2002)

**Figure 2.28 Example of Ordinal Risk Matrix**

Risk matrices are a common risk assessment tool within SCM and compliment other assessment techniques such as risk indices (Jiang & Chen, 2014). There are noted weaknesses to this technique, including subjective calculation logic limitations and the fact that it is too simple to assess more complex risk events (Z. P. Li, Yee, Tan, & Lee).

### 2.9.3.9 Cost/Benefit Analysis

An implicit part of all risk assessment decision making processes is that of weighing the total expected costs against the total expected benefit, in order to optimise financial results or reduce the impact of risk events (ISO, 2010) and is commonly based on the ALARP principle (Aven, 2009). Aven adds that the idea of the ALARP method is to assign monetary values to a list of costs and benefits, and summarize the “goodness” of alternatives by the expected net present value (NPV) and provides an attractive approach



for comparing options and evaluating risk reducing measures. According to Xu and Lambert (2015) cost-benefit analysis can increase transparency and accountability for the use of decision making. When comparing the engineering and construction NPV's or lifecycle costs and the future benefits associated with motorway projects, Xu and Lambert suggest is something that can be applied to any large scale decision making activity. It has been claimed that as all SCM decision making activities will have a monetary consequence, therefore the need for cash flow analysis techniques like NPV is strong (Naim, 2006).

NPV based equilibrium models have been used successfully to determine optimal RSC prices, profits, and implicit equity values of RSC firms vulnerable to economic uncertainty and financial risks (Liu & Cruz, 2012). Mathematical programming is a common method in optimising RSC NPV cash flow cycles (Gupta & Dutta, 2011), although Robison, Barry, and Myers (2015) add that inconsistencies created by unequal periodic cash flow and difference in implied reinvestment rates, terms and initial investment sizes mean NPV is an unreliable analysis technique.

### **2.9.3.10 Multi-Criteria Decision Analysis (MCDA)**

“The practice of multi-criteria decision analysis (MCDA) methods of dealing with complex systems and associated risks have been evolving since the 1980's with the fundamental principle that many alternatives can be evaluated with respect to many quantitative and/or qualitative criteria (Kennerley & Neely, 2002). In short MCDA is concerned with the evaluation of a set of possible courses of action or alternatives” (Durbach & Stewart, 2012). Available MCDA techniques can be grouped into 3 main categories; (i) methods of the unique approach of synthesis such as TOPSIS, SMART,

Weighted sum, MAUT, MAVT, UTA, AHP, ANP; (ii) the outranking methods of synthesis as PROMETHEE, ELECTRE and ORESTE and (iii) interactive local judgment approach, with trial-error interaction which alternate calculation steps, giving successive compromising solutions, (Zardari, Ahmed, Shirazi, & Yusop, 2015).

MCDA is a popular technique with RM, but has limited coverage within SCRM. Although it is a common analysis technique within SCM decision making, especially within the field of performance management (Chorfi, Berrado, & Benabbou, 2015; Gattorna, 2009). According to ISO31000 standards, MCDA has significant limitations to consider, such as it can be affected by bias and poor selection of the decision criteria; and most MCDA problems do not have a conclusive or unique solution (ISO, 2010).

### **2.9.3.11 Failure Modes Effect Analysis (FMEA)**

FMEA systematically identifies possible modes of failure, after which it establishes the impact of each type of failure (Waters, 2011). Waters claims this analysis technique is similar to a “risk register”, where decision makers list all activities and processes within a system and identify all possible ways they can fail. Traditionally a quality management risk assessment tool (James R. Evans & Lindsay, 2016), FMEA is normally utilised in eliminating any quality or risk issues from a product or system design process (Mihalakis Giannakis & Papadopoulos, 2016).

The technique has not been published frequently within the SCRM domain. Giannakis and Papadopoulos (2016) successfully used the technique to assess the relative importance of RSC sustainability risks, and identify their potential causes and effects of failure while ultimately testing potential correlations between the identified risks. SCM system complexities and associated risks are also evident in the research of Nabelsi and

Gagnon (2015), who utilised FMEA to identify constraints within the data collection and warehousing process of a major RSC project between two hospitals. It can be argued that FMEA is extremely time-consuming, tedious, and error-prone because it demands a detailed and systematic examination of the operation of all aspects of the design and process of a system (Gan, Xu, & Han, 2012).

### **2.9.4 Evaluate Risks**

Evaluating risks is the process of prioritising risk events, traditionally from a value at risk (VaR) perspective and determining for each risk whether mitigation (Section 2.10.5) actions are required or whether the risk is acceptable (Supply Chain Council, 2014). Then following evaluation techniques are recommended by ISO31000 with strong connections to the risk assessment and identification methods outlined in previous sections.

#### **2.9.4.1 Structured <<What If>> (SWIFT)**

Structured <<What If>> (SWIFT) analysis is very similar to other risk management tools such as brainstorming, HAZOP and FMEA in that it is very efficient in both identifying and assessing hazards and risk events. ISO31000 states that this technique is normally linked to a risk analysis or risk evaluation technique (ISO, 2010) and is not evident in recent SCRM or any other risk literature.

#### **2.9.4.2 Reliability Centred Maintenance**

Reliability centred maintenance (RCM) is an evaluation or dependability test for RM processes. RCM can be described as a systematic approach for identifying effective and efficient decision making tasks, by means of risk and function analysis (Hansson et al., 2003). Moubray (1997) describes the technique from a preventative failure perspective and as an evaluation extension of FMEA, defining it as the process used to determine the

maintenance requirements of any physical asset or activity in its operating context. Moubray adds that RCM is a cross functional evaluation technique based on asking 7 questions about the asset or system under review, which have been converted into system orientated steps by Deshpande and Modak (2002), also cited in (Afefy, 2010). The steps are;

**Step 1:** System selection and data collection

**Step 2:** System boundary definition.

**Step 3:** System description and functional block.

**Step 4:** System function functional failures.

**Step 5:** FMEA.

**Step 6:** Logic tree diagram.

**Step 7:** Task selection.

RCM as the name suggests, focuses on machine-based industries with high risk hazards such as chemical engineering/manufacturing (Fonseca & Knapp, 2000), underground distribution systems (Reder & Flaten, 2000), rail/road networks (Carretero et al., 2003), electrical power distribution (Dehghanian, Fotuhi-Firuzabad, Aminifar, & Billinton, 2013) and even nuclear energy production (Y. Chen & Zhang, 2012). There is no significant use of the methodology in RSC literature apart from underground distribution (Reder & Flaten, 2000).

### **2.9.4.3 Bayesian Statistics and Bayes Nets**

Bayes statistics extends the theorem of conditional probability, which revises historical probabilities based on updated information and learnings (J R Evans, 2007) and is a very effective methodology in evaluating the influence of risk on system performance such as

RSCs (Badurdeen et al., 2014). According to Pai et al. (2003) Bayes theorem (Equation 2.3) states that:

$$P(H_1|E) = \frac{P(E|H_1)P(H_1)}{\sum_{k=1}^n P(E|H_k)P(H_k)} \quad (2.3)$$

Equation 3 can be interpreted as the probability of hypothesis  $H$ , given some evidence  $E$ , is equal to the ratio of the probability that  $E$  will be true given  $H_1$  times the prior probability or subjective belief of the occurrence of the hypothesis  $H_1$  over the sum of the probability of  $E$  over the set of every hypotheses times the probability of these hypotheses, given the set of all hypotheses being mutually exclusive and exhaustive (Pai et al., 2003). When evaluating RSC risks from a performance perspective, (Badurdeen et al., 2014) replaced  $H$  with a parent risk  $P$ , and  $E$  with a child performance measure  $M$ . The authors add that beginning with a first-level independent risk, relevant to a given RSC event, and moving one level at a time, the likelihood of each event occurring can be calculated by the chain rule application of Bayes' theorem (Badurdeen et al., 2014). That is, if one child event is dependent upon two parents, the required inputs are then the estimated probability of the independent first-level events and the conditional probability of the occurrence of the dependent event. Garvey et al. (2015) use a similar Bayes chain rule, also known as Bayes Net or Networks when developing a supply network risk propagation framework. Abolghasemi et al (2015) through their research highlight the effectiveness of Bayes networks in measuring SCRM performance metrics based on SCOR performance attributes. Bayes networks have also been very effective in evaluating RSC TCO and accounting for system uncertainty (Dogan & Aydin, 2011).

### 2.9.4.4 Simulation

RSC experimentation and decision making in the real world can have detrimental effects (such as distorted and amplified supply and demand) on companies when they go wrong (Holweg & Bicheno, 2002). Traditional approaches to mitigating against real system experimentation are the analytical methods already discussed in Section 2.10. Young Hae and Sook Han (2000) say that when analytic solutions cannot give measurable performance indicators simulation should be used. According to Greasley (2008) simulation is the use of a model to mimic operation of a system, resulting in the ability to observe performance over an extended period of time very quickly and under multiple scenarios. He adds that a simulation project normally consists of the process of model building and the conducting of experiments on that model.

Simulation offers a more thorough, measurable evaluation of a systems data (such as risk) including; the examination of parameter variability, operational uncertainty, and the accurate estimation of probability distribution that statistically fits the data set (Arisha & Young, 2004). Systems that are best suited to simulation have distinct characteristics such as; being dynamic where behaviour varies overtime; highly interactive consisting of several components which interact with each other; and are complex systems with many interacting and dynamic objects (Michael Pidd, 2009). All RSC systems have these characteristics, as do risk management structures and therefore simulation is an ideal tool for SCRM decision making with many applications and empirical research within the literature. Simulation-based SCRM applications and frameworks within literature mainly centre on three different simulation techniques; *agent-based modelling (ABM)*, *discrete-event simulation (DES)*, and *system dynamics (SD)*.

### **2.9.4.4.1 Agent-Based Modelling**

ABM is the study of social agents as evolving systems of autonomous interacting entities, using computer based infrastructures (Janssen & Ostrom, 2006). Often categorised as a form of artificial intelligence (AI), ABM is characterised as a simulation model capable of autonomous decisions independent of human interaction, with the ability to react to changes in the environment and communicate to other agents within the model (M. Giannakis & Louis, 2011). Greasley (2008) explains that it is popular when the behaviour of autonomous decision making agents such as humans, animals or AI software entities need to be considered in a simulation study. From a SCRM perspective it is applicable in studies that involve human behavioural variables and decision making evaluation within a system. Giannakis and Louis (2011) have developed an ABM to be used as a conceptual base for a larger DSS to enhance collaboration against software entity driven risk of supply disruptions.

The AI capabilities of ABM have been used by Costas et al. (2015) to prove through experimentation that the theory of constraints (TOC) can reduce the bullwhip effect of a system under certain parameters. Autonomous modelling of high risk events such as SCD is also very effective, as appreciated by Bearzotti et al. (2012), who have created a SCD event management tool. The authors agent-based support tool is designed to study and experiment on high risk frequency but low impact events in a multi-echelon RSC.

### **2.9.4.4.2 Discrete Event Simulation**

DES is the modelling of complex systems in which the state variable changes only at a discrete, or a distinct set of time-points (Banks, 2010). The capabilities of DES to replicate uncertainty are high, mainly as it is capable of manipulating the variability and

uncertainty of a discrete system, such as a RSC (Mahfouz, Ali Hassan, & Arisha, 2010). In SCRM, DES' capability to replicate uncertainty at discrete points and present results after extensive experimentation is very attractive to decision makers when evaluating risk metrics. Even at a very basic level, DES can be very powerful. For example, Tromp et al. (2012) built a simple DES model of a FMCG RSC integrating with a spreadsheet based Monte Carlo simulation approach to analyse the risk of OOS retail shelves due to expiry date issues. The authors successfully experimented the concept of managing the shelf-life of high risk grocery products such as meat with a dynamic expiry dates as opposed to the traditional fixed dates.

The risk evaluation strengths of DES are also evident in the research of Schmitt and Singh (2012), who have extensively investigated how resilience in a multi-echelon FMCG RSC can be achieved through the evaluation of SCR drivers demand uncertainty and disruptions. In the event of major SCD's, Iakovou et al. (2014) use DES to evaluate emergency sourcing strategies and associated total cost risks to humanitarian supply performance. Similarly, but as part of a combined SCRM framework, Elleuch et al. (2014) combine DES with analytical hierarchy process (AHP) to assess and evaluate risk mitigation scenarios in a pharmaceutical RSC.

### **2.9.4.4.3 System Dynamics**

SD modelling is best suited to problems associated with continuous processes where feedback significantly affects the behaviour of a system, producing dynamic changes in system behaviour. As a SCR evaluation tool, it evaluates long term trend, where the consequences and impact of risk events are continuous, affecting the system as a whole. SD is particularly suitable at taking an external view of an extended multi-echelon RSC,



as with the extended 4 echelon FMCG RSC SD model developed by Kumar and Nigmatullin (2011). In this research, the authors use the model to dynamically observe and evaluate the relationships within the system under different risk policy changes, including demand variability and supplier lead time reliability. With model results clearly showing a bullwhip effect pattern on order flow through the 4 echelon system. In this context, Villa et al. (2015) argue that through SD modelling, the known bullwhip effect driver of hedging against orders can be evaluated. The authors, using case study methods modelled the ordering behaviours of retailers after sudden increases in consumer demand due to promotional discounts. Results show an inflated order pattern upstream to the suppliers and FMCG manufacturers.

The system thinking origin of SD modelling is evident in the research of Ghadge et al. (2013), who tested the viability of a systems approach to modelling SCR within the UK aerospace industry. Under certain parameters the researchers were able to predict supply failure points within the system and also evaluate the overall risk event impact, measuring total cost and delays. The evaluation of external risks is another advantage of using a continuous modelling method. With its stock and flow structure, an SD model can have many different external variables influencing input and output rates, the probability of an earthquake for example and its impact on short life cycle product supply (Briano, Caballini, Giribone, & Revetria, 2010).

A recent worldwide survey made by the MIT department of transportation and logistics found that nearly 70% of all organisations have never used simulation to evaluate RSC risk and disruptions (Arntzen, 2009). Greasley (2009) attributes this to a lack of

understanding and fear of simulation projects and is something that will be strongly considered in the framework development stage of this research study.

### 2.9.5 Mitigate Risk

According to ISO31000 vocabulary, risk mitigation is the process to modify risk, and is also known as risk treatment in acknowledgement that risk can be an also be an opportunity to an organisation (ISO, 2009a). Selecting the correct risk mitigation option is normally made by balancing the potential costs resources of the decision versus the perceived value or benefit of making the decision. This is normally done as part of or directly after risk evaluation using techniques such as crossover charts, cost/benefit analysis, sensitivity analysis, NPV and optimisation. It is recommended that risk mitigation decision making should be collaborative, where organisations should engage with suppliers and customers before agreeing any future treatments (Hajmohammad & Vachon, 2016). There are main strategies to treating risk; *avoidance*, *opportunistic*, *transfer*, and *retention* (ISO, 2009b; Kouvelis, Dong, Boyabatli, & Li, 2011; Zsidisin & Ritchie, 2008).

Risk avoidance is normally chosen when the impact and consequences of a risk event are severe and should be avoided, for example vehicle and road accident risks (Hu et al., 2017), counterfeit goods transactions (Miyamoto, Holzer, & Sarkani, 2017) or contaminating the food chain (Shimshack, Ward, & Beatty, 2007) to name a few. Opportunistic risk is more associated with financial initiatives in the literature (Sanchez, Robert, & Pellerin, 2008), but it can be argued that all risk treatment is opportunistic, creating value and opportunities through risk mitigation and control. Risk transfer is a contentious risk treatment strategy, and for SCM is a barrier to effective BPO,

collaboration and value. As outlined in section 2.8, business processes are assets, and if treated similar to financial asset management, are vulnerable to the impact of risk transfer. As explained by Acharya et al. (2013), risk transfer in financial asset management is meant to spread the finance risk between the banking sector and external investors. The authors claim that it was the manipulation of this risk treatment that led to the 2008 global finance crisis, as mortgage-back securities and conduits were transferring to external investors but the risk remained within the banking sector.

From a SCRM perspective there are learnings to be made, and the parallels in asset management of business processes should reflect the transfer of RSC securities both upstream and downstream. Risk transfer can also be considered from a capability and regulation perspective. In the context of grocery retail, this can equate to transferring capability or in other words outsourcing to skilled service providers; or from a regulation perspective transferring the risk of food product disposal to a certified disposal and recovery service provider. In contrast risk retention is when an organisation will choose to contain the probability of risk within the control of its business processes and is also frequently used in the banking sector. Risk retention is “acceptance of the burden of loss or benefit of gain from a risk” (Aven, 2012), p.177). From a SCRM perspective risk retention can lie in whatever incoterms an organisation agrees with a supplier, where there are many different freight terms that can be chosen resulting in different levels of burden on the shipper and receiver (Coetzee, 2013).

### **2.9.6 Monitor and Review**

SCRM should be a continuous process with mechanisms in place to monitor and review its effectiveness and decide if any of the other SCRM processes should be revisited.

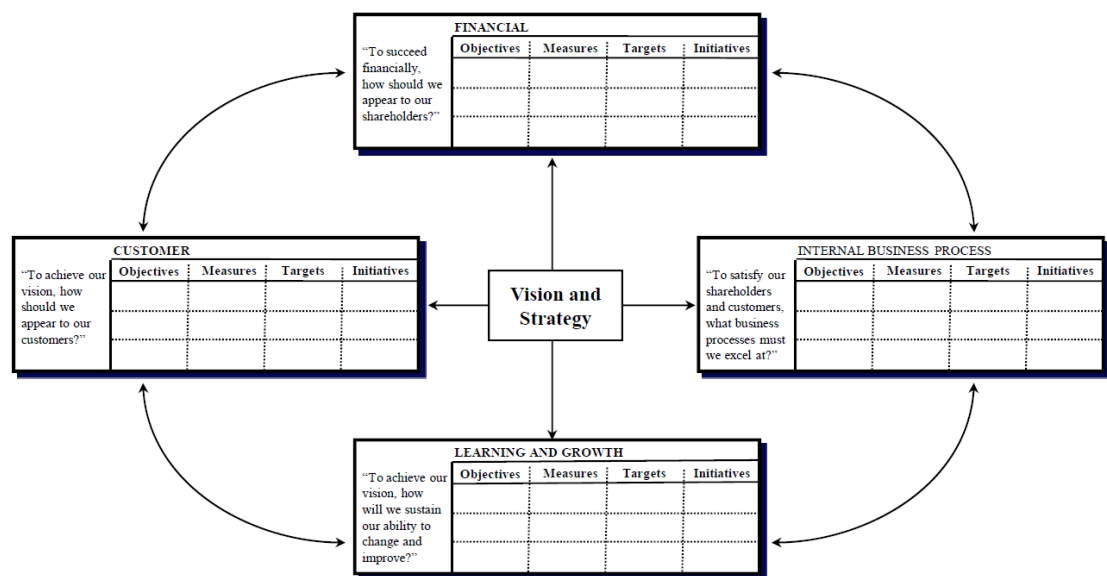
SCOR11 recommends that this stage of SCRM should follow an initiate reporting flow that includes; inspections, measurement, sampling, and self-assessment (Supply Chain Council, 2014) in addition to reinforcing awareness, training and education and change management (Waters, 2011). Waters also adds that although monitoring and reviewing SCRM is an ongoing process, it is particularly important when introducing a new product/service or process, equipment, facilities, suppliers or customer accounts. The balanced scorecard (BSC) is a performance management technique that has potential to be the foundations of any strategic SCM system (Bhagwat & Sharma, 2007).

### **2.9.6.1 The Balanced Scorecard (BSC)**

The BSC, pioneered by Kaplan and Norton in 1992, is a systematic methodology that uses strategy-linked leading and lagging performance measures and actions for planning and implementing an organization's strategy (Robert S. Kaplan & Norton, 2001). Among the main benefits of applying the BSC are; 1) an excellent way for communicating and gaining insights into strategic initiatives, key objectives, and actions among decision makers and other staff, 2) a comprehended and easy structure for captivating the improvement initiatives of an organisation as it encourages and facilitates the analysis of weaknesses, and potential for improvements. At its basic level, the BSC provides a framework to look at strategy used for value creation through four perspectives, *financial*, *customer*, *internal business process*, and *learning and growth* (figure 2.29), as Kaplan and Norton explain below:

- 1. Financial** - The strategy for growth, profitability, and risk views from the perspective of the shareholder.

2. **Customer** - The strategy for creating the value and differentiation from the perspective of the customer.
3. **Internal Business Process** - The strategic priorities for various business processes, which create customer and shareholder satisfaction.
4. **Learning and Growth** - The priorities to create a climate that supports organizational change, innovation, and growth (Robert S. Kaplan & Norton, 2001).

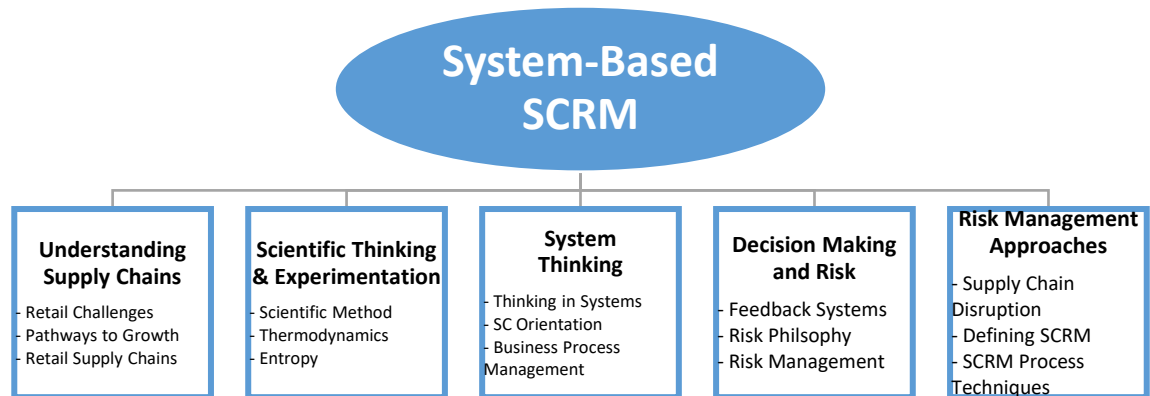


Source: (Robert S Kaplan, 2009)

**Figure 2.29 The Balanced Scorecard**

With many successful implementations at different organisations, BSC is considered as a popular model and effective means for performance management and strategy execution within SCM (Bhagwat & Sharma, 2007; Brewer & Speh, 2001; Hult et al., 2008). The BSC perspectives themselves are also closely aligned with the top RSC challenges outlined in table 2.3. Although, there is no evidence in the literature to support this claim in terms of risk management, even with the similarities and potential advantages of using the method for monitoring and review, highlighting a significant research gap.

## 2.10 Discussion



**Figure 2.30 A Taxonomy of System-Based SCRM Literature**

Any significant disruptive event to a RSC will follow a very distinctive pattern in terms of its effect on the RSCs performance, with specific aftereffect time-points. Whether measured through total costs, profit margins, production levels, on-shelf availability, or customer service once a disruptive event occurs the profile of its impact and consequences are known as illustrated in section 2.9.1. Despite attempts to manage the risk of disruptive events through risk management frameworks and international standards, there is still ambiguity in truly understanding the SCD pattern sufficiently beyond the boundaries of an organisation to be able to robustly mitigate against it. With the objective of bridging the ambiguity gap in managing the risk of SCD, this chapter has proposed a taxonomy of system-based SCRM literature and related supporting topics (Figure 2.30). It has been found that the FMCG retail sector has faced many external challenges over the past 10 years. There have been ambitious attempts from the Irish Government to invest long-term in the extended FMCG and food industries, but there is no evidence in the literature of the pathways to growth initiative or attempts to risk mitigate the long terms costs/benefit of it from a SCM perspective. The complexities of the RSC have also been sufficiently

researched in the literature with key challenges such as factory gate pricing, returns management and on-shelf availability being common themes.

The benefits of using the scientific method and experimentation in business application was also discussed with a distinct lack of acknowledgment from the SCM community on the topic. Even though much of the quantitative papers studied followed the scientific method steps, there seems to be an apparent disconnect between the authors and their main audience, non-quantitative academic and pragmatic industry decision makers. Literature linking system thinking to enhanced RSC understanding was also investigated based on the principles and philosophies of; Taylor, Deming, and Forrester. Although there is some conflicts in defining what a system is in the literature, there is one constant in all knowledge about systems research that was studied, thinking in systems is a vast research topic, crossing all domain boundaries, from the physical sciences, cybernetics, social systems and engineering to name a few. Because this topic is so prevalent in all research disciplines, it was assumed that there would be obvious interchanging of system-based theories and knowledge. There was evidence of physical sciences practices being adapted to business process problems, specifically the laws of thermodynamics. Although a very small research community with limited publications, there was no evident disagreement or retorts to the theoretical application of thermodynamics, or entropy in a business environment. Equally the literature discussing the parallels between system thinking, total quality philosophies and business process orientation were also sufficient to validate the innate link between system thinking and managing a business organisation and associated risks. Research into RSC risk has been growing exponentially over the past 15 years, with annual publications growing by 500% between 2000 and 2015, based

on the Web of Science database. Common research themes over this time-period included categorising risk drivers, identifying risk and risk assessment. Robust validation of research into these topics was very valuable to this research study as it was deemed unnecessary to have to collect data and develop risk category and risk type constructs.

### **2.10.1 Research Gap Analysis**

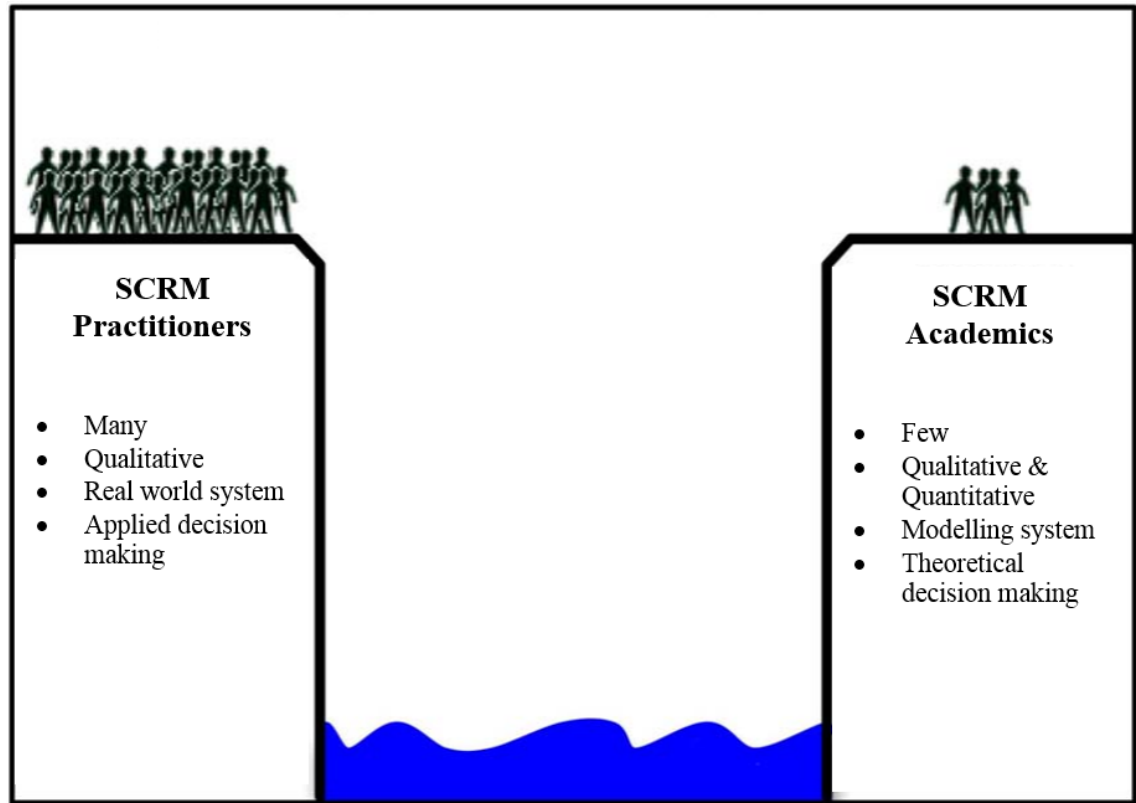
Much of SCRM integrated frameworks that do include the full end-to-end process are conceptual in design with limited validation or application in industry. As alluded to in section 2.10.2, integration driven SCRM techniques such as simulation are not actively in application within organisations worldwide, with nearly 70% of respondents to a global MIT empirical study into SCRM practices admitting they have never used simulation within their organisation (Arntzen, 2009). During the same study, it was also uncovered that 40% of organisations do not have a dedicated risk or contingency manager. An empirical study to understand SCRM business requirements from an industry perspective in 2005 resulted in findings concerned with the level of ambiguity and understanding of SCRM from practitioners (Jüttner, 2005), something that still resonates over a decade later. This highly suggests that the level of integrated SCRM capabilities within organisations has an equally low application percentage. Integration can be defined as the combination of qualitative and quantitative methods within a given stage of inquiry (J.W. Creswell, Plano Clark, Gutmann, & Hanson, 2003). Structuring the combined methods into a formal process or guidelines is an integrated framework. The globally recognised SCRM integrated frameworks of ISO31000 and SCOR11 were surprisingly not as established in the literature as expected. Initial search results found that there are a considerable amount and variety of SCRM frameworks in the literature. As highlighted



in the SCRM process examples provided in sections 2.10.1 to 2.10.4, a lot of the research frameworks have centred on individual processes such as risk assessment and risk identification, with little advances in the end-to-end structure. This opinion has been reiterated in the extensive SCRM literature review by Ho et al. (2015) who says the majority of integrated frameworks focus heavily on risk analysis and evaluation. For example, Bandaly et al. (2014) claim to have developed an integrated SCRM framework by combining operational methods and financial instruments to manage the direct RSC risk of a beer manufacturing company. Although a very insightful paper with good use of optimisation and DOE, the model is an integrated framework for risk evaluation with no reference to the other key processes.

There is also a publication trends that suggests that SCRM may be challenged by a theory-practice gap. The majority of end-to-end SCRM process frameworks published were conceptual models with no indication of implementation plans or future collaborations with practitioners. Those papers that had validation through empirical data collection, were surveys and structured interviews and ultimately resulted in conceptual findings. Case study research papers did tend to have more collaboration between researcher and practitioner, but apart from data collection phases, the research was heavily weighted to an academic audience, with many of the research methodologies being mathematical or simulation based models. Over 1,100 academic journals were studied during this literature review and although the majority communicated a very clear message of the objectives of the research, there was a lesser frequency stating who the target audience was. Considering the fact that it is SCM practitioners who will benefit most out of

advances in SCRM, it is logical that they should be considered as a target audience for a high proportion of SCRM research.



*Adapted from (Cabrera, 2006)*

**Figure 2.31 Practitioner v Academic Audience Chasm**

## Chapter 3. Research Methodology

*“A goal without a method is cruel.”*

— W. Edwards Deming

### 3.1 Introduction

In “real life” systems, research draws attention to the issues and complexities involved; whilst generating a degree of informed enthusiasm for challenging and/or important contributions to the system (Robson, 2002). Research can be defined as the “systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions” (Oxford Dictionary, 2011). The source of such systematic investigations is a *research methodology*, which reflects the shared beliefs of the research community (Murshed & Zhang, 2016). Research methodologies highlight how samples are chosen, questions are asked and procedures are used to generate insights into specific system challenges (Kuhn, 1970). Whilst there are three core research methods: qualitative, quantitative and mixed methods; there is no standard set of methodologies that can be applied across all research problems, but rather a methodology selection based on the nature and scope of the topic at hand and the type of data available (J. Bell, 2010).

For example, Creswell (2014) explains that traditionally qualitative and quantitative approaches are viewed as rigid, distinct polar opposite categories and citing (Newman & Benz, 1998), argues this actually is not the case and instead, “they represent different ends of a continuum”. Creswell adds that a research study will tend to be more quantitative than qualitative or vice versa, or somewhere in between, as in mixed methods. The advancements in information system technologies is sparking great interest in combining

methods within the *research continuum*, integrating a variety of new mixed methods designs and analytical practices (Hesse-Biber, 2010). Therefore, when developing their research project, researchers should think beyond the traditional boundaries of methodology, gaining in-depth knowledge and understanding of alternative or combined research methods that will best fit and justify their selected methodology based on their research objectives. The research methodology of this real life system study will be presented primarily based on the works of (Robson, 2002), (John W. Creswell, 2014), (Saunders, Lewis, & Thornhill, 2016) and (Tashakkori & Teddlie, 2003).

The chapter discusses research philosophy in the literature and highlights the main research paradigms and approaches relevant to the study. The paradigmatic stance of the research is then explained along with its associated research methods. Research design is composed of six distinct research stages and each stage has its own sub-objectives, administration procedure, and techniques employed in order to achieve the ultimate research goal. Finally, ethical issues and the measures taken to address them are clarified.

### **3.2 Research Philosophy**

A philosophy is an all-encompassing term relating to a system of beliefs and assumptions about the development of knowledge, examples of which include the central themes of this research; system thinking and business process management. The nature of such knowledge development in relation to research is known as a research philosophy (Saunders et al., 2016). The philosophical stance of a research study is normally achieved firstly by means of a research paradigm, or the “basic set of beliefs that guide action” (Guba, 1990). This can be extended to a researcher’s worldview or conceptual model of a system, complete with the assumptions that are associated with that viewpoint

(Mertens, 2003). There are three types of research assumptions that a researcher's viewpoint and philosophy are built upon: ontology, epistemology and axiology.

At its simplest level *ontology* is a view of what a real-world system is, or contains (Checkland, 1999). As a philosophy, it studies the nature of reality and the essence of its existence (Burrell & Morgan, 1992; Saunders et al., 2016). In social science research, there are three main ontological perspectives: objective, subjective and social constructive (Bryman, 2012; Saunders et al., 2016). *Objectivism* “asserts that social phenomena and their meanings have an existence that is independent of social actors” (Bryman, 2012). Holden and Lynch (2004) expand this view by claiming objective thinking is based on the belief that the world “predates individuals” and will continue to exist as a tangible entity regardless of people's actions, this is the foundation of natural science. *Subjectivism* however, is somewhat of a polar opposite to objective beliefs, incorporating assumptions of the arts and humanities by asserting the view “that social reality is made from perceptions and consequent actions of social actors”, mainly people (Saunders et al., 2016). The third, an extension of subjectivism, is that of *Social Constructionism* or *Nominalism* where there is no underlying reality to the “social world” beyond what social actors attribute to it. Burrell and Morgan (1979) explain that because each social actor's experience and perception of reality is different, it is logical to talk about multiple realities rather than a single reality that is the same for everyone. Although business process management is most associated from an objective, scientific viewpoint, there is increasing claims that from a macro, economic or whole system perspective, business processes equally follow subjective behaviours driven by individual and social

perceptions - the perceived value of a free-market for example (Calcagno, Hall, & Lawson, 2010).

*Epistemology* is the relationship of the “knower to the known” (Lincoln & Guba, 1985). Erzberger and Kelle (2002) add that this concerns questions about whether and how valid knowledge about reality can be achieved. Saunders et al. (2016) suggest that whereas ontological assumptions initially are quite abstract, the multidisciplinary nature of business processes expands the legitimacy of different types of knowledge ranging from data driven facts to narrative based interpretations. The authors list five major philosophies in business and management: positivism, critical realism, interpretivism, postmodernism and pragmatism (Table 3.1). *Positivism* traditionally was the “so called standard view” or philosophy of natural science (Robson, 2002) and has had many different interpretations since the work of Auguste Comte in the early 1900’s (Outhwaite, 1987). A positivist assumes that objective knowledge is gained through direct observation or experience and is the only knowledge available to science, both natural and social (Robson, 2002). This philosophical stance is characterised by the researcher’s readiness to concede primacy to the given known system through experimental evidence (Checkland, 1999). Checkland says in contrast, *interpretivism* also known as *phenomenology*, is a philosophical position that is characterised by the readiness to concede primacy to the mental processes of observers rather than to the external system. The author adds that the most important founder of this stance is Edmund Husserl whose work on *intentionality* introduced the concept that all conscious mental activity is thinking about something. Researchers adopting this philosophy do not believe that the *absolute* understanding can be achieved, but only *an* understanding (Hudson & Ozanne, 1988).

The interpretivist researcher's primary concern is the nature and content of our thinking about the world rather than the world itself as something independent to all observers of it (Checkland, 1999).

*Realism* is another path in which the epistemological basis of the natural sciences has been interpreted (Bryman, 2001). It has crossed over to the social sciences, but one of the most significant has been Bhaskar's (1989) work on *critical realism*. Although its creation was in direct response to the philosophical gap between positivism and postmodernism, critical realism accepts neither subjective nor objective ontology but instead takes a view that the "social world is reproduced and transformed in daily life" (Bhaskar, 1989). For the critical realist, reality is the most significant philosophical consideration where a structured and layered ontology is essential (Fleetwood, 2005). There are two stages to fully understanding the world from a critical realism perspective; firstly through the events and sensations experienced; and secondly the mental processing that occurs post event/experience, when events are reasoned backwards from the initial experience "...to the underlying reality that might have caused them", which is also referred to as *retroduction* (Reed, 2005). An antithesis to postivism is the philosophy of *postmodernism*, which displays a dislike for "master-narratives" (Bryman, 2001), emphasising the role of language and of power relations (Saunders et al., 2016). Postmodernist researchers seek to expose dominant realities of power relations through exclusion and inclusion of meaning, accepting that such weighted relations are unavoidable and therefore crucial for researchers to be open-minded about their moral and ethical stance (Calás & Smircich, 1997, 1999).

**Table 3.1 Comparison of five business research philosophies**

	<b>Ontology</b>	<b>Epistemology</b>	<b>Axiology</b>	<b>Typical Methods</b>
<b>Positivism</b>	<ul style="list-style-type: none"> <li>• Real, external, intendent</li> <li>• One true reality</li> <li>• Granular, ordered</li> </ul>	<ul style="list-style-type: none"> <li>• Scientific method</li> <li>• Observable and measureable facts</li> <li>• Law-like generalisations</li> <li>• Causal explanations</li> </ul>	<ul style="list-style-type: none"> <li>• Value-free research</li> <li>• Researcher is detached, neutral and independent of what is researched</li> <li>• Researcher maintains an objective stance</li> </ul>	<ul style="list-style-type: none"> <li>• Deductive, highly structured</li> <li>• Large samples, measurement, typically quantitative methods of analysis</li> </ul>
<b>Interpretivism</b>	<ul style="list-style-type: none"> <li>• Complex, rich</li> <li>• Socially constructed through culture and language</li> <li>• Multiple meanings, realities</li> <li>• Flux of processes, experiences, practices</li> </ul>	<ul style="list-style-type: none"> <li>• Theories and concepts too simplistic</li> <li>• Focus on narratives, stories, perceptions and interpretations</li> <li>• New understandings and worldview as contribution</li> </ul>	<ul style="list-style-type: none"> <li>• Value-bound research</li> <li>• Researchers are part of what is researched, subjective</li> <li>• Researcher interpretations key to contribution</li> <li>• Researcher reflexive</li> </ul>	<ul style="list-style-type: none"> <li>• Inductive</li> <li>• Small samples, in depth investigations</li> <li>• Qualitative methods of analysis</li> </ul>
<b>Critical Realism</b>	<ul style="list-style-type: none"> <li>• Stratified/layered, empirical</li> <li>• External, independent</li> <li>• Intransient</li> <li>• Objective structures</li> <li>• Causal mechanisms</li> </ul>	<ul style="list-style-type: none"> <li>• Epistemological relativism</li> <li>• Knowledge historically situated and transient</li> <li>• Facts are social constructions</li> <li>• Historical causal explanation as contribution</li> </ul>	<ul style="list-style-type: none"> <li>• Value-laden research</li> <li>• Researcher acknowledges bias by worldviews, culture/experience</li> <li>• Researcher tries to minimise bias</li> <li>• Researcher is as objective as possible</li> </ul>	<ul style="list-style-type: none"> <li>• Retroductive</li> <li>• In-depth historically situated analysis of pre-existing structures and emerging agency</li> <li>• Range of methods and data types to fit subject matter</li> </ul>
<b>Postmodernism</b>	<ul style="list-style-type: none"> <li>• Nominal, complex, rich</li> <li>• Socially constructed through power relations</li> <li>• Some meanings, interpretations, realities are dominated and silenced by others</li> <li>• Flux of processes experiences and practices</li> </ul>	<ul style="list-style-type: none"> <li>• What counts as truth and knowledge is decided by dominant ideologies</li> <li>• Focus on absences, silences and oppressed/repressed meanings</li> <li>• Exposure of power relations and challenge of dominant views as contribution</li> </ul>	<ul style="list-style-type: none"> <li>• Value-constituted research</li> <li>• Researcher and research embedded in power relations</li> <li>• Some research narratives are repressed and silenced at the expense of others</li> <li>• Researcher radically reflexive</li> </ul>	<ul style="list-style-type: none"> <li>• Typically deconstructive – reading texts and realities against themselves</li> <li>• In-depth investigations of anomalies</li> <li>• Range of data types, typically qualitative</li> </ul>

*Source: adapted from (Saunders et al., 2016)*



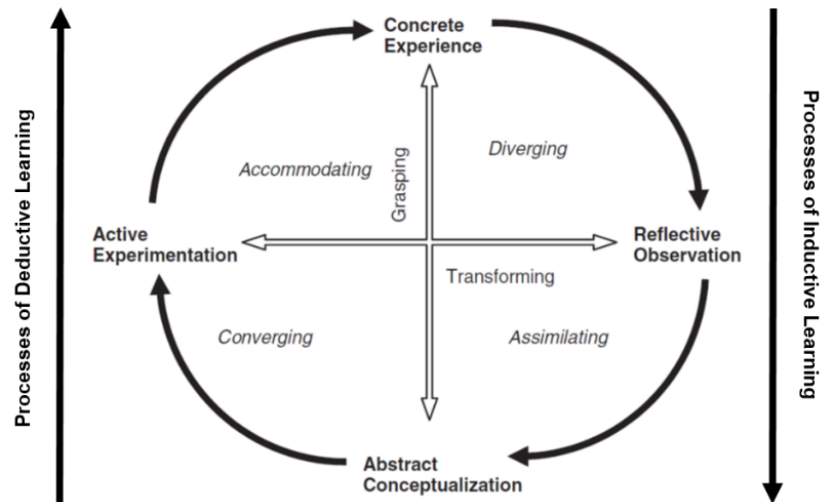
Commonly known as the *paradigm wars*, qualitative and quantitative purists have been engaged in an “ardent” paradigm dispute for over a century now (H. D. Johnson & Dasgupta, 2005). Both sets of purists view their paradigms as the ideal school of thought for research, and, indirectly if not openly, they advocate the *incompatibility thesis* (Howe, 1988), which claims that qualitative and quantitative paradigms, including associated methodologies, cannot and should not be mixed. Although Chubin and Restivo (1983), cited in (Gill, Johnson, & Clark, 2010), claim that management researchers are neutral and fallible, and in fact should accept a more “partisan” participation in what is an interest loaded discussion. In theory the researcher should “divest themselves of allusions to the role of detached observer” (Chubin & Restivo, 1983). This allows researchers to embrace practical appropriateness that is necessary to sustain an instinctive research approach, or what is known as *pragmatism*. The basic belief of pragmatists is that the research objective dictates the research method (Golicic & Davis, 2012), or “whatever philosophical and/or methodological approach works for the particular research problem under study” (Tashakkori & Teddlie, 2003). The pragmatic maxim states that the existing meaning or “provisional truth value” of an expression is to be determined by the experiences or practical consequences of the “belief in” or the “application of” the expression in the real world (Murphy & Rorty, 1990) cited in (R. B. Johnson & Onwuegbuzie, 2004). It is suggested that the balanced or *pluralist* position that pragmatism provides will potentially improve collaboration among researchers with different paradigms as they attempt to advance knowledge (Maxcy, 2003). This encourages a mixed method approach to research with recent literature claiming a pragmatist approach is a move to *normal science* (Biddle & Schafft, 2015).

The third philosophy assumption, *axiology*, refers to the role of values and ethics in research inquiry (Lincoln & Guba, 1985) and is an often overlooked but important aspect of research philosophy (Biddle & Schafft, 2015). Biddle and Schafft add that most researchers, regardless of paradigms, will allow axiological influences drive and structure both research questions and possibly further their interest in particular fields of inquiry over others. Heron (1996) claims that all researchers have an ability to articulate their values as the foundation for making decisions about what research they are conducting and how they execute it, demonstrating a high capability in axiological skill.

### 3.3 Research Approach

The complicated task of balancing the varying role both theory and practice play in the development of a research theory is addressed by using two research approaches: *deduction* and *induction*. Deductive reasoning involves the development of a conceptual and theoretical structure that is tested through observations (Gill et al., 2010). The development involves the testing of a theory by applying a research strategy specially designed for the purpose of such tests (Saunders et al., 2016). Deduction follows highly structured methodology and often investigates causal relationships between variables to explain a certain phenomenon and generates generalised findings (Easterby-Smith, Thorpe, & Lowe, 2002). Inductive theory development on the other hand, occurs as a result of the observations of empirical and other research data (Saunders et al., 2016). Tashakkori and Teddlie (1998) extend this theory, clarifying that inductive inference creates consistent explanations through the integration of; current knowledge sourced from the literature; robust observations and facts; and results from a research project data analysis phase. An important link to both theory development approaches was made by

Kolb et al. in the late 1970's through the development of the experiential learning cycle (Figure 3.1).



*Adapted from: (Kolb, 1995)*

**Figure 3.1 Inductive and Deductive Learning**

The authors claim that although inductive and deductive terminologies are “somewhat different”, they are linked to how human beings learn (Kolb, 1995). According to Kolb, “learning might start inductively with the experience of an event or stimulus, which the individual then reflects upon in trying to make sense of it” (Gill et al., 2010; Kolb, 1995). Kolb also adds that learning can also start deductively where the abstract conceptualisation can be inherited from the works of peers by the researcher and subsequently tested and applied.

Another important aspect of a research approach is recognising the purpose of the research's overall design. According to Saunders et al. (2016), research can be designed to fulfil *exploratory*, *descriptive*, *explanatory* and *evaluative* purposes. Exploratory research is an effective approach when a researcher needs to determine the “What” (what

is happening) and “How” (gain insights) of a topic of interest (Saunders et al., 2016). Whilst a descriptive purpose attempts to portray an accurate profile of events, scenarios and societies and requires extensive previous knowledge of the situation being researched (Robson, 2002). Robson continues by stating that most commonly through the form of causal relationships, explanatory research seeks reasons for a particular problem or situation with the aim of explaining patterns relating to any phenomena being researched. Finally, evaluative research is concerned with the evaluation of real-world interventions in the social world (Bryman, 2001) and is similar in design to another research purpose known as *emancipatory* inquiry (Robson, 2002). The two main research approaches outlined in this section are compared in Table 3.2.

**Table 3.2 Research Approaches**

<i>Research Approach</i>	<b>Deduction</b>	<b>Induction</b>
<i>Approach to investigation</i>	Highly structured	Flexible
<i>Paradigm</i>	Positivist	Interpretivist
<i>Sequence of Investigation</i>	<ol style="list-style-type: none"> <li>1. Theory</li> <li>2. Hypothesis</li> <li>3. Observation</li> <li>4. Confirmation</li> </ol>	<ol style="list-style-type: none"> <li>1. Observation</li> <li>2. Patterns</li> <li>3. Hypothesis</li> <li>4. Theory</li> </ol>
<i>Purpose</i>	Explanatory; Explanation of causal relationships between variables	Exploratory; Gaining an understanding of the phenomena
<i>Data Collected</i>	Quantitative	Qualitative
<i>Generalisation</i>	Need to generalise conclusions	Less concern with generalisation

*Source: Adapted from (Saunders et al., 2016)*

### 3.4 Research Methods

Although the development of a research philosophy, approach and purpose form the backbone of a researcher's research design there is still the important underlying choice of research method to consider. As introduced in Section 3.1, there are three core research methods: *qualitative*, *quantitative* and *mixed methods*. Qualitative methods can be used for a varied amount of research objectives, including theory development and testing, construct validation, and the uncovering of new or emerging phenomena (Garcia & Gluesing, 2013). Qualitative methods rely mainly on text and visual/image data and associated data sourcing and analysis techniques (Creswell, 2014). Typical qualitative data sources include; interviews, observations, documents and audio visual aids to name a few. According to Creswell (2014), the researcher is a key instrument in qualitative research and analyses data both inductively and deductively as outlined previously.

Alternatively, the key instrument referred to in quantitative methods is the relationships among variables that are designed objectively and in often high numerical frequency using statistical and graphical techniques (Newman, Ridenour, Newman, & DeMarco Jr., 2003). As outlined by Saunders et al. (2016), quantitative research in general, is associated with positivism through highly structured and predetermined data collection techniques. Quantitative research methods include experiments, surveys, structured observations, and structured interviews and are traditionally the most utilised methods in business management research (Gill et al., 2010). It can also be argued that many researchers can make the mistake of assuming quantitative complexity is the same as methodological sophistication, which is not the case (Peng, Peterson, & Shyi, 1991).

Some common contrasts between qualitative and quantitative research are summarised in Table 3.3.

**Table 3.3 Contrasts in Quantitative and Qualitative Research**

<b>Quantitative</b>	<b>Qualitative</b>
Numbers	Words
Point of view of researcher	Points of view of participants
Researcher distant	Researcher close
Theory Testing	Theory emergent
Static	Process
Structured	Unstructured
Generalisation	Contextual understanding
Hard, reliable data	Rich, deep data
Macro	Micro
Behaviour	Meaning
Artificial settings	Natural Settings

*Source: (Bryman, 2001)*

As noted previously, qualitative and quantitative research methods are not polar opposites but more two sides of a research continuum, and therefore should complement each other with potential of mixing or integrating multiple methods. There are two core approaches to multiple methods; *mixed methods* (*QUAL + QUANT*), and *multimethods* (*QUAN + QUAN or QUAL + QUAL*) (Hunter & Brewer, 2003). Stemming from Campbell and Fiske's (1959) development of a multitrait-multimethod (MTMM) matrix, mixed method research is becoming increasingly popular in recent years due to the synergies and benefits it brings (Tashakkori & Teddlie, 2003). Greene et al. (2001) claim that the purpose of mixed methods research is give the researcher a better understanding of particular social phenomena with a great reduction in uncertainty. The authors (Greene et al., 2001) elaborate this as follows:

1. **Enhanced validity and credibility of inferences.** This is illustrated by the definitive mixed-method *triangulation* design, in which different methods – ideally with offsetting biases – are used to measure the same phenomenon with intended convergence of results and thus the ruling out of various threats to validity.
2. **Greater comprehensiveness of findings.** More complete accounts of social phenomena are made when different methods are used to offer different perspectives on a social program.
3. **More insightful understandings.** Some mixed-method designs yield findings that do not converge, but rather challenge or even conflict with one another, giving opportunity for further analytic questioning and probing by the researcher.
4. **Increased value consciousness and diversity.** Mixed methods increase the likelihood of including diverse value stances and perspectives through multiple stakeholder views, multiple theoretical stances and multiple analytic strategies, inviting *value pluralism*.

### 3.5 Justification of Selected Paradigm

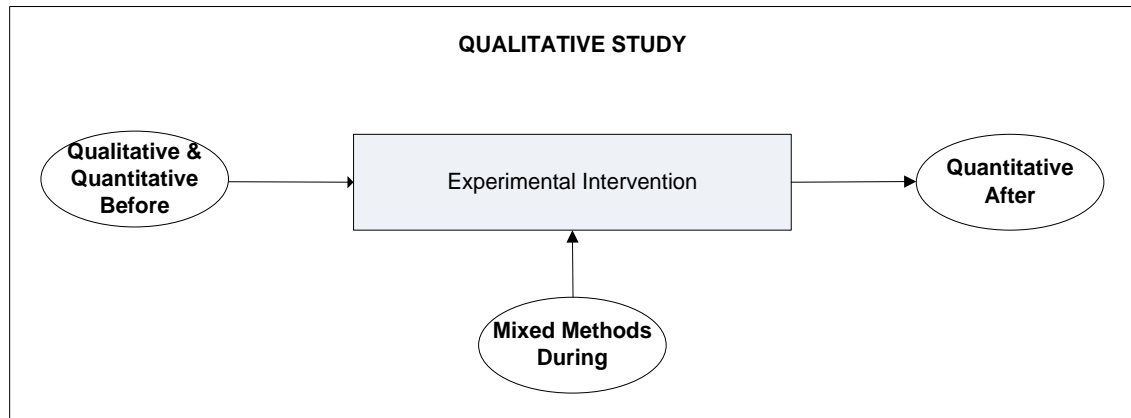
The pragmatic paradigm has been selected as the underlying philosophy of this research study. Due to the system-based, multi-level nature of this research, pragmatism is able to answer the research questions comprehensively with the practical appropriateness that is necessary. Pragmatism encourages the researcher to adopt different paradigms that will compliment research objectives at different stages of the research study. It allows the researcher to identify and apply of the best-suited, or most practical research methods and techniques at each stage, resulting in an effective research process which would yield relevant and robust results. Most importantly, alternating between epistemological

positions under a single pragmatic paradigm allows the use of mixed methods including both qualitative and quantitative techniques in data collection and analysis. Benefits of such combination for this research include triangulation and complementarity of findings, in addition to a rigorous process for framework development. A pragmatic philosophical approach through mixed methods also enhances and improves the researchers understanding of the overall research. Interaction between methods will continuously challenge and probe research objectives throughout the research study.

### 3.6 Research Design

Section 3.4 has outlined that the design of a research project is a challenging process for both qualitative and quantitative approaches and often becomes even more challenging if the researcher decides to use mixed methods. Influenced towards a pragmatist paradigm, this research study has conducted a *fixed* mixed methods design, the *embedded design*, as endorsed by Creswell and Plano Clark (2011). This design (Figure 3.2) is applicable when a researcher collects and analyses both quantitative and qualitative data within a more traditional quantitative or qualitative design. Creswell and Plano Clark say the embedded design is used to enhance the more traditional qualitative or quantitative design. Important emphasis is put on the rationale and timing of the collection and analysis of any supplemental data relative to the primary design of the research. Popular in health sciences, this design is best suited to investigating a process or program within an applied setting (John W. Creswell, 2014). However, similar to *multiphase* mixed method design, this requires a significant investment in time and resources, and a high level of expertise in the chosen supplementary and primary data collection and analysis techniques to achieve overall objectives.





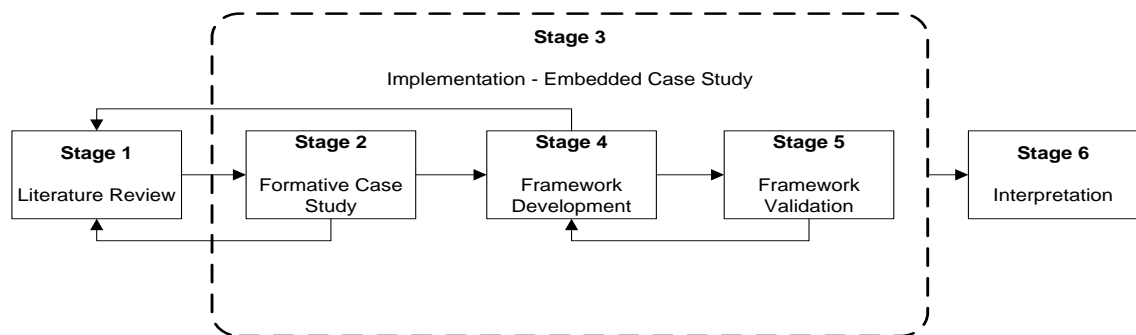
*Adapted from: (Creswell & Plano Clark, 2011)*

**Figure 3.2 Embedded Mixed Method Research Design**

There are 4 distinct stages to this research study's embedded design. The first stage is the overall design of the primary qualitative study/experiment and deciding why an embedded supplementary study is required. Second is the implementation of a mixed method strand before the primary experiment to validate the use of the supplementary study and refine data collection and analysis techniques. The first two phases of an embedded design are essential in developing an effective plan of the overall qualitative study structure and milestones. Third, an extensive exploratory sequential mixed method strand is implemented during the primary study with the goal of developing a multilevel understanding of RSC risk management, incorporating participant experiences, business process mapping and micro and macro system modelling. The use of exploratory mixed methods during the primary study is to enhance the overall outcome of the research through experimental intervention. And finally fourth, the interpretation of the primary study is achieved through a quantitative strand after the experimental intervention. This final stage validates the application of the study describing why outcomes occurred and what long term effects could be experienced.

### 3.7 Research Plan

To fulfil objectives and achieve the most comprehensive, accurate and novel findings, this research study has been planned and conducted in six embedded stages as illustrated in Figure 3.3 and detailed in Table 3.4. The rationale and aims of the methods used at each stage are explained in the following sections. Although the research plan stages in Figure 3.4 are sequential, it is important to note that the embedded mixed method design itself is not sequential, but runs concurrent to all other stages. This is based on the comments made by Creswell and Plano Clark (2011), who state that a researcher using an embedded design should develop and make procedural decisions before; during; after; and/or in some form of combination, based on the purpose of embedded support data (formative case study, framework development and validation) within the larger mixed methods design (embedded case study). A more detailed diagram representing the research plan can be seen at the end of this chapter in Figure 3.7



**Figure 3.3 The Research Stages**

Therefore, and although unconventional, the embedded mixed methods case study begins before the research framework has been created and plays an integral role with its development throughout the research plan execution. The concurrent nature of the

research plan is also subjected by the strong influence system thinking puts on dynamic, concurrent analysis with causal loop feedback. This is also why feedback mechanisms play a central role in the research stages outlined in figure 3.4 and the thesis layout, detailed in figure 1.3.

**Table 3.4 Research Plan**

	Stage	Approach	Methodology	Method
1	Literature Review	Inductive & Deductive	Qualitative	Qualitative Analysis
2	Formative Study	Inductive	Mixed	Exploratory Sequential
3	Implementation	Deductive	Mixed	Embedded Case Study
4	Framework Development	Inductive	Qualitative	-
5	Framework Validation	Inductive & Deductive	Mixed	Hybrid Simulation
6	Interpretation	Deductive	Qualitative & Quantitative	Behaviour Analysis & DOE

### 3.7.1 Literature Review

As explained in section 2.2, a systematic, concept-centric approach to reviewing literature was chosen as a secondary data collection method for this research study. The objective of this data collection phase was to answer the research questions RQ1 and RQ2 of this study which is; *“How applicable are existing solution techniques in handling the dynamics and complexity within supply chain systems and how effective are they in mitigating risk?”* and *“What are the correlations between system thinking and understanding supply chain risk?”* To achieve this the literature review evolved into a sequential, five phase plan, structured taxonomically on a system-based SCRM foundation (Figure 2.2). Firstly, an in-depth understanding of the chosen topic and field of study, SCM within the grocery retail sector was required. Specifically focused on profiling the sector itself from an Irish perspective, a clear understanding of performance,

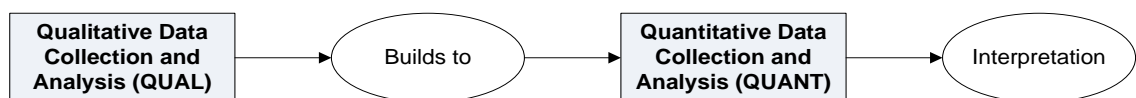
initiatives and challenges for SCM decision makers was gained. Then, with an increased knowledge base of retail SCM, the concept of scientific method and experimentation and its gap in business research was discussed, acknowledging opportunities through the analogy of the laws of thermodynamics.

This alluded to the importance of system thinking in mainstream business decision making processes. The relationship between risk and the decision-making processes was then studied with particular emphasis on the feedback mechanisms within high risk decisions and overall risk management approaches, tools and techniques. Finally, the concept of risk management as a business process management technique was developed. As noted in chapter 3, a combination of deductive and inductive approaches were used to classify articles and although it was not based on a predefined classification like many SCRM reviews, a systematic approach was followed, using wide-ranging and varied data to form the generalisations listed in the five phase sequence outlined above.

### **3.7.2 Formative Case Study**

According to Yin (2014), a *pilot study* is more formative than a *pretest*, designed to assist researchers in developing relevant research questions and possibly to improve overall clarification of the concepts and research design that will be used in the formal primary case study. Yin also adds that pilot data should not be reused in the formal case study. The main criteria in selecting the formative case in general followed a commonly used pattern, where convenience, access, and proximity to facilities were core influencers. The only parameters that needed to be consistent were that the formative case study needed to be run in a RSC organisation with an FMCG background. The scope of the pilot data was to provide the researcher with significant insights into the basic challenges and issues

initially developed in the research questions and objectives outlined in chapter one, and also to test the success of simulation based tools and techniques in an applied SCRM environment. In parallel, this data was utilised in the ongoing review and updating of relevant literature throughout the research study. Moreover, the dual sourcing of information at this early stage helped ensure that the actual embedded case study and overarching research design was informed by both theoretical and empirical observations, resulting in a more robust reflection of polices and questions relevant to real-world cases (Yin, 2014). Methodologically, the formative case study followed an exploratory sequential mixed methods approach as illustrated in Figure 3.4.



*Source: (Creswell & Plano Clark, 2011)*

**Figure 3.4 Exploratory Sequential Mixed Methods**

The qualitative data collection phase of the formative study was conducted using semi-structured interviews, onsite observations and business process modelling. Building on the information provided at the qualitative phase provided, the quantitative analysis phase was achieved through DES modelling and design of experiments (DOE) results analysis. Both phases of this mixed methods formative case followed the simulation study steps outlined by Banks (2010). These steps will be discussed in detail in Chapters 4 and 5. Reporting on the formative study explicitly focuses on the lessons learned about the chosen research design for the main case study. The interpretation of the pilot includes analysis of the simulation study results, the actual success of implementation within the chosen case organisation, follow up interviews with organisation decision makers and reflection of both literature review and research design robustness.

### 3.7.3 Implementation: Embedded Case Study

In mixed method research, there are two core typology clusters, *component designs* and *integrated designs*. Component designs use methods that are discrete aspects of the overall study and remain separate throughout the study (Caracelli & Greene, 1997), similar to the exploratory sequential design used in the formative case study (Fig 3.4). An integrated design on the other hand, combines methods from different paradigms (subjective and objective), with potential to providing more insightful understanding of the system being studied (Caracelli & Greene, 1997). The embedded case study falls under this typology cluster.

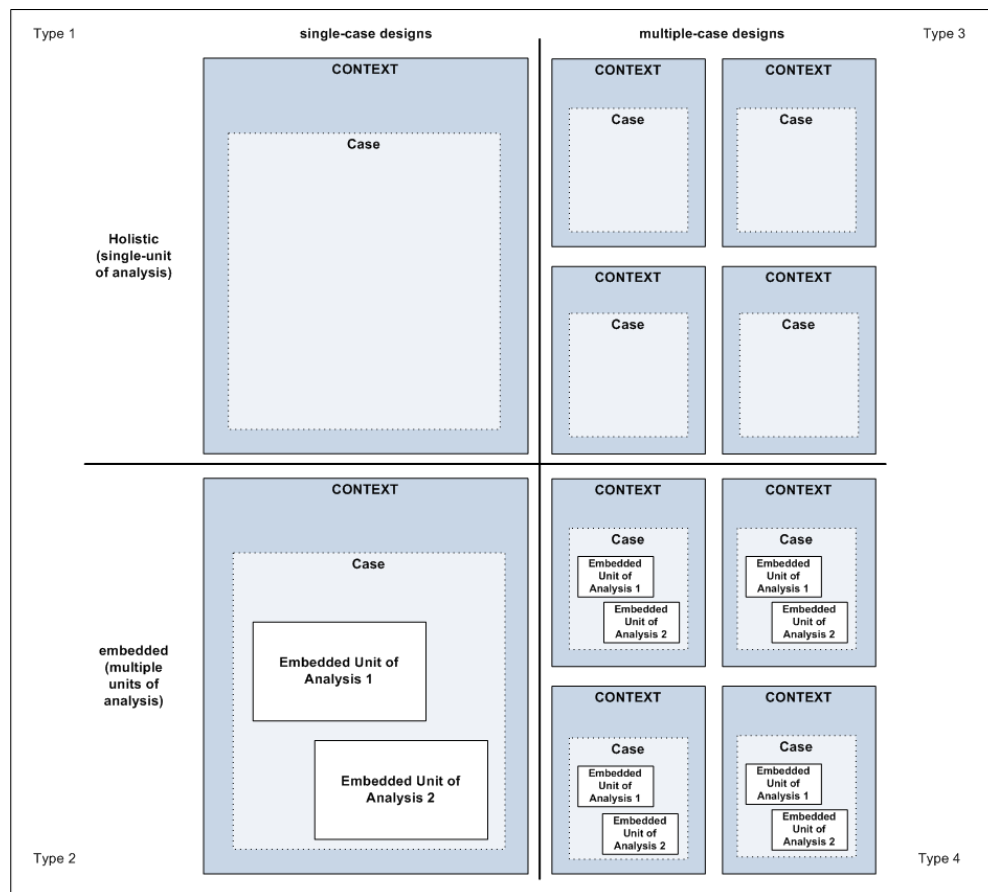
According to Yin (2014), when designing a case study a distinction between *single-* and *multiple-case study* designs is needed. Yin adds that these two case variants reflect different design situations with either unitary or multiple units of analysis, as illustrated in the matrix in Figure 3.5. This research study has used type 2, the embedded single case study with multiple units of analysis and is justified. As explained by Siggelkow (2007) for a single case study to be justified, it should allow the reader experience the real-world phenomena being studied, especially if they are unfamiliar with the topic or its literature. From a practitioner perspective, this is very important to the objectives of this research study, but the rationale for choosing a single case study is still needed.

Yin (2014) suggests that there are five single-case rationales to reflect on when considering the design appropriateness of a research study. That is having a critical, unusual, common, revelatory, or longitudinal case to build or validate theories on, as detailed in Table 3.5.

**Table 3.5 Single Case Appropriateness - Five Rationales**

Rationale	Description	Consider when?
Critical	The critical test of a significant theory	Important to researchers theoretical proposition
Unusual	Deviates from theoretical norms	Where a specific extreme case provides a distinct opportunity worth exploring
Common	Capture the circumstances and conditions of an everyday situation	To provide lessons about social processes related to a theoretical interest
Revelatory	A phenomenon previously inaccessible to social science inquiry	A researcher has an opportunity to observe and analyse a previously inaccessible phenomenon
Longitudinal	Studying the same single case at two or more different points in time	Where a theoretical proposition specifies how certain conditions and their underlying processes change over time

*Source: adapted from (Yin, 2014)*



*Source: (Yin, 2014)*

**Figure 3.5 Basic Case Study Designs**

### 3.7.3.1 Case Selection

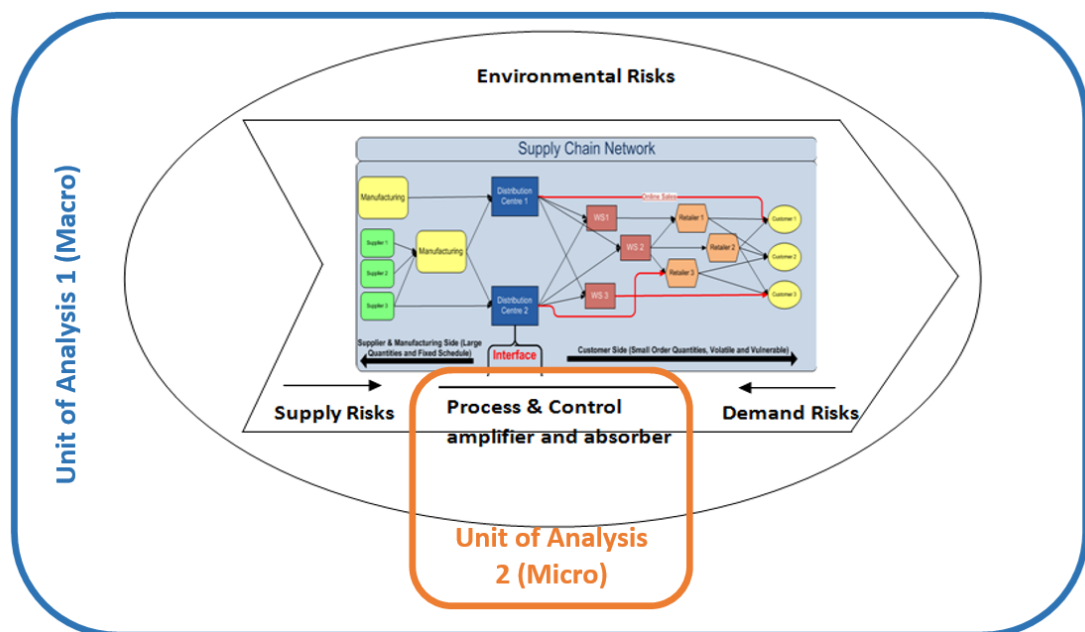
In this research study, the researcher's choice of a single-case study as the primary research design centred on critical and common rationales, as detailed in table 3.4. A single-case study had critical appropriateness as it was important to the researcher's theoretical proposition of a system thinking orientated RSC that a single, extended RSC was studied. Equally, a common rationale was also prevalent, as the everyday importance and impact of a RSC to every aspect of a social system is a fundamental message of this research studies primary objective. And although a holistic viewpoint is essential to a system thinking framework, the researcher acknowledges the complex, dynamic nature of an extended RSC and the appropriateness of an embedded solution over a holistic one. As explained by Yin (2014), attention needs to be given to subunits where analysis might include different outcomes from embedded units within the primary case. In terms of this research, this can include different organisations within the extended RSC, such as retail outlets, manufacturers and distribution centres. According to Li et al. (2010), an extended RSC case study provides an opportunity to study a phenomenon (such as SCRM) in its own real world setting, where complex links and underlying meanings can be explored, while also enabling the researcher to study the RSC system holistically.

To achieve this, when selecting the case subject(s), it is important that they are representative of the field of study (Seuring, 2008). From a single-case study perspective, and especially one as large as an extended, multi-echelon RSC, case subject selection needs to ensure proportionate representation of the entire RSC. For this reason, the researcher targeted specific RSC organisations within the FMCG RSC that when combined, represented the market leaders in the manufacturing, distribution and retail



selling of a specific FMCG category, savoury foods, within the Irish retail marketplace. In the end, the extended RSC comprised of a leading global FMCG manufacturer with over 60% category market share, a nationwide wholesaler that distributes five thousand pallets of finished goods weekly and a market leading retail outlet chain that has over one million customers per day.

The embedded structure included two core units of analysis representing *SCRM strategic* and *operational* decision making levels within the primary study. Expanding upon the drivers of RSC risk discussed in chapter 2, the two embedded units of analysis encompass the holistic, system-wide perspective of risk and associated disruptions, whilst also acknowledging the important factor that micro level processes have in amplifying and absorbing event consequences (Figure 3.6).



Adapted from: (Jüttner, 2005)

**Figure 3.6 Embedded Units of Analysis from a SCRM Perspective**

Unit of Analysis 1, observes the extended multi-echelon RSC from a strategic perspective, incorporating 2 large FMCG organisations and four RSC relationships; the manufacturer, distributor; retailer; and consumer. This embedded analysis is achieved through the strategic modelling technique of system dynamics. Unit of Analysis 2 on the other hand, focuses on more micro level, operational aspects of the studied RSC and has been designed and implemented through discrete event simulation modelling. Unit of Analysis 2 focuses on the distribution centre of the 3-echelon RSC, as the internal processes of warehouses and distribution centres, through the accumulation of inventory are a source of amplifying and absorbing both supply and demand risk metrics (Zylstra, 2006).

### **3.7.3.2 Simulation as an Embedded Case Study Research Method**

When an embedded mixed methods research design is chosen, both qualitative and quantitative research methods need to be integrated to enable the experimental intervention of the primary qualitative study. Section 3.4 has highlighted the advantages and disadvantages of both quantitative and qualitative research methods and how mixed methods is an increasingly popular method of utilising the strengths of both approaches. Simulation as a mixed methods research approach is very beneficial in dealing with the weaknesses of both traditional research methods. This is because when simulation is used in mixed methods research, it is capable of using quantitative and qualitative primary data collection and transforming it into quantitative and qualitative information. According to Eldabi et al. (2002), information is any data retrieved from the simulation model by the researcher and can be classified as either *tangible* or *intangible*. The authors explain that tangible information is any quantifiable output data from the model that can be used in

experimentation and testing hypothesis. This represents simulation as a quantitative tool following an inductive reasoning approach. On the other hand, intangible outputs from a simulation study are the unexpected, unquantifiable forms of research information. Intangible information can be retrieved at all stages of a simulation study, including data collection, time and motion studies, process mapping and is a valuable source of deductive feedback to improve the overall simulation study and follows gives simulation its qualitative research attributes (Eldabi et al., 2002).

There is debate within the simulation community on the applicability of the technique as both a quantitative and qualitative research method (Michael Pidd, 2009). Pidd adds that much literature within the disciplines of engineering, operations research and management science imply that only quantitative research and modelling is of interest. As alluded to when referring to the “paradigm wars” in section 3.2. This is in direct contradiction to the research of Checkland on soft-modelling and soft systems methodology (Checkland, 1981, 1999, 2012). Which states that observations based on intangible information should be considered and “known-to-be-desirable ends cannot be taken as given” (Checkland, 1999), p.318). As system thinking strongly influences the epistemological foundations of this research study, the researcher has decided that the claims of Eldabi et al. (2002) on the advantages of simulation as a mixed method research are the best option to implement within an embedded case study.

### **3.7.3.3 Hybrid SD-DES Simulation**

As noted, simulation is a widely used analytical and evaluation modelling technique in SCRM. Two of the most established approaches are that of SD and DES (M. Pidd, 2004). SD methodology is best suited to problems associated with continuous processes where

feedback significantly affects the behaviour of a system, producing dynamic changes in system behaviour, similar to the macro level Unit of Analysis 1 in the embedded case study. DES models, in contrast, are better at providing a detailed analysis of systems involving linear processes and modelling discrete changes in system behaviour (Sweetser, 1999), as in the micro level detail of Unit of Analysis 2 in the embedded case study. A very accurate review of the fundamental differences between SD and DES was written by Lane in 2000, Table 3.6 gives an overview of these differences.

**Table 3.6 Fundamental differences between SD and DES**

	<b>System Dynamics</b>	<b>Discrete Event Simulation</b>
<b>Perspective</b>	Holistic; emphasis on dynamic complexity	Analytic; emphasis on detail complexity
<b>Resolution of models</b>	Homogenized entities, continuous policy pressures and emergent behaviour	Individual entities, attributes, decision and events
<b>Data sources</b>	Broadly drawn	Primarily numerical
<b>Problems studied</b>	Strategic	Operational
<b>Model elements</b>	Physical, tangible, judgmental and information links	Physical, tangible and some informational
<b>Human agents</b>	Executive policy implementers	Decision makers
<b>Model outputs</b>	Understanding behaviour, location of key performance indicators and effective policy levers	Predictions, detailed performance measures across a range of parameters, decision rules and scenarios

*Adapted from: (Lane, 2000)*

When modelling a complex system, it is sometimes very difficult to define the boundaries of a model that appears to be a closed loop with its external environments (Brailsford, Desai, & Viana, 2010). This is often the case with hierarchical levels of a multi-echelon RSC. Similar kinds of uncertainties occur at different hierarchical levels of organizations, yet they are nearly always handled independently at each level. Integrating SD and DES can be very effective in studying the impact interaction between each level has on the system (Venkateswaran, Young-Jun, & Jones, 2004). Hybrid simulation by integrating

both SD and DES can create valuable synergies. By integrating each technique hierarchically, “both paradigms symbiotically enhance each other’s capabilities and mitigate limitations to by sharing information” (Chahal & Eldabi, 2008), which is very attractive to SCRM decision makers. Combining SD and DES capabilities into one hybrid simulation is the main structure of this research studies design and will be explained in detail in chapter 5.

### **3.7.4 Framework Development**

Building on the insights obtained from the literature review and the formative cases simulation study, the fourth stage of the research was the development of the integrated system-based SCRM framework. It is discussed in detail in Chapter 5.

### **3.7.5 Framework Validation and Interpretation**

The embedded case study itself is validation of the proposed framework in this research study which will be discussed in detail in chapter 6.

## **3.8 Ethical Considerations**

Research ethics refer to the execution of the research process in a moral and responsible manner which respects the rights of those who are the subject of the research work, or those who are affected by it (Saunders et al., 2016). A number of ethical issues could arise during research and need to be addressed by the researcher. Bryman (2012) identifies a number of key ethical concerns in research, which include: lack of informed consent, harm to participants, invasion of privacy, and deception. These issues were hence taken into account when planning and conducting research activities for this project.

Before the researcher began his work, institutional approval to commence the research was granted from the Ethics Research Committee at DIT after the committee established that there were no risks or ethical implications to the work. During the data collection stages, informed consent was obtained from practitioners who voluntarily agreed to take part in the steering groups, and case studies (Easterby-Smith et al., 2002). Furthermore, the researcher preserved the anonymity of respondents and the confidentiality of data throughout the research and ensured the identity of organisations and individual respondents was never disclosed (J. Bell, 2005). The possibility of invoking stress upon participants by being intrusive or demanding was avoided by acknowledging their right to withdraw at any stage of the research process (Zikmund, 2003). Finally, academic integrity was maintained during the reporting of research findings by presenting results with transparency and within their context, and accurately attributing other researchers' work by proper referencing.

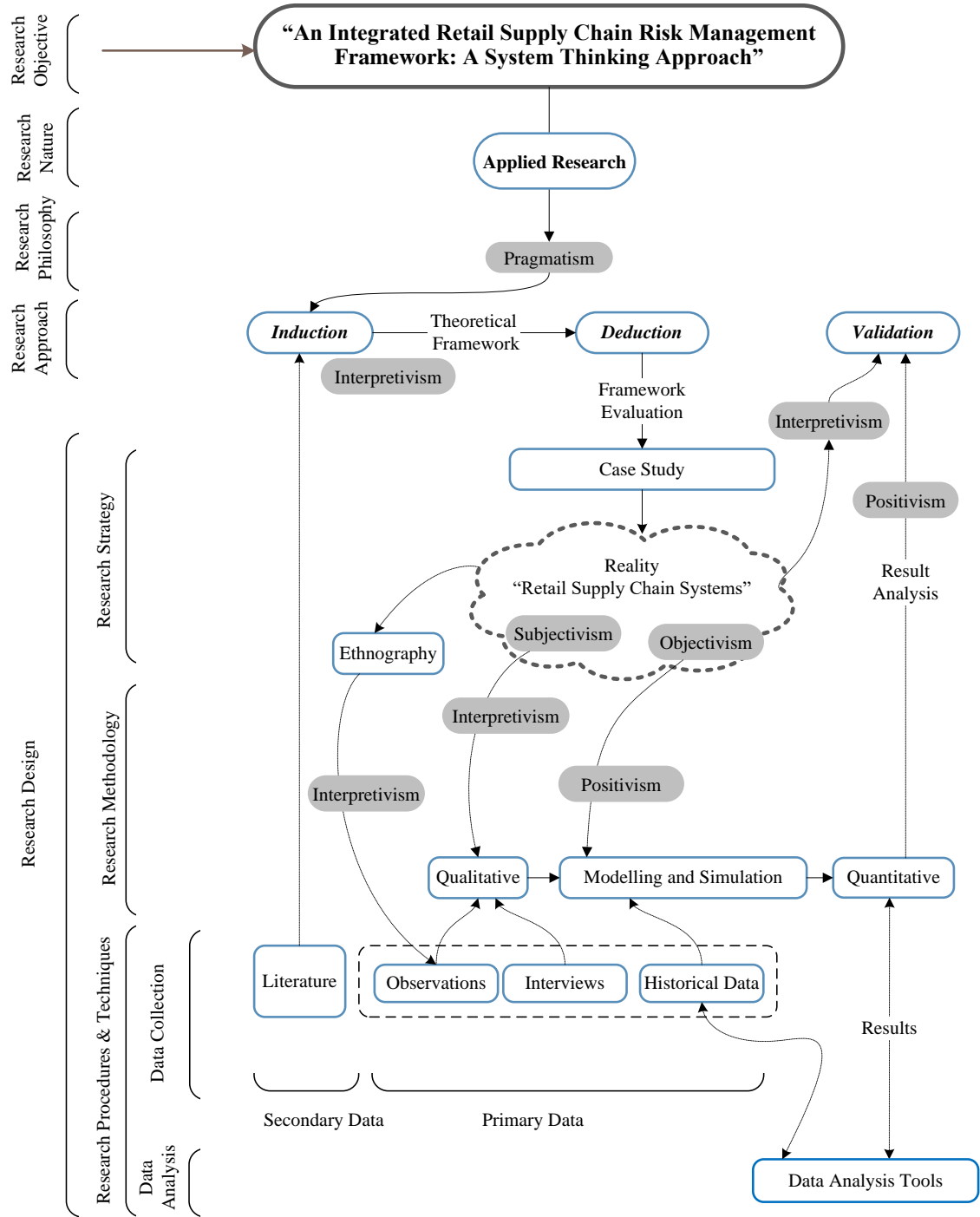


Figure 3.7 Research Plan

## Chapter 4. Formative Case Study

*“No amount of experimentation can ever prove me right; a single experiment can prove me wrong.”*

— Albert Einstein

### 4.1 Introduction

A formative case study section of this research was chosen as an exploratory study into using BPM and simulation techniques to manage SCRM decision making within an RSC organisation. Influenced by scientific method and using initial literature review learning as a theoretical background the formative studies design was to test the implementation of a simulation study within a real-system environment. Practitioner involvement was essential to the success of the study. Primarily through feedback on practitioner perspectives on simulation based techniques to manage decision making risks within a busy FMCG distribution centre for the retail hardware sector. Timing, availability and proximity to the pilot location were the main reasons for choosing the formative case organisation (Bryman, 2012; Saunders et al., 2016). It is important to note that this was the first individual simulation study that the researcher had managed and also the first consultation assignment in industry with expected implementation results from the industry partner.

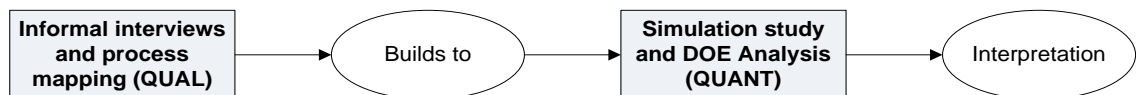
The objective of the formative case is that with practitioner feedback and a reflective learning exercise the researcher will be able to:

1. Refine data collection methods
2. Review the scope of inquiry



3. Improve project management of a simulation study
4. Refine data analysis methods
5. Validate research methods through peer reviewed international conference presentation and publication

An exploratory sequential mixed methods approach has been chosen as the research design of the formative case study as explained in section 3.7.2. There are two main phases to the formative case; firstly frequent informal face-to-face interviews with the warehouse operations manager were undertaken to gather data and to build a series of basic flowcharts and dataflow diagrams (DFD); secondly the simulation model itself was built and final analysis was achieved through DOE experimentation and analysis of variance (ANOVA) testing on chosen decision variables. The simulation study follows the DES study workflow by Banks (2010) which will be discussed in detail in section 5.4.3.



**Figure 4.1 Formative Case Study Design**

### 4.2 Background

The unprecedented fall of the Irish economy into recession during the current global economic crisis has been partly caused by the dependency on an oversized domestic construction industry (Duran, Liu, Simchi-Levi, & Swann, 2007). The sudden collapse in the property boom has led to a decrease in construction output volume of 36.9% between 2008 and 2009 (Central Statistics Office, 2009). As a result of this collapse, the plumbing

and heating (P&H) materials distribution system has been affected greatly due to the consequences of demand risk events with the impact of losing a considerable number of their customers and a remarkable decline in sales figures. Therefore, the application of economic management strategies for the P&H distribution industry has become crucial to survive these extraordinary circumstances. One of the biggest challenges the P&H distribution industry faces is the need to sustain a competitive advantage, by satisfying customer demands and fulfilling orders at the lowest cost. Without an efficient RSC and strong inventory management strategies, it is becoming more difficult to achieve this target and gain a competitive advantage (Christopher & Jüttner, 2000). Improved inventory management contributes to lower costs, increased revenue and greater customer satisfaction (Schwartz & Rivera, 2010).

### **4.2.1 Formative Case Study Organisation**

P&H Distribution firm has about 3,000 different stock keeping units (SKU) that are stored in a large dedicated P&H warehouse. Many suppliers around the world (e.g. China, UK, France... etc.) are listed in the P&H supplier list. Monthly forecasts for all items based on twelve month sales historical data is the main source of input for that system. Due to the uncertainty of suppliers lead time, demand fluctuation, changeable prices and high shortage cost, the strategy of keeping safe inventory levels for fulfilling unexpected demand is currently applied. The high cost of on-hand inventory versus the cost of a stock out and late delivery drove the warehouse manager to target the balance between minimizing the inventory level and keeping on time service level at an optimum point. The result of changes in this balance and its impact on customer satisfaction level has to be predicted and investigated. To model such systems that contain a large number of entities

with a stochastic nature for all its processes, a simulation modelling technique is recommended (Azadivar, 1999). This is due to its capability in modelling the dynamic nature of the systems as well as their variability. DFD and flow charts are integrated before the development of simulation to conceptually model the system. This integration provided synergies by merging the information and object flow in one conceptual model. Finally, a DOE has been developed to investigate the significance of process parameters and examine various customer management scenarios.

The purpose of this study is to investigate two demand risk scenarios centring on customer order policies; customer equality (no segmentation) policy and customer segmentation policy. To identify the best policy that achieves high levels of customer satisfaction, two performance indicators will be used to represent customer satisfaction level – delivery time and total cost. The study also aims to analyse the influence of the changes in the selected scenarios and two process parameters (i.e. forecasted order quantity (FOQ) and safety stock level (SSL)) on system performance and get the best combination of them that achieves the best performance measures.

### **4.3 Problem Definition**

The studied company (AC) is a leading construction merchant in the Irish market. The company reported a turnover of €370 million for the 2009 fiscal year. Approximately €140 million of this figure was generated by the company's P&H retail distribution division. This study will focus on the inventory management system based in the central warehouse of AC's P&H division. The central warehouse acts as a wholesale distributor to the company's retail outlets and other external customers.

The primary function of the P&H inventory management process is to satisfy customer demand through the continuous availability of stock. To achieve this, over 95% order fulfilment accuracy needs to be achieved. To determine the ultimate measure in order fulfilment, the ‘perfect order’ framework was created (Amer, Luong, & Lee, 2010). Such an order meets the customer’s deadline, is delivered on time, is damage-free, and has perfect invoice accuracy (Amer et al., 2010; Holt, 2005). From this framework, it can be highlighted that the inventory management department play a crucial role in order fulfilment. For example:

- To meet a customer’s deadline, sufficient inventory levels need to be available in stock.
- To deliver damage-free and good quality goods, the best products need to be sourced from the best suppliers available.
- To have perfect invoice accuracy, the previous two steps need to be clear of error.

There are various challenges that need to be addressed when trying to achieve the ‘perfect order’ at AC’s P&H central warehouse. A balance between the cost of ordering stock, holding stock and out of stock cost is required to ensure that there are no stock outs or over stocked items. There is a threshold between losing customer sales and losing capital investment tied up in unused stock. Forecasting demand accuracy is an issue that will affect this threshold in the inventory management process’s performance. With a product range of over 3,000 SKU’s, the forecasting of sales data and stock level reviews are crucial activities within the inventory management function. FOQ and SSL are considered two important process parameters that have an impact on system performance indicators. The

examination of the significance of their influence on performance indicators is a very important issue.

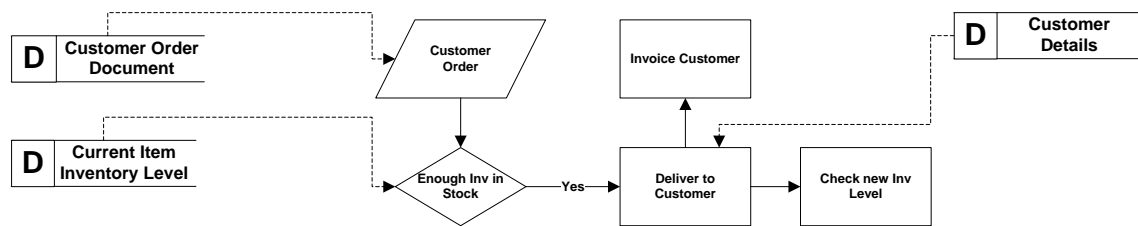
The inventory management process is further complicated by the need to prioritise orders within the company's 25 retail outlets. Customer segmentation has been introduced internally because the cost of stock outs is greater in the larger retail stores. Unlike traditional inventory management systems, where all customer demands are treated equally and served on a first-in-first-served basis (i.e. Customer equality policy), with customer segmentation, customers are classified into groups according to their importance (e.g. by sales volume) to the P&H department (Loo Hay et al., 2005). Customer segmentation is the process of dividing customers into classes for decision-making purposes such as value proposition and customer profitability (Epstein, Friedl, & Yuthas, 2008). In production and RSC management, many firms are exploring when customers may be segmented into different groups based on service levels and priority. This will help to balance supply and demand and increase customer satisfaction (Duran et al., 2007). To effectively manage the inventory flow at AC, there is a need for the development of a structured, systematic inventory management methodology that will evaluate the cost and service level for customers from different segmentations. The methodology will integrate the business process modelling techniques of flowcharts and DFD's with simulation to achieve the following objectives: (i) build a clear and effective conceptual model to understand the inventory management process at AC, (ii) develop a DES simulation model to examine inventory management process parameters under different scenarios, (iii) find the optimal combination of process parameters and studied scenarios in order to enhance inventory management performance.

### 4.4 Business Process Model

A process can be defined as a; “structured, measured sets of activities designed to produce a specified output for a particular customer or market” (Davenport, 1993). These “structured, measured activities” are the relationship between inputs and outputs (Aguilar-Savén, 2004), and it can be suggested that every time a person performs any kind of action, a process is carried out (Holt, 2005). As a result of this broad generalisation of the term, there have been many definitions published in relation to the topic.

Business process modelling (BPMo) is a presentation of the sequences of system processes, procedures and resources and shows the relationship between a system’s objects, such as customers and products, and their status during the systems process (Mahfouz et al., 2010). Many modelling methods have been developed and studied in BPMo literature (Shen, Wall, Zaremba, Chen, & Browne, 2004). Flow charts and DFD’s are two effective conceptual modelling techniques that were used individually in different publications. Flowcharts are a graphical representation of a process in which symbols are used to represent such things as operations, flow direction and organisational charts (Shen et al., 2004). Along with Gantt Charts, flow charts are the main method of graphically showing the sequence and duration of a process’s activities. They are clear and flexible in use, but there is a risk of missing important details of the modelled process such as information flow (Mahfouz et al., 2010). DFD is a very effective way of modelling information and data flows within a process. DFD’s are used to provide a specification of the flow of data from external entities into logical data storages, via various data processing steps (Sun, Zhao, Nunamaker, & Sheng, 2006). Because the current model focuses on ordering processes and customer/supplier relationships, rather than the

physical flow of items inside AC's warehouse, integration between items flow in the ordering process and information flow is required. Flow chart methodology and DFD is used to develop the conceptual model of AC Company. The integration will be done according to Figure 4.2, as each process represented in the flow chart will have a link with a DFD block which identifies the kind of data that this process may need.



**Figure 4.2 Process Mapping Structure**

#### 4.4.1 The Conceptual Model for AC Company

Each BPMo method has its own advantages and disadvantages and each individual method is limited with regard to presenting an accurate and effective view of a business (Aguilar-Savén, 2004). Understanding business processes clearly is a key to define the required modelling techniques. In some cases, there is a need to adopt more than one modelling technique to describe a system graphically from more than one point of view (Shen et al., 2004). For example, although DFD's provide a clear description of information flow, they lack the ability to express logical terms such as flow charts. The conceptual flow of the studied BPMo's can be explained as follows. The inventory management process begins with receiving orders either by a customer or forecast data. Customer orders are classed as one-off orders received by external customers and forecasts are orders calculated according a continuous review of historical sales data, re-order points, safety stock levels, special projects and professional knowledge. For most suppliers, the inventory manager

aims to keep between 1.5–2 months stock with the re-order points about 1.2 months, depending on lead-times. To extend supplier credit periods and decrease the amount of capital tied up in inventory, all purchase orders are placed at the beginning of each month. Hedging foreign currencies and commodity prices are also factors that influence the placing of orders, especially when dealing with non-euro zone suppliers (e.g. China). For example, if the price of copper is unusually high, the ordering of bulk brass items might be delayed until the price decreases to normal levels.

Two conceptual models, (Figures 4.3 and 4.4) are developed representing ordering processes for forecasted items and customer demand respectively. When annual sales data are analysed, a forecast of what needs to be ordered to cover two months' sales is calculated (Figure 4.3). If current inventory levels, without safety stock, can cover the forecasted quantity, then order processing stops as there is enough stock on-hand. If it is not, the difference needs to be ordered from the selected supplier by issuing a purchase order (PO) that includes; PO number, order quantity, material codes, delivery date and address information. Depending on supplier lead-times, the waiting period between order and delivery varies. After a quality check on receipt, if the order is correct regarding to quantity and quality, it is accepted and the inventory levels are updated accordingly. The payment process for the supplier can then proceed. If the order is not correct, further investigation is required. At this stage there are three possible quality issues:

- i. The wrong product has been received. In this case the product will be returned, or kept if it is a high turnover product. In both cases a new order is needed for the original product.



- ii. The product is of poor quality. If it is within a certain tolerance set by the quality department it will be accepted, if not, the order is returned and the order process needs to be repeated.
- iii. The quantity is either over or under the ordered amount. If the order is returned a new PO needs to be placed. If the order is accepted with the difference, the inventory levels on the system are updated. The PO also needs to be adjusted to account for the difference and a new order for shortages is required.

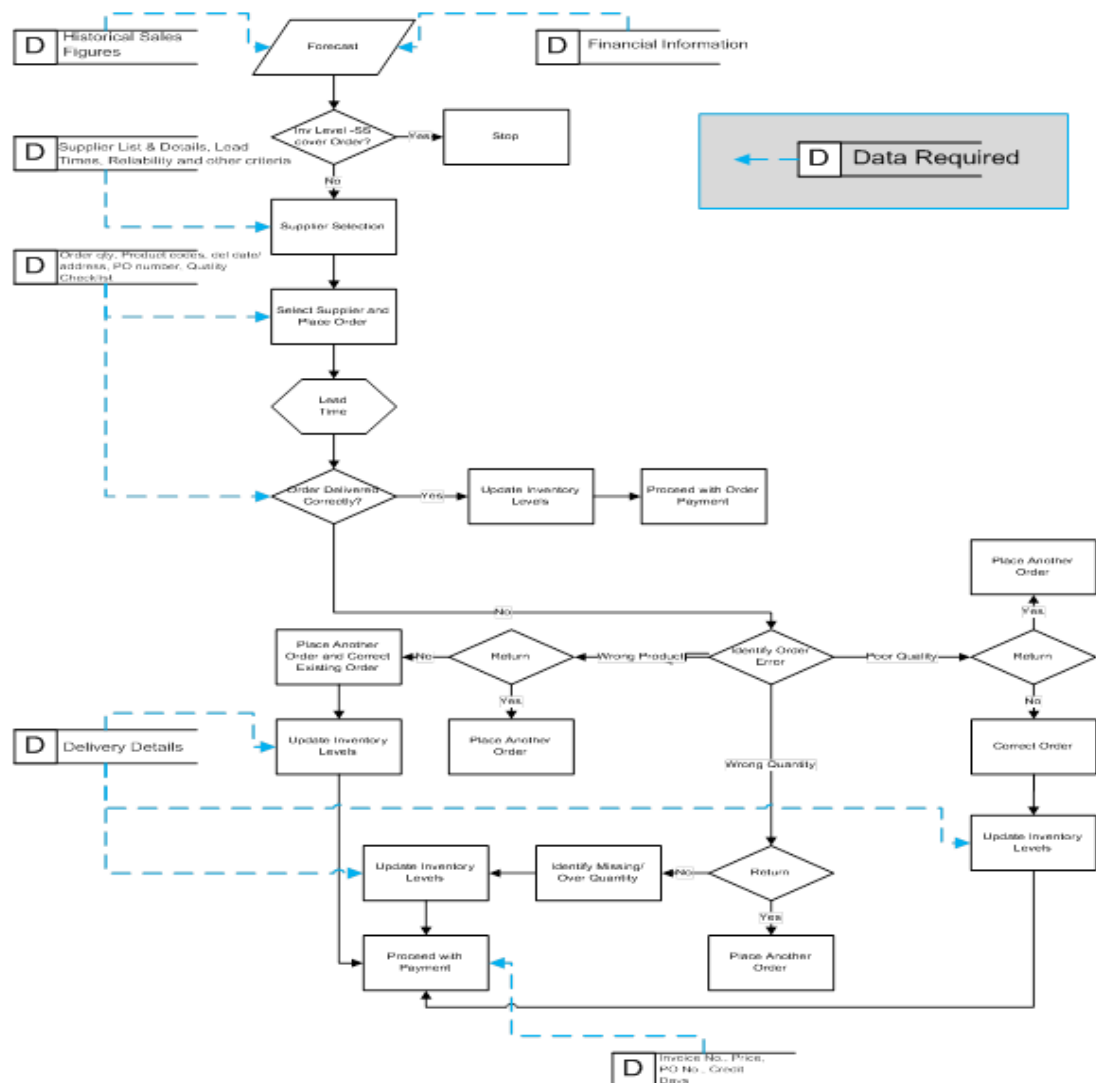
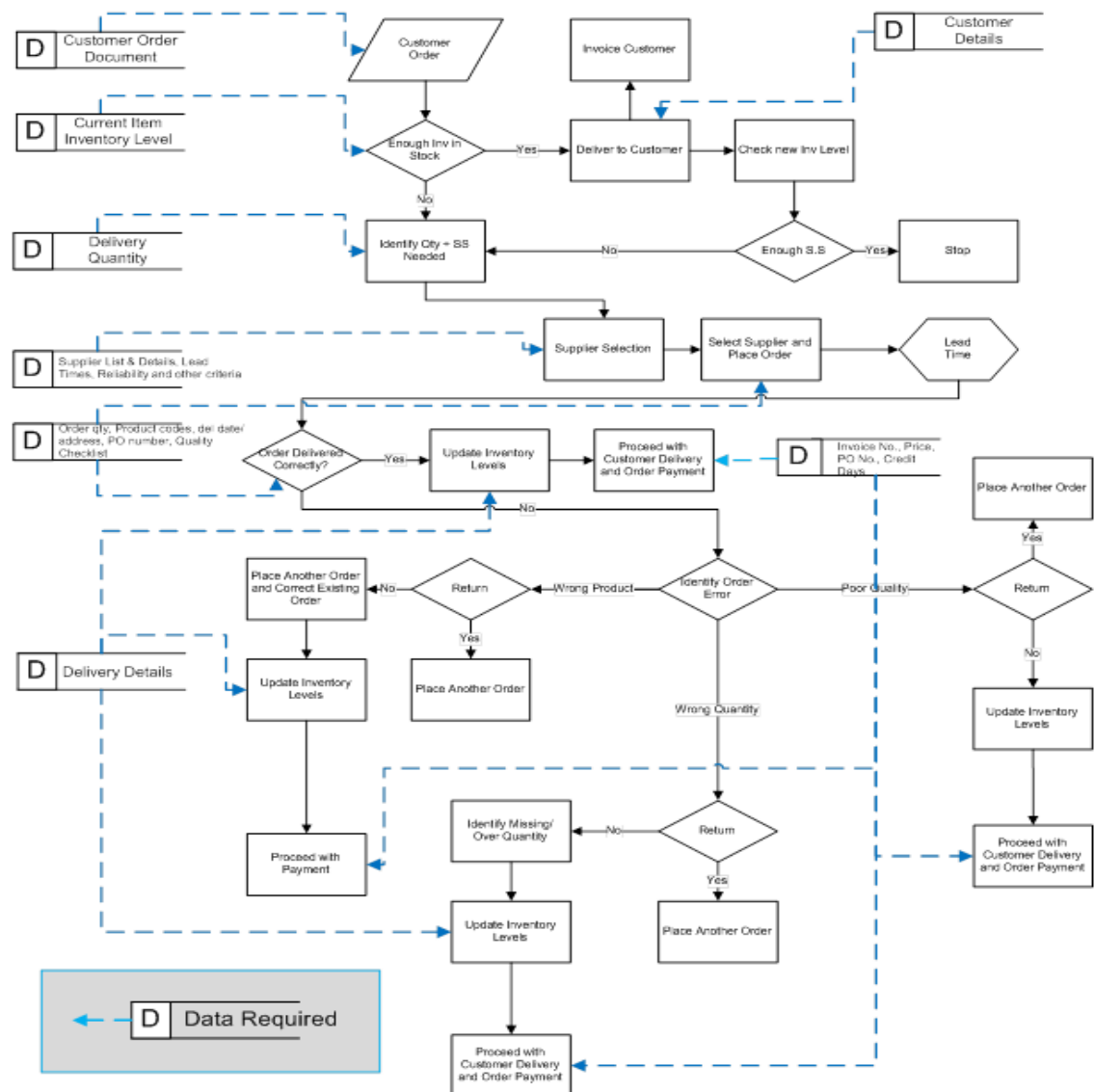


Figure 4.3 Forecasted Order Quantity Model using Flowchart Method



### Figure 4.4 Customer Order Quantity Model using Flowchart Method

The process flow of customer orders (Figure 4.4) consists of the following steps. When a customer order is received, the inventory levels on-hand is checked to see if the order can be fulfilled. If there is enough stock on hand, the order is delivered to the customer and inventory levels are updated on the system. If not, the required quantity including the safety stock difference is ordered. 75% of customers accept the delay of delivery due to items out of stock (i.e. patient customers), while the other 25% will cancel their order and

go elsewhere, incurring substantial lost sales costs to AC. The process of supplier selection onwards is identical to that of the forecasting approach in figure 4.3.

### **4.5 DES Simulation Model**

A stochastic technique of DES modelling is chosen as it is capable of powerful computation techniques for studying the variability and uncertainty of inventory systems (Keskin, Melouk, & Meyer, 2010; Willis & Jones, 2008). Demand quantities, sales orders arrival time, suppliers' lead time and defective rate of received items are the main uncertainty elements that need to be taken into consideration in the modelling process. A computer simulation model based on the conceptual models (Figures 4.3 and 4.4) was developed to mimic the real-life application characteristics of the inventory system. The model assumptions are (i) Forecasted item quantities are assigned based on the inventory manager's experience rather than using quantitative forecasting techniques (ii) No disruptions are expected for system suppliers (iii) Holding cost of all items in inventory is constant. Customer segmentation policy, regarding to sales volumes, was investigated against customer equality policy using delivery time and total cost as two performance indicators. For each policy, the significance of two important process parameters, FOQ and SSL were tested using ANOVA.

There are two main streams in the simulation model as in Figure 4.5. With each a different demand pattern was applied. First input is the monthly forecasted quantity for each item that needs to be ordered to keep a safe inventory level that can be used to cover uncertain demands. This quantity relies totally on the inventory managers' experience and the sales' figures of the last twelve months. Customer demand, the second input stream, is randomly

arrived in a form of individual sales orders that contains multiple product types with different quantities. Sales orders are dispatched to individual items and then the current inventory level of each item is checked. If inventory levels are not enough to fulfil the demand of this item, an ordering process is conducted with the required quantity. Ordering cost, shortage cost and holding cost are three cost elements that compose the total cost formula of this model. Items importance varies (i.e. must not be out of stock at any time). If these items are out of stock for any reason, the inventory manager has to place an order immediately, regardless of the supplier or the price. This action usually causes cost pressures on the manager. Once order quantities are delivered, a quality check takes place followed by updating the inventory level of received items.

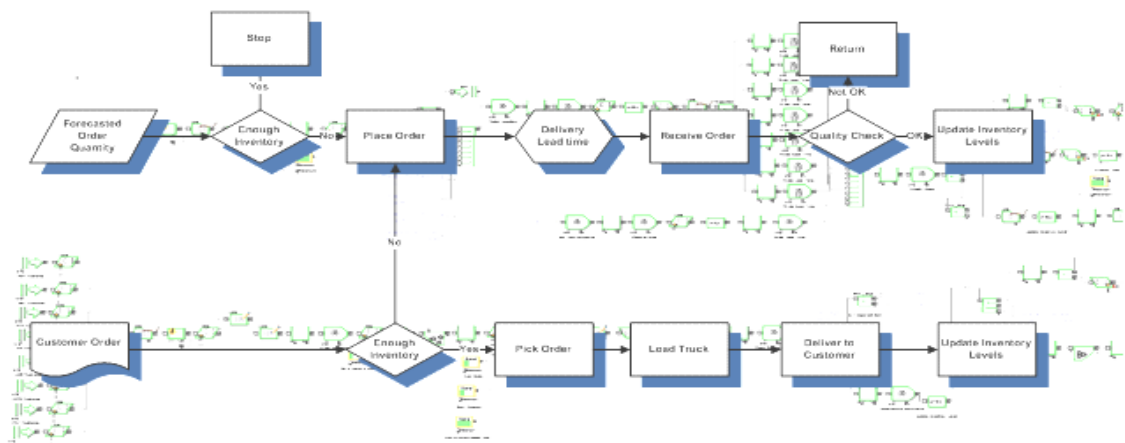
A one year historical sales data record was supplied by the operations manager to analyse and create statistical distributions for input data used in this model:

1. Inter-arrival time for customer sales orders.
2. Number of items, items types and items quantities in received customer sales order.
3. Forecasted order quantities for each item.
4. Suppliers lead time.
5. Percentage of refused items due to quality results.

For the model to reach its steady state condition, the warm-up period is one month. Every simulation run represents a year of actual timing. Each experiment result is an average of ten independent replications.

### 4.5.1 Verification and Validation

Validation and verification are an integral part of building a simulation model. The accuracy of the decisions made using simulation is a direct function of the validity of the output data (Arisha & Young, 2004). For the verification process, a decomposition method (i.e. verify every group of blocks) and simulation software built-in debugger is used. After that the model was validated using two techniques. The first is *Face Validation* that was done by interviewing the operations manager and warehouse manager in order to validate simulation model results. *Comparison Testing* is the second approach used which was performed by comparing the model output with system output under identical input conditions. The deviation between simulated and actual results recorded 10% average percentage based on a sample of 50 sales orders.



**Figure 4.5 Simulation Model of Inventory System**

### 4.6 DOE and Result Analysis

The uncertain nature of customer demands and suppliers' lead time makes it difficult to select the optimal combination of system's process parameters that can achieve high levels of customer satisfaction (i.e. short delivery time) and minimum costs. The impact of FOQ

and SSL (main process parameters) is one of the main aims of this study. Referring to classical inventory management models, the increase in both process parameters causes short delivery time, while on the other hand; high total cost is expected due to the increasing of holding costs. Using the simulation model, two levels of each process parameter have been examined against delivery time and total cost, based on the DOE matrix supplied in table 4.1. The first level of process parameters represents their current values in the real case, while the second level is higher than the first level by 20%.

**Table 4.1 Design of Experiments**

Customer Management Scenario (CMS)	Parameters		Response	
<i>Customer Equality (CE) = 1</i> <i>Customer Segmentation (CS)= 2</i>	<i>FOQ</i>	<i>SSL</i>	<i>Delivery Time (DT) Days</i>	<i>Total Cost (TC) €</i>
1	1	1	18.56	1500
1	1	2	16.32	1843.82
1	2	1	3.32	7749.82
1	2	2	3.27	7749.5
2	1	1	15.32	647
2	1	2	18.96	1302.05
2	2	1	3.44	7542.15
2	2	2	4.73	7169.15

Using ANOVA, the main effect of the two process parameters is examined for the two customer management scenarios. The principle of ANOVA model is testing null hypothesis – change of one or more factors levels does not cause variation for response's means – against the alternative hypothesis that has at least on variant response mean. The available combinations of customer management scenarios, the two process parameters and impact on performance indicators are shown in Table 4.1. For customer management,

level 1 indicates the first scenario, customer equality, while level 2 is the customer segmentation scenario.

Changes in customer management scenarios caused no impact on delivery time indicator, according to results in Table 4.1. On the other hand the total cost is clearly influenced by the changes in those scenarios. Table 4.1 shows a decline of total cost in the case of applying the customer segmentation scenario. Moreover the changes in FOQ levels result in decreasing delivery time and increasing total cost due to the increasing of holding cost; however changes in SSL level did not have this remarkable impact in both indicators.

The observations that are deduced from Table 4.1 were supported by ANOVA tables that analysed the main effect of the two process parameters on selected performance indicators. At both customer management scenarios, FOQ shows significant effect on delivery time and total cost indicator with a high F value and a P value less than 0.05. Looking at Table 1, changes in FOQ levels impinge both indicators in opposite directions, decreasing delivery time with (20%) and increasing the total cost by (18%).

Whenever the 'P' value is greater than 0.05, the parameter is not significant. SSL has not shown any significant impact on delivery time and total cost indicator under the two scenarios Table 4.2 and Table 4.3. This result is confirmed at Table 4.1 with no influence of SSL on performance indicators.

According to results, to achieve the optimum delivery time, using the second level of FOQ was most effective with or without customer segmentation. Changes in SSL and CMS had no significant impact. On the other hand, customer segmentation was the most effective CMS for decreasing total costs when combined with the first level of both FOQ and SSL.

**Table 4.2 Main Effect of Process Parameters for CMS using DT Indicators**

CMS	Source	Total Cost Indicator				
		<i>Sum of Square</i>	<i>Df</i>	<i>Mean Square</i>	<i>F</i>	<i>P</i>
CE	FOQ	200.229	1	200.229	159.41	0.006
	SSL	1.312	1	1.312	0.13	0.92
CS	FOQ	170.366	1	170.336	45.672	0.021
	SSL	6.077	1	6.077	0.071	0.815

**Table 4.3 Main Effect of Process Parameters for CMS using Total Cycle Time**

CMS	Source	Total Cost Indicator				
		<i>Sum of Square</i>	<i>Df</i>	<i>Mean Square</i>	<i>F</i>	<i>P</i>
CE	FOQ	51545938.2	1	51545938.2	61.72	0.016
	SSL	1622744.77	1	1622744.77	0.068	0.825
CS	FOQ	40718756.3	1	40718756.3	286.64 1	0.003
	SSL	19888.051	1	19888.051	0.001	0.978

#### 4.7 Formative Case Study Interpretation

The rapidly changing construction market, fluctuation in demands along with cost and price pressure requires efficient management strategies for Plumbing & Heating inventory systems (AC Company). To balance on-hand inventory with more efficient total costs and high customer service in such a dynamic environment is a big challenge with significant demand risk. Therefore, it becomes necessary to choose an effective approach to model this complexity and to investigate different management strategies that can be used for performance enhancement whilst mitigating the risk in making real-system decisions. Due to the interaction between information and object flow in the inventory system, data flow



diagram and flow chart have been integrated to develop the system's conceptual model. This integration facilitates the development of a simulation model that is used to mimic the relationship and real life interdependences between the two flows. The simulation model was run under two scenarios - customer segmentation and customer equality (no segmentation). Two process parameters – forecasted order quantity and safety stock level- were investigated using the developed model. Order delivery times and total costs were the two performance indicators measured. The significance of process parameters on system performance was analysed using factorial design experiments.

Results show that for AC's inventory system, forecast order quantity parameter had a greater impact on performance indicators (i.e. delivery time and total costs) than safety stock levels, whether customers were segmented or not. Increasing the forecasted order quantity by 20% (Second Level) resulted in the most efficient delivery times. Total costs decreased most when the original forecast order quantity was used with customer segmentation.

### **4.8 Discussion and Summary**

The objective of the formative case study was to explore the use of simulation as a method of case study research within an applied environment. Reflective learning was used as a method of interpreting the outcomes of the study, pursuing an objective of using the information to refine and improve the development of the overall research study. *Reflexivity* is the self-examination and evaluation of a researchers attitudes and beliefs and their reaction to data and results (Saunders et al., 2016). The researcher also needs to be reflexive, in the context of interpretation of results through interactions with those who

take part in the research and acknowledge other participants attitudes and beliefs (Saunders et al., 2016), while scrutinising the impact this has on the overall research strategy (Gill et al., 2010). A summary of the reflexive results of both the researcher and formative case study practitioner are below.

### **4.8.1 Practitioner Reflexivity Summary**

The practitioner was encouraged to keep a reflective log during the course of the formative case study, logging the practitioner expectations and final attitude of the project (Bryman, 2012). The practitioner's detailed log has been summarised into the following bullet points:

- The practitioners overall expectation from the formative study was to gain insights into customer order challenges now faced due to the collapse of the construction retail sector and how inventory management improvements could mitigate against future demand risks.
- The practitioners overall attitude towards the simulation study was positive, claiming the project was managed in a very professional manner by the researcher and the end results were as expected. Implementation of the decision variable changes modelled in the study were signed off by the practitioner with the expectation that they would be embedded into the organisation current inventory management model.
- The structure of the simulation study, in particular initial problem definition work, data collection and BPMo through flowcharts were all seen as excellent “tools for learnings” by the practitioner.

- Although the practitioner did not reflect on the simulation model building and experimentation as positively as the qualitative phase of the exploratory study. In terms of being an active participant in this stage, the practitioner did not feel that they contributed. Outlining:
  - They felt overwhelmed by the way the researcher explained the simulation process leading to a lack of confidence in contributing without direction.
  - The pace of the simulation build was too fast and didn't give them time to fully understand how it worked.
  - Did not understand the experimentation process and was very confused by how the researcher explained the ANOVA testing.
  - Although the practitioner did comment that the end results were clearly communicated and understood from an operational perspective, there was a level of trustworthiness in accepting the researcher's results due to the ambiguity caused during the simulation and analysis stages.
- Although the practitioner was happy with the way the project was planned and managed by the researcher, feedback suggested that practitioners would benefit from pre-prepared support material and guidelines before the project began. The practitioner referred to this as "pre-read material", that was the norm within the organisation.

### **4.8.2 Researcher Reflexivity Summary**

The researcher kept a detailed research notebook during the course of this research study. Reflexivity was an important aspect of research for the researcher due to the epistemological viewpoint of system thinking and feedback loop learning. During the

formative study the researcher reflected from two viewpoints; firstly, a personal reflection on the researchers own progression through the pilot project; and secondly reflecting on the feedback the practitioner provided, as outlined in section 4.8.1.

### **4.8.2.1 Researcher Personal Reflection**

As this was the first simulation based project that the researcher was project lead within his research group, there was a learning curve to consider when planning the study. This was a major influence in undertaking a formative case test, which is the ability to learn and refine research project skills before partaking in the primary research case study. Some learnings made from the researchers notes included:

- Although the researcher had expert knowledge on the simulation project process, communicating this to a non-analytical practitioner was a challenge.
- More preparation was needed in giving information on project plans including Gantt charts and timelines.
- The combining of flowcharts with DFD was time consuming and the end result was not sufficient to incorporate all input data (resources, times, regulations etc.) needed to build the DES model in one BPMo, alternatives needed to be considered.
- The researcher needed to increase understanding of SCRM techniques to support simulation.
- The focus of the formative study was only to evaluate demand risk by changing internal business process parameters to which DES capabilities were sufficient. But if all sources of risk were to be considered, limitation in modelling discretely were evident.

- The literature review needed to be refined to include continuous simulation and a more detailed look into SCRM techniques.

### **4.8.2.2 Reflection on Practitioner Feedback**

Practitioner feedback was very valuable to the researcher. The constructive feedback allowed the researcher to perform a very beneficial post-mortem of undertaking a research project and uncover weaknesses in both personal and academic approaches to research. What the researcher really benefitted from, was the intangible information gained from the practitioner that would be impossible to gain from the simulation model itself. In particular the way the researcher own attitude and approach to communicating the project to the practitioner had caused anxiety, confusion and a level of fear about the overall project. This was the main reason for the development of a conceptual model in chapter 5 as a practitioner support mechanism in managing a simulation study. It also allowed the researcher to reflect on how the review of literature was approached, with a new found understanding of how important the target audience when writing an academic journal, resulting in the development of the target audience diagram, figure 2.31.

An opportunity was also seen in the positive feedback the practitioner had given in the qualitative phase of the formative case study. The researcher acknowledged these learning with renewed vigour in approaching the problem definition, data collection and BOMo phases of the primary case study, using the conceptual reference model as a bridge between any potential qualitative-quantitative gaps with practitioners.

## Chapter 5. Framework Development

*Children are natural system thinkers, we need to resuscitate these intuitive capabilities and strengthen them in the fire of facing our toughest problems.*

— Peter Senge

### 5.1 Introduction

This chapter introduces the proposed integrated decision support framework for SCRM that has been developed during this research study. Through succeeded appreciation of the epistemological foundation set out in chapter 3, a two phased integrated SCRM decision support framework has been created to achieve research objectives 3a and 3b as outlined in Chapter 1. Firstly, established on the feedback from the formative case study application gaps and the benefits of using reference models learned in Chapter 2, a BPM based conceptual framework, *The P<sup>6</sup> Coefficient*, has been developed. Its objective is to support decision makers with the less analytical aspects of implementing a SCRM project, such as project management, collaboration, benchmarking, and strategic alignment. Secondly, the conceptual framework through integration, will compliment and support the primary framework of this research study; a hybrid simulation based SCRM tool, using synergies of DES and SD modelling integration. In both phases of the framework, each component will be explained in detail before the chapter is concluded by clarifying how the framework will be implemented within an extended RSC context.

### 5.2 Epistemological Foundation

The epistemological foundation of this research study has grown from one of the main research objectives: *to highlight the need for a system thinking approach to decision*

*making to truly understand RSC risk.* All organisations whether they are aware of it or not, are part of an extended global RSC. Recognising this, it should be realised that RSC organisations are “caretakers” of global resources and have a responsibility that spans all risk; from finance to the environment; or food safety to feeding 9 billion mouths by 2050. Chapter 2 has described in detail the dynamic nature of RSC systems and their associated risks. RSCs are complex systems with non-linear feedback structures and multiple loops. In such a process, a number of different organisations regulate different parts of the process, where no entity is really in charge of the system as a whole. Therefore according to Wolstenholme (1990), when strategies within a system are not integrated, the process will not flow smoothly. Casey (2014), in agreement suggests that a sudden disruption to system integration means a VUCA environment is inevitable.

According to Floyd (2007), it is in these “industrial-age systems driven by human agency” that the laws of thermodynamics, and in particular *entropy* are most prevalent, as these complex systems are in need of continuous dispersal of energy. The author explains that the “complexification” of human agent based systems such as RSCs, disperse forms of energy at many levels, or in cascading waves of growth and decay that are themselves within an overall cycle of growth and decay of systems, or system of systems. Incorporating the fundamental laws of thermodynamics and entropy into the management processes of business systems is a small but effective and emerging paradigm, as outlined in Chapter 2. Entropy-based analytics has been applied successfully in the building of a SCM assessment tool for the sharing of information through the end-to-end order fulfilment process (Martínez-Olvera, 2008). The commonalties of entropy and RSC risk has also been effectively utilised by Amoo Durowoju et al. (2012) when developing an

entropy assessment tool for RSC disruptions. They claim that entropy theory, in the form of an entropy scorecard, can be used to quantify the level of chaos the disruption of information can have on an extended RSC. Jaber, Bonney, & Moualek (2009) use the understandings of thermodynamics 2<sup>nd</sup> Law to add cost uncertainty to inventory management models, where entropy cost is a controlling variable.

Revisiting the journey from scientific method to SCRM discussed in Chapter 2's literature review, the following statements fully represent the epistemological foundation of this research study.

- *RSC decision makers need to use scientific method*

The sequential process of the scientific method, which is so engrained in mathematical and science subjects through second level education, somehow loses its grip through third level education and industry practice for many non-scientific disciplines such as business administration and SCM. It has also been argued that even within core scientific disciplines, such as physics and psychology, there are inconsistencies in its application (Powers, 2007). Most management decision makers are aware of the history of scientific methods within management disciplines and can probably name important founders of management science. For example, Frederick Winslow Taylor, who believed that scientific method was an essential part of management education leading to his perennial publications, *Shop Management* and *The Principles of Scientific Management* in the late 1940's (Lauer Schachter, 2016). But it is in its everyday application that the potential strength of the sequence of hypothesis building, identification of observable phenomenon, designing experiments and the replication of such experiments, is being misunderstood or possibly under



appreciated by the majority of business disciplines. Exceptions however are those disciplines focused within risk management, in particular risk assessment (Aven, 2011), but these are directed more at quantitative, analytical decision makers who utilise mathematical and simulation models to manage risk. This research study aims to leverage these strengths, while also learning from the present advances within risk assessment to reignite scientific thinking within non-analytical oriented decision makers.

- *RSC decision makers need to think in systems*

Information, material, and capital flows are entropic energies within RSC systems that are under continuous dispersion. With a simplified approach to the principles of thermodynamics, coupled with the foundations of system thinking based on the industrial dynamics work of Forrester and also the business process theories of Deming, it is a firm objective of this research study to improve managers' holistic understanding of decision making. Especially within SCM, where the majority of uncertainty is external to an organisation, a macro-level understanding of the entire system is essential. What makes this scenario even more difficult is the fact that both the drivers and sources of uncertainty are interconnected in a complex web of discrete events with consequences, multiple feedback loops, causal relationships and uncertain entropic ripple effects. Barratt (2004) explains this very effectively, stating that a lack of whole system understanding meant that most cost efficiency initiatives remain within the boundaries of an organisation. Barratt adds that this inevitably pushes the costs onto other RSC partners and that all organisations will either directly or indirectly incur these costs again within the chains cash-to-cash life cycle.

- *RSC decision makers need to embrace the philosophy of risk*

The definition of risk is very simple and relatively easy to understand. As defined by the ISO, risk is the “effect of uncertainty on objectives” (ISO, 2009a). They continue by attributing risk as “the combination of the probability of an event and its consequences”, both positive and negative. It is in the latter attribute of risk where ambiguity and difficulty in grasping the true meaning of risk can arise. Decision makers without an appreciation for scientific method or a system thinking perspective of RSCs will inevitably struggle with the complexities of combining both the probability and consequences of risk in complex systems. Therefore, based on the quantitative definition of risk developed by Kaplan, Haimes, and Garrick (2001) (Equation 2), this research study aims to integrate the philosophy of risk into the heart of the framework development.

### 5.3 The $P^6$ Coefficient – A Dynamic BPM Reference Model

As explained in Section 1.2.1’s research problem definitions, there is a significant difference between accepting complexity and understanding it. Any project undertaken within an organisation that involves the analysis of an end-to-end change/improvement to business processes such as; Six Sigma manufacturing; route network design; emergency department patient flow; outsourcing business processes; or indeed SCRM, encounter several barriers to a successful implementation. All complex business processes are owned by a diverse group of stakeholders, and even with the best intentions and goals does not guarantee alignment (Stroh, 2015). When an extended RSC is considered, the diversity of stakeholders not only spans internal functions and external partners, but continental boundaries, cultures and multiple different industries. Therefore,

in any complex change management project, there is always a proportionate emphasis put on planning, defining, communicating, understanding and aligning the project vision and objectives. The importance of the role of stakeholders in system decision making is rapidly gaining attention in current management research and literature as organisations have found that in order to create sustainable, ethical and responsible value, it is necessary to balance the interests of various stakeholders (de Gooyert, Rouwette, van Kranenburg, & Freeman, 2017). Therefore, and based on findings from objectives 1, 2 and 3a of this research study in Chapters 2 and 4, a BPM project conceptual framework has been developed, extending the work of the SCOR11 reference model.

### 5.3.1 A Topology of Business Process Referencing

Business process reference models are often a popular knowledge base choice when developing a management conceptual framework. Examples of commonly used reference models as described in detail in Chapter 2 include philosophies such as TQ and BPR and more structured approaches including ISO31000 and the SCOR11 model. The SCOR11 model for example, through specific model architecture has enabled users of the reference model, through support and direction, an enhanced understanding of; how processes interact, how they perform, how they are configured and what human resource requirements are needed to operate the process, (Supply Chain Council, 2014).

The SCOR11 model separates each of these questions into 4 core “P” sections; *performance, process, practice* and *people*. Rotaru et al (2014) claim that these sections standardise information into a universal language that the SCOR11 model users and stakeholders can use to describe their RSC, manage it, and collaborate with other RSC partners. This enhanced level of collaboration and transferable RSC system

understanding and knowledge, according to Poluha (2007) obeys one of SCM's main objectives; to find optimal efficiency levels between organisations within the system and to harmonise any conflicting objectives they may have.

### **5.3.1.1 Reference Model Limitations**

One important gap when utilising business process reference models is the capability of accurately aligning the strengths of the model to a company's overall business needs (Pajk & Kovacic, 2013). In fact, according to Dijkman et al. (2011), on average, a standard ERP system for a large organisation may have between 500 and 1000 reference or repository processes. Furthermore, by applying a basic discrete mathematical product rule to the SCOR11 4P sections and their subordinates, there are hundreds of thousands of different reference process sequences to choose from, depending on the number of ways allowed to achieve each task. Emphasising this, Bolstorff & Rosenbaum (2007) claim that for all their potential and sophistication, reference models are a static list of directions, a glossary of definitions for processes, best practices and metrics – or a series of nouns. The authors suggest that to transform these nouns into verbs requires the addition of more dynamic attributes such as project and change management skills, problem solving capabilities and business process management.

### **5.3.1.2 BPM Reference Model Requirement Sets**

In BPM there are three principles developed by Chang (2006) that identify the dynamic requirements for successful business process interaction. They are:

1. *Asset Management (Am)*. All processes have customers, therefore in their very nature, are assets that create value for customers. Both external and internal customers are recipients of a process output. From a process orientation perspective, it is important

to note that organisational functions or individuals do not create value for customers. For example, a sales function does not produce revenue for an organisation. Although the perception traditionally is that revenue creation is achieved primarily through sales and marketing teams, their overall importance is often amplified. Customer value and in turn revenue is not achievable without the end-to-end order fulfilment process, including accounting, production and customer service to name but a few. Processes are responsible for value creation and organisations should invest in them as they would any other strategic asset.

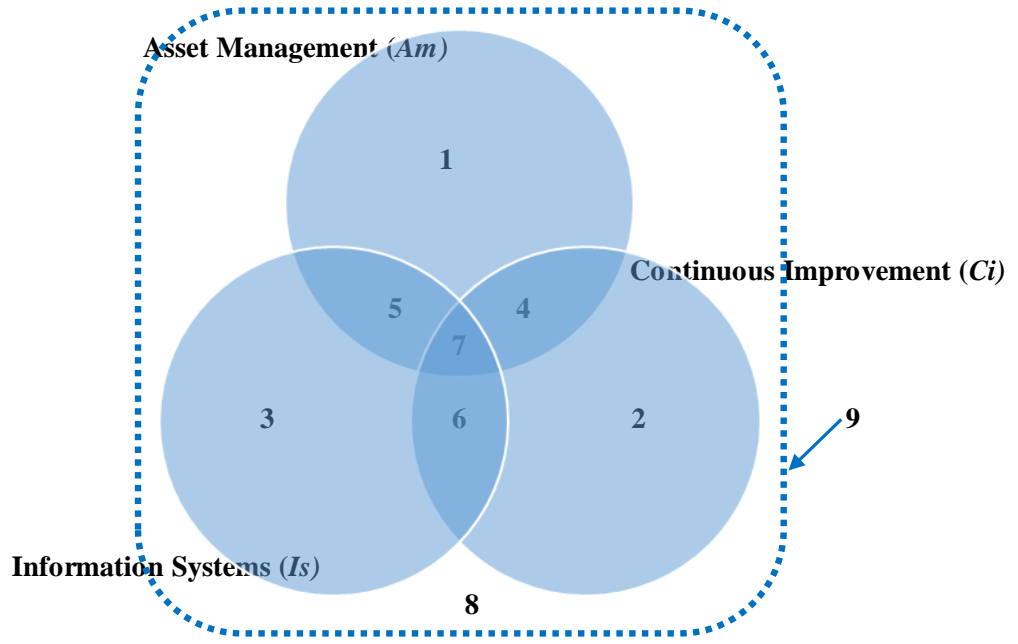
2. *Continuous Improvement (Ci)*. Because of their value creation potential, business processes need effective and careful asset management. A well-managed asset produces consistent value and sets the foundations for continuous improvement, similar to Deming's chain reaction principal (Deming, 2000). And when an asset is a process, its information allows an organisation to suggest future improvements through the prediction, recognition and diagnosis of process deficiencies. Continuous improvement is the natural result of effective BPM (Chang, 2006), but its facilitation is only made possible through the availability of robust process information.
3. *Information Systems (Is)*. If process information facilitates natural continuous improvement within an organisation, then information systems are an essential enabler. Chang (2006) comments that although information systems are not specifically classified as an element of many BPM philosophies and reference models, its influence is very evident. For example, information and associated infrastructures are not emphasized in many process orientated approaches, including TQ or SCRM; but they do emphasise the need for information and management through analysis and

fact. The most important element of information systems to BPM is the availability of real-time data and information required to monitor and control business processes. In particular, due to the discrete nature of RSC systems, with many independent partners, information sharing infrastructures are essential in mitigating against the innate organisational behaviour of self-preservation (Pillai & Min, 2010).

Based on the attributes of the BPM principles and system orientated tools and techniques discussed in Chapter 3's literature review, eight types of BPM approaches can be identified. They are:

1. Reference Models
2. Standards/Regulations
3. Philosophies
4. Analytical/Quantitative
5. Conceptual
6. Enterprise
7. Dynamic
8. Not System or Process Orientated

Structured similar to the research of Co and Barro (2009) on stakeholder theory, a set based topology of BPM reference methods is shown in Figure 5.1. The purpose of this Venn diagram is to both visually and quantitatively measure the integration of current BPM methods to the overarching principles of BPM and in turn, system thinking applications.



**Figure 5.1 A Venn Diagram Representation of BPM Principles**

Each method set and combined union are further classified based on the business process maturity model (BPMM) classifications pioneered by McCormack et al. over the past decade (McCormack et al., 2009), which are *ad hoc*, *defined*, *linked*, *integrated* and *dynamic* (Table 5.1). Each attribute is mapped to a binary variable, where  $x$  equals one if the attribute is present, otherwise  $x$  will be zero. An ordered three-tuple  $[Am, Ci, Is]$  defines each BPM method. To be classified as a fully integrated BPM method, there needs to be a combined union of all three sets (Set 7), as in equation (5.1) below:

$$F(Am, Ci, Is) = Am + Ci + Is = 1 + 1 + 1 = 3 \quad (5.1)$$

Conversely, a non-process orientated union (Set 8) is where:

$$F(Am, Ci, Is) = Am + Ci + Is = 0 + 0 + 0 = 0 \quad (5.2)$$

**Table 5.1 Topology of BPM Reference Methods**

Set	Value of Attribute x			Classification	Method
	<i>Am</i>	<i>Ci</i>	<i>Is</i>		
8	0	0	0	Ad hoc	Not Process Orientated
1	1	0	0	Defined	Conceptual Model
2	0	1	0	Defined	Philosophy
3	0	0	1	Defined	Analytical Model
4	1	1	0	Linked	Reference Model
5	1	0	1	Linked	Financial Model
6	0	1	1	Linked	Standard/Regulation
7	1	1	1	Integrated	Enterprise Model
<b>9</b>	<b><math>1^n</math></b>	<b><math>1^n</math></b>	<b><math>1^n</math></b>	<b>Extended</b>	<b>Dynamic Model</b>

The objective of this research study is to expand beyond the maturity levels of the BPM methods discussed in chapter 3's literature review that represent Sets 1 to 8 of the BPM topology (Table 5.1). The goal is to create a BPM reference model that will support SCRM from an extended classification, utilising the integrated potential of the SCOR11 model, but from an enterprise model perspective. Through this concept, it is hoped that a more dynamic approach to managing a BPM project can be achieved from an extended BPMM classification.

An extended classification is driven by the system thinking theme of this research study, where the sequential approach to process integration between an organisation and its suppliers and customers is insufficient in capturing the dynamic, VUCA nature of a RSC system and associated risks. Therefore an additional set, Set 9, has been added to Table 5.1 to represent a more accurate BPM model requirement for a SCRM system. Such a model, like any complex system it aims to support, is not sequential, but has many set unions, directions, combinations and permutations. In table 5.1 this is acknowledged through the power function  $1^n$ .



### 5.3.2 Creating the $P^6$ Coefficient

The foundations of the  $P^6$  Coefficient BPM reference model are built on the 4P's of the SCOR11 framework; as explained in detail in chapter 3 and discussed further in section 5.3.1. Accepting the limitations of the SCOR11 model and other BPM reference techniques, coupled with the learnings made when implementing the formative study, it is very evident that organisations need an easy to understand reference model when implementing a BPM project. Reflecting on this, the objective is to create a highly visual model that incorporates the excellent guidelines of the SCOR11 4P principle, but also extending to accept the complexities, challenges and dynamic nature of RSC's. With a continuation of SCOR's 4P approach, the proposed model is extended by a further 2P's, resulting in a 6P reference concept centring on: *People*, *Processes*, *Practice*, *Performance*, *Potential* and *Pace*. In the initial phases of this concept, it was referred to the 6P Cycle (Fig. 5.2).

#### 5.3.2.1 People

The most important resource in any RSC is the people who manage, operate, decide, solve, grow, convert, supply, sell and purchase along it. The knowledge and skill base along a RSC holds all the data and solutions required to effectively mitigate and control high risk processes.

#### 5.3.2.1 Processes

To gain a better understanding of the RSC and the resources, information and controls needed to execute it, business process analysis is essential. Adapted from the SCOR11 model, P6 will conceptually model and simulate the entire RSC at two hierarchical levels;

strategic and operational. Discrete event and system dynamic simulation techniques will be used, along with effective process mapping and analytical modelling methods.



**Figure 5.2 The 6P Cycle**

### **5.3.2.2 Practices**

Investigate and master the best-in-class management practices that are proven to produce significantly better process performance and risk management. Through collaboration with RSC managers, best fit practices for the chosen RSC will be investigated, including: lean management, forecasting techniques, reverse logistics, facility layout efficiencies, inventory management, and technology innovations.

### 5.3.2.3 Performance

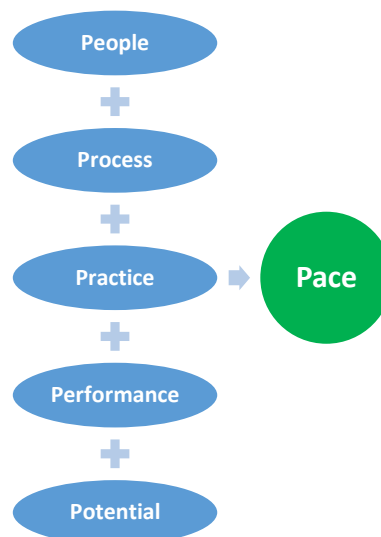
Monitor and manage key performance indicators at both strategic and operational levels using adapted balance scorecard structures, critical success factors and value-at-risk metrics.

### 5.3.2.4 Potential

Though continuous improvement techniques such as; six sigma, risk analysis and mitigation, and process optimisation using both mathematical and artificial intelligence algorithms, the potential for growth, efficiencies and continuous improvement are increased by using the 6P cycle.

### 5.3.2.5 Pace

The end result of cycle, it enables a QR approach to the FMCG nature of RSCs. This follows a simple arithmetic logic, based on Deming's chain reaction that the accumulation of the first 5P's will enable agility and pace within a system (Fig. 3). From a SCRM perspective, the pace of decision making is essential at every stage of the SCD curve outlined in Figure 2.19.



**Figure 5.3 The 6P Chain Reaction**

### 5.3.3 Structuring the 6P's

As already explained, complex systems are not sequential and have many combinations and permutations. Any attempt to visually support such systems conceptually through reference models needs to reflect this. Popular visual approaches to reference frameworks such as the use of acronyms, basic flowcharts and shapes can be very linear and sequential and do not sufficiently capture the complex VUCA nature of business systems. Equally, any attempt to visually represent complexity can actually add more difficulty than understanding, therefore a balance is required. In an attempt to graphically represent the 6P's in a more dynamic form, accepting there are more combinations of each P than linear representations (Fig 5.2 and 5.3), the basic rules of discrete mathematical counting or combinatorics has been utilised.

#### 5.3.3.1 Discrete Mathematical Combinatorics

Counting is an important part of analytical problem solving and a fundamental part of determining complex algorithms (Rosen, 2011). Many problems can be solved by finding the number of ways to arrange a specific number of elements of a set, or from this research studies perspective a system (and sub-systems) of a particular size. In many ways, this is a very close reflection of scientific experimentation explained in section 2.6. The *binomial coefficient* is a simple method of expressing combinations and arrangements within a system. The binomial coefficient is the number of  $r$  combinations from a system with  $n$  elements and is often denoted by (Equation 5.3):

$$\binom{n}{r} \tag{5.3}$$

In equation 6, the numbers occur as coefficients in the expansion of *binomial expressions*, which are simply the sum of two terms, such as  $x + y$  and is best utilised in the expansion of the powers of the expression, as in Equation 5.4:

$$(x + y)^n \quad (5.4)$$

The *binomial theorem* as proved by Rosen (2011) gives the coefficients of the expansions of powers of binomial expressions. This theorem can also be satisfied using different identities such as *Pascal's Identity*, where  $n$  and  $k$  are positive integers with  $n \geq k$ . Therefore

$$\binom{n+1}{k} = \binom{n}{k-1} + \binom{n}{k} \quad (5.5)$$

It is possible to prove Pascal's identity using algebraic manipulation based on equation 6. As explained by Rosen (2011), Pascal's identity, together with the initial conditions  $\binom{n}{0} = \binom{n}{n} = 1$  for all integers  $n$ , can be used to recursively define coefficients. Rosen adds that this recursive definition is useful in the computation of binomial coefficients because multiplication of integers is not needed, only addition. Under these conditions, Pascal's identity is the basis for the geometric arrangement of the binomial coefficients in a triangle as illustrated in Figure 5.4.

Known as *Pascal's Triangle*, this shows that when two adjacent binomial coefficients in the triangle are added, the binomial coefficient in the next row between the previous two coefficients is produced, as encircled in Figure 5.4. This can be expressed as the  $n$ th row in the triangle consisting of the binomial coefficients:

$$\binom{n}{k}, k = 0, 1, \dots, n. \quad (5.6)$$

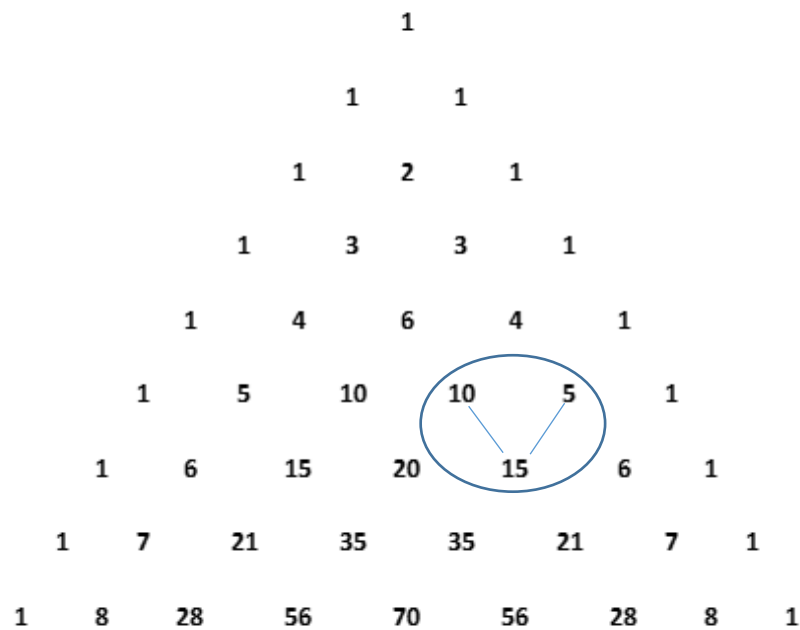


Figure 5.4 Pascal's Triangle

From a 6P perspective the initial conditions  $\binom{n}{0} = \binom{n}{n} = P$  for all integers  $n$  are used to recursively define each  $P$  coefficient. This is expressed as the  $n$ th row in the triangle consisting of the binomial coefficients:

$$\binom{n=6}{p}, p = 1, 2, 3, 4, 5, 6. \quad (5.7)$$

where 1 = *people*, 2 = *process*, 3 = *practice*, 4 = *performance*, 5 = *potential*, and 6 = *pace* (Figure 5.5). Therefore, when two adjacent  $P$  coefficients are added, the coefficient in the next row between them is produced. From a conceptual point of view, it is the combination of coefficient properties that produces the next rows coefficient results. This is important from a reference model point of view as it encourages the user of the model to think about the important interdependencies and causal relationships of each coefficient.

For example, an organisation will not gain full understanding of its processes without collaboration and knowledge transfer of its people. Equally it is the coefficient expression of people and process that produces best practices and quality standards, as in TQ, Six Sigma and accepted in many other quality management techniques. It is also through the embracing of process management that an organisation accurately measure performance. Note the important addition of the people coefficient to this identity, as it is the intrinsic knowledge of employees and other process stakeholders that fully understand the end-to-end metrics of an organisations system.

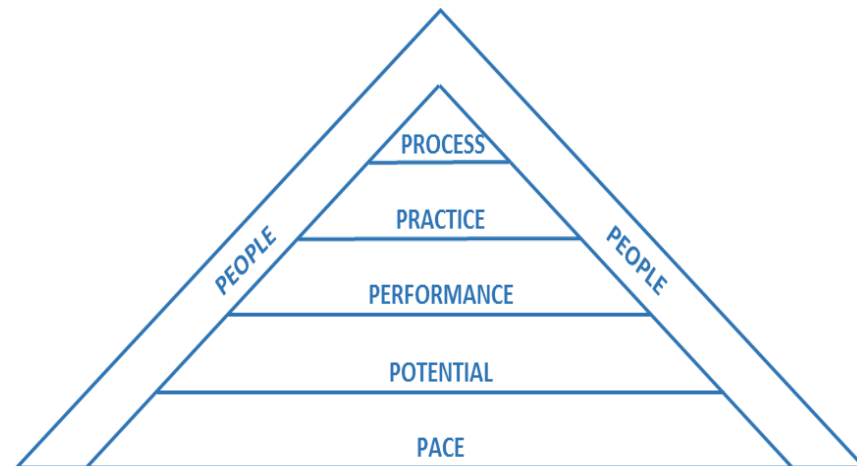


**Figure 5.5 P6 Pascal Triangle**

It is also the expansion of people, practice and performance that allows an organisation to leverage each coefficient to potentially optimise BPM decisions and projects. Overall and most importantly, the P6 Pascal Triangle shown in Figure 5.5 illustrates the combinatorial power of coefficients, and in the context of BPM, still gives an end result

of pace and agility, like the P6 Chain Reaction, but is not limited to a linear static sequence.

### 5.3.3.2 The $P^6$ Coefficient



**Figure 5.6 The  $P^6$  Coefficient Reference Model**

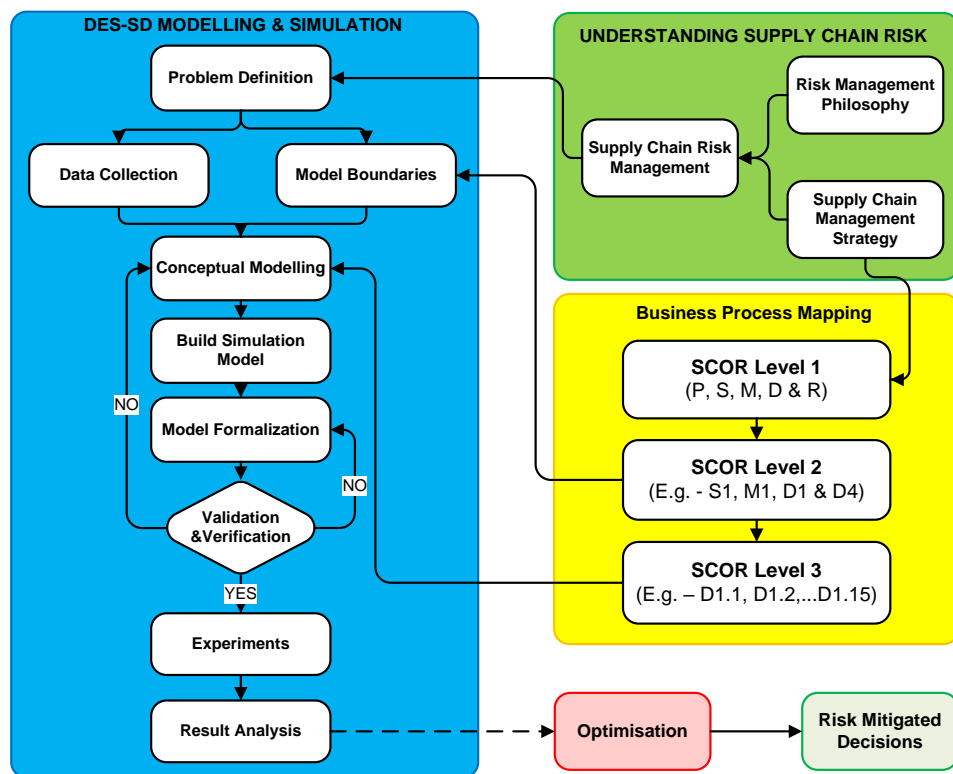
Figure 5.6 is the end-product of the binomial coefficient rules use as a BPM reference model and is aimed at achieving the extended, dynamic model highlighted as Set 9 in both Table 5.1 and Figure 5.1's Venn diagram. It keeps the overall structure and layout of the P6 Pascal Triangle, but has been merged into layers for ease of use and simplification of understanding. People is the principal coefficient, needed in each binomial progression, an acknowledgement of the importance of knowledge in system thinking and SCRM's diverse stakeholder group consensus. Retaining the triangular shape is essential to remind decision makers that this is not a sequential sequence but a combination of any sequence the user expresses as important to the system. The changing of P6 into a power function ( $P^6$ ) is also an indicator that this model should not be seen a linear or sequential flow. It is a binomial coefficient that expands the powers of the 6P expressions, specifically the synergies that can be achieved through effective



combinations. The actual formatting of the triangle is also carefully aligned with the layout of the ISO 31000 RM process (Fig. 2.18) as this reference model is a gateway point to both educating organisations and planning an SCRM project using the Hybrid Simulation based SCRM framework that will be introduced in detail in section 5.4.

## 5.4 Hybrid Simulation Based SCRM Framework Design

The following sections introduce the hybrid simulation based SCRM framework structure, including all components, interactions and causal relationships (Figure 5.7).



**Figure 5.7 Hybrid Simulation-Based SCRM Framework**

### 5.4.1 Understanding RSC Risk

Although using simulation is a technical issue involving model development and analysis, it is also an organisational issue involving change management (Greasley, 2008). As

experienced during the formative case study in Chapter 4, not introducing and explaining a simulation based project sufficiently to an organisation can be counterproductive to the objectives of the project. Greasley suggests that there are certain steps to introducing an organisation to a complex change management project. Which are selecting a project sponsor, evaluate the potential benefits of the project, estimate resource requirements, software and hardware requirements and finally training if needed. Using the  $P^6$  Coefficient as a tool to channel risk understanding within an organisation, several techniques are used to ensure stakeholder engagement and alignment in the initial phases of the hybrid framework development based on Greasley's recommendations.

### 5.4.1.1 The $P^6$ Coefficient – A Simulation Project Gateway

The reference model developed in section 5.3 is the conceptual catalyst of the hybrid simulation framework development. The model is used as both a reminder of what properties are essential to successful complex system initiatives and also as an index to direct users to useful tools and techniques available through SCOR11 and ISO31000 and other standards.

### 5.4.1.2 Delphi Study

Evans and Lindsay (2013) claim that developing any strategic decision needs more than a group of managers sitting around a room generating ideas, stating a systematic approach is needed. Therefore, before approaching any project steering group about risks within their system, a Delphi study introduction to the steering group was used centring on quantitative definition for risk by Kaplan et al (2001) as explained in equation (2);

$$\{<Si, Li, Xi>\}_c \quad (2)$$

where  $S_i$  is the  $i$ th “risk scenario”,  $L_i$  is the likelihood of that scenario, and  $X_i$  the resulting consequence, or “damage vector”. Subscript “ $c$ ” denotes that all possible scenarios of  $S_i$  should be considered. Using this equation, the Delphi process detailed in figure 2.20 is implemented with the specific task of treating each member of the steering group as an expert. The process entails;

1. Development of projections using the equation of risk.
2. Selection of experts/stakeholders of the complex system aligned with the coefficient expression properties of the  $P^6$  Coefficient.
3. Collecting of qualitative data through one-to-one meetings, informal focus group sessions and Skype calls.
4. Data analysis through the creation of a problem definition.

### 5.4.2 SCOR11 Business Process Mapping

To support the engagement of an organisation, especially one that is embarking on a complex system project with unfamiliar tools and techniques, preparation is essential. From a RSC system perspective, a very beneficial approach is to provide the organisation with support information that is familiar, easy to understand and above all related to their day-to-day operation. Remaining consistent to the standard, universal languages SCOR11 and ISO31000 communicate to organisations, a natural progression from the understanding risk phase is to provide the steering group with self-prepared information packs before requesting from them, the often intimidating task of data collection and model conceptualisation.

The SCOR11 model gives organisations the ability to describe system process architecture in a way that makes sense to other partners within their system. It is especially useful for describing RSC processes that cut across multiple functions and organisations, providing a common language for managing such processes (Supply Chain Council, 2013). The SCOR11 Process section is the core SCM knowledge base for the development of the simulation models in the framework, and is divided into 4 hierarchical levels. Level 1 consists of six strategic RSC processes: Plan (P), Source (S), Make (M), Deliver (D), Return (R), and Enable (E). Level 2 describes core processes. Level 3 specifies the best operational practices of each process and Level 4 is specific activities to the organisation. For the purposes of this research study, Levels 1-3 are used.

### **5.4.2.1 SCOR11 Level 1**

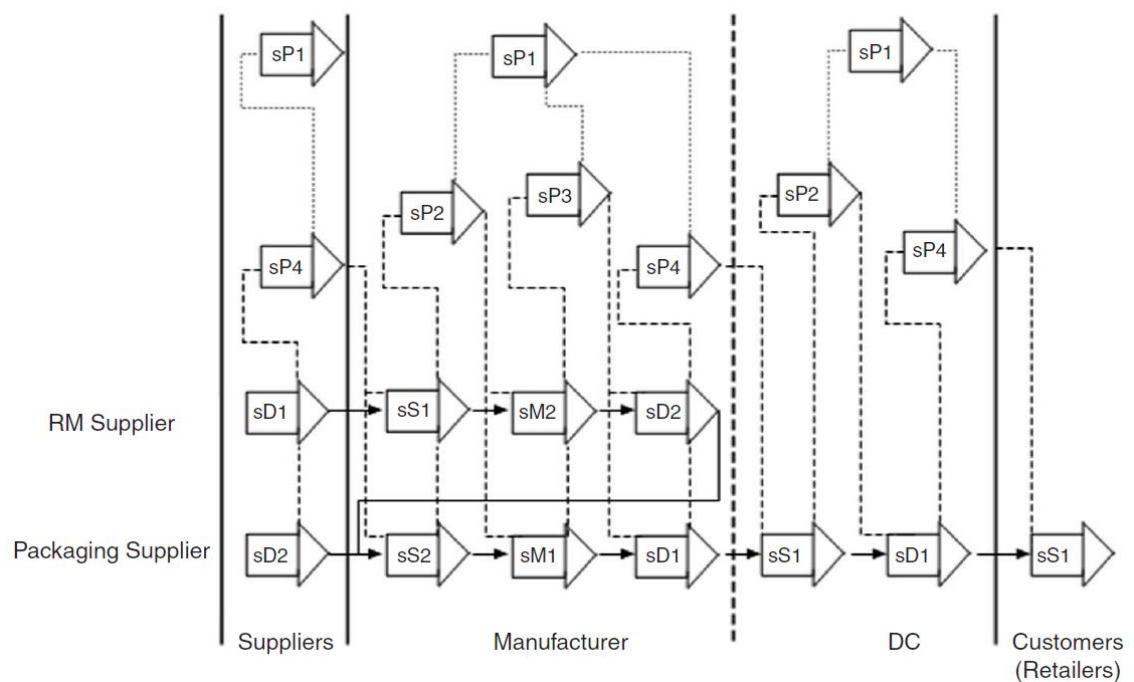
SCOR11 Level 1 processes are the core management processes that are put in place to achieve the overall RSC strategy of an organisation. A FMCG strategy is that of agility and responsiveness in the distribution of consumer goods to retailers. For this reason, organisations would follow a SCOR11 RSC model which is inventory driven, has high fill rates and short turnarounds, or what is known as Deliver-to-Stock (DTS). As all partners in a RSC offer a distribution service provider the core strategic management processes centre on P, S, D, and R, with the integrated framework acting as E.

### **5.4.2.2 SCOR11 Level 2**

SCOR11 Level 2 categorises and configures the sub-processes of Level 1. The SCOR11 thread process diagram (figure 5.8) is a system relationship map that focuses on the material flow (D), material strategy (M, S) and planning processes (P). The example thread diagram disaggregates the DTS model further into level 2 processes.

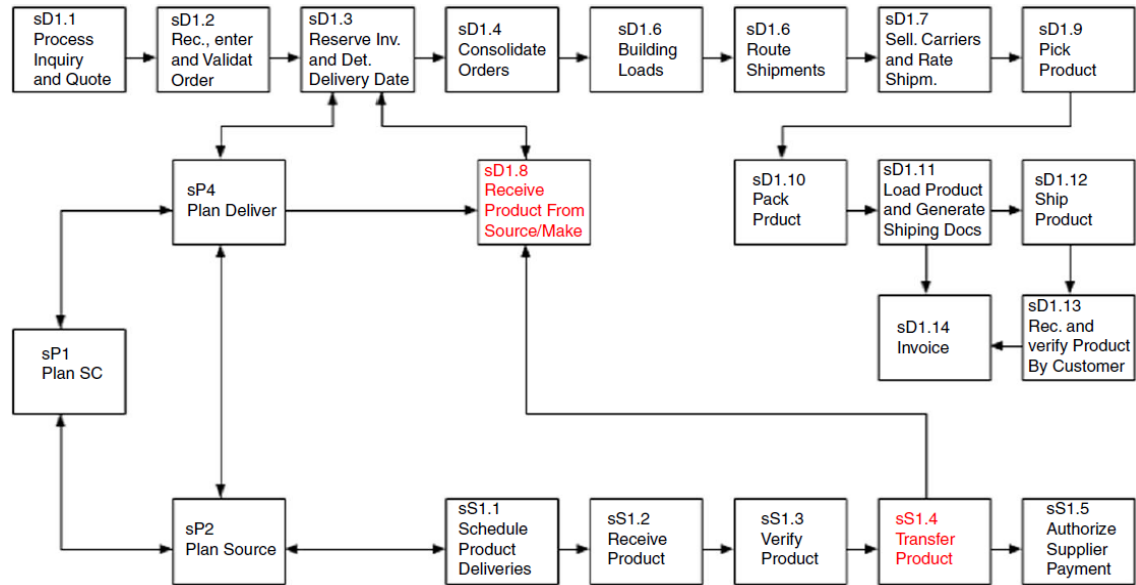
### 5.4.2.3 SCOR11 Level 3

Level 3 processes describe the steps performed to execute Level 2's more tactical processes. The sequence in which these processes are executed influences the performance of Level 2 and the overall RSC system. The example used in this framework is that of D1, or deliver stocked item to customer. Figure 5.9 shows the hierarchical breakdown of Level 2 process D1 into its Level 3 sub-processes, D1.1 to D1.15. These are generic activities within any warehouse, distribution centre or RSC function, ranging from process order inquiry to invoicing.



Source: (Dweekat, Hwang, & Park, 2017)

**Figure 5.8 A Thread Diagram example of SCOR11 Level 2.**



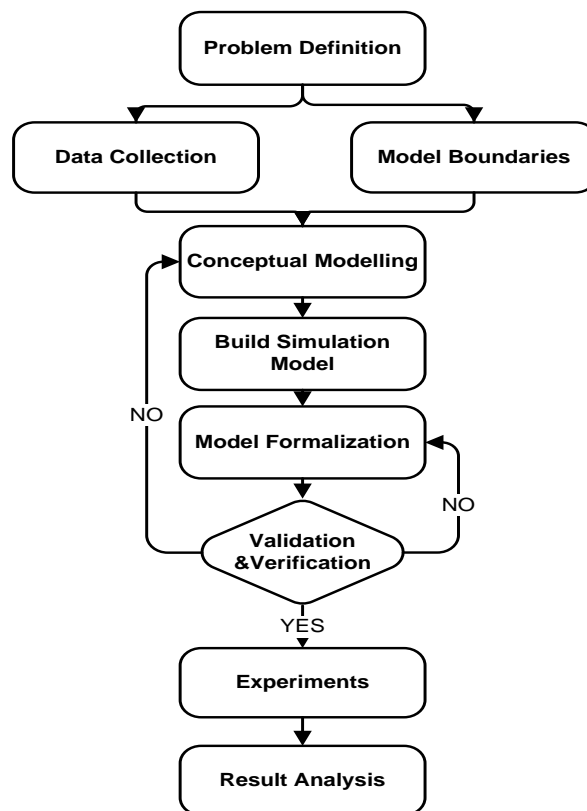
Source: (Dweekat et al., 2017)

**Figure 5.9 A flowchart of SCOR11 Level 3 Processes for D1**

### 5.4.3 Discrete Event Simulation (DES)

The development of the DES model is based on the first seven steps in a simulation study by Banks (2010), as in figure 5.10. Experimentation and result analysis will be discussed as part of the model integration sections of the framework. Banks makes a very important point when stating that unlike mathematical models, which are deductive analytical methods, DES employs numerical methods, following a more inductive approach where models are run and experimented on rather than solved. It is this inductive approach that makes DES such a popular decision making tool, as captured in chapter 2 literature review as it is of interest to decision makers to be able to study a complex system with the aim to understand the relationships between discrete components and experiment without affecting the real-life system.

Because a discrete systems state variables change in an isolated set of points in time, similar to that of RSC functions (retailer, distribution centre, farm etc.), it is useful in investigating the claim that business processes can potentially amplify or absorb internal risk events within a system, as explained in section 2.8.2. It is especially powerful in experimenting at an operational level, similar to the processes of SCOR11 Level 3 shown in figure 5.9.



*Adapted from: Banks (2010)*

**Figure 5.10 Steps in a simulation study**

#### **5.4.3.1 Problem Formulation**

In this step of the DES model journey, the logical flow to developing a problem definition discussed in the literature review will be used. This requires the following seven step workflow:

1. Start off on the right foot
2. Work on the right problem
3. Manage expectations
4. Question skilfully
5. Listen without judgement
6. Communicate openly
7. Predict the solution

It is important to highlight that although this workflow theme is very similar to the “establishing the context” flow of the understanding risk and BPM stages of the framework, these seven steps are for the simulation study only. Therefore there is no risk of duplication of effort or redundant work and in fact synergies can be made with both the initial phases of the hybrid framework, in particular the association with the  $P^6$  Coefficient.

### 5.4.3.2 Data Collection

Keeping in line with the nonlinear viewpoint of the  $P^6$  Coefficient, the steps of a simulation study are not necessarily sequential. During the emerging years of simulation research, Shannon (1975) says that there is a constant interplay between input data collection and building a simulation model. As a model progresses the required data elements can also change, therefore this step in the DES study is revisited at every other stage. There are two groups of data collection requirements within any DES study; *logic data* required for process mapping; and *additional input data* required to build the simulation model (Greasley, 2008).



**Table 5.2 Data Collection Groups**

<b>Data Required</b>	<b>Group</b>	<b>Description</b>
Process Routing	Logic	All possible routes of people/components/data through the system.
Decision Points	Logic	Decision points using conditional and/or probability methods.
Process Timing	Additional	Durations of all relevant processes.
Resource Availability	Additional	Resource availability schedules for all relevant resources (staff, machinery etc.) including shifts and downtime.
Demand Pattern	Additional	An understanding of demand schedules which will drive the model.
Process Layout	Additional	Facility/process layout plans and schematics to aid simulation animation and layout development.

Source: Adapted from (Greasley, 2008)

It is very common to encounter data availability challenges in a simulation study, specifically sourcing data in suitable formats. There are four main sources of data best suited for this DES model; *Historical records*, *observations*, *interviews*, and *process owner estimates* (Greasley, 2008). Historical records are any diagrams, schedules and raw data and can be either in paper form, (e.g. Lever-arch files) and electronic (e.g. Databases and ERP systems). Observations is a valuable source of primary data and methods include time studies, site walkthroughs and resource shadowing. While both interviews and process owner estimates are based on leveraging the knowledge of core stakeholders to the system at all management and operational levels.

#### **5.4.3.3 Model Boundaries**

In any simulation-based decision support tool, it is important not to over complicate things and model more than is required to solve the problem definition. The model boundaries decision is assisted by the thread diagrams and SCOR11 process flows

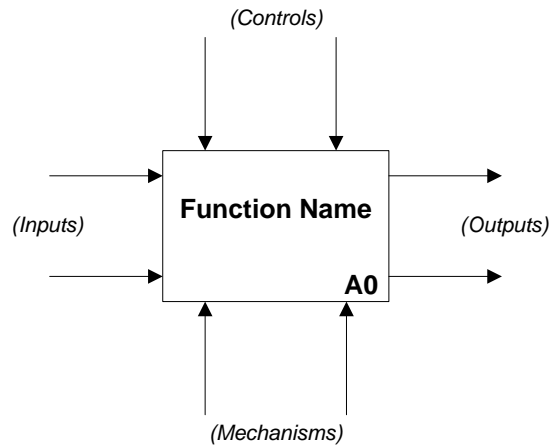
provided in section 5.4.2. The boundary decision will be influenced by the outcome of the initial problem formalisation, focusing on the internal and external business processes most affected by the problem.

### 5.4.3.4 Conceptual Modelling

As explained in section 5.4.2, business process mapping is a representation of a systems processes, procedures and resources. It also shows the relationship between system objects and their status during a systems life cycle, hence the data requirements listed in table 5.2. There are two modelling techniques used in the Hybrid framework specifically for the development of the DES model, they are *integrated definition for function modelling (IDEF)* and *basic flowcharts*.

The IDEF family of conceptual modelling was developed in the 1970's to model systems from different input perspectives, for example resources, information or processes (Ross & Schoman, 1977). There is a hierarchical structure to the modelling family, with a top level model that can be broken down into several more detailed levels, making it an ideal technique to capture SCOR11's top down process levels in more detail. From a business process perspective, the most relevant IDEF modelling techniques are IDEF0 (functions), IDEF1X (realworld data sets), and IDEF3 (activity and object flow). The hierarchical modelling approach using IDEF0 allows users (e.g. strategic managers, operational engineers and system analysts) to comprehensively understand the sequence of system's functions. An activity block which is the main unit for IDEF0 describes the main function of the process. ICOMs (Input, Control, Output and Mechanism) are represented by horizontal and vertical arrows as shown in Figure 5.11. Process control can be company regulations, standards or legislation, whereas process mechanisms are usually the agents

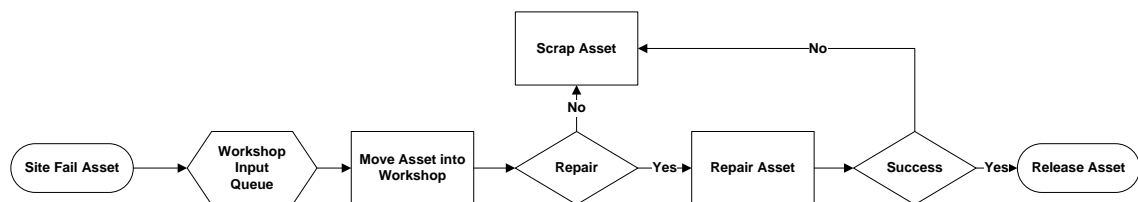
which facilitate the activity, such as warehouse or call centre operatives, information systems or material handling equipment.



**Figure 5.11 IDEF0 Activity Block**

A natural hierarchical progression from IDEF0 is to map more detailed process activities, decision points and route paths using IDEF3. The languages compliment each other and for experienced modellers, easliy understood. But for members of a project steering group who are not as experienced in conceptual modelling techniques, new often complicated tools and techniques can be difficult to understand and be more of a barrier than enabler to project cohesion. This can potentially disengage members of the project steering group and is in direct contridiction to the importance of people within the  $P^6$  Coefficient and also the fact that process mapping is a key method of understanding a problem for project steering groups (Browning, 2010). For this reason, the basic process flowchart is used to map lower levels of IDEF0 functional models. This is also the reason why other popular modelling techniques such as business process modelling and notation (BPMN) were considered but ultimately too sophisticated for the decision makers who would be implementing the framework.

According to Aguilar-Savén (2004), it is in its simplicity, flexibility and communicability that the strengths of a flowchart can be realised. An effective process flowchart can be built using a library of only 3-4 nodes to represent, an activity normally with a rectangle, a decision point with a diamond, a queue using a hexagon and start and finishing points normally distinguished as an oval shape. Figure 5.12 gives a simple example of a business process flowchart, explaining the flow of an asset through a workshop activity for an electronic supplier's retail warranty service. Another strength of the flowchart is that they are easy to illustrate freehand, during a meeting session or interview for example.



**Figure 5.12 A basic business process flowchart**

### 5.4.3.5 Building the DES Model

Also known as model translation, this is process of translating the real-world system into model form. Because of the size and complexity of the RSC system to be modelled, simpler approaches to DES model translation such as excel based Monte Carlo simulation was not capable of handling the great deal of information storage and computation needed. Therefore a more sophisticated, software based format was required. A computer simulation model based on the IDEF0/flowchart conceptual models was developed. The developed simulation model uses system entities to describe item and value movements through the system, while resources represent equipment and labour force which modify the entities. Resources are characterised by their capacity and availability, whilst the

attributes of the entities are arrival time and processing time. Logical entities simulate the decisions for creating, joining, splitting, buffering and branching entities. Each product type has its own information including level of inventory, safety stock level, forecasting range and its supplier and can be inputted into the model in spreadsheet form or the software's built in database.

The DES process in this study has used a generic simulation package – ExtenSim8 – and is customised using Java and XML technologies. This selection provides a flexible and efficient simulation model for three reasons; (1) it helps to provide object-oriented hierarchical and event-driven simulation capabilities for modelling such large-scale applications, (2) It utilises breakthrough activity-based modelling paradigms (i.e. real world activities such as assembly, batching and branching), and finally (3) it also used to customise objects in the package to mimic the real-life application characteristics.

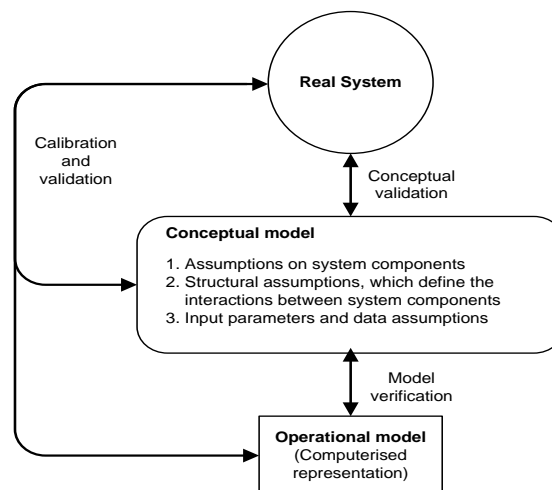
### **5.4.3.6 Model Formalisation**

Not normally a separate step in a generic simulation model build, but based on learnings from the formative case study this step has been added as an additional verification of the model attributes before performing actual model verification and validation. Often known as face validation, model formalisation performs two separate tasks; firstly, all data inputs, specifically formulae and probability distributions are listed, categorised and checked outside of the model; secondly the layout of the model is reviewed from a format and visual aesthetic point of view. This can involve other members of the project steering group with the objective of ensuring common aesthetic queries such as layout and animation do not distract the more important aspect of model validation, ensuring the model reflects both the conceptual model and real-world system as expected.

#### 5.4.3.7 Verification and Validation

For the verification process, a simulation software built-in debugger and decomposition model (i.e. to verify every group of blocks) were used. A decomposition approach is effective in the detection of errors and insuring that every block functions as expected. Validation of the model is provided through the iterative process of comparing the model against actual system behaviour, using any deviations as an opportunity to improve the accuracy of the model. This process is repeated until the model performs within an accepted deviation from the real-world system.

It is important to note that keeping with the nonlinear, combinatorial theme of this framework, verification and validation should be an iterative process at every stage of the DES study workflow to fully realise the model objectives versus a real-world system. Banks (2010) backs up this claim, stating that model building is not a linear process with multiple steps. Instead, the model builder needs to revisit each step many times to verify and validate the model whilst building. Figure 5.13 depicts the model building process with ongoing feedback loops for validation and improvements through calibration.



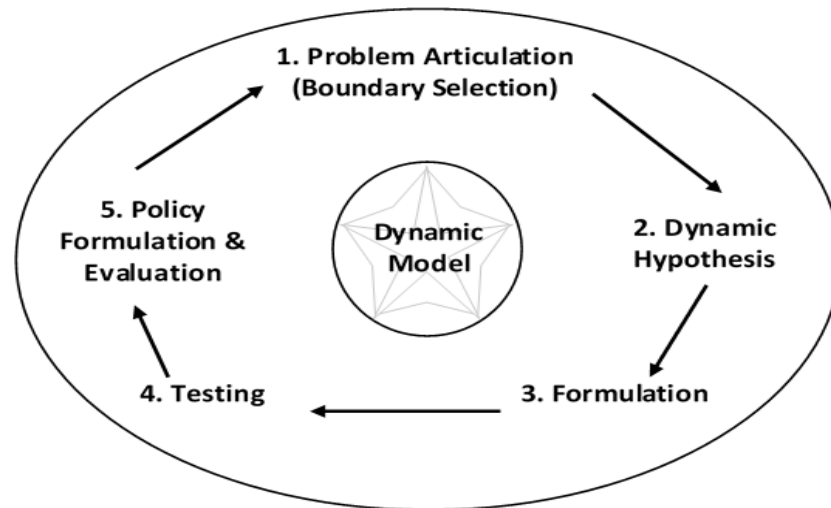
*Adapted from (Banks, 2010)*

**Figure 5.13 Model building, verification and validation**

### 5.4.4 System Dynamic Modelling

Just as DES can be used to model the absorbing and amplifying effects of business processes to internal risks at an operational level, there are also effects to an extended RSC system at a strategic level that need to be understood and explained. This more strategic orientated amplification is better known as the bullwhip effect and is one of many patterns of behaviour that can remain hidden from an organisation. Partly because they are whole system risk events whose vastness are hard to comprehend, but also because organisations rarely measure performance beyond a single echelon RSC system. This is very evident in simulation studies, where organisation tend to focus on operational and internal problems, and not from a system thinking viewpoint. Continuous simulation is a strong method for modelling patterns of behaviour within a RSC system from a strategic, holistic point of view. Unlike in a discrete event system, in a continuous system state variables change continuously over time. System dynamics (SD) is a popular approach to continuous simulation modelling.

As introduced in the literature review, SD was developed at the end of the 1950s at MIT's Sloan School of Management by Professor Jay Forrester (Forrester, 1958). He employed the principles of engineering feedback control and techniques to management and social science and then applied to any type of complex systems that exhibits dynamic behaviour over time. The SD approach seeks to support the decision-making processes that should lead to the improvement of the system, it is also very effective in improving learning in complex systems (J. Sterman, 2000). The development of the SD segment of the hybrid-model is achieved using the first four steps of Sterman's SD modelling process, figure 5.14.



*Adapted from (J. Sterman, 2000)*

**Figure 5.14 System Dynamic Modelling Process**

#### **5.4.4.1 Problem Articulation**

Morecroft (2007) claims that problem articulation is the most important step in a SD model as it shapes the entire study. According to Sterman (2010), it is at this stage that a modeller and project steering group identify the issue or concern, agree on the time frame, the scale of analysis and model boundaries. Unlike the detailed DES problem definition workflow, the preference during an SD study is to characterise the problem dynamically determining what are key variables to be considered? Then an understanding of what the historical behaviour of the key variables and possible future behaviours is needed. There are two techniques used to determine this, *reference models* and the setting of *time horizons*.

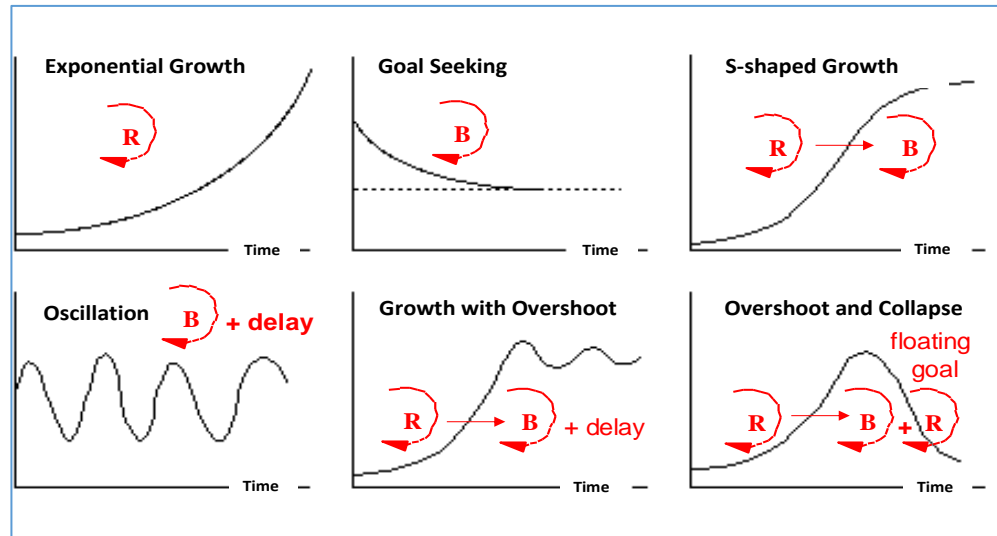
Reference models are literally a library of graphs and other descriptive data that show the development of problems over time. They are named reference models as a modeller will refer back to them over the course of the modelling process. In terms of time horizons, reference models have to extend far enough back in time to show how a problem emerged



and describe symptoms. They should be capable of extrapolating far enough into the future to capture delayed effects to disruptive events and policy changes. Sterman (2010) says that most organisations underestimate the length of possible time delays to a system and select far too short time horizons. Pidd (2009) adds that this is because our impressions of the world are always partial as we cannot experience everything and what we do experience may well be biased. One example of this is the human deficiency in mental modelling which has a tendency to think of cause and effect as local and immediate (J. Sterman, 2000). Modellers must be aware of a client's tendency to underestimate time horizons, with an accepted rule being that the time horizon should be at least several times as long as the longest time delays in the system.

### 5.4.4.2 Dynamic Hypothesis

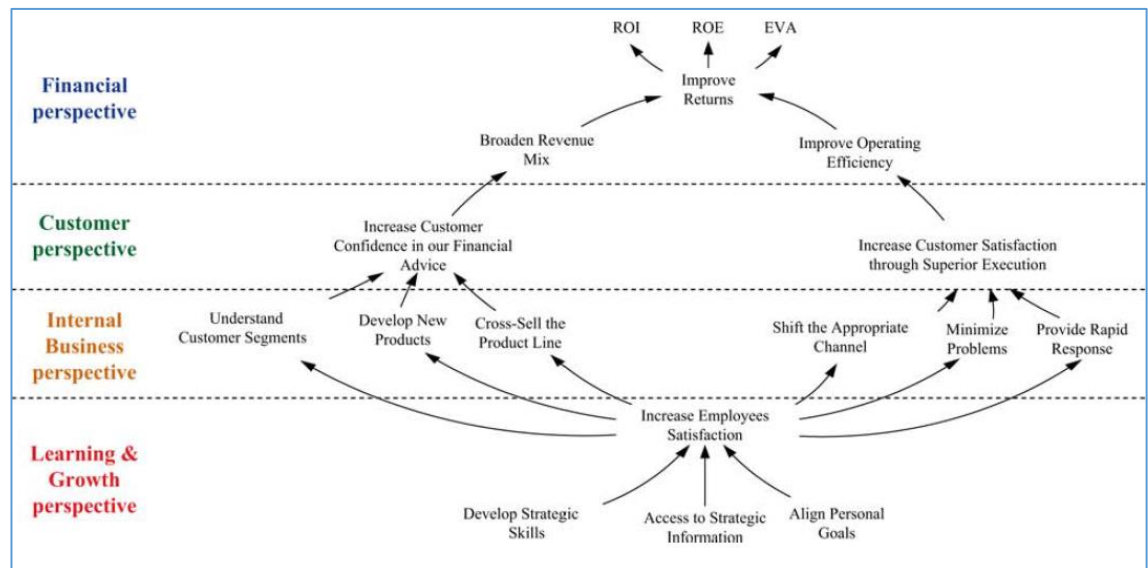
The initial hypothesis generation evaluates the different theories of the problematic behaviour. A dynamic hypothesis is a working theory that guides the project steering group by focusing on critical structures. Figure 5.15 outlines the fundamental modes of dynamic behaviour that are typically formulated as a dynamic hypothesis. SD seeks explanations for phenomena through endogenous means. The term endogenous is a term used to explain “having an internal cause of origin” (Oxford Dictionary, 2011). Therefore, in an SD model, the dynamic behaviour of a system is generated from the interaction of variables and agents within the system itself. Sterman (2010) adds that by specifying how a system is structured, with associated rules of interaction, the various behaviours illustrated in figure 5.15 can be explored. In this framework, there are three primary methods used to specify the structure of the system; *strategic road maps*, *causal loop diagrams (CLD)* and *stock and flow maps*.



*Adapted from (Morecroft, 2007)*

**Figure 5.15 Fundamental Modes of Dynamic Behaviour in a System**

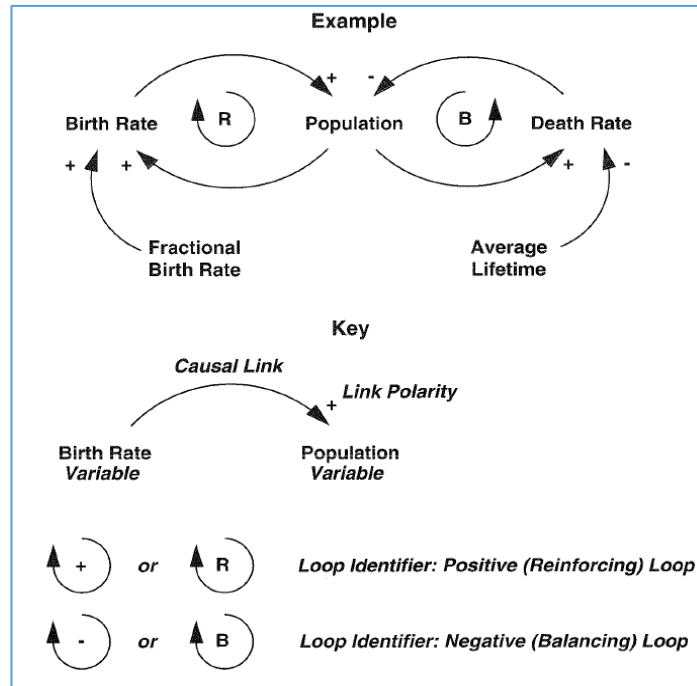
Strategy maps are very common within change management projects. This research study follows a BSC approach to strategy mapping (Fig. 5.16), as developed by Barnabé (2011), whose research paper centred on a SD-based BSC to support the decision making process. According to Barnabé, “a strategy map is a diagram that describes how an organisation creates value by connecting strategic objectives that are in explicit cause-and-effect relationships with each other into the four BSC perspective”, as in figure 5.16. It also a qualitative and illustrative method of providing a holistic, system view of an organisation’s strategy, prior to constructing CLD’s or stock and flow maps. CLD’s are flexible system thinking tools used to map the feedback structures of a system. They are maps that show the relationship between variables (independent and dependent) in a system with arrows showing the cause and effect flow. These are what are known as *causal links*, which are assigned a polarity, either positive (+) or negative (-). The polarities indicate how an independent variable will change when a dependent variable changes.



Source: (Barnabé, 2011)

**Figure 5.16 An Example of a BSC Strategy Map**

Put simply, if there is a positive causal link, this means that if the cause increases the effect will increase above normal rates, or if a cause decreases the effect will decrease below normal rates. A positive causal link is also known as a reinforcing effect, represented by the letter as *R*. A negative causal link occurs when a cause and effect have opposite effects. That is, if a cause increases the effect will decrease at a rate below what it normally would and vice versa if a cause is decreasing. This is known as a balancing effect, or *B*. An example that clearly explains both balancing and reinforcing feedback loops between variables in a system is the relationship between death and birth rates on population (Fig. 5.17). An important limitation of CLD's to note is that they do not capture the stock and flow structure of a system, or in basic terms the rates of inputs and outputs (flows) and associated influence on an accumulated inventory (stock).



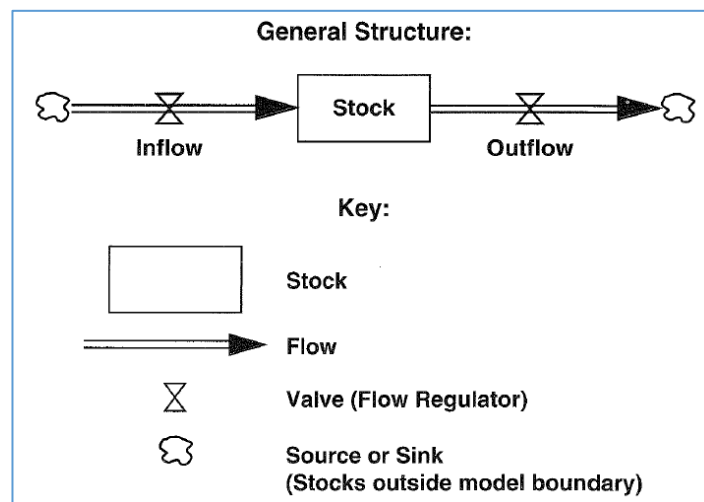
**Figure 5.17 Example of Causal Loop Diagram Notation**

*Source: (Sterman, 2010)*

As stated, stocks are accumulations and symbolise the health of a system and generate the necessary information needed to make decisions and deliver actions. Flows are the rate of inputs and outputs of the accumulating stock and in a continuous system, the accumulative nature of stocks provide time delays in the continuous flow and in turn provides valuable memory to the system. This logic is similar to the way to calculate energy within a closed system based on the first law of thermodynamics (equation 1). Stock and flows are common in everyday systems, a bathtub for example, is used as a descriptive analogy to a dynamic continuous system. The plughole/drain and tap represent the input and output flows and the bathtub itself is the stock which accumulates with water dependent on flow rates. There is a standard notation in SD modelling when drawing a stock and flow diagram, as mapped in figure 5.18.

Sterman (2010) explains each:

- *Stocks* are represented by rectangles (suggesting a container holding the contents of the stock, like the bathtub).
- *Inflows* are represented by a pipe (arrow) pointing into (adding to) the stock or the flow of water out of a tap.
- *Outflows* are represented by pipes pointing out of (subtracting from) the stock, as in the bathtub drain example.
- *Valves* control the flows.
- *Clouds* represent the sources and sinks for the flows. A source represents the stock from which a flow originating outside the boundary of the model arises; sinks represent the stocks into which flows leaving the model boundary drain. Sources and sinks are assumed to have infinite capacity and can never constrain the flows they support.

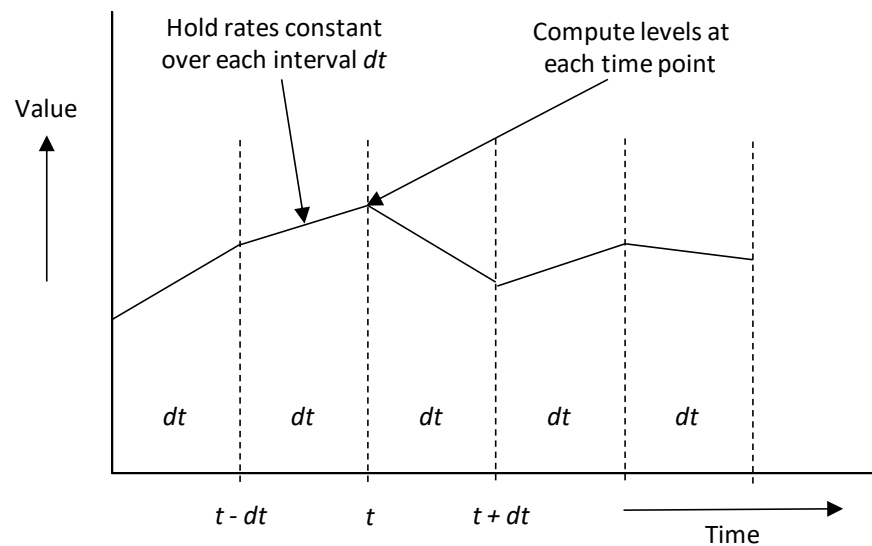


Source: (Sterman, 2010)

**Figure 5.18 Example of Stock and Flow Map Notation**

### 5.4.4.3 Formulation

The formulation stage of an SD study is the move from conceptual model to a formal representation of the real world system, complete with a move from conceptual model to fully formal model complete with equations, and initial conditions and parameters of the model. The formulation of the SD model in this research study uses the *time-slicing* technique as explained by Pidd (2004). Time-slicing acknowledges that it would take too much resources, time and computational capability to record and playback in detail an entire real-world simulation. What is preferable and equally as powerful is to compute what is happening at regular points of time within the system and hold rates constant over each interval, similar to what a TV nature programme would do when using time-lapse photography to film plant activity for example. Figure 5.19 expresses this in trend-line form, highlighting the time-slice intervals and constant rates in-between.



*Adapted from (Pidd, 2009)*

**Figure 5.19 Time-handling in system dynamics**

Using the time increment  $dt$ , SD computes what is happening in the system at regular time points, each one separated by  $dt$  (Pidd, 2009). Because the model is using the fixed times points ( $dt$ ), it is known that at any time point ( $t$ ) the previous time point computation is ( $t-dt$ ) and the next one will be ( $t+dt$ ). Pidd adds that SD model equations can be split into equations for stocks or level equations and those for flow which are rate associated equations. The resulting time-handing computations will follow a certain method:

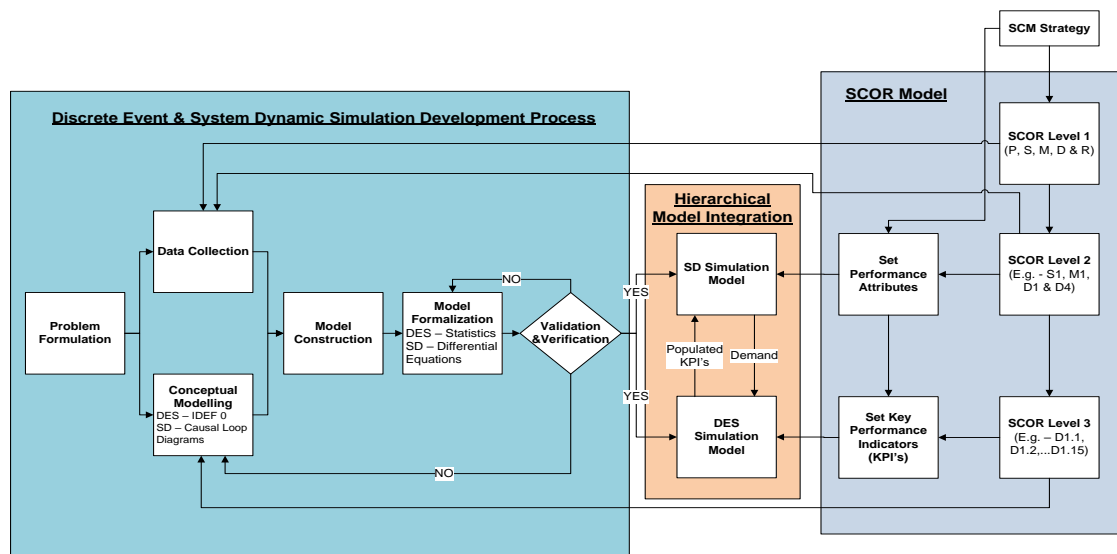
1. At time  $t$ , compute the new values for the levels or stocks, using the level or stock equations. Use the current values of the rates or flows, computed at time  $t - dt$ , for this purpose.
2. Now compute the values that the rates or flows will hold over the next time intervals  $dt$ . These will depend on information about the current values of the levels.
3. Move time forward by one increment ( $dt$ ) and repeat the process. (Pidd, 2009)

#### **5.4.4.4 Testing**

The testing of the SD model is another step in the modelling process that occurs during all stages and not limited to sequential phasing. The core testing of the dynamic model normally begins when the first equation is written. Initial testing compares the simulated behaviour of the model against the actual behaviour of the system. Every equation for the formalisation of the model is also checked to ensure consistency and the model should also be tested under extreme conditions, usually those that may never occur in the real world system. This is an important test as it can uncover fundamental flaws to the model that may not be uncovered under normal testing environments.

### 5.4.5 Model Integration

When modelling a complex system, it is sometimes very difficult to define the boundaries of a model that appears to be a closed loop with its external environments (Brailsford et al., 2010). This is often the case with hierarchical echelon levels of a RSC system. Similar kinds of uncertainties occur at different hierarchical levels of organisations, yet they are nearly always handled independently at each level. Integrating SD and DES can be very effective in studying the impact each level has on the system (Venkateswaran et al., 2004). Hybrid simulation by integrating both SD and DES can create valuable synergies. By integrating each technique hierarchically, “both paradigms symbiotically enhance each other’s capabilities and mitigate limitations by sharing information” (Chahal & Eldabi, 2008), which is very attractive to RSC decision makers.



**Figure 5.20 DES-SD Model Integration**

Figure 5.20 illustrates the integration of the DES and SD models into a hybrid model with the principle link being the transfer of demand patterns and SCOR11 driven key performance outputs. Excel sheets are the link between the two simulation models, and



used as both input and output integration. Each model runs independently to each other and data is transferred via input and output excel sheets generated by the SD and DES models. Forecasted demand created in the SD model is transferred to the DES model as customer order input.

### 5.4.6 Design of Experiments

Design of experiments (DOE) can be used to test a number of scenarios to obtain answers to the problems articulated in both the DES and SD model developments. Depending on the set up of the model and the number of the parameters, the amount of potential scenarios and experiments increases significantly due to the multiple possible parameter combinations (Kleijnen, 2008). For the purpose of this research study and the potentially high number of possible experimentation permutations of a hybrid simulation model, a mixed factorial design using orthogonal arrays was the preferred option. The Taguchi method for robust design uses orthogonal arrays from the DOE theory to study a large number of variables with a small number of experiments (Phadke, 1995). This method distinguishes between *control variables* (inner array), which are the factors that can be controlled, and *noise variables* (outer array), which are the factors that cannot be controlled except during experiments. This research study follows the approach as adapted by Shang et al (2004), whose use Taguchi's robust DOE as part of a hybrid simulation model to assist firms in understanding the dynamic relationships between factors in a RSC.

#### 5.4.6.1 Orthogonal arrays in the Taguchi Method

The aim is to provide the maximum amount of information from the hybrid model with the minimum amount of trials. Depending on the number of levels and

parameters/variables for both inner and outer arrays, an array selector table, or software is needed to determine what orthogonal array is needed. An example of an array selector can be seen in table 5.3. From this table it is easy to understand why this DOE method is popular within simulation studies. For example if a simulation study necessitated the experimentation of 6 controllable variables at 3 levels, that is a factor of  $3^6$ , which would result in 729 trials needed to cover all combinations. Using orthogonal arrays, this would only be 18 trails, or  $L_{18}$ .

#### 5.4.6.2 Signal-to-noise (S/N) ratio measurements

Simulations are made after all factors are assigned to the selected orthogonal array. A follow up to this there is an option to use Taguchi's S/N ratio to identify optimal parameter/variable levels based on the simulation results generated from orthogonal array design (Shang et al., 2004). Typically optimal settings are based on a univariate response variable and since RSCs are multivariate, Shang et al suggest using the approach recommended by Rustagi et al. (1992) who generalized Taguchi's S/N ratio for the "smaller the better" criterion. The ratio follows:

$$10\log_{10}|S_0| \quad (5.8)$$

where

$$S_0 = \frac{1}{n} \begin{bmatrix} \sum_j y_{1j}^2 & \sum_j y_{1j}y_{2j} & \dots & \sum_j y_{1j}y_{kj} \\ \sum_j y_{2j}y_{1j} & \sum_j y_{2j}^2 & \dots & \sum_j y_{2j}y_{kj} \\ \dots & \dots & \dots & \dots \\ \sum_j y_{kj}y_{1j} & \sum_j y_{kj}y_{2j} & \dots & \sum_j y_{kj}^2 \end{bmatrix}. \quad (5.9)$$

In equation (12),  $y_{kj}$  is the response value (simulation output),  $k$  is the  $k$ th response ( $k = 1, 2$ ), and  $j$  is the  $j$ th outer array, ranging from 1 to 4 (two uncontrollable factors with two levels each).

**Table 5.3 Taguchi Robust Design Array Selector Table**

Number of variables	Number of levels			
	2	3	4	5
2, 3	L4	L9	LP16	L25
4	L8	L9	LP16	L25
5	L8	L18	LP16	L25
6	L8	L18	LP32	L25
7	L8	L18	LP32	L50
8	L12	L18	LP32	L50
9, 10	L12	L27	LP32	L50
11	L12	L27	N./A.	L50
12	L16	L27	N./A.	L50
13	L16	L27	N./A.	N./A.
14, 15	L16	L36	N./A.	N./A.
from 16 to 23	L32	L36	N./A.	N./A.
from 24 to 31	L32	N./A.	N./A.	N./A.

*Source: (Cavazzuti, 2012)*

It is important to explain that for the hybrid framework, the “smaller the better” criteria is preferred over the “larger the better” S/N Ratio because the core response variables need to be minimised, as in the total cost of ownership of risk in the system.

#### **5.4.7 Value at Risk (VAR) Metrics**

It has been a common theme throughout this research study to communicate the reality that many organisations manage their businesses as a closed loop system. This has particular resonance from a performance management perspective. Where the majority of performance metrics; whether service levels, costs, profit or indeed risk of disruption do not extend beyond the traditional boundaries of a closed supplier-organisation-customer looped system. But according to Chen (1999), business processes are ongoing, where the inflow and outflow of materials, information and capital remain in a steady state. Therefore, under these conditions an organisation should be seen as an open system with a continuous flow of material, services and capital. It is because of this that the

fundamental rules of physics in open systems, in particular thermodynamics, can be applied to business processes, as discussed in the literature review. This section presents a system thinking, open system approach to managing value at risk (VAR) metrics, influenced by the entropic properties of thermodynamics second law.

#### 5.4.7.1 VAR Metric 1: System Capability

System capability refers to an organisations overall competence in managing the risk of disruptive events to their system. Competencies can include; the level of technology utilisation, knowledge management understanding; employee morale; marketing proficiency, operations efficiencies; quality of service/product output; and overall agility of the organisation to change/disruption. Based on Chen's research, the transfer of heat (energy) in a thermodynamic system can be applied to the system output of a business process (Table 5.4).

**Table 5.4 The Laws of Thermodynamics Applied to Business Processes**

Law	Thermodynamics	Business Process
1 <sup>st</sup>	Energy is conserved in closed systems and in open systems at a steady state	A useful output is equal to the input minus the losses throughout the process
	$\Delta E = Q - W$	$W_{output} = Q_{input} - U_{loss}$
2 <sup>nd</sup>	It is impossible to operate in such a way that the sole result would be an energy transfer of heat from a cooler to a hotter body	It is impossible for a firm to mitigate risk if the output characteristics of a business process are below critical levels expected by customers
	Spontaneous increase of entropy (i.e. decrease of distinguishability) will occur in an isolated thermodynamic system	In a socio-economic system, decrease of firm's distinguishability will occur spontaneously through, for example, dissemination of intellectual property.
	The maximum thermal efficiency of a power cycle is: $\eta_t = \frac{W_{cycle}}{Q_h} = 1 - \frac{Q_c}{Q_h} = 1 - \frac{T_2}{T_1} < 1$	The maximum obtainable efficiency of a business process to satisfy risk is: $\eta_b = \frac{W_{output}}{C_s} = 1 - \frac{C_e}{C_s} < 1$

*Adapted from (W.-H. Chen, 1999)*

Derived from Chen's interpretation of the 2<sup>nd</sup> Law of Thermodynamic, this research study defines the law in the context of SCRM as:

*"A RSC systems output will sustain risk events of disruption only if its SCRM capability ( $C_s$ ) is not lower than that of competitors or the external environment ( $C_e$ )"*

Where  $C_s$  and  $C_e$  are the SCRM capabilities of the system and external environment respectively. Obeying the energy loss ( $U_{loss}$ ) rule of the 1<sup>st</sup> law of thermodynamics, stipulates that all outputs from the system must be less than or equal to the external environment, or  $C_s \leq C_e$ . For instance, although all output capabilities of the system are fixed and constant, there is inevitable loss as they flow through the system. This rule suggests that even if an organisation is a dominant market leader with significant resources and SCRM capabilities, they will inevitably lose out to external system disruptions and competitors. Such loss can be something as disruptive as the impact of a natural disaster to delivery lead-times, or the loss long-term of system knowledge due to compulsory redundancies or high frequency of retirements.

Through analogical comparison to thermodynamics 2<sup>nd</sup> law, the maximum obtainable SCRM capability ( $\eta_b$ ) of an organisation can be expressed by the following (Equation 5.10):

$$\eta_b = \frac{W_{output}}{C_s} = 1 - \frac{C_e}{C_s} < 1 \quad (5.10)$$

where  $W_{output}$  is the potential product/service output by an organisation through the customer order-to-cash cycle. Equation (5.10) importantly imposes a constraint on the maximum value of efficiency, stating the ideal efficiency is a ratio of  $C_s$  and  $C_e$ , and cannot be 100% due to capability loss within the system. For example, an organisations

efficiency ratio may be high if they have successfully maintained ISO31000 qualifications for 10 years running and the external environment average is less than this.

### 5.4.7.2 VAR Metric 2: Total Cost of Ownership (TCO)

Continuing with the theme of the extended RSC being an open system in a steady state of continuous flow, a risk metric was needed that would encompass the holistic nature of the system and embrace the philosophy of causal loop relationships influencing value outputs. TCO is an effective VAR metric that captures the extended life-cycle costs of an extended system. As stated in section 2.6.7, the TCO of the lifecycle of any service, product or disruption extends significantly beyond the basic product or service cost. In fact there are as much as 50 fixed, variable and hidden costs that accumulate between the initial basic cost and the ultimate cost/value to the end consumer. Using the list of TCO costs by Cavinato (1992) as a starting point (see figure 2.11), this research will apply a basic a TCO cost risk model to the hybrid-model outputs (Aven, 2012) as follows (Equation 5.11):

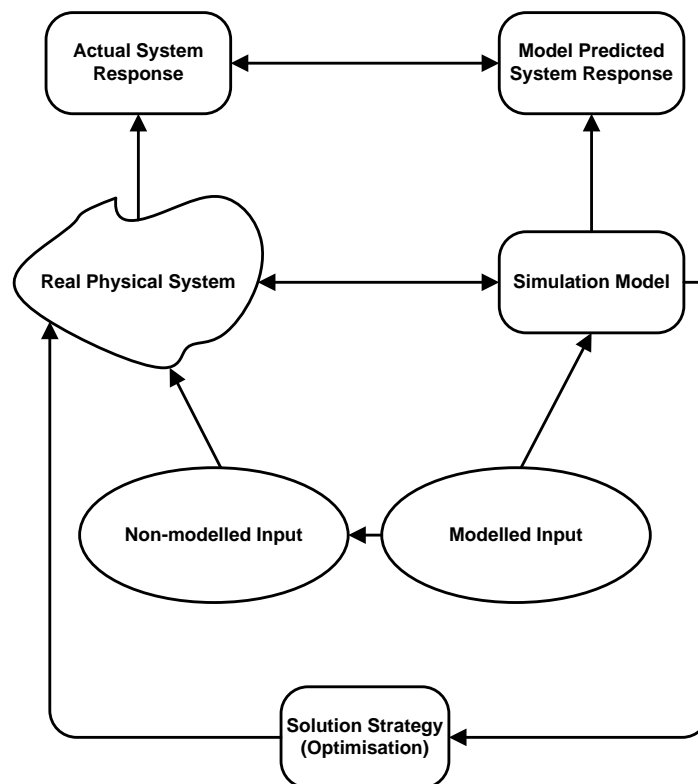
$$Y = \sum_{i=1}^k X_i \quad (5.11)$$

where  $Y$  represents the TCO related to a project and the  $X_i$ ,  $i = 1, 2, \dots, k$ , represent more detailed cost elements from Cavanato's hierarchical cost table. Assuming  $X_i$  are independent cost elements is also beneficial as they can be analysed using probability distributions in both the DES and SD models.

### 5.4.8 Result Analysis and Optimisation

As explained by Haimes (2002) to obtain a way to control or manage a physical system, an optimal model that closely represents the physical system, such as the simulation

techniques in this framework, are often the best option. But as a simulation model does not solve the physical systems problems, only experiment on it, an additional result analysis technique, or solution strategy is needed (figure 5.21). As claimed by Van Der Aalst et al. (2003), although simulation modelling can effectively contribute to the understanding and analysis of business processes, it does not provide the capability of finding the optimum values of decision variables and optimising a business process. Business process optimisation involves a wide range of techniques and methods from many business disciplines such as decision support systems, artificial intelligence, modelling and simulation, expert systems, and operations research. The one thing most techniques have in common is that they follow the basic optimisation principles outlined in section 5.4.8.1.



*Adapted from (Haimes, 2009)*

**Figure 5.21 System Modelling and Optimisation**

#### 5.4.8.1 Optimisation Principals

Optimisation problems can be defined as determining the set of values of the decision variables that are located in the feasible area determined by the underlying system constraints that gives the optimum values of all objective functions. Formally:

Optimise:

$$f_i(x) \quad i = 1, \dots, I, \quad (5.12)$$

Subject to:

$$\begin{aligned} g_j(x) &\leq 0 & j = 1, \dots, J, \\ h_k(x) &\leq 0 & k = 1, \dots, K \end{aligned} \quad (5.13)$$

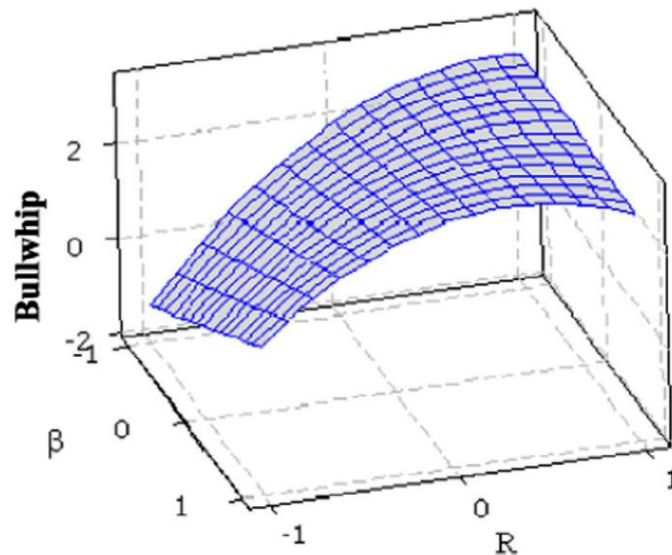
Where  $f_i(x)$  is the objective function  $i$ ,  $g_j(x)$  and  $h_k(x)$  are the set of inequalities and equality constraints. The decision variables are represented as a vector  $x \in S$ ; where  $S$  is the region of search space that defines all possible combinations of decision variables that satisfy all constraints.

#### 5.4.8.2 Response Surface Methodology

Using the optimisation techniques map developed by Abo-Hamad and Arisha (2011) to support the choice of optimisation method most applicable for a RSC simulation model, a meta-model based approach, response surface methodology (RSM) will be used. RSM will establish a robust regression model and find optimal results for the studied factors of the framework output, acknowledging the  $P^{Potential}$  expression of the  $P^6$  Coefficient. A sequential procedure, RSM makes the fitting of a series of regression models into a response function possible. The technique seeks to estimate a functional relationship between one or more responses and a number of independent variables in order to explore the optimum operation conditions for the system (Sahoo, Tiwari, & Mileham, 2008).



Figure 5.22 shows a 3D representation of response functions from an analysis into causes of bullwhip effect from two dimensions of order and inventory variance using the RSM (Hassanzadeh, Jafarian, & Amiri, 2014).

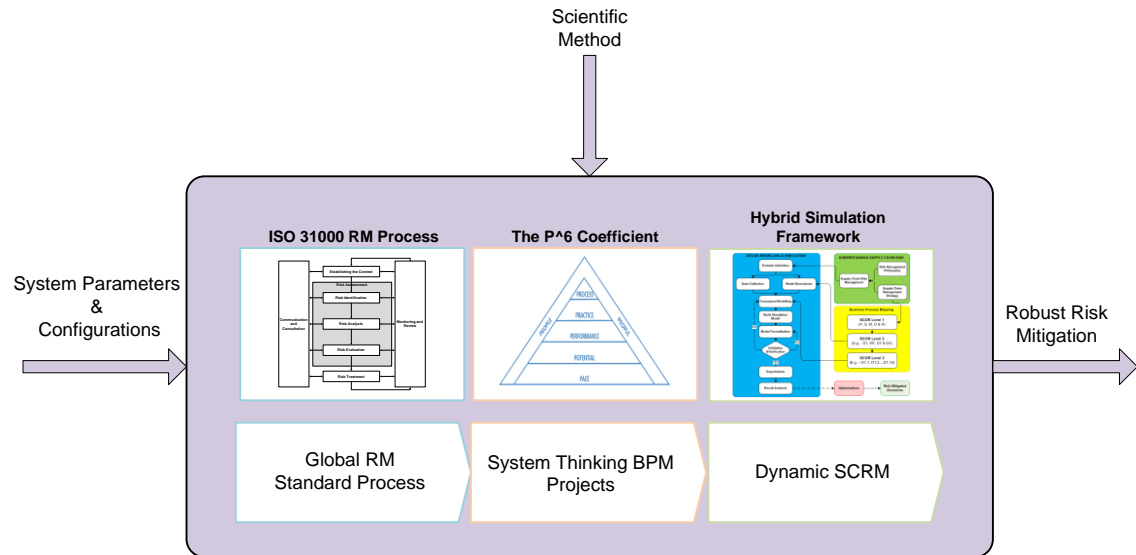


**Figure 5.22 Example of 3D Representation of RSM Analysis into Bullwhip Effect**

### 5.5 Framework Implementation Process

The structure of the hybrid simulation-based framework has been purposely designed to mirror the globally recognised risk management processes of ISO31000. The process sequence of; establish the context; risk assessment; and risk treatment; with ongoing communication, consultation and monitoring at each stage are clearly aligned with the flow of the hybrid simulation study processes adapted from the generic guidelines of both Banks (DES) and Sterman (SD). The *P<sup>6</sup> Coefficient* reference model is the catalyst between ISO31000 RM process and the hybrid simulation-based SCRM framework (figure 5.23). Its aim is to act as a conceptual reference and qualitative relief to what is otherwise a heavily quantitative framework. As a reference model for managing a

complex BPM project, the coefficient will encourage users to apply prior knowledge and reignite scientific experimentation into their approach to decision making.



**Figure 5.23 Theoretical Implementation of Hybrid Simulation Framework**

## Chapter 6. Framework Evaluation and Validation – An FMCG Case Study

*“Nothing in life is certain except death, taxes, and the second law of thermodynamics.”*

— Seth Lloyd

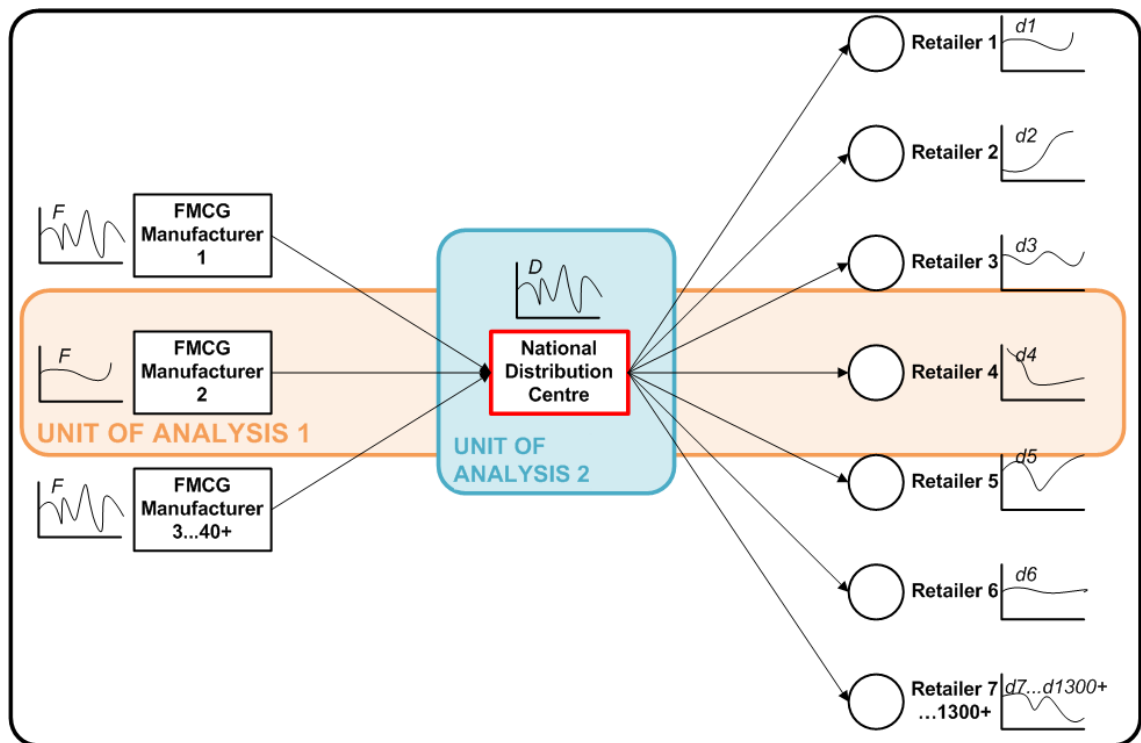
### 6.1 Introduction

The design and development of the integrated SCRM framework is complemented by an extensive validation phase. The critical validation aim is to examine the quality of the theoretical propositions of earlier stages of this research and to evaluate the integrated SCRM framework from a practitioner perspective. The third and fourth research objectives are consequently achieved during this phase by investigating the validity, generalisability, and applicability of the integrated framework as an SCRM solution. Validation was undertaken in one embedded case study separated into three stages; Unit of Analysis 1 which is the extended three echelon RSC; a national distribution centre representing Unit of Analysis 2; and the  $P^6$  Coefficient as a support reference model. This chapter discusses the results and reflects on the findings of both units of analysis.

### 6.2 Embedded Case Study – A Three Echelon RSC

The three echelon RSC chosen as the primary case study for this research study is one of the largest extended FMCG RSCs in operation on the island of Ireland. The RSC is made up of over 40 FMCG brand manufacturers mainly based in the UK and Europe, one state-of-art national distribution centre and over 1300 franchised retail outlets, see figure 6.1. The scope of inquiry of this research study is to focus on the largest FMCG brand manufacturer, the retail distribution company and associated franchised retailers. A short

profile of the organisations involved in the embedded case study are provided in the next sections. It is important to note that the researcher was limited to very broad descriptions of both organisations due to confidentiality agreements made at the beginning of the research study.



**Figure 6.1 Three Echelon FMCG RSC**

The FMCG grocery market in Ireland is very competitive, as outlined in section 2.3, and the participating organisations do not want any material that either highlights strategies, threats or opportunities to filter back to competitors. As per the guidelines of Saunders et al. (2016) the researcher has ensured the maintenance of anonymity of those taking part in the research study and also processed all data, quantitative and qualitative, to make it non-attributable. This also increased the trust and confidence of participating

organisations to the research study, enhancing the probability that data provided was reliable and accurate (Saunders et al., 2016).

### **6.2.1 FMCG Brand Manufacturer**

As a global company, the FMCG Brand manufacturer (to be referred to as FMCG) owns some of the world's best-known brands in Personal Care, Home Care, Foods and Refreshment. FMCG has 40 key brands within the Irish FMCG market, of which over 50% are market leaders. The focus of this validation chapter is on the savoury foods category, which includes soups, stocks, meal packs and sauces, a category they are Irish market leader in with a sustained market share of over 60% for many decades. As a global brand manufacturer, a lot of the risk sources were at a macro, strategic level where regional and global decisions such as organisational restructuring, outsourcing and RSC network design are the norm.

### **6.2.2 National Distribution Centre (NDC) and Franchised Retailers**

NDC is a leading grocery retail and wholesale distribution company operating in Ireland and the UK. The company sources products from more than 550 suppliers and services more than 1,400 retail franchise customers, selling over 6,000 consumer good products. The scope of this research study is to focus on one product category, "savoury foods". Through its franchised retail estate, NDC serves in excess of one million end consumers every day in Ireland. The company operates three main retail divisions in Ireland; Foods Retail Division, Foods Wholesale Division, and Wines & Spirits. Recently, the company has amalgamated its regional distribution centres' into one main state-of-the-art national hub for ambient products, with a capacity of 22,500 pallets. Strategically located near Dublin, the new NDC's aim is to meet the volatile demand requirements of customers

nationally. Meeting orders, due dates and NDC costs represent priorities for NDC, with the strategic aim to retain customers and sustain profits in a very competitive market place. The FMCG Brand Supplier modelled is the biggest supplier of savoury brands to this retail chain.

Distribution centres often perform more than one function within a RSC system, including make-bulk/break-bulk consolidation, cross docking, product fulfilment and as a depot for return management (Higginson & Bookbinder, 2005). According to Lu and Yang (2010) they are so important to RSCs that they are often seen as a point of leverage in terms of RSC performance in terms of cost, pipeline time and quality of service. For this reason, the researcher, with equal access to both organisations decided to use NDC as the primary case study participant for both data collection, observation and practitioner involvement. NDC is also the applied environment where the conceptual  $P^6$  Coefficient reference model was first used.

### **6.3 Communication & Consultation - The $P^6$ Coefficient Reference Model**

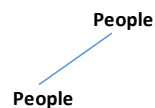
The  $P^6$  Coefficient Reference Model was first introduced to NDC in a formal research proposal presentation made by the researcher to the national operations director and a select number of cross-functional senior managers of NDC, including the operations manager, inventory manager, customer services manager and warehouse lead supervisor. Before the researcher had discussed a simulation project, the  $P^6$  Coefficient was used as a visual aid to channel discussion from the group on implementing a BPM project. It had the desired effect, with the triangle design and focus on people already gaining

momentum during the proposal presentation with feedback from the audience on creating a project steering group to develop requirements for each of the 6 P's.

As expected the  $P^6$  Coefficient Reference Model acted as a bridge between practitioner and a complex simulation-based framework whilst also acting as the equivalent to ISO31000's communication and consultation process for the remainder of the validation process. Although not a sequential reference model, the coefficient regressions were used as pre-simulation data collection methods and tools for educating the steering group.

### 6.3.1 People

Human capital is a concept in defining human resources within an organisation, focusing on all capabilities, knowledge, experience and skillsets of all the organisations employees and managers that adds value and future earnings to an organisation (Edvinsson, 2013).



**Figure 6.2  $P^{people}$  Coefficient Expression**

Building organisational support is a fundamental requirement of any case study, especially an embedded study where the participating organisation may be contributing to more than one unit of analysis. Using the  $P^6$  Coefficient Reference Model as a method, the researcher wanted to *educate for support* within the NDC organisation, based on the research of Bolstorff and Rosenbaum (2007) on organisational change projects using SCOR11. The authors recommend building a project team with an executive sponsor, an evangelist, and a core steering group plus analytical design support. As detailed in table

6.1, the steering group was made up of various NDC senior management with analytical design support from the researcher and a recently hired business graduate intern.

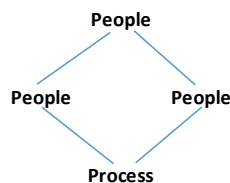
**Table 6.1 Embedded Case Study Steering Group**

<b>Role</b>	<b>Description</b>	<b>Actual Project Member</b>
Executive Sponsor	Organisation leader who will sign off resources and has the most to gain or lose from the project.	NDC Operations Director
Evangelist	Person within the organisation who can learn the framework and sell it to senior management.	NDC Operations Manager
Steering Group	Important decision makers within the organisation chosen by the evangelist to establish core team buy-in to the project.	Researcher Operations Manager Customer Service Manager Inventory Manager
Analytical Design	People who will spend time analysing the NDC, collecting data and building problem definitions.	Researcher NDC Graduate Intern

*Adapted from (P. Bolstorff & Rosenbaum, 2007)*

### 6.3.2 Process

A process can be defined as a; “structured, measured sets of activities designed to produce a specified output for a particular customer or market” (Davenport, 1993).



**Figure 6.3  $P^{process}$  Coefficient Expression**

Understanding organisational processes is critical to the success of any SCRM project. Continuing with the theme of educate for support outlined in section 6.3.2, and reflecting on the formative case study feedback on pre-read material for the steering group, the



researcher provided a detailed information pack, with basic flowcharts of core SCOR11 level 2 processes that best fitted the NDC organisation. These included:

**Table 6.2 SCOR11 Level 2 Pre-read Processes**

<b>Level 2 Process</b>	<b>Code</b>	<b>Core Activity</b>
Plan Source	<b>P2</b>	Aggregate Planning
Plan Make	<b>P3</b>	Aggregate Planning
Plan Deliver	<b>P4</b>	Aggregate Planning
Source Stocked Product	<b>S1</b>	Procurement
Source Make-to-Order Product	<b>S2</b>	Procurement
Make-to-Stock	<b>M1</b>	Production Planning
Make-to-Order	<b>M2</b>	Production Planning
Deliver Stocked Product	<b>D1</b>	Distribution Planning
Deliver Make-to-Order Product	<b>D2</b>	Distribution Planning
Deliver Retail Product	<b>D3</b>	Distribution Planning

With the pre-read material distributed to the steering group, the objective was to quickly obtain an overview of the RSC strategy of NDC and associated processes to fulfil such strategies. Through several meetings, both internally at the NDC and remotely through Skype calls, a profile of the NDC was quickly developed with the visual aid of thread diagrams with lower level flowcharts.

#### **6.3.2.1 NDC SCOR11 Level 1**

SCOR11 Level 1 processes are the core management processes that are put in place to achieve the overall RSC strategy of an organization. NDC's RSC strategy is that of agility and responsiveness in the distribution of consumer goods to retailers. For this reason, the company follows the SCOR11 SC model which is inventory driven, has high fill rates and short turnarounds, which is DTS. As a distribution service provider the company's core strategic management processes centre on P, S, D, and R, with the integrated framework acting as E.

### 6.3.2.2 NDC SCOR11 Level 2

SCOR11 Level 2 categorises and configures the sub-processes of Level 1. The NDC SCOR11 thread process diagram (figure 6.4) is a RSC relationship map that focuses on the material flow (D), material strategy (M, S) and planning processes (P). The thread diagram disaggregates the DTS model further into level 2 processes. There are two main inputs to the process, firstly the source of supply from NDC's regular supplier, who produce and hold product in stock for customers such as NDC to order periodically. The regular supplier (FMCG) sources raw material to produce the savoury foods category (S1), makes-to-stock for future customer orders (M1) and distributes customer orders to NDC within a LT of  $x$  days (D1). Supplier number 2 is a backup supplier NDC use when there are shortages in FMCG's inventory, peaks in demand, or when an expedited order is needed. NDC's trading department executes the S1 and S2 processes, while D1 (distribution) and D4 (deliver to retailer) are generic warehouse functions that receive, store, pick, load and deliver, along with information and capital flows. P2, P3 and P4 are the planning activities that support the movement of material and information along NDC's SC. The boundary of NDC's initial scope of inquiry using the  $P^6$  Coefficient Reference Model is highlighted in the thread diagram in figure 6.4 also. However the thread diagram exercise did introduce the steering group, visually and descriptively to the three echelon RSC that would be studied in Unit of Analysis 1.

### 6.3.2.3 NDC SCOR11 Level 3

Level 3 processes describe the steps performed to execute Level 2's more tactical processes. The sequence in which these processes are executed influences the performance of Level 2 and the overall RSC. The example used in this chapter is that of

NDC D1, or deliver stocked item to customer. Figure 6.5 shows the hierarchical breakdown of Level 2 process D1 into its Level 3 sub-processes, D1.1 to D1.15. These are generic activities within any distribution centre, ranging from process order inquiry to invoicing and was an important preparation for the more detailed BPMo required in the Unit of Analysis 2's DES study process.

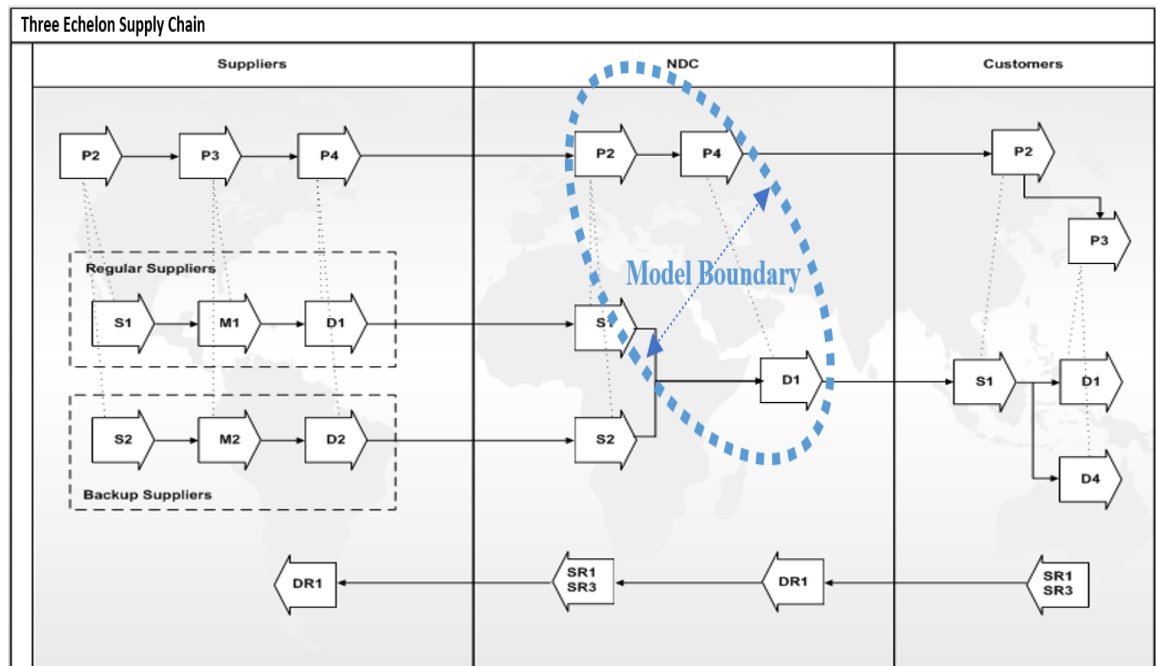


Figure 6.4 Thread diagram of NDC SC – SCOR11 Level 2.

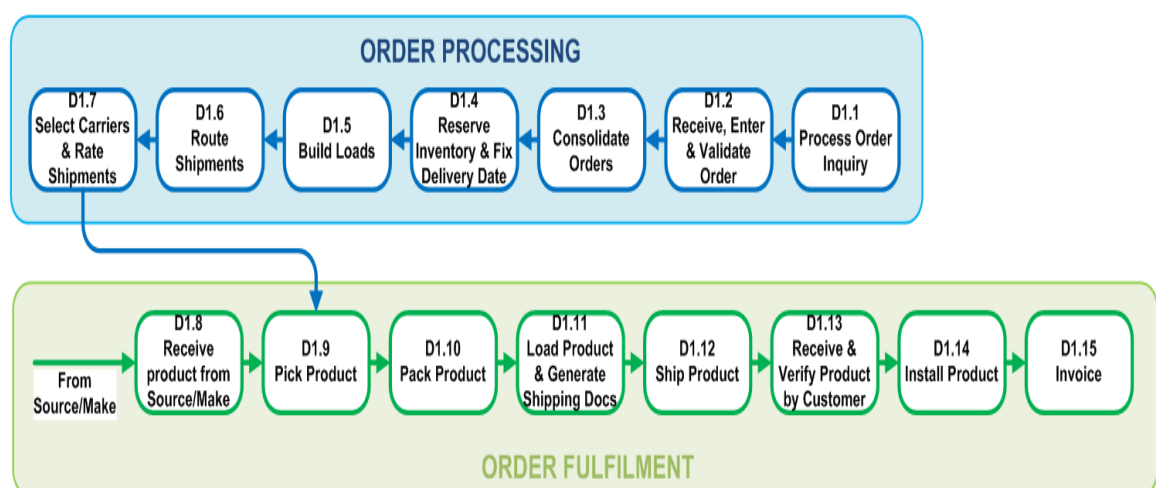
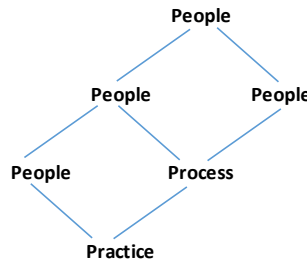


Figure 6.5 SCOR11 Level 3 Processes for D1

### 6.3.3 Practice

“Benchmarking is a continuous search for and application of significantly better practices that leads to superior competitive performance” (Watson, 1993), p.2).



**Figure 6.6  $P^{practice}$  Coefficient Expression**

As part of the  $P^6$  Coefficient Reference Model’s goal to support the communication and consultation phase of the project, the steering group reviewed best practices within the warehousing sector to increase the educate to support journey to developing a simulation study. NDC are a very effective organisation with brand new facilities and experienced, professional staff and efficient operations. They were already actively measuring core key performance indicators (KPI) for the majority of activities shown in table 6.3, although they did not have any external targets or benchmarks to measure them against, so an objective was set to find best practice benchmarks to compare against.

As part of the analytical design team, the researcher set the graduate intern an assignment to gather a minimum of 15-20 weeks’ data on the core KPI’s NDC use, highlighting which were most important to operations efficiencies and management decision making. The goal was to gain a better understanding of the type of metrics important to the organisation and influence what was the best source of benchmarking to search for. As expected the KPI report provided by the intern was generic and therefore any reliable industry best

practices would be applicable. The closest fit best practices to NDC's operations where that of the Warehousing Education and Research Council (WERC), who are one of the few professional research organisations focused on logistics management alone (WERC, 2017). A full list of WERC's warehousing best practice metrics can be seen in table 6.3 and were provided to NDC by the researcher for a comparative analysis. The researcher also provided WERC formulae used to measure each metric to ensure NDC used as close to these calculations as possible for consistencies.

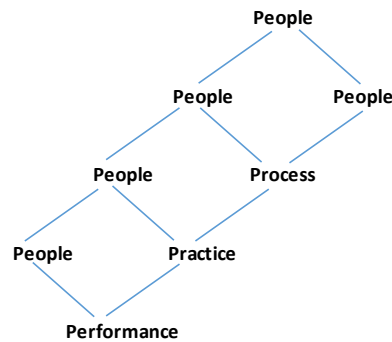
**Table 6.3 WERC Distribution Centre Best Practice Metrics**

Distribution Center Performance Metrics					
Customer Metrics	Poor Practice	Inadequate Practice	Common Practice	Good Practice	Best Practice
On-time Shipments	Less than 95.7%	>=95.7 and < 98%	>=98 and < 99.1%	>=99.1 and < 99.8%	>= 99.8%
Total Order Cycle Time	Greater than 72 hrs	>= 48 and < 72	>= 22.9 and < 48	>= 5.4 and < 22.9	< 5.4 Hours
Internal Order Cycle Time	Greater than 36 hrs	>= 24 and < 36	>= 8 and < 24	>= 3 and < 8	< 3 Hours
Perfect Order Completion Index	Less than 83.6%	>= 83.6 and < 94.8%	>= 94.8 and < 97.3%	>= 97.3% and < 99%	>= 99%
Backorders as a Percent of Total Orders	Greater than 7.4%	>= 2.2 and < 7.4%	>= 1 and < 2.24%	>= 0.2% and < 1%	< 0.2%
Backorders as a Percent of Total Lines	Greater than 5%	>= 2 and < 5%	>= 1 and < 2%	>= 0.2 and 1%	< 0.2%
Backorders as a Percent of Total Dollars/Units	Greater than 9.2%	>= 2.3 and < 9.2%	>= 1 and < 2.3	>= 0.2 and < 1	< 0.2 %
Internal Process Metrics	Poor Practice	Inadequate Practice	Common Practice	Good Practice	Best Practice
INBOUND METRICS					
Dock to Stock Cycle Time, in Hours	Greater than 18 hrs	>= 8 and < 18 hrs	>= 4 and < 8 hrs	>= 2 and < 4 hrs	< 2 hrs
Suppliers Orders Received per Hour	Less than 1 per hr	>= 1 and < 2	>= 2 and < 4.7	>=4.7 and < 10	>= 10 per Hour
Lines Received & Putaway per Hour	Less than 5 Lines per Hour	>= 5 and < 13.2	>=13.2 and < 20	>= 20 and < 48	>= 48 per Hour
Percent of Supplier Orders Received with Correct Documents	Less than 90%	>= 90 and < 95%	>= 95 and < 98%	>= 98 and < 99%	>= 99%
Percent of Supplier Orders Received Damage Free	Less than 95%	>= 95 and < 98%	>= 98 and < 98.5%	>= 98.5 and < 99%	>= 99%
On-time Receipts from Supplier	Less than 85%	>= 85 and < 91.8%	>= 91.8 and < 95%	>= 95 and < 98%	>= 98%
OUTBOUND METRICS					
Fill Rate - per Line	Less than 95%	>=95 and < 98%	>=98 and < 99%	>=99 and < 99.8%	>= 99.8%
Order Fill Rate	Less than 90.3%	>= 90.3 and < 97%	>= 97 and < 99%	>= 99 and < 99.8%	>= 99.8%
Lines Picked and Shipped per Hour	Less than 14 Lines per Hour	>= 14 and < 25	>= 25 and < 43	>= 43 and < 81	>= 81 per Hour
Orders Picked and Shipped per Hour	Less than 2 Orders per Hour	>= 2 and < 5	>= 5 and < 12	>= 12 and < 29	>= 29 per Hour
Cases Picked and Shipped per Hour	Less than 31 Cases per Hour	>= 31 and < 65	>= 65 and < 140	>= 140 and < 255	>= 255 Cases per Hour
Pallets Picked and Shipped per Hour	Less than 7 pallets per Hour	>= 7 and < 14	>= 14 and < 20	>= 20 and < 27	>= 27 per Hour
On-time Ready to Ship	Less than 95.4%	>=95.4 and < 98%	>= 98 and < 99%	>= 99 and < 99.8%	>= 99.8%
Percent of Orders Shipped Complete	< 92%	>= 92% and < 96%	>= 96% to < 98.5%	>= 98.5% and <99.3%	>= 99.3%
Order Picking Accuracy	< 98%	>= 98% and < 99%	>= 99% and < 99.5%	>= 99.5% and < 99.9%	>= 99.9%
STORAGE & INVENTORY CONTROL METRICS					
Average Warehouse Capacity Used	< 78%	>=78% and < 85%	>=85% to <87%	>=87% and < 95%	>= 95%
Peak Warehouse Capacity Used	< 90%	>= 90% and < 95%	>= 95% to < 98%	>= 98% and < 100%	>= 100%
Inventory Count Accuracy by Location	< 95%	>= 95% and < 98%	>=98% and < 99%	>= 99% and < 99.9%	>=99.9%
Lost Sales (% SKUs Stocked Out)	Greater than 5.7%	>=2% and < 5.6%	>= 1 and < 2%	>= 0.28 and < 1%	< 0.29%
Days of Finished Goods Inventory on Hand	>= 90 days	>= 51 and < 90	>=30 and < 51	>= 14 and < 30	< 14 days

*Adapted from (Manrodt, Vitasek, & Tillman, 2012)*

### 6.3.4 Performance

Performance is “a task or operation seen in terms of how successfully it is performed” (Oxford Dictionary, 2011).



**Figure 6.7 *Performance* Coefficient Expression**

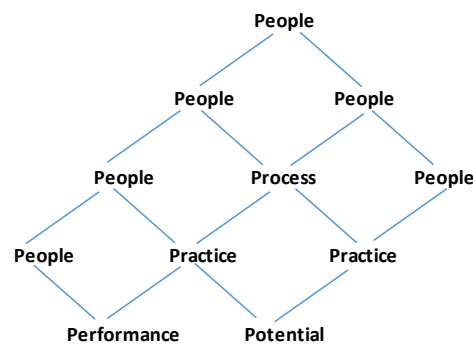
A selection of results from the comparative analysis can be seen in table 6.4. From a research study this was very powerful, as it laid the foundations for a very robust problem definition development to both the micro level Unit of Analysis 2, and start discussions on possible causal relationships with macro level risks from Unit of Analysis 1.

**Table 6.4 Best Practice Comparative Analysis**

KPI	Poor Practice	Inadequate Practice	Common Practice	Good Practice	Best Practice	Current NDC (WK 22 - 39)	Risk Level
Total Order Cycle Time	Greater than 72 hrs	>= 48 and < 72	>= 22.9 and < 48	>= 5.4 and < 22.9	< 5.4 Hours	Can vary greatly depending on customer and the order time	2
Internal Order Cycle Time	Greater than 36 hrs	>= 24 and < 36	>= 8 and < 24	>= 3 and < 8	< 3 Hours	48 hours	1
Dock to Stock Cycle Time, in Hours	Greater than 18 hr	>= 8 and < 18 hrs	>= 4 and < 8 hrs	>= 2 and < 4 hrs	< 2 hrs	This is a putaway?? Cannot be measured accurately	1
Lines Received & Putaway per Hour	Less than 5 Lines per Hour	>= 5 and < 13.2	>= 13.2 and < 20	>= 20 and < 48	>= 48 per Hour	19.79 Per Hour	2
Percent of Supplier Orders Received Damage Free	Less than 95%	>= 95 and < 98%	>= 98 and < 98.5%	>= 98.5 and < 99%	>= 99%	Currently not Measured	1
On-time Receipts from Supplier	Less than 85%	>= 85 and < 91.8%	>= 91.8 and < 95%	>= 95 and < 98%	>= 98%	Currently not Measured	1
Lines Picked and Shipped per Hour	Less than 14 Lines per Hour	>= 14 and < 25	>= 25 and < 43	>= 43 and < 81	>= 81 per Hour	104.3 Lines Per Hour	3
Orders Picked and Shipped per Hour	Less than 2 Orders per Hour	>= 2 and < 5	>= 5 and < 12	>= 12 and < 29	>= 29 per Hour	Not relevant to us??	2
Cases Picked and Shipped per Hour	Less than 31 Cases per Hour	>= 31 and < 65	>= 65 and < 140	>= 140 and < 255	>= 255 Cases per Hour	170 Cases per Hour	3
Percent of Orders Shipped Complete	< 92%	>= 92% and < 96%	>= 96% to < 98.5%	>= 98.5% and < 99.3%	>= 99.3%	98.60%	3
Order Picking Accuracy	< 98%	>= 98% and < 99%	>= 99% and < 99.5%	>= 99.5% and < 99.9%	>= 99.9%	99.97%	3
Average Warehouse Capacity Used	< 78%	>= 78% and < 85%	>= 85% to < 87%	>= 87% and < 95%	>= 95%	65 - 68%	1
Lost Sales (% SKUs Stocked Out)	Greater than 5.7%	>= 2% and < 5.6%	>= 1 and < 2%	>= 0.28 and < 1%	< 0.29%	Total Out of Stock = 1.34%, (Breakdown: No Stock = 1.19%, Late Deliveries from Suppliers = 0.11%, NDC Miss Pick = 0.026%)	2
Days of Finished Goods Inventory on Hand	>= 90 days	>= 51 and < 90	>= 30 and < 51	>= 14 and < 30	< 14 days	26.46 Days	3

### 6.3.5 Potential

Organisations are increasingly developing integrated approaches to risk management in order to improve the management of potential threats and opportunities to the business (ISO, 2009a).



**Figure 6.8 *P<sup>potential</sup>* Coefficient Expression**

As an educate for support exercise for the main simulation study, the steering group performed a detailed time and motion study on a select few of the core activities detailed in table 6.4. The objective of this exercise was to measure important value added activity times as accurately as possible, or in other words find the potential activity times of the internal processes. Based on the eight step time and motion study outlined by Heizer and Render (2014), p.446), a sample of the following activities were measured; Unloading; Putaway; Replenishment; Picking; and Marshalling (Loading). Using the eight step process the objective is to measure the true activity time of a labour intensive activity by determining the standard time based on the average observed times adjusted with the following factors:

1. *Performance Rating Factor* – An efficiency factor based on worker performance versus best practice and also observations from researcher.

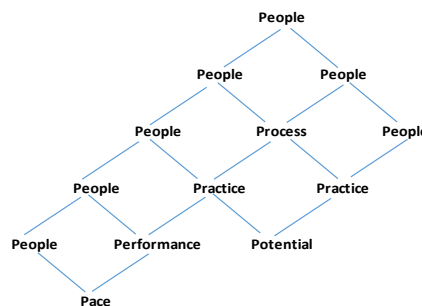
2. *Allowance Factor* – Delay factors such as fatigue, noise, physicality of work etc.

The final results of the time and motion study are shown in table 6.5, with details on a sample report in Appendix A. The deviation from observed averages was significant but based on discussions with the steering group, the standard times were validated on experience and referral back to system driven KPI metrics. As all picking, for example, is voice activated, NDC's ERP system holds accurate start and finish times for each order picked, with the standard time calculation was closer to system data than the observed time. The time and motion study was popular within the steering group and the operations manager in particular was interested in the allowance factor, as they had always wanted to find a way of factoring fatigue in KPI's.

**Table 6.5 Time and Motion Study Results**

Activity	Metric	Observed Average Time (min)	Performance Rating Factor	Normal Time (min)	Allowance Factor	Standard Time (min)	Deviation from Observed Average (min)
Unloading	per Pallet	1.03	0.97	0.9991	0.02	<b>1.01949</b>	<b>-0.011</b>
Quality Check	per Pallet	2.1476	0.97	2.083172	0.1	<b>2.314636</b>	<b>0.167</b>
Putaway	per Pallet	3.125	0.71	2.21875	0.04	<b>2.311198</b>	<b>-0.814</b>
Replenishment	per Pallet	3.5	0.82	2.87	0.04	<b>2.989583</b>	<b>-0.510</b>
Picking	per Case	0.355	0.88	0.3124	0.08	<b>0.339565</b>	<b>-0.015</b>
Pallet Wrap	per Pallet	1.5	0.84	1.26	0.06	<b>1.340426</b>	<b>-0.160</b>
Loading	per Pallet	3.18	0.78	2.4804	0.04	<b>2.58375</b>	<b>-0.596</b>

### 6.3.6 Pace



**Figure 6.9  $P^{pace}$  Coefficient Expression**



The momentum of interest in the *potential* Coefficient Expression within the steering group was significant, validating the combination of coefficient properties explained in section 5.3.3. The progress from creating a steering group, through processes and practices to actively seeking to understand how to potentially optimise activities was encouraging for the integrated framework implementation as a whole. To sustain the interest and momentum, and before embarking on Unit of Analysis 1, the researcher decided to use the information already gathered to build a value stream map (VSM) (figure 6.9) for the operations manager to report back to the project executive sponsor, NDC's operations director. To identify the sources of waste, non-value added activities and potential of improvement, value added activities can be mapped using VSM (Rother & Shook, 1998).

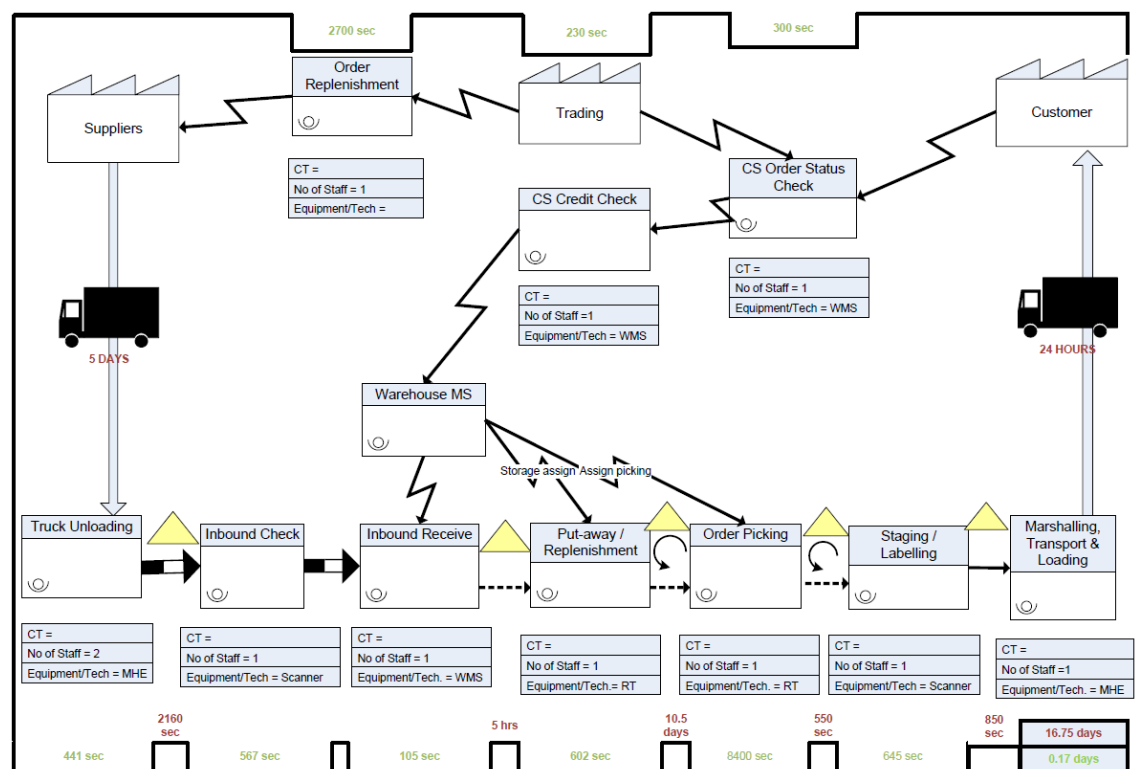


Figure 6.10 Value Stream Map of NDC

A value stream can be defined as the collection of activities (value added and non-value added) that are operated to produce a product or service or a combination of both to a customer (Singh, Kumar, Choudhury, & Tiwari, 2006). Although not in scope for this research study, the researcher believed the VSM map would increase the pace of feedback from the executive sponsor to release resources for the more labour hour heavy simulation studies.

### **6.4 Unit of Analysis 1 – Three Echelon RSC**

NDC's extended three echelon RSC was studied in this section using the framework design outlined in selection 5.4.4. The focus of this unit of analysis was macro level causal relationship behaviours of the entire system under both internal and external sources of disruptive risk.

#### **6.4.1 Problem Articulation**

As explained in chapter 5, a SD study was chosen as the SCRM research method for this stage of the embedded case study. As Unit of Analysis 1 extended beyond the NDC's organisational boundaries, the members of the steering group were insufficient to articulate the problems faced by the whole RSC system. For this reason, members of FMCG's business unit in Ireland were invited to participate in this step of the SD project, and included a brand category manager, customer account manager, and a RSC customer service specialist.

##### **6.4.1.1 Informal Delphi Study**

Due to access restrictions to both facilities and practitioners during the problem articulation process, the researcher decided to follow a basic Delphi Study (Section

5.4.1.2) structure and gather data through brief open questionnaires. The aim of the questions was to identify risks perceived important to the practitioners. For consistency and reduced researcher bias, the questions were categorised directly from the SCC's top challenges to SCM, whilst referring to equation (2)'s risk philosophy.

Top 5 RSC Challenges	Delphi Study Questions
1. Customer Service	What are the main sources of risk that affect your organisation getting the right product to the right customer at the right time?
2. Cost Control	Does your organisation measure the cost of RSC disruption?
3. Planning & Risk Management	Does your organisation manage RSC risk?
4. Relationship Management	What is your understanding of relationship management within your organisations RSC?
5. Talent	Can you please comment openly on RSC talent and knowledge retention within your organisation?

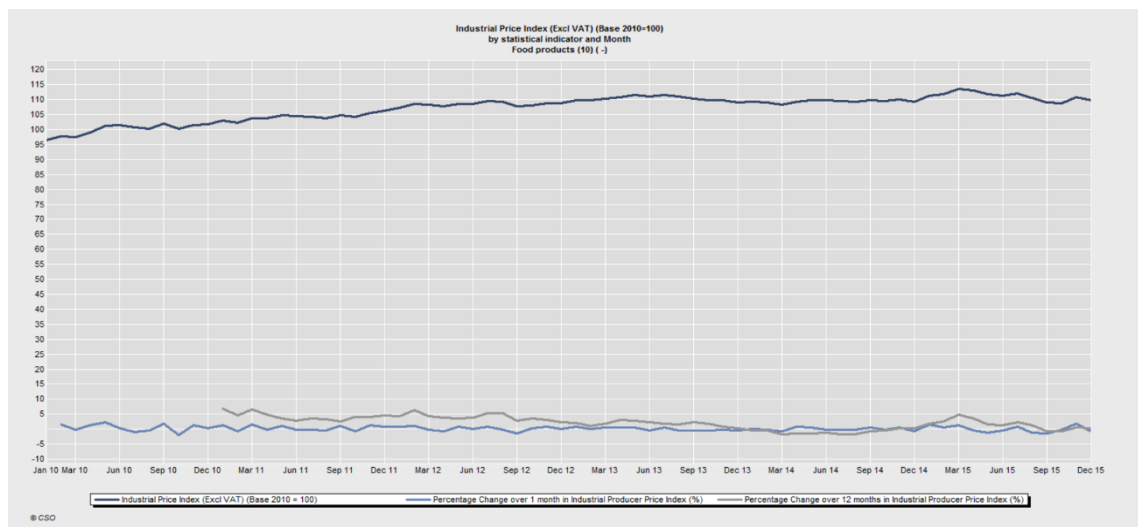
### 6.4.1.2 Disruption Variables

The main outcome of the Delphi Study was that disruptions were a key variable, with 80% of answers discussing disruptive risks for all five RSC challenges. From a customer service perspective there was concern about both demand and supply disruptive events to the RSC, including sudden increases in demand due to promotions or supply disruptions downtime with a manufacturing line. Disruption to service based on knowledge loss due to staff turnover and retirements was also seen as a key risk variable to consider. Feedback also showed there was active risk management within all function of the three echelon RSC but mainly finance. The Delphi study, although not sophisticated gained results strikingly similar to the challenges outlined in section 2.4.

### 6.4.1.3 Time Horizon

Articulating a macro level problem is a difficult task, therefore sometimes it is beneficial to look back in time to look at trends and behaviours that might influence how far in the future the simulation study needs to look. The main time horizon used in this research

study was that of the wholesale industrial price index for food products, as in figure 6.11. This graph articulates one of the core challenges of grocery FMCG markets, the sharp rise in wholesale food prices between 2010 and 2012, at over 20%. For the SD model time horizon it was also important as a reference mode, the fact that the price index had remained steady between 2012 and 2015 gave the steering group confidence in initially investigating macro level behaviours for between a 1 and 3 year length.



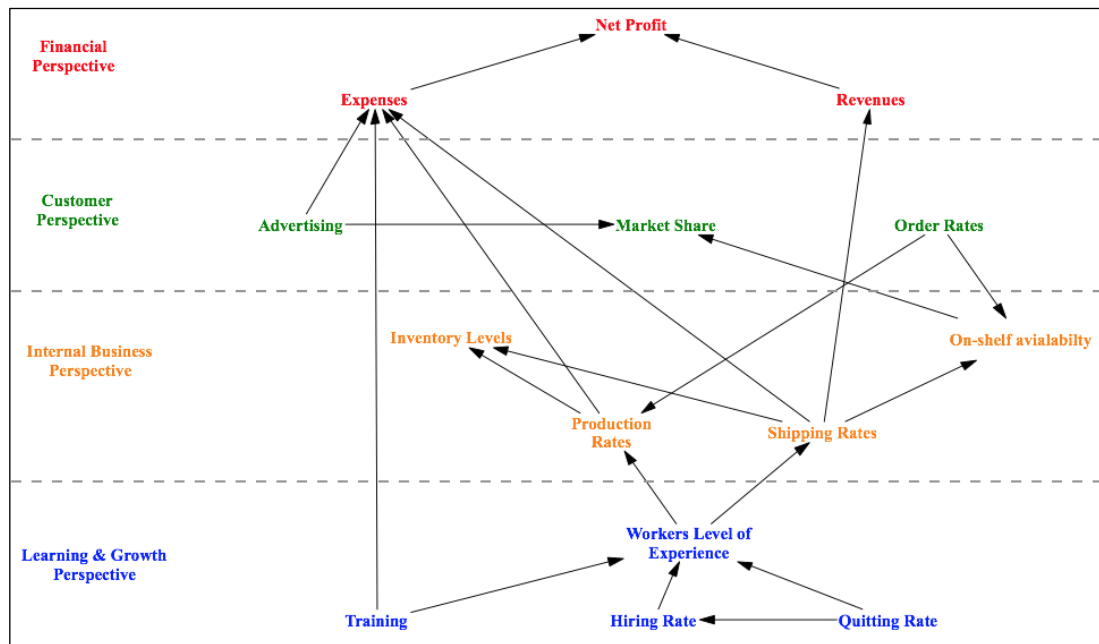
*Source: (CSO, 2016)*

**Figure 6.11 Industrial Price Index for Food Products 2010-2015**

### 6.4.1.4 Strategic BSC Road Map

A BSC strategy map was also created to achieve an external, cross-organisational view of important variables within the system. As the BSC structure closely followed the theme of the RSC challenges in section 6.4.1.1, and as it encourages the use of non-financial metrics it was seen as an effective fit in articulating the complex problems of this system. In the roadmap, each important strategic variable was validated by both FMCG and NDC organisations and separated into the BSC categories. The BSC roadmap has influenced the practitioners to apply system thinking to the simulation study and allowed them to

visually see the relationship links, for example between training and on-shelf availability, or shipping rates and revenue.



**Figure 6.12 RSC Strategic BSC Roadmap**

#### 6.4.1.5 Dynamic Problem Definition

Ultimately, the purpose is to provide decision makers across the studied RSC system with a comprehensive model that can be used to understand unique risk behaviours, particularly effects of disruptions on the RSC performance over a 1-3 year period.

#### 6.4.2 Formulation of Dynamic Hypothesis

The formulation of the dynamic hypothesis will be developed using the following three stages; steering group theories of problematic behaviour, causal loop diagrams, and stock and flow mapping. Based on the expertise and experience of the steering group practitioners from both FMCG and NDC, coupled with the information gained from the problem articulation stage, the following current theories into the system problematic behaviour have been developed.

### **6.4.2.1 Problematic Behaviour Theories**

#### **6.4.2.1.1 Promotions**

Although FMCG's market share of the savoury category in Ireland is very stable at 60%, there are constant efforts made to increase growth in the market. Primary strategic growth initiatives historically centred on brand market investment (BMI) which focuses on advertisement channels and promotions. These are typically; Buy one get one Free (BOGOF); % off marked price or % free incentives; Online competitions and prizes; and Media campaigns and PR events. Apart from the promotion costs itself, advertising costs also increase during the discount period to increase potential demand for the products.

#### **6.4.2.1.2 Production Disruption**

The main reasoning behind this scenario disruption is that Ireland as a market has only a 1% market share of total FMCG Europe sales turnover. It is a common occurrence that either Ireland's production capacity is reduced or supply lead times extended due to larger countries such as the UK, France and Germany getting scheduling priority. Ireland's production runs are normally placed at the end of these larger throughputs. The other reason for this disruption is that producing using the full capacity may lead to a drop in this capacity (e.g. maintenance problems) that will cause a decrease in production.

#### **6.4.2.1.3 Staff Turnover (Quitting Rate) FMCG**

According to IBEC (2013), there is on average a 7.5% annual staff turnover rate in the wholesaler/grocery sector in Ireland. This is a close fit to FMCG's quit rate, but it seems to happen in clusters during the year. There are two drivers of these quitting clusters: Firstly, in certain departments within FMCG, there is an aging workforce who retire at the same time annually before the new financial year ends and they gain the most out of

annual bonuses and pension lump sums. Secondly, as a large multi-national, FMCG is continuously reviewing its organizational structure to reduce costs and optimize efficiency. There is a trend of outsourcing roles moving positions in-house to cheaper countries within FMCG. For example, moving the Irish RSC planning function to FMCG in Poland.

### **6.4.2.1.4 Staff Turnover (Quitting Rate) NDC**

Similar to the previous scenario, in this scenario it is assumed that during the first two quarters of the model run, one experienced worker quits every month from the NDC. That will lead to a drop in the overall experience level within NDC and consequently delivery lead time will raise. The staff turnover rate in NDC is driven by a younger workforce who move roles more frequently.

### **6.4.2.2 Causal Loop Diagrams**

There is an emphasis on particular sub-modules in the model which is related to the scenarios agreed with the company. Causal loop diagrams for the main variables within these sub-modules will be highlighted and described in this section. The flow of products through the RSC from FMCG (upstream) to the shelves of NDC retailers (downstream) is illustrated in figure 6.13. The market share is the main driver of the feedback loops that control the retailer's behaviour. The products availability on-shelves of the retailers positively affect this market share, and consequently the overall consumption of the products leads to reducing product availability on-shelves (loop B1). The change in consumption has a delayed effect on the perceived market demand for the retailers, based on that, they adjust their ordering decisions from the NDC. These decisions affect the overall orders backlog of the NDC and, consequently, the shipping of the products from

the NDC to the retailers which, at the end, affect both on-shelf availability and market share (loop R1). Loops B2, B3, B5, B6, B7 and B8 demonstrate how the internal system at the three echelons of the underlying RSC are seeking a balanced state (equilibrium) where they will be able to regulate their orders' rates in order to fulfill customers demand taking into consideration the upstream delivery lead time (e.g. production lead time for FMCG). On the same direction, loop B4 demonstrates the embedded effort of the overall chain towards a balanced state as well. Hence, this RSC is expected to seek a steady state under disruptions. It will lose the current steady state for a certain time period but the internal dynamics of its components interactions will work on either returning to that state or finding a new one.

The key decision at each echelon in the underlying RSC is the daily number of cases (order size) to be ordered subject to two factors. The first factor is the "demand forecast" (expected demand): in this model it is assumed that retailers adjust their expected demand based on the last two weeks consumption while both NDC and FMCG do that based on last month demand from their downstream partners. These forecasting mechanisms create delayed effects of any sudden changes (disruptions) in consumer's behaviour on retailers, NDC and FMCG decisions. The second factor is the "delivery lead time": within this RSC there are three lead times: 1) production lead time for FMCG; 2) delivery lead time from FMCG to NDC; and 3) the lead time from NDC to retailers. In this model, these lead times are affected by the experience level of workers within FMCG for the first two lead times and the experience level of the workers in NDC for the third one.



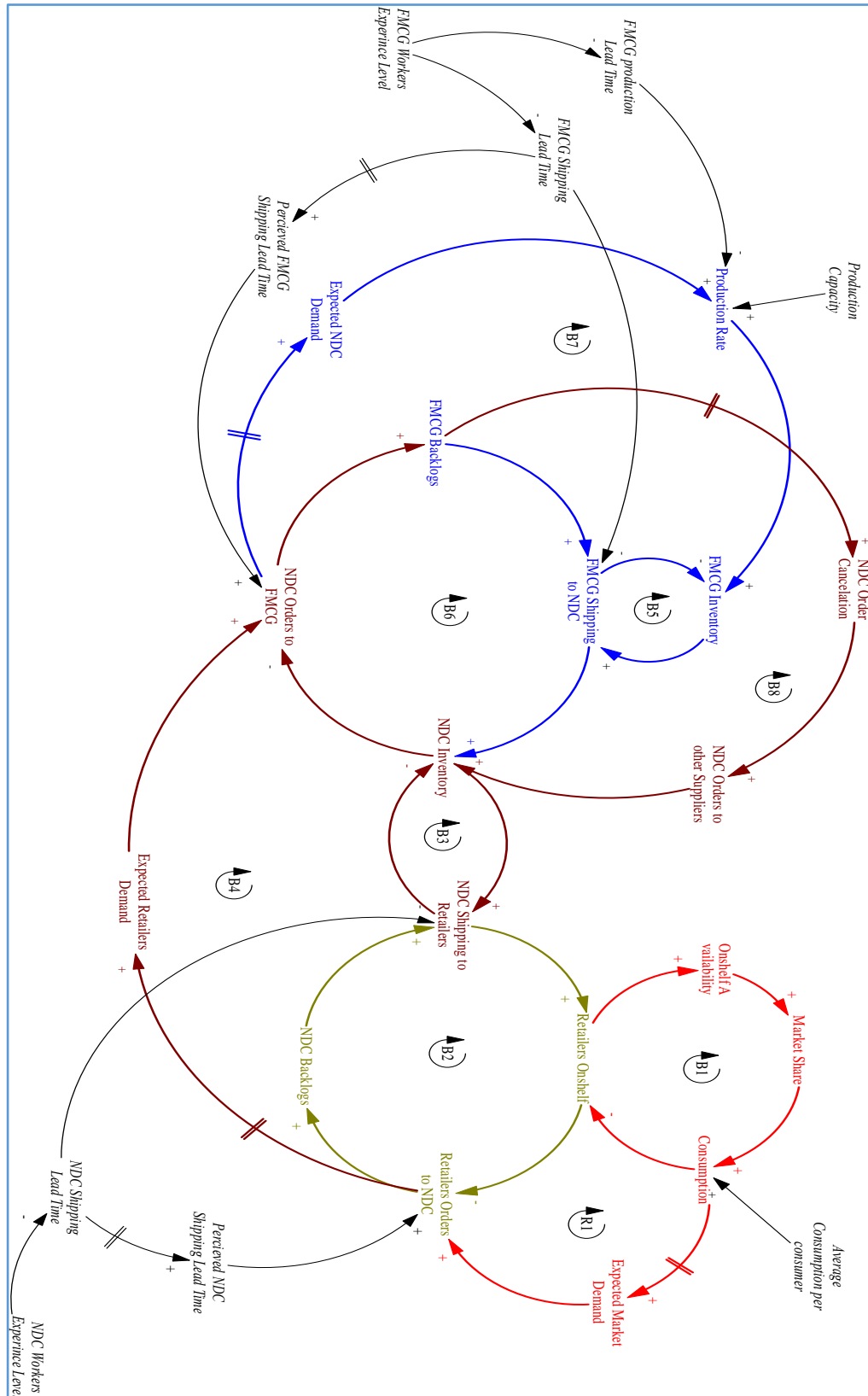


Figure 6.13 The Feedback CLD of the Underlying Three-Echelon SC

Causal loops that are responsible for the changes in the overall experience level within FMCG and NDC are shown in Figures 6.13 and 6.14. Similar to “demand forecast”, there is a delay to perceive the changes in the lead time from one echelon to its downstream customers. As a result of this delay, along with the aforementioned delay of expected demand, there will be a delayed response of decision makers at all echelons to adjust their daily order sizes to upstream suppliers. That will create additional delayed effects back and forth on the other variables in the system (e.g. inventory levels).

CLD’s are very effective in the beginning of a SD modelling study to support the problem articulation stage and also to capture mental models of the practitioners and of the researcher as an observer (Sterman, 2000). But one of the most important limitations of CLD’s is that they are unable to capture the stock (inventory/accumulations) and flow (input/output rates) structure of the studied RSC system.

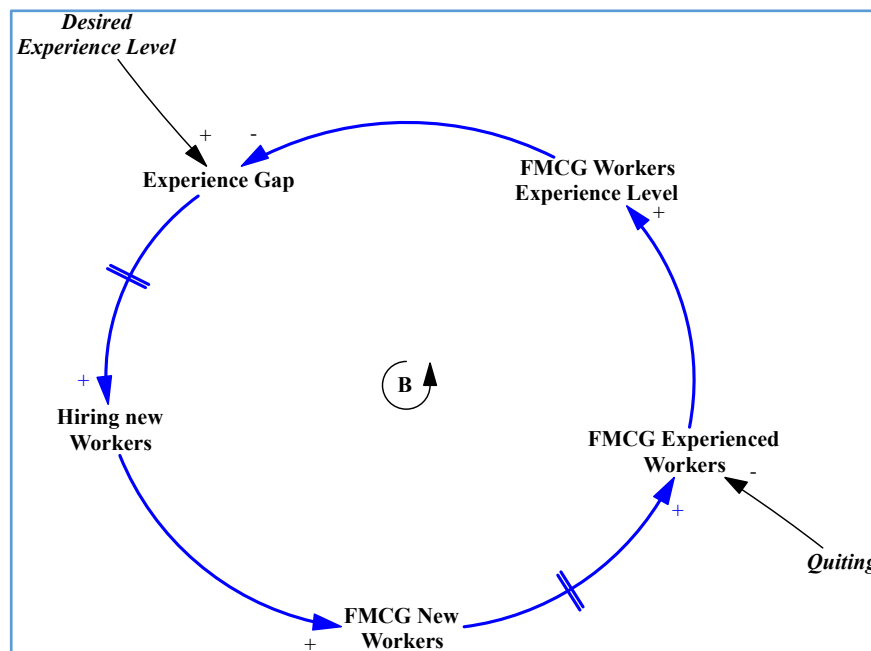
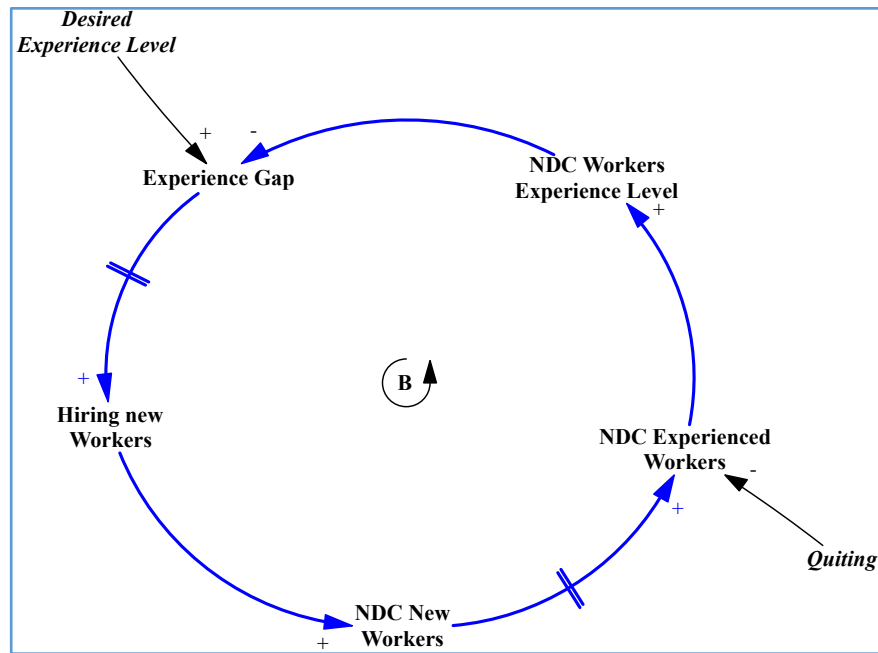


Figure 6.14 The Feedback Loop Diagram of Worker Sectors in FMCG

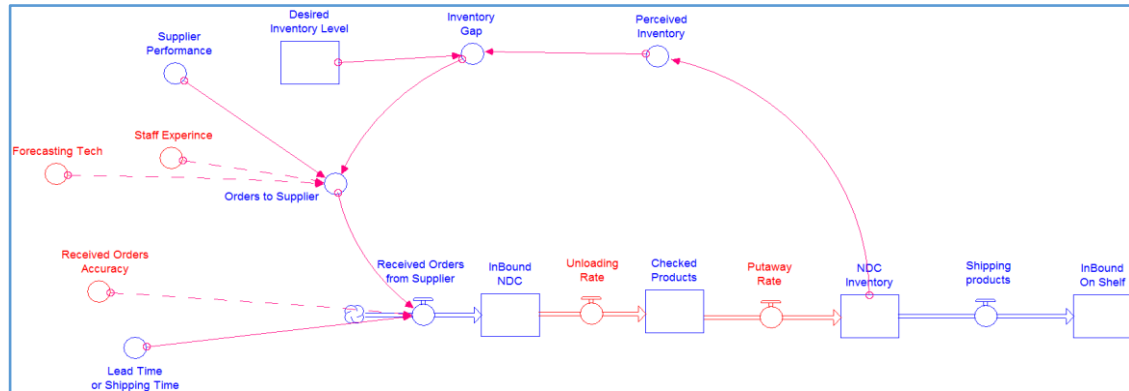


**Figure 6.15 The Feedback Loop Diagram of Worker Sectors in NDC**

### 6.4.2.3 Stock and Flow Maps

As stock and flows, coupled with feedback loops are the fundamentals behind SD, the structure of the CLD's needed to be transformed into stock and flow maps. Figure 6.16 is a segment of the extensive stock and flow map that has been built for this research study. The valves (circle with large arrow) are the input and output rates feeding each stock accumulator (rectangles). For example the input rate for orders from suppliers accumulate in the NDC inbound area until they are unloaded at the specific rate into the quality check queue. Once checked the continuous flow continues with the Putaway activity. The independent circles are constants and variables that generate equations for the rate of flow into and out of stocks via the valves.

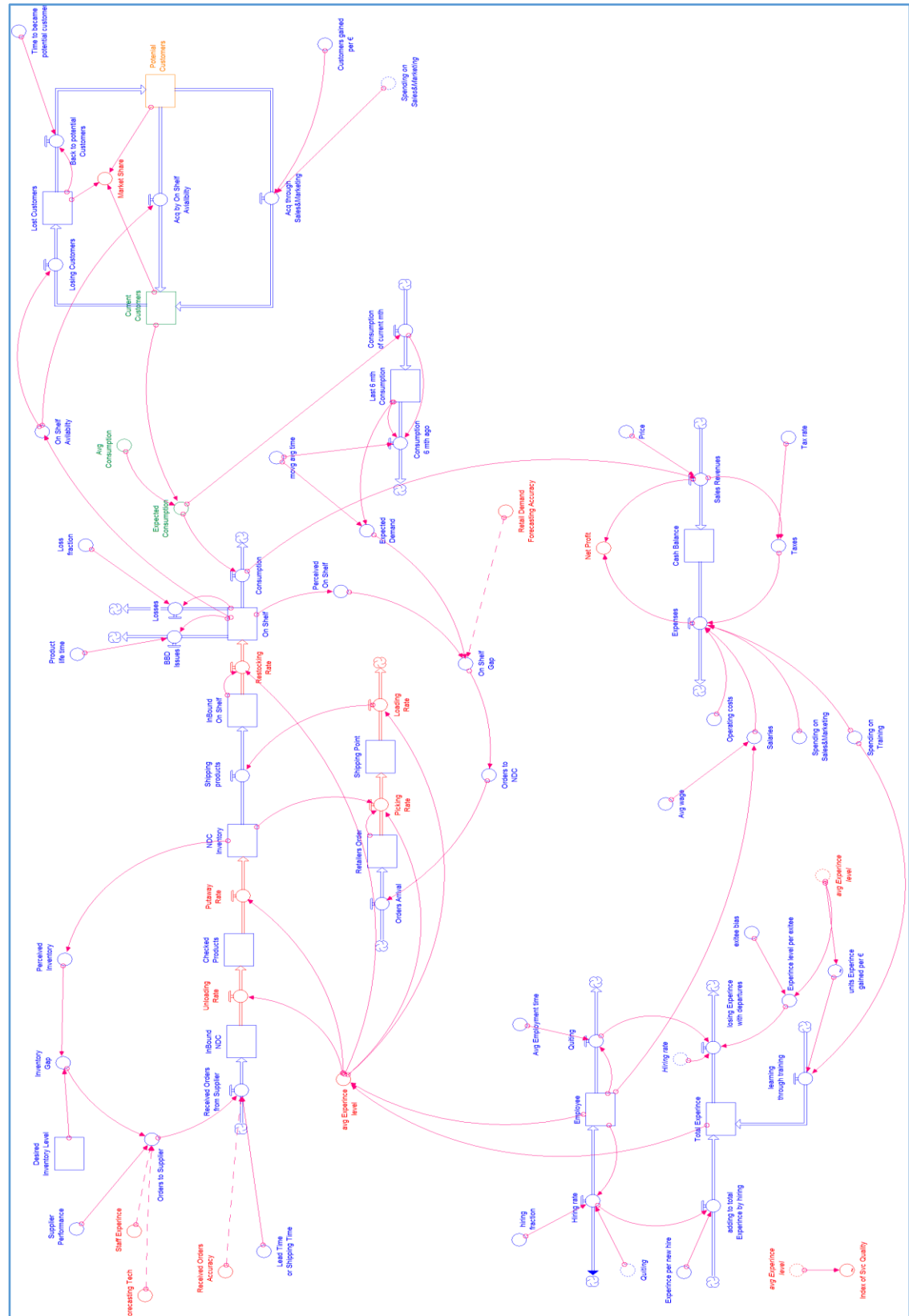
No data or information has been embedded into the stock and flow diagrams at this stage, they are still only conceptual maps that the case study practitioners have assisted the researcher in creating to accurately add a continuous flow to the CLD structure.



**Figure 6.16 Stock and Flow of NDC**

### 6.4.3 Formulation

The formulation of the stock and flow map to enable simulation testing and experimentation was an extensive exercise. With over 140 different nodes to formulate, this was a continuous task that started long before the building of the SD model. Collaboration with the case study practitioners was essential and the researcher gathered as much data as possible from initial communication and consultation stages (Section 6.2) and from FMCG and NDC ERP. The researcher also gather formulation data during the CLD modelling, especially when working with practitioners. The intern at NDC and the customer service specialist at FMCG were important channels of information. Any constants and variables needed, that could not be accessed through the case study practitioners were sourced through industry standards, best practices and statistical assumptions. A full representation of the stock and flow map that was formulised can be seen in figure 6.17 and a snapshot of the embedded formulae can be seen in figure 6.18. All equations can be found in Appendix B and further stock and flow maps in Appendix C, note the data has been processed by the researcher and is non-attributable to either NDC or FMCG. The main output metric of *Cash-flow* and *Market-share* were modelled based on the TCO and system capability VAR metrics (section 5.4.7) respectively.



**Figure 6.17 Complete Stock and Flow Diagram of Unit of Analysis 1**

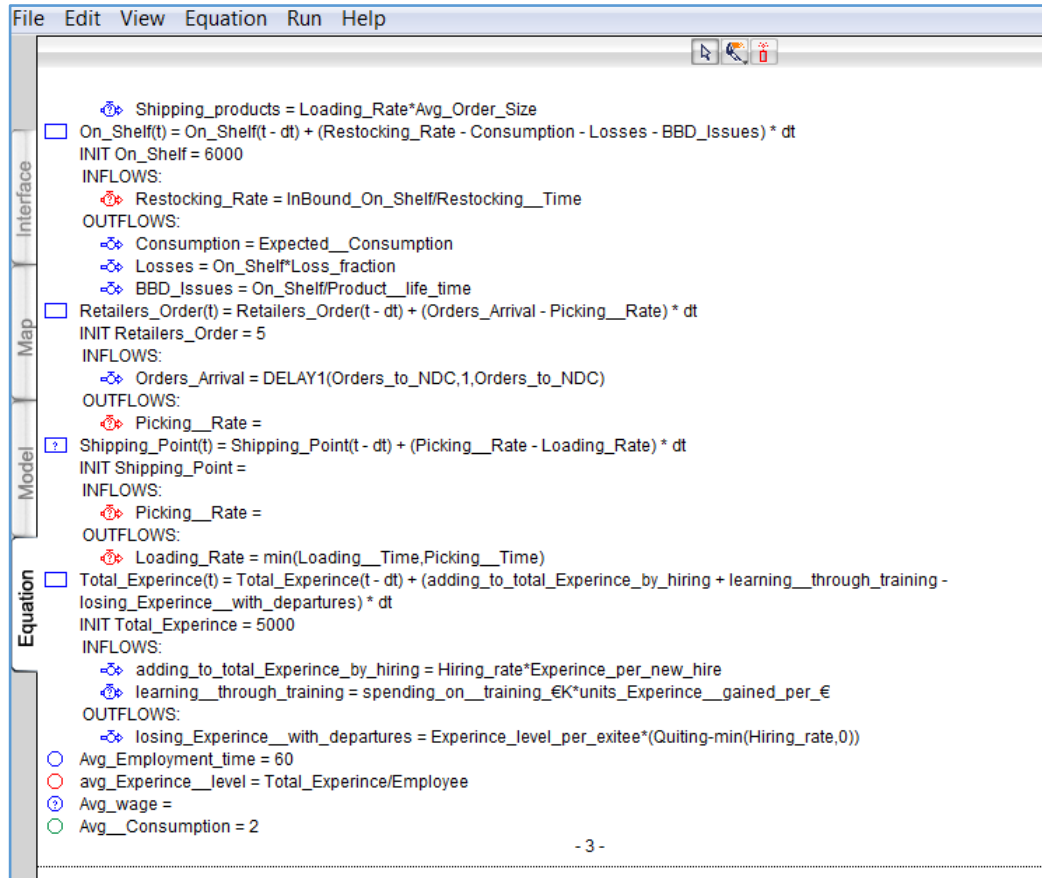


Figure 6.18 SD Model Equations

#### 6.4.4 Testing and Policy Evaluation

Based on interviews with NDC and FMCG decision makers, an agreed set of scenarios of disruptions in RSC are developed to examine the dynamical behavior of the extended RSC. The model is initialized in order to be in a steady state with constant consumer demand since the purpose of the study is finding out the impact on the overall stability of the RSC network (Gonçalves, Hines, & Sterman, 2005). In the steady state, the consumer demand is constant and therefore the flow of products from the production phase at FMCG down to the retailers are relatively steady. Steady state in this context means business as usual scenario (BAU). The model was also tested under extreme disruptive

conditions and reacted as expected. A brief description of the disruption scenarios is given below, based on section 6.4.2.1 information.

### **S1 - Promotions**

After the increase in demand for the category during a promotion, there is at least a 20% reduction in demand for 2-4 weeks due to customers having full cupboards of the product at home to use. This pattern is also evident with the wholesaler as they also are fully stocked because of the promotional discount that was available. Also notable, is that the NDC are 15 – 16% of FMCG Retail Customer base and their savoury category products represents 90% of NDC retailers sales of the overall savoury category. In the model, this scenario assumes that after one month from the steady state the promotion becomes active and the daily consumption raises by 50% for two months (the promotion period) and after that the consumption will drop by 20% of its original pattern for one month before it returns to that pattern. S1 is used to that scenario in this work, this scenario will be used as well in the next scenarios in conjunction with the other chosen disruptions.

### **S2 - Production Disruption**

In the model to simulate such a production shortage scenario, it is assumed that after six weeks from when the promotion will begin, the production capacity will drop by 25% and the production lead time will raise by 50%. The reference to this scenario will be S2.

### **S3 - Staff Turnover (Quitting Rate) FMCG**

The assumption for this scenario in the model will be based on the first driver, so that the model assumes that during the first two quarters of the model run one experienced worker quits every month from the FMCG. That will lead to a drop in the overall experience level

within FMCG and consequently both production and delivery lead times will raise. This scenario is referred to as (S3).

### **S4 -Staff Turnover (Quitting Rate) NDC**

Similar to the previous scenario, in this scenario it is assumed that during the first two quarters of the model run one experienced worker quits every month from the NDC. That will lead to a drop in the overall experience level within NDC and consequently delivery lead time will raise. S4 is used to refer to this scenario.

### **S5 - Staff Turnover (Quitting Rate) FMCG and NDC**

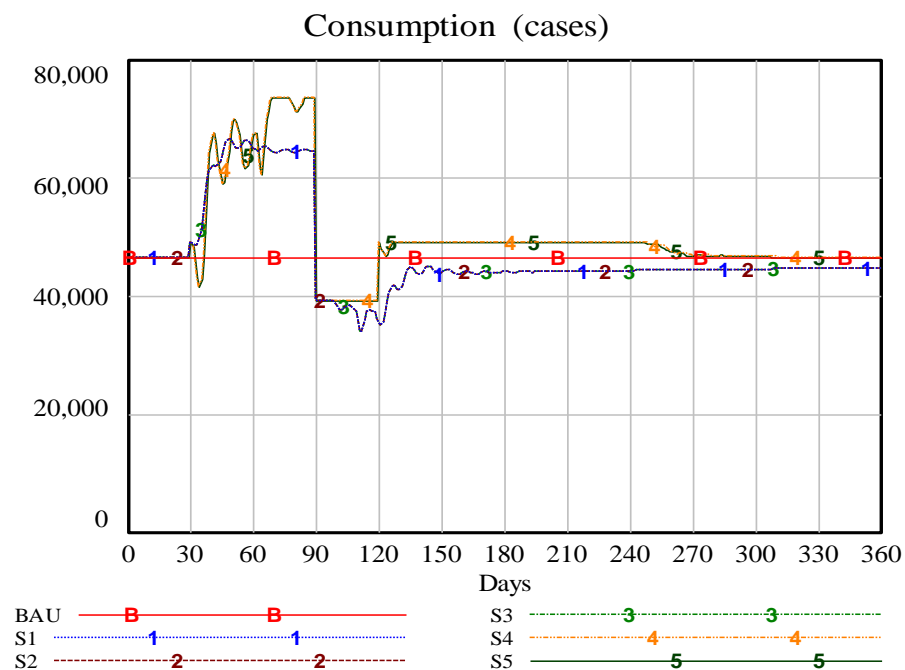
This scenario combines the previous two scenarios (S3 and S4). It is assumed that during the first two quarters of the time period, one experienced worker quits every month from both FMCG and NDC. That will lead to a drop in the overall experience level within the FMCG and NDC and consequently production and delivery lead times will raise. S5 is used to refer to this scenario.

#### **6.4.4.1 Simulation Analysis and Results**

The model is used to simulate the underlying RSC for one year. As mentioned previously, the system is initialized in a steady state, and all the scenarios take place after one month from the run start. The promotions scenario is included solely in S1 and in the other four scenarios in conjunction with other disruptions. Simulation results show the effect of promotions on consumption behaviour. In all scenarios, one can see that consumption has raised during promotions period and then dropped for one month before it raises again to levels close the BAU's consumption (Figure 6.19). On the other side, the market share has dropped when the promotions become active (Figure 6.20). Loops B1 and R1 in Figure 6.13 control dynamics of the market share, when consumption raised, B1 change



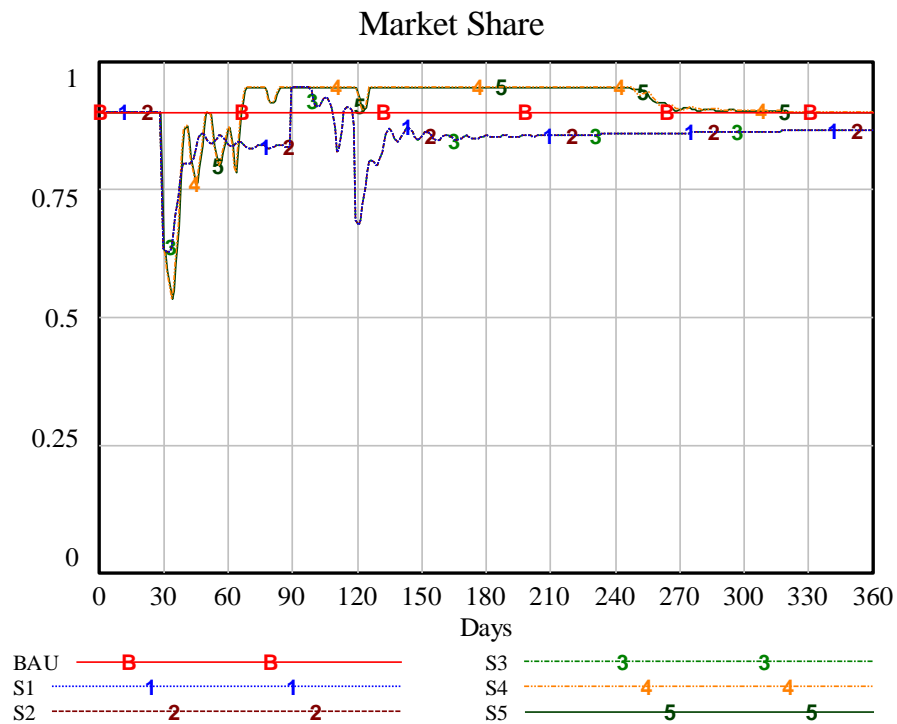
the on-shelf level to a lower value and hence the market share. The feedback effect is supposed to reduce the consumption, but the exogenous impact of the average consumption per consumer influenced that reduction. Since B1 continued to bring down the market share until R1 becomes active, when the retailers started to adjust their daily order sizes in an attempt to absorb the rise in consumption. The shift in dominance (J. D. Sterman, 2000) from B1 to R1 after approximately two weeks from the promotions will encourage the reinforcement growth of the market share by growth of the consumption until B1 retrieves the dominance back at the end of simulation and limits that growth back to BAU's market share (scenarios 4 and 5) or at a new stable point (scenarios 1 to 3).



**Figure 6.19 Consumption (cases)**

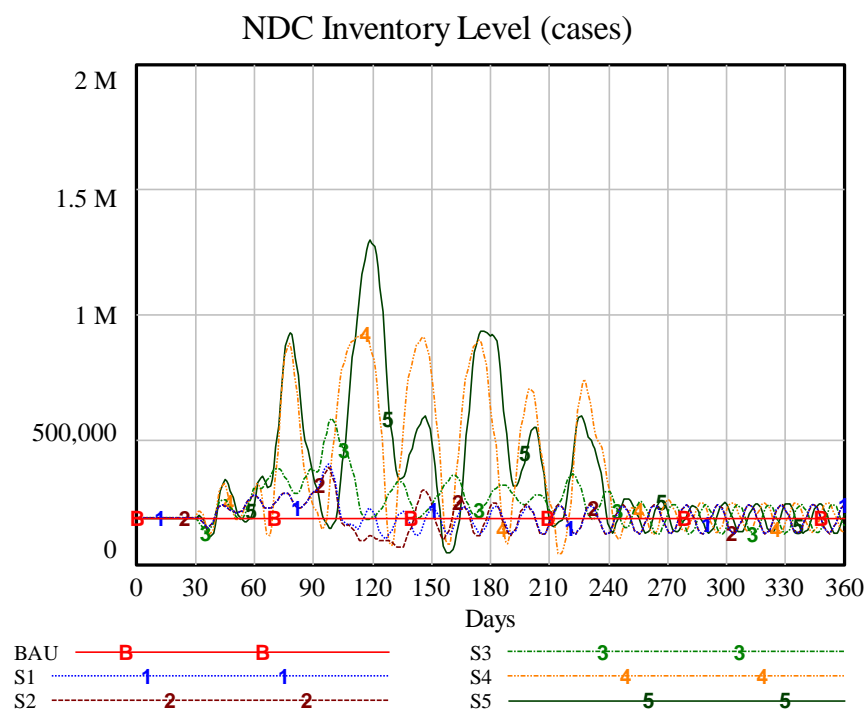
This tug of war between B1 and R1 is repeated during the simulation runs and has impacted the retailers on-shelf levels resulting in oscillatory behaviour accompanied with high amplitudes in scenarios S4 and S5 (Figure 6.21). The reason for this significant

difference in behaviour from the market share's behaviour, is that on-shelf level is involved with two other loops (B2 and B4) and both of them were incentivized by the NDC workers quit disruption introduced in S4 and S5 during the first two quarters of the simulation.

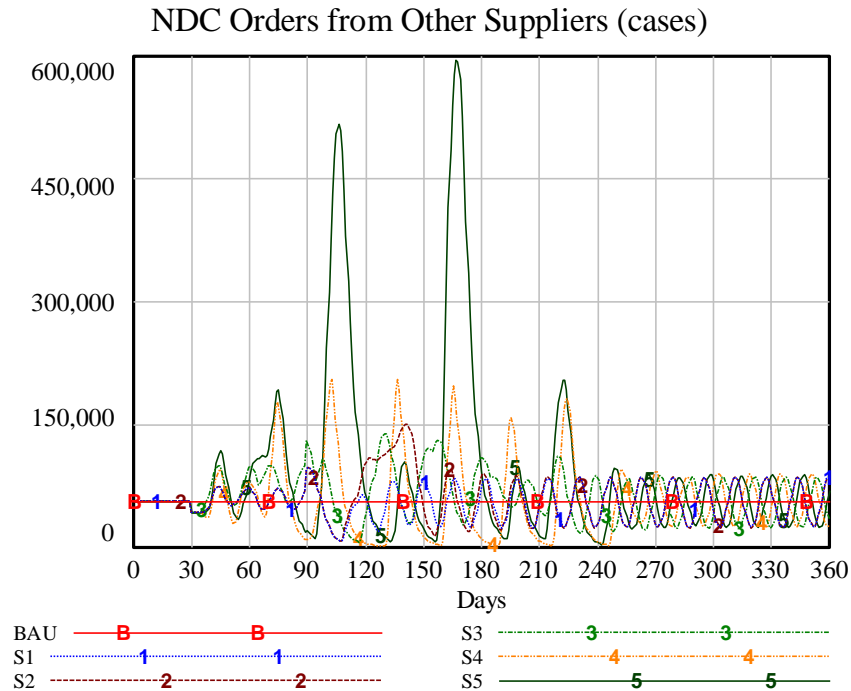


**Figure 6.20 Market Share**

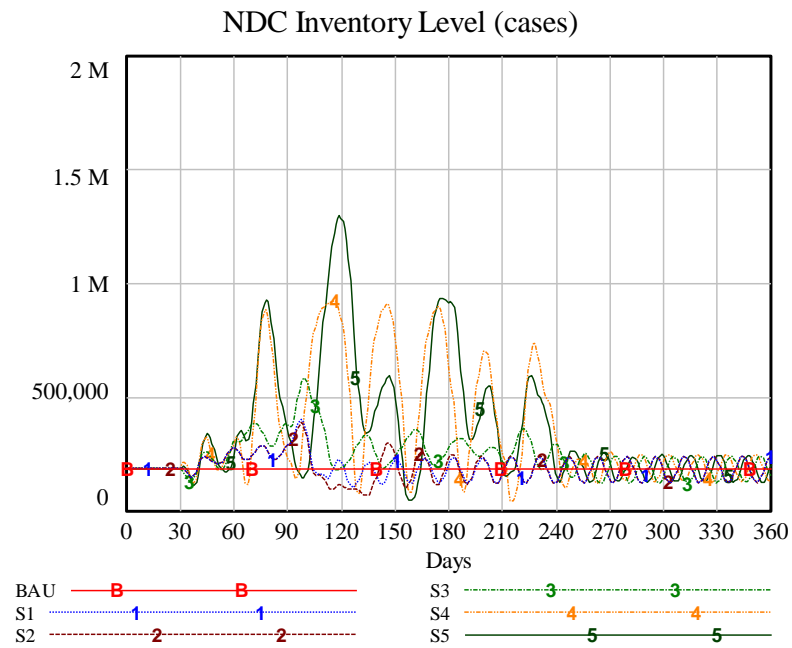
It can be noticed that the behaviour of the on-shelf level is almost the same in scenarios S1 to S3. This note indicates that disruptions introduced in S2 and S3 within FMCG echelon have no significant impact on the retailer's echelon. This may be in contradiction with B4 (Figure 6.13) that has a holistic impact on the entire RSC, so that any disruption at any part of the chain should affect the three echelons. The simulation results in Figure 6.22 give justification to why that is not happening (i.e., no significant impact on retailers) when disruptions take place at the FMCG echelon.



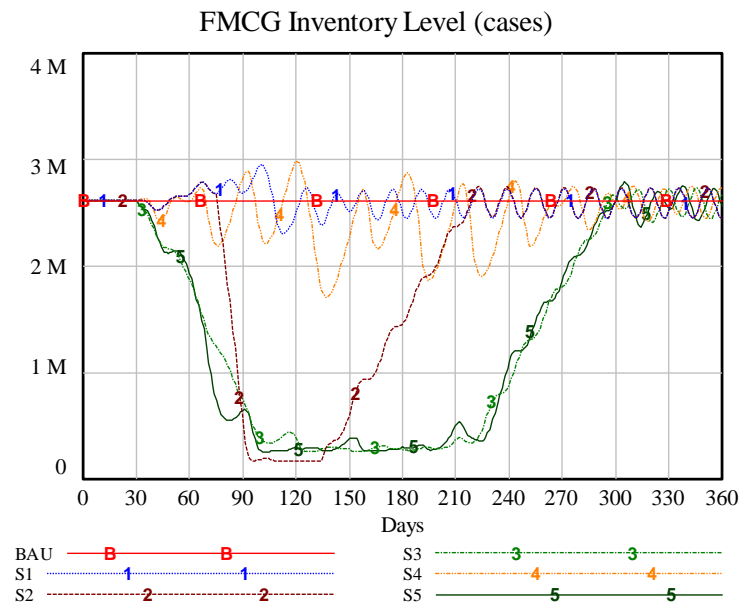
**Figure 6.21 NDC Inventory Level (cases)**



**Figure 6.22 NDC Order from Other Suppliers (cases)**



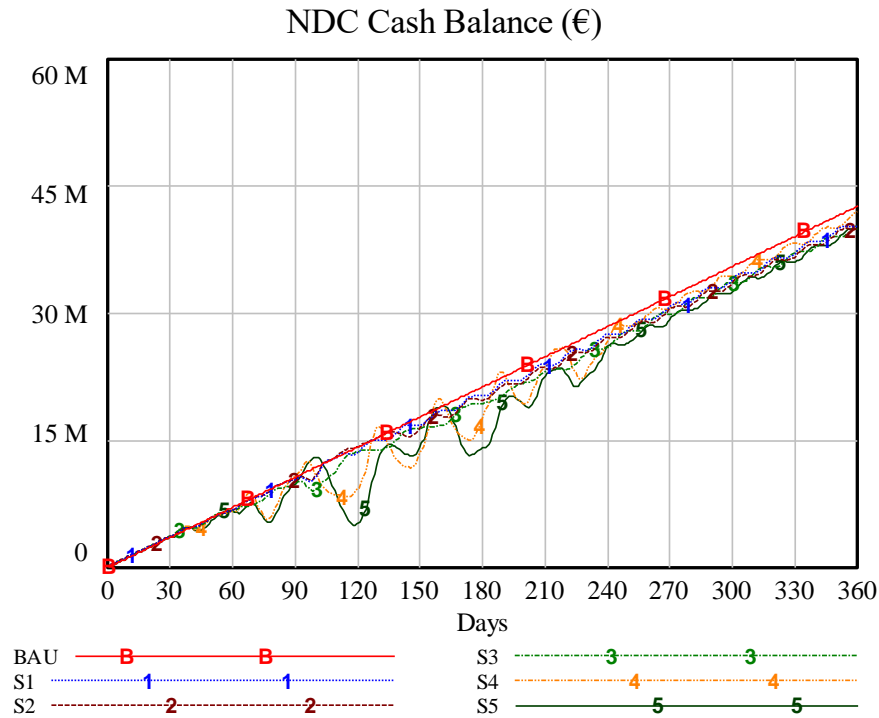
**Figure 6.23 NDC Inventory Levels (cases)**



**Figure 6.24 FMCG Inventory Levels (cases)**

Actually, B8 (Figure 6.13) eases the effect of the disruption at the FMCG echelon on the retailers echelon. The growth in FMCG Backlogs, due to production disruption in S2 or

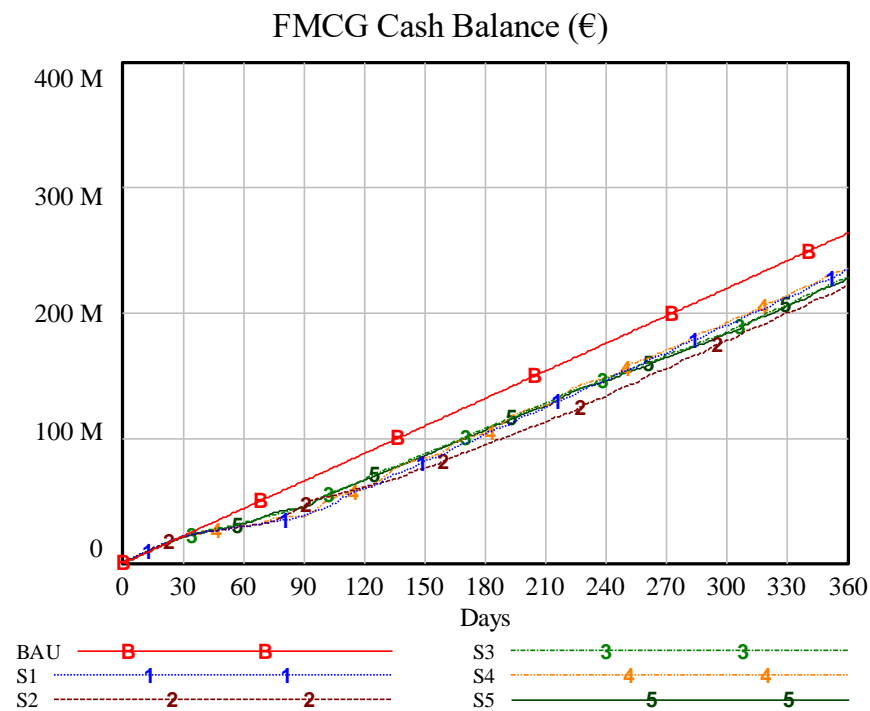
workers quitting in S3, incentivized a higher rate of orders cancelation from the NDC side due to the pressure of their Backlogs growth as well. As a substitution, NDC expedite orders from alternative suppliers, but with a 20% increase in the regular case price and this increase has an effect on their cash balance, see figure 6.25.



**Figure 6.25 SD Results for NDC Cash Balance (€)**

Although all disruptions take place within the first quarter of the time period of simulation, it can be seen that resulted consequences effect continued to feature until the end of the third quarter in all scenarios, and they even get extended to the fourth quarter in some cases (S3 and S5 in Figure 6.24), similar to the SCD pattern in figure 2.19. As mentioned before, the embedded mechanism in the underlying RSC is driving the overall behavior of the RSC to a steady state point. The simulation results suggest, that the retailer's echelon retrieves the equilibrium state in shorter time comparing to NDC and

FMCG echelons (Figures 6.21 to 6.24). The inventory levels at the latter echelons have oscillatory behavior with almost fixed amplitudes and cycle times. However, this steady oscillatory behavior can be considered as a steady state for these echelons. Despite the longer impact of workers disruptions (S3 and S5) on the inventory level of FMCG (from month 1 to 10) comparing to the production disruption (S2) (from month 2 to 7), the production disruption has a higher impact on the decrease in cash balance (Figure 6.20-6.24 and 6.26). The results also demonstrate how the disruption at downstream echelons could impact the upstream echelon financially, such as S4, where the disruption takes place at the NDC workers sector has significant effect on the cash balance of FMCG.



**Figure 6.26 SD Results for FMCG Cash Balance (€)**

## 6.5 Unit of Analysis 2 – National Distribution Centre

Section 6.4 has given a clear and powerful understanding of the dynamical behaviour of the extended three-echelon RSC under certain SCD risk drivers. Results have shown that the NDC is very sensitive to the variation in demand and supply that disruptions cause. In Unit of Analysis 2, the researcher and the embedded case study steering group takes the learnings from Unit of Analysis 1 and take a more detailed, micro level look at the NDC facility itself. As the fulcrum point for all three echelons, the NDC is very capable of absorbing and amplifying (Jüttner, 2005) both the impact and consequences of the disruptive scenario's listed in section 6.4.4. Using a DES study process, this section will investigate the operational performance of NDC under certain risk driven scenario changes.

### 6.5.1 Problem Definition

A fundamental part of NDC's long term strategy is to provide more reliable and leaner distribution processes to sustain profitability. The variation in cash-flow results in Unit of Analysis 2 further enhanced this strategic mind-set within the steering group. Lean initiatives can be very successful but can also be a high risk decision making process. After in-depth discussions with the NDC steering group on implementing lean to the operation, the following lean initiatives were shortlisted for implementation risk assessment (Table 6.6). *Forecast Accuracy* – NDC want to investigate the possibility of using a pull replenishment strategy in the NDC. Accurate demand data is required to implement this successfully. Double exponential smoothing forecasting technique is used to forecast monthly customer demand (FQ). There are two levels using an aggregate planning "level strategy", level 1 is a minimum demand strategy at 1000 units/month and

level 2 is a an average demand strategy at 1500 units/month. Using an economic order quantity inventory ordering technique, two different order frequencies (OF) are required; 1 order/wk and 1 order/2wks respectively. *Buffer Strategy* – Lean distribution and pull replenishment leaves RSC’s vulnerable to possible stock-outs and poor on-shelf availability, leading to potential loss of customers. Buffer strategies are a critical linkage in maintaining smooth flow of products (Zylstra, 2006) to the retail stores. Three levels of buffer, or safety stock (SS) have been chosen as a % of FQ. They are 0%, 5% and 10%. *Supplier Lead-Time* – In RSC’s, product life-cycles are very short and in general supplier lead-times (LT) are too long. To increase the leanness of NDC operations and increase the accuracy of both FQ and OF, the different levels of LT are; 7 days, 3 days and 24 hours. It is suggested that the more lean the NDC becomes, the more viable shorter LT’s will be (Zylstra, 2006). Although an assumption that purchasing costs increase with shorter LT’s is assumed in the simulation study.

**Table 6.6 NDC System Factors and Levels**

Factor	Name	Units	Type	Level 1	Level 2	Level 3
A	OF	Orders/WK	Quantitative	1	0.5	
B	FT	Demand/Month	Quantitative	1000	1500	
C	SS	% of FT	Quantitative	0	5	10
D	LT	Days	Quantitative	7	3	1

### 6.5.2 Model Boundaries and Data Collection

In any simulation-based decision support tool, it is important not to over complicate things and model more than is required to solve the problem definition. The model boundaries for Unit of Analysis 2 are based on the pre-simulation work done based on SCOR11 process flows. The boundary of this study will focus on the D1 process flow illustrated in figure 6.5. Further interviews, data collection and analysis sessions were



conducted with the NDC steering group in order to frame an understanding of the internal processes of NDC's end-to-end warehouse function. A more operational level of data collection was introduced to collect DES data than the strategic behavioural requirements of Unit of Analysis 1.

A significant proportion of data collected for Unit of Analysis 1 was applicable to Unit of Analysis 2, therefore utilised. Data collection for Unit of Analysis 2 was executed in parallel with the conceptual modelling phase.

### **6.5.3 Conceptual Modelling**

To develop the simulation-based framework, it was important to choose the best fit conceptual models for each simulation technique used. For Unit of Analysis 1, a strategic viewpoint was needed, therefore using Level 1 and 2 of SCOR11 as a foundation, strategy maps, CLD's and stock and flow maps based on a BSC structure were used. For this stage of the hybrid model implementation, DES requirements were more operational, needing discrete activities within the NDC to be mapped, attached with all associated data requirements gathered in section 6.5.2. A combination of IDEF0 for core internal process level, and basic flowcharts for the lower levels of each internal process have been used to BPMo NDC's business processes. Figure 6.27, highlights the hierarchical relationship between IDEF0 and the flowcharts. IDEF0 was chosen because its hierarchical structure compliments the SCOR11 processes the steering group were now very comfortable with. IDEF0 also directed the researcher when requesting relevant data and information on all inputs, mechanisms, controls and outputs needed to formulate the DES model.

A top-level IDEF0 block was created for each of the main NDC processes was created by the researcher and steering group senior managers. During these sessions a Level 0 (figure

6.28) viewpoint of NDC's extended RSC was also created, based on the CLD structure in figure 6.13. The lower level flowcharts were drafted by the researcher with information given by the managers, but final verification of the models was made by each activities frontline supervisor, who had the greatest understanding and knowledge of each process flow.

A full library of the IDEF0 and process flowcharts created for this research study can be seen in Appendix D.

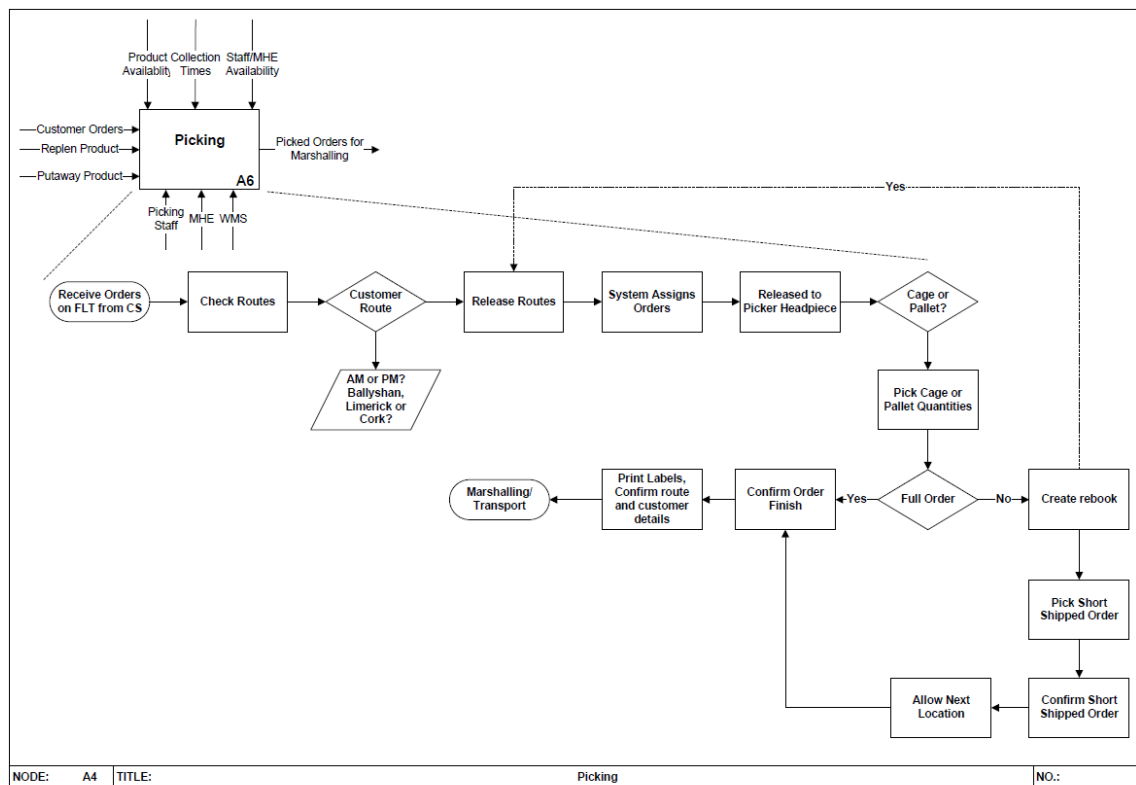
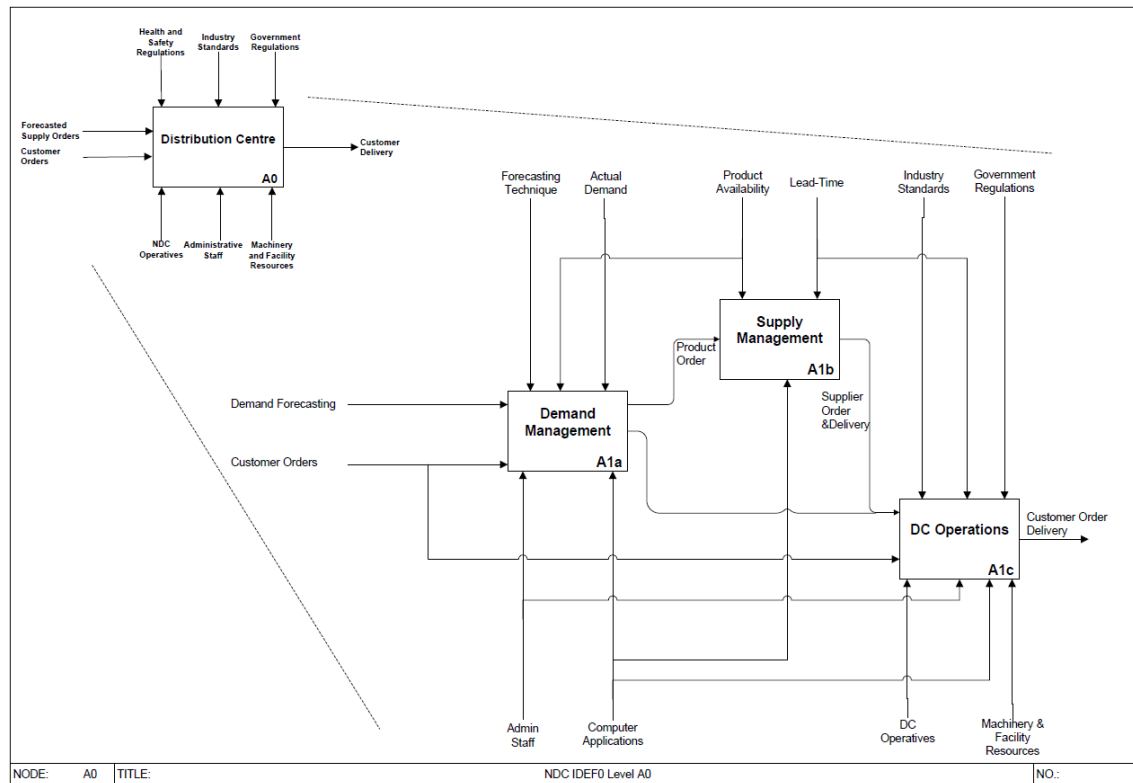


Figure 6.27 IDEF0-Flowchart Model of the Picking Activity



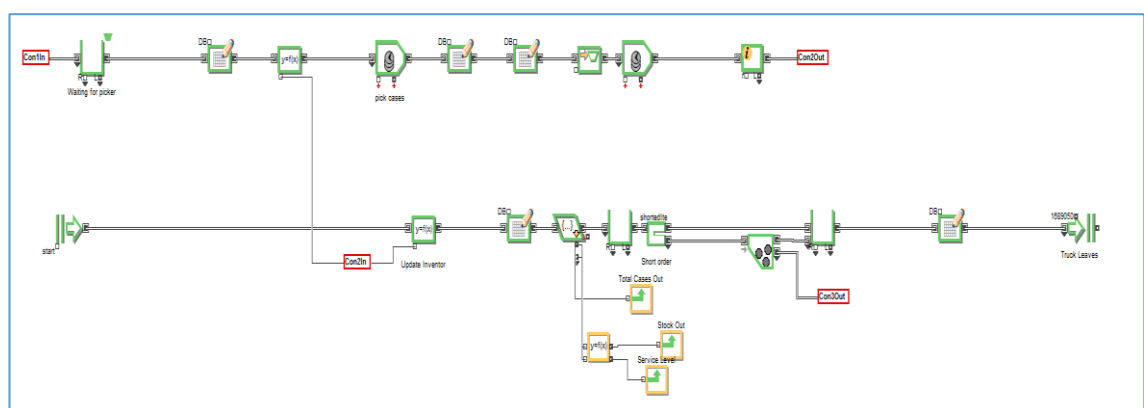
**Figure 6.28 IDEF0 Representation of Three Echelon RSC**

#### 6.5.4 DES Model Building

A DES model based on the IDEF0 and flowchart BPMo's was developed. The simulation process in this study has used a generic simulation package – ExtenSim8 – and customised it using Java and XML technologies. This selection provides flexible and efficient simulation models for three reasons; (1) it helps to provide object-oriented hierarchical and event-driven simulation capabilities for modelling such large-scale application, (2) It utilises breakthrough activity-based modelling paradigm (i.e. real world activities such as assembly, batching and branching), and finally (3) it is also used to customise objects in the package to mimic the real-life application characteristics. In order to represent the stochastic nature of the system's parameters such as customer orders arrival time, number of SKUs in an order, handling equipment unit breakdown rate and

repair time, a theoretical statistical distribution and database schedules were employed. The analysis of customer orders arrival rate resulted in a detailed daily schedule based on sales historical records. Service time was proportional to the required SKUs quantities and followed a normal distribution. Suppliers lead times were constant based on supplier's locations and conditions of delivery. Finally, the frequency of equipment maintenance plans was also taken into consideration as well as the rates of breakdown and repair time. A snapshot of the DES simulation model is illustrated in Figure 6.30, note the KPI dashboard structure based on benchmarking study done in section 6.3.3.

Resources were characterised by their availability and breakdown frequency, whereas the product entities were attributed by arrival time, processing time, and products characteristics (e.g. processing routing and products type). Logical entities make decisions for creating, joining, splitting, buffering, and branching product entities. 245 blocks in a hierarchical form representing; queues, activities, branching points, item value, database read/write and equations have encompassed the simulation model. Figure 6.29 represent the flow of these DES library blocks through the picking process, as conceptually modelled in figure 6.27.



**Figure 6.29 DES Blocks for Picking Process**

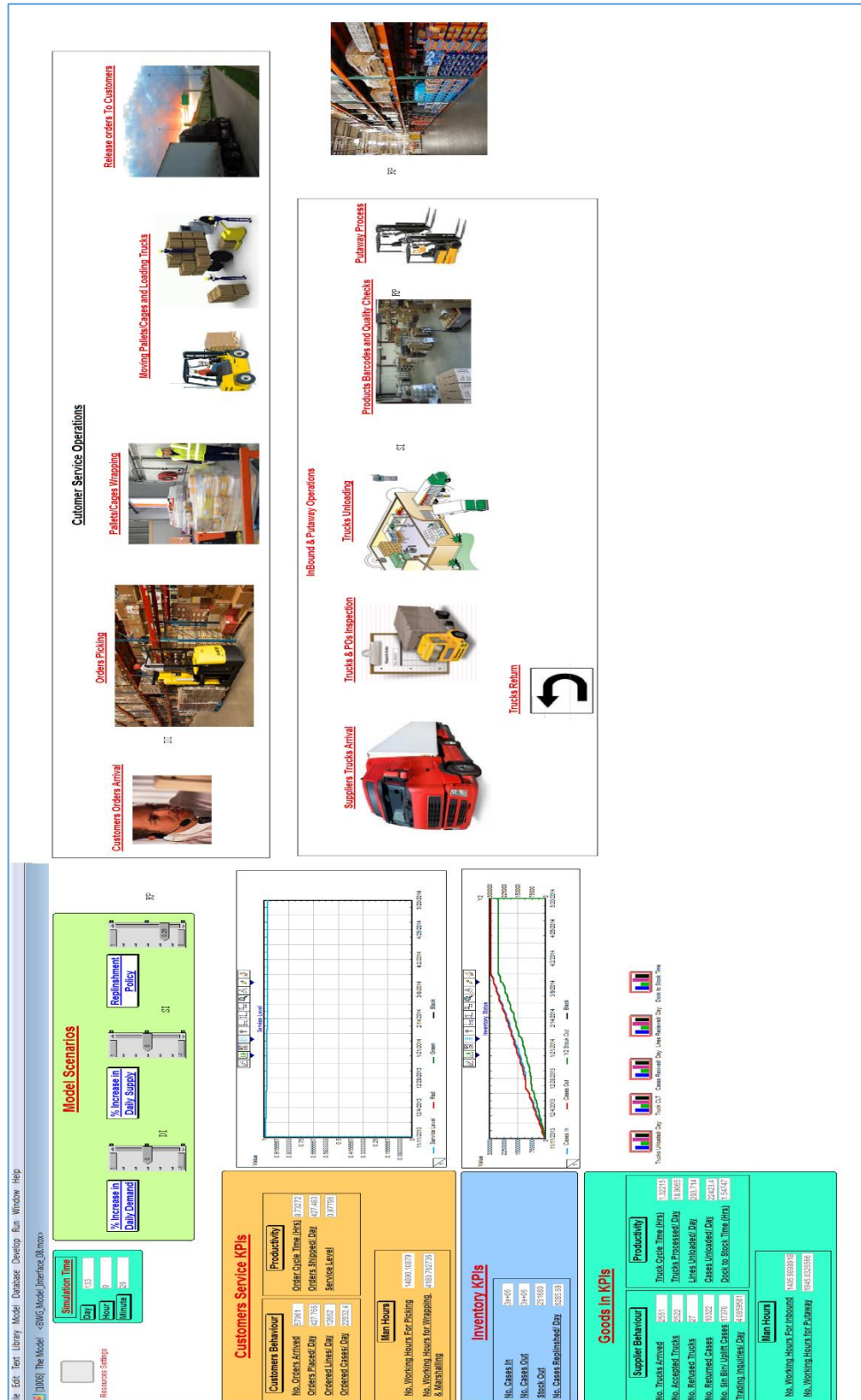


Figure 6.30 Screenshot of DES Model Dashboard

The model assumptions are (1) no returnable items are modelled and (2) the resource availability rates are based on data collected from managers. For the model to reach its steady-state condition, the warm-up period was found to be one month. Every simulation run represents one year of actual timing. Each experiment result is an average of 10 independent replications. Each model runs independently of each other and data is transferred via input and output Excel sheets. Forecasted product demand, order rates and aggregate plans are created in the SD model and transferred to the DES model as customer order input. Cycle time, average inventory, NDC costs and late jobs are the variables transferred back to the SD model to measure lean factors outlined in Table 6.6.

### **6.5.5 Verification and Validation**

In an effort to create an accurate representation of NDC operations, various verification and validation methods were employed. For the verification phase, the decomposition method (i.e. verify every group of blocks) was used to ensure that all 245 blocks functioned as expected. A built-in simulation debugger was also used to avoid any coding bugs. Out of ten validation methods that had been stated in Rabe (2009), three validation methods have been applied on the DES model; (1) data collection phase, (2) conceptual modelling phase and finally (3) simulation results phase. The validation process of the data collection phase was as follows; (1) no measurement errors in data collection process, (2) generated data have to match the pattern of historical data and (3) set attribute values within specified range. To achieve that, a detailed examination of data documentation quality and consistency was done with the cooperation with the steering group. After that, the conceptual model was validated based on interviews with senior managers to ensure that all specified processes, structures, system elements, inputs and

outputs are considered correctly. The modelling team also examined the accuracy and consistency of the conceptual model to the problem definition. Finally, “Face validation” approach was used to validate the final simulation results.

### 6.5.6 DOE and Result Analysis

This phase has 2 objectives; (1) substantiate a valid relationship between the identified lean factors and their corresponding response variables (i.e. cycle time, total costs and short/late delivery), and (2) identify the critical factors that have a significant influence on the response functions (or subscript “*c*” in equation 1). Table 6.7 identifies a mixed level factorial design. Since a large number of experiments ( $2^2 \times 2^3 = 36$ ) are required to determine the optimum combinations of the studied parameters, three levels orthogonal array was selected. The Taguchi method uses orthogonal array from the design of experiments theory to study a large number of variables with a small number of experiments (Phadke, 1995). L18 design for mixed factors was selected and analysed to develop the experimental matrix in Table 2 (Tsui, 1992). The main and interaction effects of the studied factors were analysed using 90% confidence interval (Tables 6.8 to 6.10). The main effect analysis is conducted by changing one single factor at a time while all other parameters are fixed, whereas the interaction effect is based on changing two or more factors and examine their impacts on the response functions.

No single factor has made a significant impact on all response functions. The closest is LT (D) with ( $P < 0.05$ ) in both cycle time and short/late deliveries. Time affects both responses significantly; therefore there is no surprise in LT being a major influence on outputs and shows lower P value interactions with all factors, although still  $> .01$ . OF (A) is the only significant main effect on total costs ( $P < 0.01$ ). This is due to OF’s impact on

both ordering costs and holding costs. The sensitivity of short/late deliveries to both SS and LT also highlights the importance of buffer strategy and supplier performance on order fulfilment. The interaction of these factors with factors OF and FQ (AD & BC) also show the influence both demand and replenishment strategies have on late/short deliveries, and in-turn, customer satisfaction. It is interesting to note that FQ (B) has made no main effect on any response function. For NDC, this was the most strategically important factor in this study. Although it is important to note, that this factor is a tactical level aggregate plan that was used to identify and calculate the outputs of factors A and C. This is possibly validated by the relatively lower interaction effect P values for AB and BC under cycle time and short/late delivery response functions. After identifying the main and interaction effects of the studied lean factors, an optimization investigation of the studied factors' is required.

**Table 6.7 Design Matrix for Factors Combination under Response Functions**

Experiment	A: OT	B:FT	C:SS	D:L T	Response Functions		
					Cycle Time	Total Costs	% Late/Short Del
1	1	1	1	1	3.478	1987054.03	12.3
2	1	1	2	2	3.128	2113458.9	6.7
3	1	1	3	3	0.781	2598096.21	1.7
4	1	2	1	2	1.988	2356009.26	8.9
5	1	2	2	3	1.223	1956209.07	5.4
6	1	2	3	1	2.036	2167324.82	6.3
7	1	2	1	3	1.378	1999637.87	10.8
8	1	2	2	1	3.348	2013598.99	6.7
9	1	2	3	2	2.789	2415756	1.2
10	2	1	1	3	1.256	1876035.11	9.9
11	2	1	2	1	3.212	1450003.49	7.8
12	2	1	3	2	2.835	1670935.13	0.2
13	2	2	1	1	3.458	1504378.09	13.4
14	2	2	2	2	1.809	1780319.11	2.3
15	2	2	3	3	0.539	1908003.05	0.1
16	2	2	1	2	1.654	1560071.44	5
17	2	2	2	3	0.519	1670335.58	0.03
18	2	2	3	1	2.368	1649389.05	6.9

**Table 6.8 Main and Interaction effect of Factors against Order Cycle Time**



Source of Variation	Df	Mean Squares	F Ratio	P Value
A:OF	1	0.0202	0.0719	0.7993
B:FQ	1	0.0117	0.0418	0.8461
C:SS	1	0.7346	2.6134	0.1669
D:LT	1	2.0545	7.309	0.0426
AB	1	0.7155	2.5453	0.1715
AC	1	0.1966	0.6994	0.4411
AD	1	0.4307	1.5321	0.2707
BC	1	0.3047	1.0838	0.3455
BD	1	0.2888	1.0276	0.3572
CD	1	0.9834	3.4987	0.1203

**Table 6.9 Main and Interaction effect of Factors against Total Costs**

Source of Variation	Df	Mean Squares	F Ratio	P Value
A:OF	1	6.46E+11	18.1286	0.008
B:FQ	1	7.11E+09	0.1996	0.6738
C:SS	1	5.04E+10	1.4158	0.2875
D:LT	1	1.34E+11	3.7515	0.1105
AB	1	1.55E+08	0.0043	0.95
AC	1	7.84E+08	0.022	0.8879
AD	1	4.50E+07	0.0013	0.973
BC	1	1.96E+10	0.5494	0.4919
BD	1	3.62E+10	1.0151	0.3599
CD	1	1.60E+10	0.4497	0.5322

**Table 6.10 Main and Interaction effect of Factors against % Short/Late Deliveries**

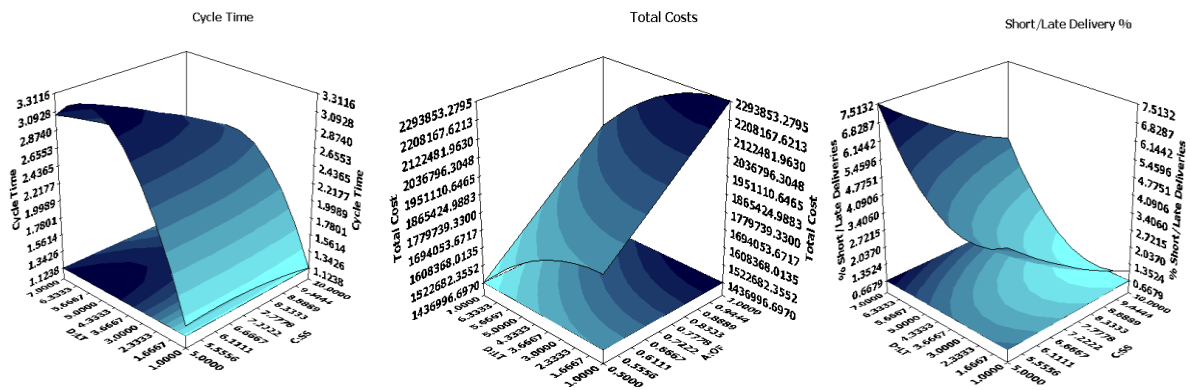
Source of Variation	df	Mean Squares	F Ratio	P Value
A:OF	1	0.5884	0.3245	0.5936
B:FQ	1	0.593	0.327	0.5922
C:SS	1	21.1727	11.6762	0.0189
D:LT	1	12.0113	6.6239	0.0498
AB	1	0.5015	0.2765	0.6215
AC	1	3.3212	1.8316	0.2339
AD	1	19.8759	10.9611	0.0212
BC	1	8.2839	4.5684	0.0856
BD	1	6.5831	3.6304	0.1151
CD	1	0.0625	0.0345	0.86

### 6.5.7 Optimisation - Response Surface Methodology (RSM)

RSM was used to establish a robust regression model and find optimal results for the studied factors. A sequential procedure, RSM makes the fitting of a series of regression models into a response function possible. The technique seeks to estimate a functional relationship between one or more responses and a number of independent variables in order to explore the optimum operation conditions for the system (Sahoo et al., 2008).

Using the values of the three response functions, Table 6.7, using a quadratic model based on Shang et al. (2004) research, it was found that all three functions fit RSM.

Based on the results of the ANOVA models (Tables 6.8-6.10) and to determine the optimal values of each response function, 3D representations of the functions were developed using a contour mesh for regression coefficient (6.31). The mesh surfaces of Cycle Time and Short/Late Delivery % functions are based on factors LT (D) and SS (C), their most significant factors. Totals Costs surface has been developed using its lowest P value factors, LT (D) and OF (A). The optimal settings of each lean factor for the response functions illustrated in the mesh surfaces can be seen in Table 6.11.



**Figure 6.31 3D Representation of Response Functions**

**Table 6.11 Optimal Value for each Response Function**

Response Function	OF	FQ	SS	LT	Function Value
Cycle Time (days)	0.5	1500	5	1	0.364
Total Costs (€)	0.5	1000	5	7	1.33E+06
Short/Late Deliveries (%)	0.5	1500	5	1	0.715

The optimal values presented in table 6.11 have highlighted some interesting findings for NDC. Order cycle time (0.364 days) and average short/late delivery rate (0.715%) are

achieved by implementing the same OF rate (0.5 order/wk), forecast quantity (1500 products/month), SS (5%) and a LT of 1 day. Total costs using this level of factors are €1,629,000 per year. Increasing the LT to 7 days and reducing the forecasted aggregate plan or FQ to 1000 products/month will decrease total costs significantly, to €1,330,600 per year, but at the same time it has increased the % of late deliveries to 7.88% and order cycle time to over 3.42 days. The significance of OF, SS levels and LT have again been highlighted when in an optimal state, regardless of what level of FQ was applied. Although the FQ parameter has changed (1000cases/month) in the total costs function, it does not contribute much to the total costs when 1500cases/month is used.

Assessing these response surfaces has been very important from a risk assessment perspective for NDC. In lean terms, optimal values for cycle time and late/short deliveries result in short lead times, maintainable SS and less frequent ordering. Results have shown that these optimal levels come at the expense of total costs, as holding costs and product costs increase to avail of this solution. Further research is needed in this area with a possible cost analysis study using life-cycle activity based costs to increase the robustness of decision making when implementing lean.

### **6.6 Discussion and Summary**

The key findings of this chapter can be summarised as follows:

- Although the  $P^6$  Coefficient Reference Model is a conceptual reference model, building on already well established BPM constructs in literature, its validation during the communication and consultation phase of the embedded case study was very encouraging. Findings show that there was a very evident improvement in both the

project management effectiveness of the researcher and also confident engagement of the practitioners than in the formative case study.

- Visually the triangle shape of the  $P^6$  Coefficient Reference Model responded well with the practitioners and the 6 P expressions were very relevant to the practitioners and could be contextualised in many different ways, highlighting the robust constructs they are built on.
- Evidence suggests the  $P^6$  Coefficient Reference Model is a dynamic conceptual model that with further empirical evidence can be applied within any complex BPM project process.
- Unit of Analysis 1 has highlighted that RSC's compete in a very volatile market with high levels of demand uncertainty and promotion driven order patterns leaving them vulnerable to disruption. Results validated the literature, claiming that all disruptions follow a similar eight step pattern, For example, in the SD testing stage, results showed delayed order and experience patterns caused a BWE pattern downstream to FMCG.
- The potential of utilising an integrated SCRM framework to support accurate decision making at an extended RSC level was very attractive to senior managers within both FMCG and NDC.
- From this holistic viewpoint, interaction with practitioners from a metrics perspective moved from operational benchmarks as seen in section 6.3 to strategic metrics such as marketshare, TCO and its effect on cashflow.
- By integrating the strategic performance management of the BSC with the dynamic, behavioural and feedback capabilities of SD, high level, accurate RSC decision

making was realized, providing decision makers with a model that can be used to understand unique behaviours, particularly the effect of disruptions on the RSC performance.

- Results show that there was less impact on retailer inventory levels and order patterns than with both NDC and FMCG. Moreover, the results demonstrate how the disruption at downstream echelons have significant impact on the upstream echelons financially. Future work in this model includes developing policy interventions that allow decision makers to test their decisions against these disruptions and understand how the system behaviours will react.
- The use of DES methods for Unit of Analysis 2 fitted all the requirements of an operational level SCRM project. The simulation study was an excellent “foot-in-door” mechanism with NDC and was very effective in building interest within the senior management to embrace a simulation study.
- The ability to track all activities, resources and equipment resulted in a very robust activity based costing VAR tracking tool that could be run under different risk scenarios, and contributed significantly to the end result.
- DOE and RSM application ensured robust risk treatment to decision variables and although there wasn’t significant shifts in results for any of the 3 response surfaces there was interesting information gained from Total Costs. In particular TCO unexpectedly was at an optimal level with buffer stock and longer lead-times and associated risk of holding and shortage costs.
- Both Unit of Analysis 1 and 2 from a TCO perspective were most sensitive to variation in demand.

- The oscillating pattern of NDC Inventory levels in Unit of Analysis 1 with limited effect on on-shelf availability highlight the supply risk absorbing effect of NDC's, similar to the sensitivity of Shortage/Late Deliveries to buffer stock and lead-time variation in Unit of Analysis 2.
- In the embedded case study, full integration of the SD and DES models were not needed, just consistency in input data, but the integrated framework was very effective in ensuring both modelling techniques were aligned.

## Chapter 7. Discussion and Conclusions

*“You dig deeper and it gets more and more complicated, and you get confused, and it's tricky and it's hard, but... It is beautiful.”*

— Professor Brian Cox

### 7.1 Discussion

Whether purchasing a litre of milk at your local shop or ordering the newest version of smart phone online, the RSC pervades every dimension in our lives. It is so intrinsic to our everyday activities that any potential risk of SCD can have costly impacts on the simplest of daily tasks. For an ordinary shopper, this could mean having to buy the more expensive brand of coffee; for the brand manufacturer, the potential loss of a lifetime customer. The “new normal” in modern business systems is that of global, multi-tiered, lean RSC’s that have become very vulnerable to the risk of SCD. These complex systems can be vast, encompassing hundreds of organisations globally. Therefore, the role of RSCRM is critically important to the sustainability and competitiveness of the entire system. In this research study, the integrated RSCRM framework has been developed to provide RSC practitioners with a system thinking based toolbox to truly understand and manage risk from a holistic viewpoint. This will allow RSC managers to reconsider how they approach the management of risk from both a strategic and operational level. By fulfilling this purpose, the integrated framework has answered the primary research questions of this research study and achieved the main objective of developing a system thinking RSCRM framework that will awaken scientific experimentation within a business environment. Preliminary results of the implementation within a three echelon RSC suggest that the integrated framework provides holistic RSC insights on how causal

relationships and unique system behaviours contribute to RSC risk. The generic design of the framework ensures that practitioners can take advantage of a new understanding of RSC risk and embed it into their organisations strategy to gain competitive advantage. The frameworks adaptation of globally recognised standards and reference models also ensures its extended applicability and can be seamlessly recalibrated to any supply chain from automotive to pharmaceutical. The contributions of this research study to the RSCRM domain are outlined in the following sections:

### 7.2 Research Contribution

#### **An integrated RSCRM Framework for Practitioner Application**

Answering the **primary research question**; *“Can an integrated supply chain risk management framework be developed for managing complex decision management processes in a retail supply chain from a practitioner perspective?”* fulfilling research objectives 3 and 4. The key components of the framework design that have provided **applied research contributions** include:

- Theory based conceptual reference model that supports the implementation of the integrated framework. Used as an “educate for support” tool when managing a complex business process management project and enhance RSCM understanding.
- Hybrid simulation risk assessment toolbox incorporating the strategic causal relationship modelling capabilities of SD with the discrete operational strengths of DES. The hybrid simulation toolbox of the framework is designed in such a way as it follows the standard RM process, universal to all organisations.



- The integrated framework encourages the use of standardisation in complex system solutions and has an extensive support material library of ISO31000 and SCOR11 guidelines to support practitioners during the research study. This allows customisation of business process mapping, performance metrics and project plans that can be firm specific.
- Embracing the philosophy of system thinking and scientific method, the integrated RSCRM framework has been intricately designed to encourage experimentation and system thinking with practitioners.
- Robust validation of framework applied to an extensive three-echelon RSC of Ireland market leaders in retail distribution and FMCG brand manufacturing.

### The $P^6$ Coefficient Reference Model

Fulfilling research question 3's requirement of; "**RQ3: What requirements are involved in the design and development of an integrated risk management framework for complex RSC's?**" through objectives 1, 2 and 3, the  $P^6$  Coefficient Reference Model has provided a novel, **embryonic theoretical research contribution** with strong future work potential.

Key characteristics of the reference model are as follows:

- An extension of SCOR11's 4P's, supply chain excellence and discrete mathematical combinatorics, The  $P^6$  Coefficient Reference Model has been designed to embrace the system thinking philosophy of the integrated framework.
- Designed to reduce the theory-practice gap that often occur when implementing a complex business process improvement project. The  $P^6$  Coefficient Reference Model reduces the practitioner's fear of partaking in a simulation study and will

also improve the communication and consultation skills of the researcher or modeller.

- When used as the technique for communication and consultation within an ISO31000 based RSCRM project the reference model adds another dimension to the framework that is currently missing. In ISO31010, the communication and consultation process is missing and The  $P^6$  Coefficient Reference Model take advantage of this opportunity.
- Unique conceptual design that is easy to read, understand and remember. Introduces practitioners to the fundamentals of system thinking and business process orientation.
- Validated through extensive implementation project of the integrated framework with very encouraging results from practitioners.
- Purposely designed to easily transfer to any domain that needs to manage a complex system, adhering to the “one vocabulary” theme of process standards.

### A new approach to RSCRM Literature Review – Five Section Taxonomy

Answering research questions 1 and 2; “**RQ1:** *How applicable are existing solution techniques in handling the dynamics and complexity within supply chain systems and how effective are they in mitigating risk?*” and “**RQ2:** *What are the correlations between system thinking and understanding supply chain risk?*” this **knowledge and theory research contribution** to the RSCRM research community will be a valuable sourcing literature taxonomy and also encourage RSCRM research from a systems thinking perspective.

Due to the novel contribution of the integrated RSCRM framework, especially its system thinking foundation, a new approach to planning and designing the literature review was needed. The design, similar in flow and theme to the integrated framework followed a concept-centric literature review methodology and applied both inductive and deductive learning curves through all five sections. With over 1100 academic literature reviewed and just over 500 cited in this research study, this extensive review of system thinking literature is unique, built on the philosophies of Checkland, Deming and Forrester.

### Embracing Scientific Method in Business Process Management

Influenced by research question 2; “*RQ2: What are the correlations between system thinking and understanding supply chain risk?*” this **theoretical research contribution** has potential to grow into a new BPM philosophical foundation. Although not a new concept in the literature, the application of scientific methods within business process management is still a concept with a significant research gap. This research study has initiated a preparatory exploratory investigation into the application of scientific method in research. It is believed therefore that these initial acknowledgments have contributed to the integrated RSCRM framework. The researcher’s investigation into understanding the basic theories behind the laws of thermodynamics, especially entropy and the rules of heat transfer have had an axiological influence on both the research questions and design of the integrated framework. The system capability VAR equation developed from thermodynamics first law on heat transfer (see section 5.4.7.1) was used as a theoretical background for the calculation of market share and cashflows in the SD model testing in the embedded case study Unit of Analysis 2. The theme of experimentation was also an

influencer in the development of the research plan in chapter 3, in particular the choice of an embedded mixed methods case study as the primary research method, which is not normally used in business research.

### 7.3 Research Limitations

Reflecting on the contributions of this research study, opportunities can also be found through the following research limitations.

- The findings of this research study, although contributing to the field of RSCRM are limited to one embedded case study, the three-echelon supply chain. The case study itself was extensive and the participating organisations hold a high proportionate share of the Irish consumer market which validated results, but future case studies are needed to give a broader representation of the retail sector and extended supply chain systems.
- The  $P^6$  Coefficient Reference Model needs construct validation that extends beyond conceptual design and case study application.
- Due to the lack of retail specific supply chain literature, all literature on supply chain management was contextualised into a retail perspective.
- Although an Irish case study, limited publications (outside of industry standards) meant the researcher was reliant on UK and USA research to develop the integrated framework.

### 7.4 Future Work

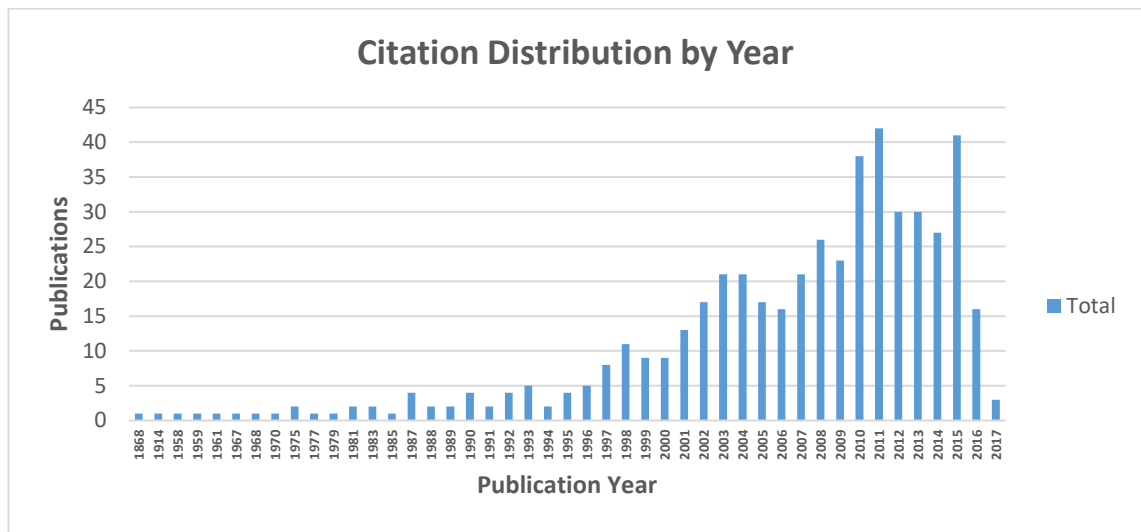
The novel contributions of this research study explained in this chapter coupled with the opportunities that will arise from the research limitations have resulted in the following future work initiatives:

- Publication of System-Based SCRM literature review paper to validate the 5-stage taxonomy developed in this research. Using citation and subject cluster analysis, a total of 1100 peer-reviewed articles have been carefully reviewed, analysed and categorised based on their specific subject matter in the context of system-based supply chain risk management and article audience. The objective of this research paper is to empirically validate the research gap in applying system thinking to SCRM and highlight the urgent need to target industry practitioners as a valuable audience when designing journal articles.
- A separate research study to validate the constructs of The  $P^6$  Coefficient Reference Model. The objective of this research study is to empirically validate the constructs and associated practices of 6 P's through a global survey of multiple supply chain industries. Validation and elimination of construct practices will be achieved through exploratory and confirmatory factorial analysis, leading to a structured equation modelling.
- Application of the integrated RSCRM framework in multiple embedded case studies to refine and improve the overall framework design. The generic design of the integrated framework needs further validation both within retail and other supply chain systems such as aeronautical, pharmaceutical and automotive. The calibration

capabilities of SCOR will be tested in each industry with multiple case data analysis through multi criteria decision analysis based on analytical hierarchy process.

- Continue to explore the application of thermodynamics in complex business process systems through collaboration with the Physics Department at DIT. Expand on the theoretical contribution of Chen (1999) and experiment the correlation of thermodynamics to business processes utilising system dynamics modelling to proof entropy in business process systems.
- A draft white paper in development based on this research study that will be proposed to the Irish Government in relation to the risk management of *BREXIT*. The objective of this research paper is to accurately model the impact of the final BREXIT exit deal between the UK and the EU on the island of Irelands economy from a macro scale and the border region from a micro scale.

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Mean	2006
Median	2009
Mode	2011
Standard Deviation	11.63
Range (Years)	149
Oldest	1868
Newest	2017
Count	502
Distribution (2000-2017)	Binomial(2.03e+003, 0.99)

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## APPENDICES

## Appendix A – Time and Motion Study Sample

NDC Function: Unloading

Date: 27/03/2013 08:45

GOODS INWARD

Cycles	Start Time	Finish Time	total time (min)	Full Pallets	Spilt Pallets	Time/Pallet (min)	Operative Name	Comments
1	9.12	9.29	17.00	26		0.653846154	paul & gary	
2	10.00	10.04	4.00	1		4	Gary	
3	10.37	10.58	21.00	29		0.724137931	paul & Marius	
4	10.59	11.02	3	5		0.6	Gary & Marius	
5	11.10	11.21	11	9		1.222222222	Gary	
6	11.52	11.59	7	13		0.538461538	Gary	
7	12.49	13.10	21	26		0.807692308	Gary	
8	10.50	11.13	23.00	25	0	0.92	paul & gary	paul & gary carried out the unloading no issues
9	12.55	13.05	10.00	22	0	0.454545455	paul & gary & Marius	paul & gary carried out the unloading for 5 mins Marius the remainder no issues
10	14.31	14.40	9.00	20	31	0.45	Gary & Paul	Gary and Paul no issues

Rate in Terms of Influence on Work

Standing

Abnormal Position

Not Awkward

Awkward

Very Awkward

Temperature

Nice

Cold

Very Cold

Warm

Very Warm

Use of Force

Light

Average

Heavy

Noise Level

Varies but Loud

Varies but very Loud

Varies but not Loud

Lighting

Good

Average

Bad

Very Bad

Tediousness

Tedious

Very Tedious

Not Tedious

Mental Strain

Complex Attention

Very Complex

Not Complex

Close Attention

Time or Exacting

Very fine or very exacting

Not fine or exacting

Rough Notes

cycle 1 the time of 23 mins looks a bit off but they had to carry the pallets 6 bays down to drop every time they took a pallet of the lorry.

Both other cycles they lifted and dropped at the bay they took from hence the difference in times

cycle 1 MARS GROCERY

cycle 2 BECK SMITH, ODLUMS, ROMA FOODS

cycle 3 BATCHELORS LTD

## Appendix B - SD Model Equations

- (001) available capacity=  
 $\max(\text{production capacity-FMCG WIP}, 0)$   
 Units: \*\*undefined\*\*
- (002) avg consumption=  
 $0.2 * (1 + (\text{step}(0.5, 30) - \text{step}(0.7, 90) + \text{step}(0.2, 120))) * s1$   
 Units: \*\*undefined\*\*
- (003) cancellation period=  
 30  
 Units: \*\*undefined\*\*
- (004) Consumption=  
 $\min(\text{On Shelf}, \text{Daily Demand} * (\text{market share}))$   
 Units: \*\*undefined\*\*
- (005) Consumption 2 weeks ago=  
 $\text{SMOOTH N}(\text{Daily Customer Consumption}, \text{retail movg avg time}, \text{Daily Customer Consumption}, 1)$   
 Units: \*\*undefined\*\*  
 $\text{SMTH1}(\text{Daily\_Customers\_Consumption}, \text{Retail\_movg\_avg\_time}, \text{Daily\_Customers\_Consumption})$
- (006) customers base=  
 232500  
 Units: \*\*undefined\*\*  
 $232500 * (1 + (\text{step}(0.5, 30) - \text{step}(0.4, 90))) * s2$
- (007) Daily Customer Consumption=  
 $\text{Consumption} * 0 + \text{percieved Daily Demand} * (\text{percieved market share}) * 1$   
 Units: \*\*undefined\*\*  
 $\text{Consumption} * 0 + \text{percieved Daily Demand} * \text{percieved market share} * 1$
- (008) Daily Demand=  
 $(\text{customers base} * \text{avg consumption}) / 0.9$   
 Units: \*\*undefined\*\*
- (009) Daily demand from NDC=  
 $\text{DELAY N}(\text{Orders to FMCG}, 5, \text{Orders to FMCG}, 1)$   
 Units: \*\*undefined\*\*
- (010) Daily Demand from retailers=  
 $\text{DELAY N}(\text{orders to NDC}, 2, \text{orders to NDC}, 1)$   
 Units: \*\*undefined\*\*
- (011) Daily Retails Demand=  
 $\text{NDC Shipping Products} * 0 + \text{Daily Demand from retailers}$   
 Units: \*\*undefined\*\*
- (012) Daily Wholesalers Demand=  
 $\text{FMCG shipping rate} * 0 + \text{Total Daily Demand}$   
 Units: \*\*undefined\*\*
- (013) Desired FMCG Inventory=  
 $\text{FMCG Expected Daily Demand} * \text{Production Lead Time}$   
 Units: \*\*undefined\*\*
- (014) Desired NDC Inventory=  
 $\text{NDC Expected Daily Demand} * \text{FMCG lead Time}$   
 Units: \*\*undefined\*\*
- (015) Desired On Shelf Level=

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- retail Expected Daily Demand\*(NDC Lead Time+1)  
Units: \*\*undefined\*\*
- (016) elasticity of marketing on market share=  
1  
Units: \*\*undefined\*\*
- (017) elasticity of on shelf on market share=  
1  
Units: \*\*undefined\*\*
- (018) FINAL TIME = 360  
Units: Day  
The final time for the simulation.
- (019) FMCG Case Cost=  
4.2  
Units: \*\*undefined\*\*
- (020) FMCG Cash Balance= INTEG (  
FMCG Revenues-FMCG Expenses,  
1000)  
Units: \*\*undefined\*\*
- (021) FMCG Consumption 4 weeks ago=  
SMOOTH N(Daily Wholesalers Demand,FMCG moving avg Time,Daily Wholesalers Demand  
,1)  
Units: \*\*undefined\*\*  
iThink :  
SMTH1(Daily\_wholesalers\_Consumption,FMCG\_movg\_avg\_time,Daily\_whol  
esalers\_Consumption)
- (022) FMCG Desired New Employees=  
FMCG Experince Gap/FMCG Experinced employee level  
Units: \*\*undefined\*\*
- (023) FMCG Expected Daily Demand=  
FMCG Last Month Sales/FMCG moving avg Time  
Units: \*\*undefined\*\*
- (024) FMCG Expenditures on marketing=  
percieved Net Profit\*market share of revenue  
Units: \*\*undefined\*\*
- (025) FMCG Expenses=  
FMCG Expenditures on marketing+FMCG spending on Training+FMCG Transportation Costs  
+production costs  
Units: \*\*undefined\*\*
- (026) FMCG Experince Gap=  
max(0,FMCG ref Exp Level-FMCG Experince Level)  
Units: \*\*undefined\*\*
- (027) FMCG Experince Level=  
FMCG Experinced employee level\*FMCG Experinced Employees+FMCG New Employee Experince level  
\*FMCG New Employees  
Units: \*\*undefined\*\*
- (028) FMCG Experinced employee level=  
1  
Units: \*\*undefined\*\*
- (029) FMCG Experinced Employees= INTEG (  
FMCG Gaining Experince-FMCG Quitting,  
20)

## APPENDICES

- Units: \*\*undefined\*\*
- (030) FMCG Gaining Experience=  
FMCG New Employees/FMCG Training Period  
Units: \*\*undefined\*\*
- (031) FMCG Hiring=  
FMCG Desired New Employees/FMCG time to hire  
Units: \*\*undefined\*\*
- (032) FMCG Inventory= INTEG (  
Production rate-Orders to other Wholesalers-FMCG Shipping to NDC,  
9\*(290625))  
Units: \*\*undefined\*\*
- (033) FMCG Inventory Gap=  
DELAY N(max(Desired FMCG Inventory-FMCG Inventory,0),1,max(Desired FMCG Inventory  
-FMCG Inventory,0),1)  
Units: \*\*undefined\*\*  
DELAY N(max(Desired FMCG Inventory-FMCG  
Inventory,0),7,max(Desired FMCG Inventory-FMCG Inventory,0),1)
- (034) FMCG Last Month Sales= INTEG (  
Daily Wholesalers Demand-FMCG Consumption 4 weeks ago,  
30\*(290625))  
Units: \*\*undefined\*\*
- (035) FMCG lead Time=  
DELAY FIXED( FMCG shipping time , 30 , FMCG shipping time )  
Units: \*\*undefined\*\*  
DELAY N( FMCG shipping time , 30 , FMCG shipping time,1)\*0
- (036) FMCG moving avg Time=  
30  
Units: \*\*undefined\*\*  
it should be 30
- (037) FMCG New Employee Experience level=  
0.25  
Units: \*\*undefined\*\*
- (038) FMCG New Employees= INTEG (  
FMCG Hiring-FMCG Gaining Experience,  
0)  
Units: \*\*undefined\*\*
- (039) FMCG num of shipping trucks=  
FMCG shipping rate/FMCG Truck capacity  
Units: \*\*undefined\*\*
- (040) FMCG performance Index=  
FMCG Experience Level/FMCG ref Exp Level  
Units: \*\*undefined\*\*
- (041) FMCG progit Margin=  
0.4\*(1+s1\*(step(-0.5,30) + step(0.5,90)))  
Units: \*\*undefined\*\*
- (042) FMCG Quiting=  
0+s3\*( ( step(1,30)-step(1,31)) + (step(1,60)-step(1,61)) + (step(1,90)-step  
(1,91)) + (step(1,120)-step(1,121)) + (step(1,150)-step(1,151)) + (step(1,  
180)-step(1,181)))  
Units: \*\*undefined\*\*
- (043) FMCG ref Exp Level=



- 20  
Units: \*\*undefined\*\*
- (044) FMCG Revenues=  
FMCG shipping rate\*FMCG Selling Price  
Units: \*\*undefined\*\*
- (045) FMCG Selling Price=  
(FMCG Case Cost/(1-FMCG progit Margin))  
Units: \*\*undefined\*\*
- (046) FMCG shipping rate=  
FMCG Shipping to NDC+Orders to other Wholesalers  
Units: \*\*undefined\*\*
- (047) FMCG shipping time = WITH LOOKUP (  
FMCG performance Index,  
((0,0)-(1.5,50)),(0.2,50),(0.4,35),(0.5,27),(0.6,21),(0.7,16),(0.8,12),  
(0.9,8),(1,5),(1.2,5) )  
Units: \*\*undefined\*\*
- (048) FMCG Shipping to NDC=  
min(NDC share of FMCG Sales\*FMCG Inventory,orders shipped to NDC)  
Units: \*\*undefined\*\*
- (049) FMCG spending on Training=  
FMCG Gaining Experince\*FMCG Training cost per employee  
Units: \*\*undefined\*\*
- (050) FMCG time to hire=  
30  
Units: \*\*undefined\*\*
- (051) FMCG Training cost per employee=  
5000  
Units: \*\*undefined\*\*
- (052) FMCG Training Period=  
90  
Units: \*\*undefined\*\*
- (053) FMCG Transportation Costs=  
FMCG num of shipping trucks\*FMCG Truck cost  
Units: \*\*undefined\*\*
- (054) FMCG Truck capacity=  
1000  
Units: \*\*undefined\*\*
- (055) FMCG Truck cost=  
50  
Units: \*\*undefined\*\*
- (056) FMCG WIP= INTEG (  
Production Orders-Production rate,  
10\*(290625))  
Units: \*\*undefined\*\*
- (057) INITIAL TIME = 0  
Units: Day  
The initial time for the simulation.
- (058) market share=  
Total effect on market\*1  
Units: \*\*undefined\*\*

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- (059) market share of revenue=  

$$0.09 * (1 + s1 * (\text{step}(0.75, 15) - \text{step}(0.75, 75)))$$
Units: \*\*undefined\*\*
- (060) marketing effect on market share = WITH LOOKUP (  
marketing index,  

$$((0, 0) - (1.5, 1.2)), (0, 0.3), (0.375, 0.4), (0.75, 1), (1.125, 1), (1.5, 1) )$$
Units: \*\*undefined\*\*
- (061) marketing index=  
total marketing expenditures/ref expenditures on marketing  
Units: \*\*undefined\*\*
- (062) NDC BackLogs= INTEG (  
Orders Placed-NDC Orders Cancelation-orders shipped to NDC,  

$$(1.395e+006/7)$$
Units: \*\*undefined\*\*
- (063) NDC Cash Balance= INTEG (  
NDC Revenues-NDC Expenses,  
1000)  
Units: \*\*undefined\*\*
- (064) NDC consumption 4 weeks ago=  
SMOOTH N(Daily Retail Demand,NDC movg avg time,Daily Retail Demand,1)  
Units: \*\*undefined\*\*  
SMTH1(Daily\_Retail\_Consumption,NDC\_movg\_avg\_time,Daily\_Retail\_Consumption)
- (065) NDC Desired New Employees=  
NDC Experince Gap/NDC Experinced employee level  
Units: \*\*undefined\*\*
- (066) NDC Expected Daily Demand=  
NDC Last Month Sales/NDC movg avg time  
Units: \*\*undefined\*\*
- (067) NDC Expenditures on marketing=  
NDC Percieved Net Profit\*NDC marketing expenditure as share of revenue  
Units: \*\*undefined\*\*
- (068) NDC Expenses=  
NDC Purchases from FMCG+NDC Expenditures on marketing+NDC spending on Training  
+NDC Transportation Costs+NDC Purchases from Others  
Units: \*\*undefined\*\*
- (069) NDC Experince Gap=  

$$\max(0, \text{NDC ref Exp Level} - \text{NDC Experince Level})$$
Units: \*\*undefined\*\*
- (070) NDC Experince Level=  
NDC Experinced employee level\*NDC Experinced Employees+NDC New Employee Experince level  
\*NDC New Employees  
Units: \*\*undefined\*\*
- (071) NDC Experinced employee level=  
1  
Units: \*\*undefined\*\*
- (072) NDC Experinced Employees= INTEG (  
NDC Gaining Experince-NDC Quiting,  
12  
)  
Units: \*\*undefined\*\*

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- (073) NDC Gaining Experince=  
NDC New Employees/NDC Training Period  
Units: \*\*undefined\*\*
- (074) NDC Hiring=  
NDC Desired New Employees/NDC time to hire  
Units: \*\*undefined\*\*
- (075) NDC Inventory= INTEG (  
shipping from different supplier+FMCG Shipping to NDC-NDC Shipping Products  
,  
4\*46500)  
Units: \*\*undefined\*\*  
625000
- (076) NDC Inventory Gap=  
DELAY N(max(Desired NDC Inventory-NDC Inventory,0),1,max(Desired NDC Inventory  
-NDC Inventory,0),1)  
Units: \*\*undefined\*\*  
DELAY N(max(Desired NDC Inventory-NDC Inventory,0),5,max(Desired  
NDC Inventory-NDC Inventory,0),1)
- (077) NDC Last Month Sales= INTEG (  
Daily Retails Demand-NDC consumption 4 weeks ago,  
651000)  
Units: \*\*undefined\*\*  
857500
- (078) NDC Lead Time=  
  
DELAY FIXED( NDC Shipping Time , 30 , NDC Shipping Time )  
Units: \*\*undefined\*\*  
DELAY N( NDC Shipping Time ,30, NDC Shipping Time,6)
- (079) NDC marketing expenditure as share of revenue=  
0.08  
Units: \*\*undefined\*\*
- (080) NDC movg avg time=  
14  
Units: \*\*undefined\*\*  
30
- (081) NDC Net Profit=  
max(0,NDC Revenues-NDC Expenses)  
Units: \*\*undefined\*\*
- (082) NDC New Employee Experince level=  
0.25  
Units: \*\*undefined\*\*
- (083) NDC New Employees= INTEG (  
NDC Hiring-NDC Gaining Experince,  
0)  
Units: \*\*undefined\*\*
- (084) NDC num of shipping trucks=  
NDC Shipping Products/NDC Truck capacity  
Units: \*\*undefined\*\*
- (085) NDC Orders Cancelation=  
NDC BackLogs/cancellation period  
Units: \*\*undefined\*\*

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- (086) NDC Percieved Net Profit=  
 $\text{DELAY FIXED( NDC Net Profit , 1 , 1 )}$   
 Units: \*\*undefined\*\*
- (087) NDC performance Index=  
 $\text{NDC Experince Level/NDC ref Exp Level}$   
 Units: \*\*undefined\*\*
- (088) NDC progit Margin=  
 $0.3$   
 Units: \*\*undefined\*\*
- (089) NDC Purchases from FMCG=  
 $\text{FMCG Shipping to NDC*NDC Purchasing price}$   
 Units: \*\*undefined\*\*
- (090) NDC Purchases from Others=  
 $\text{shippng from different supplier*NDC Purchasing price*1.2}$   
 Units: \*\*undefined\*\*  
 20% increase in selling price
- (091) NDC Purchasing price=  
 $\text{FMCG Selling Price}$   
 Units: \*\*undefined\*\*
- (092) NDC Quiting=  
 $0+s4*((\text{step}(1,30)-\text{step}(1,31)) + (\text{step}(1,60)-\text{step}(1,61)) + (\text{step}(1,90)-\text{step}(1,91)) + (\text{step}(1,120)-\text{step}(1,121)) + (\text{step}(1,150)-\text{step}(1,151)) + (\text{step}(1,180)-\text{step}(1,181)))$   
 Units: \*\*undefined\*\*
- (093) NDC ref Exp Level=  
 $12$   
 Units: \*\*undefined\*\*
- (094) NDC Revenues=  
 $\text{NDC Shipping Products*Retail Price}$   
 Units: \*\*undefined\*\*
- (095) NDC share of FMCG Sales=  
 $0.16$   
 Units: \*\*undefined\*\*
- (096) NDC Shipping Products=  
 $\text{min(NDC Inventory,Orders Shipping)}$   
 Units: \*\*undefined\*\*
- (097) NDC Shipping Time = WITH LOOKUP (  
 $\text{NDC performance Index,}$   
 $((0,0)-(1.5,50)),(0.2,40),(0.4,30),(0.5,23),(0.6,17),(0.7,12),(0.8,8),($   
 $0.9,4),(1,2),(1.2,2) )$   
 Units: \*\*undefined\*\*
- (098) NDC spending on Training=  
 $\text{NDC Gaining Experince*NDC Training cost per employee}$   
 Units: \*\*undefined\*\*
- (099) NDC time to hire=  
 $30$   
 Units: \*\*undefined\*\*
- (100) NDC Training cost per employee=  
 $5000$   
 Units: \*\*undefined\*\*

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- (101) NDC Training Period=  
90  
Units: \*\*undefined\*\*
- (102) NDC Transportation Costs=  
NDC num of shipping trucks\*NDC Truck cost  
Units: \*\*undefined\*\*
- (103) NDC Truck capacity=  
1000  
Units: \*\*undefined\*\*
- (104) NDC Truck cost=  
50  
Units: \*\*undefined\*\*
- (105) Net Profit=  
max(0,FMCG Revenues-FMCG Expenses)  
Units: \*\*undefined\*\*
- (106) On Shelf= INTEG (  
NDC Shipping Products-Consumption,  
2\*46500)  
Units: \*\*undefined\*\*  
325000
- (107) on shelf gap=  
DELAY N(max(0,Desired On Shelf Level-On Shelf),1,max(0,Desired On Shelf Level  
-On Shelf),1)  
Units: \*\*undefined\*\*  
DELAY N(max(0,Desired On Shelf Level-On Shelf),3,max(0,Desired  
On Shelf Level-On Shelf),1)
- (108) onshelf index=  
percieved on shelf/ref on shelf  
Units: \*\*undefined\*\*
- (109) onshelf index effect on market share = WITH LOOKUP (  
onshelf index,  
((0,0)-(1.5,1.2)),(0,0),(0.5,0.5),(1,0.9),(1.5,0.95),(1.5,0.95) )  
Units: \*\*undefined\*\*
- (110) Orders Arrival=  
orders to NDC  
Units: \*\*undefined\*\*
- (111) Orders Placed=  
Orders to FMCG  
Units: \*\*undefined\*\*
- (112) orders shipped to NDC=  
NDC BackLogs/FMCG shipping time  
Units: \*\*undefined\*\*
- (113) Orders Shipping=  
Retailers BackLogs/NDC Shipping Time  
Units: \*\*undefined\*\*
- (114) Orders to FMCG=  
NDC Inventory Gap  
Units: \*\*undefined\*\*
- (115) orders to NDC=  
on shelf gap  
Units: \*\*undefined\*\*

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- (116) Orders to other Wholesalers=  
 $\min(\text{FMCG Inventory} * (1 - \text{NDC share of FMCG Sales}), 244125 + (46500/7))$   
 Units: \*\*undefined\*\*
- (117) Orders to produce=  
 FMCG Inventory Gap  
 Units: \*\*undefined\*\*
- (118) percieved Daily Demand=  
 Daily Demand  
 Units: \*\*undefined\*\*  
 $\text{DELAY N}(\text{Daily Demand}, 30, \text{Daily Demand}, 3)$
- (119) percieved Net Profit=  
 $\text{DELAY FIXED}(\text{Net Profit}, 1, 1)$   
 Units: \*\*undefined\*\*
- (120) percieved on shelf=  
 $\text{DELAY N}(\text{On Shelf}, 3, \text{On Shelf}, 1)$   
 Units: \*\*undefined\*\*
- (121) percieved order cancelation=  
 $\text{DELAY FIXED}(\text{NDC Orders Cancelation}, 4, \text{NDC Orders Cancelation})$   
 Units: \*\*undefined\*\*
- (122) percived market share=  
 $\text{DELAY N}(\text{market share}, 30, \text{market share}, 3)$   
 Units: \*\*undefined\*\*
- (123) production capacity=  
 $12 * (290625) * (1 + 1 * (\text{step}(-0.25, 75) + \text{step}(0.25, 135))) * s2$   
 Units: \*\*undefined\*\*
- (124) production costs=  
 Production rate \* FMCG Case Cost  
 Units: \*\*undefined\*\*
- (125) Production Lead Time=  
 $\text{DELAY FIXED}(\text{production time}, 15, \text{production time})$   
 Units: \*\*undefined\*\*  
 $\text{DELAY N}(\text{production time}, 15, \text{production time}, 1)$
- (126) Production Orders=  
 $\min(\text{Orders to produce}, \text{available capacity})$   
 Units: \*\*undefined\*\*
- (127) Production rate=  
 $\min(\text{FMCG WIP}, \text{FMCG WIP} / \text{production time})$   
 Units: \*\*undefined\*\*
- (128) production time=  
 $\text{Production Time function} + 1 * (\text{step}(5, 75) - \text{step}(5, 135)) * s2$   
 Units: \*\*undefined\*\*  
 $+ \text{step}(5, 30) - \text{step}(5, 90)$
- (129) Production Time function = WITH LOOKUP (  
 FMCG performance Index,  
 $((0, 0) - (1.5, 70)), (0.2, 65), (0.4, 50), (0.5, 40), (0.6, 31), (0.7, 24), (0.8, 18),$   
 $(0.9, 13), (1, 10), (1.2, 10))$   
 Units: \*\*undefined\*\*
- (130) ref expenditures on marketing=  
 total marketing expenditures

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- Units: \*\*undefined\*\*
- (131) ref on shelf=  
 $2 * \text{Daily Demand} * 0.9$   
 Units: \*\*undefined\*\*  
 232500
- (132) retail Expected Daily Demand=  
 Retailers Last Two Weeks Sales/retail movg avg time  
 Units: \*\*undefined\*\*
- (133) retail movg avg time=  
 $\frac{7}{15}$   
 Units: \*\*undefined\*\*
- (134) Retail Price=  
 $\text{NDC Purchasing price} / (1 - \text{NDC profit Margin})$   
 Units: \*\*undefined\*\*
- (135) Retailers BackLogs= INTEG (  
 Orders Arrival-Orders Shipping,  
 93000)  
 Units: \*\*undefined\*\*
- (136) Retailers Last Two Weeks Sales= INTEG (  
 Daily Customer Consumption-Consumption 2 weeks ago,  
 $7 * 46500$ )  
 Units: \*\*undefined\*\*  
 418000
- (137) s1=  
 $\frac{0}{0}$   
 Units: \*\*undefined\*\*
- (138) s2=  
 $\frac{0}{0}$   
 Units: \*\*undefined\*\*
- (139) s3=  
 $\frac{0}{0}$   
 Units: \*\*undefined\*\*
- (140) s4=  
 $\frac{0}{0}$   
 Units: \*\*undefined\*\*
- (141) SAVEPER = 1  
 Units: Day [0,?]  
 The frequency with which output is stored.
- (142) shipping from different supplier=  
 perceived order cancelation  
 Units: \*\*undefined\*\*
- (143) TIME STEP = 0.0078125  
 Units: Day [0,?]  
 The time step for the simulation.
- (144) Total Daily Demand=  
 Daily demand from NDC+244125  
 Units: \*\*undefined\*\*
- (145) Total effect on market=  
 $(\text{marketing effect on market share}^{\text{elasticity of marketing on market share}}$

## APPENDICES

)\*(onshelf index effect on market share^elasticity of on shelf on market share  
)

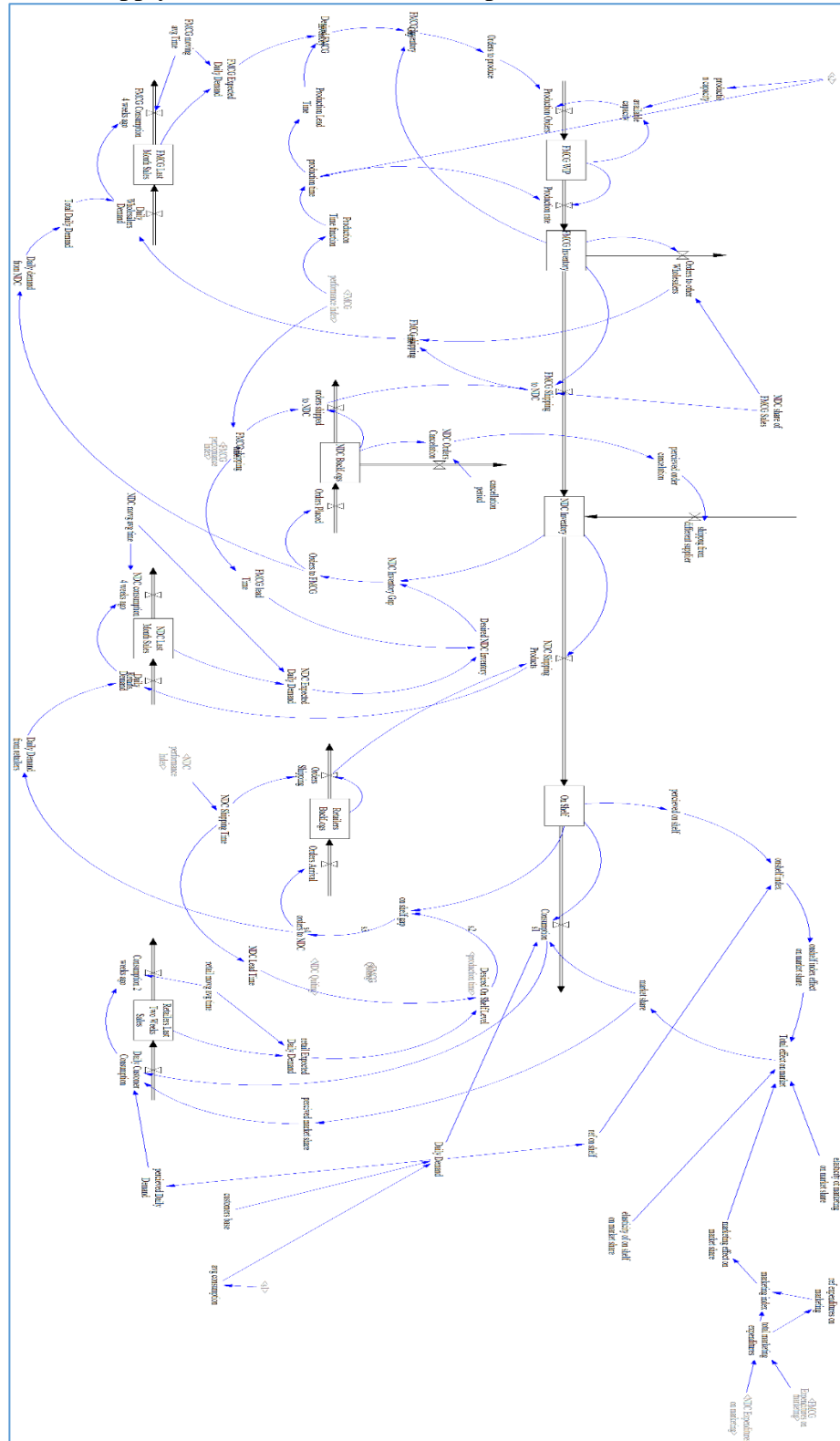
Units: \*\*undefined\*\*

(146) total marketing expenditures=  
NDC Expenditures on marketing+FMCG Expenditures on marketing  
Units: \*\*undefined\*\*

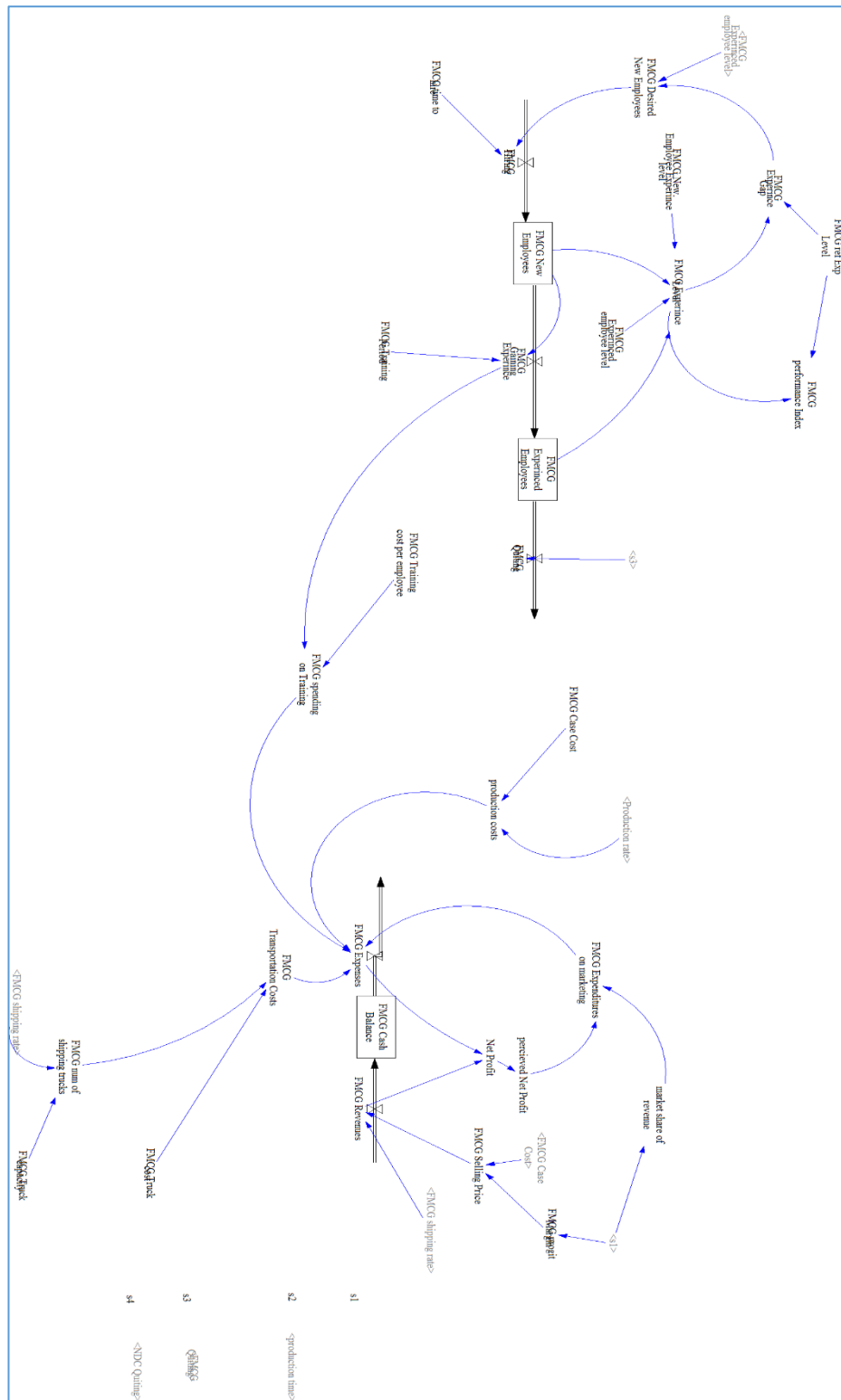


## Appendix C – SD Model Stock and Flow Maps

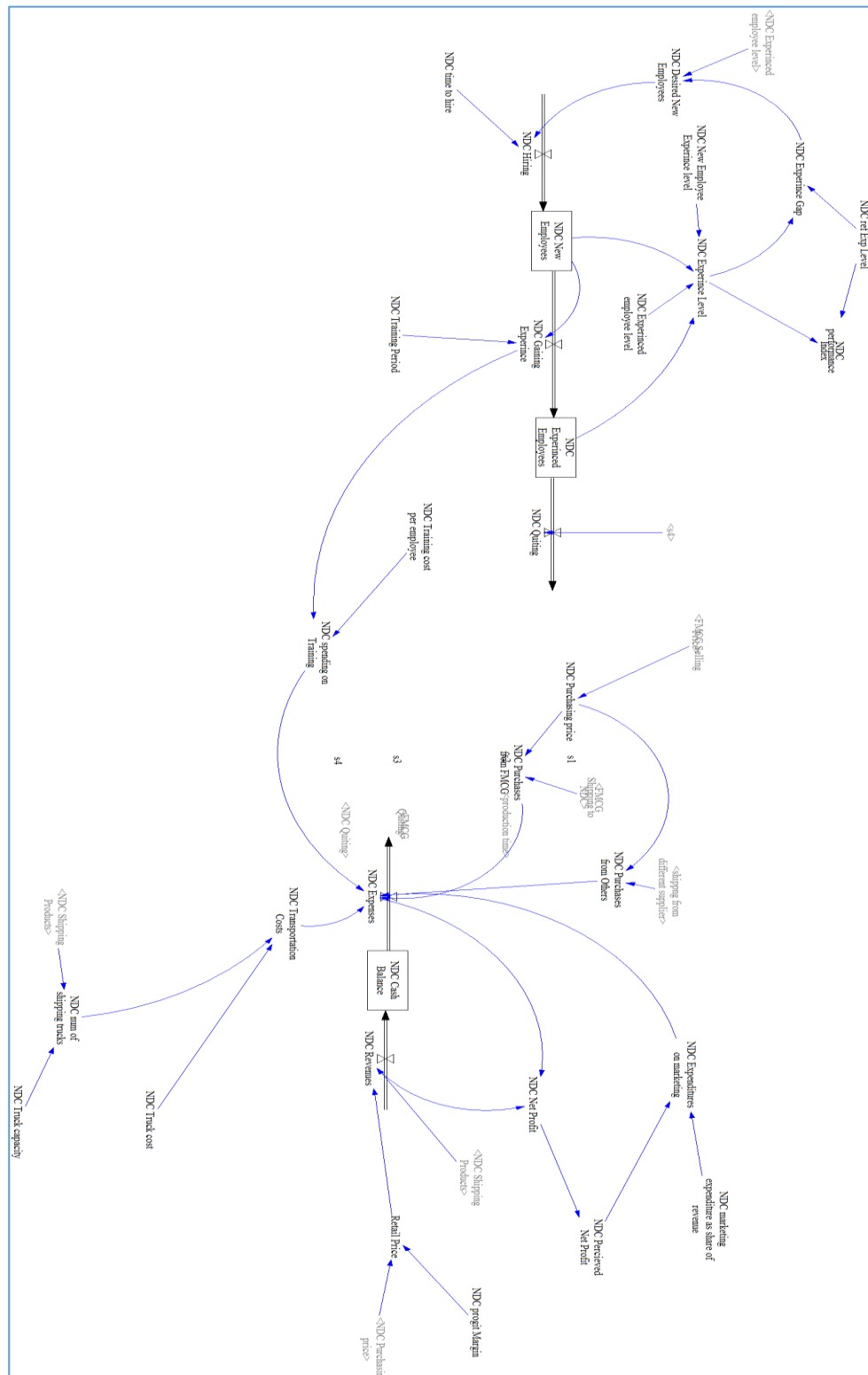
## Three Echelon Supply Chain Stock and Flow Map



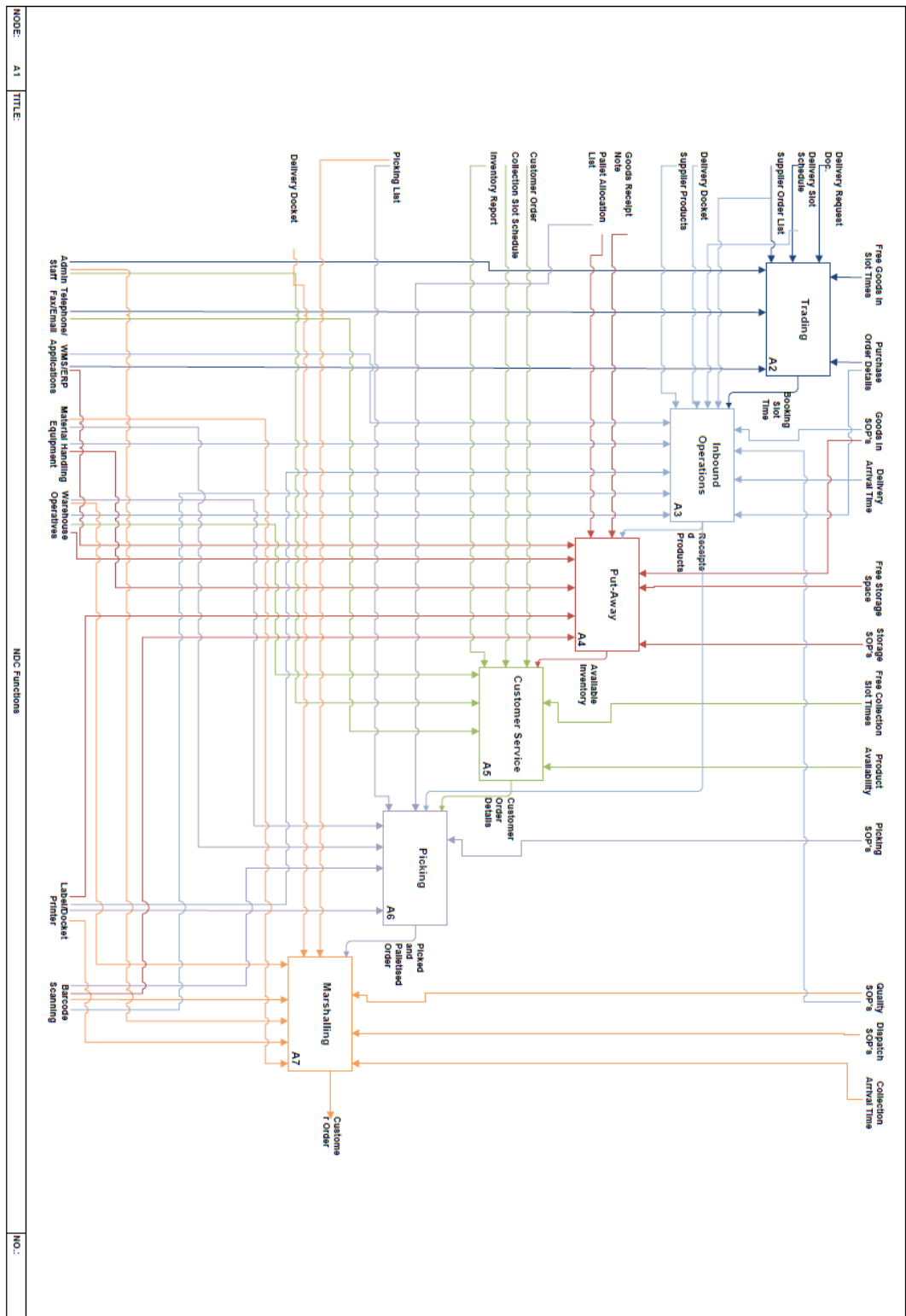
## FMCG Employee and Finance Stock and Flow Map



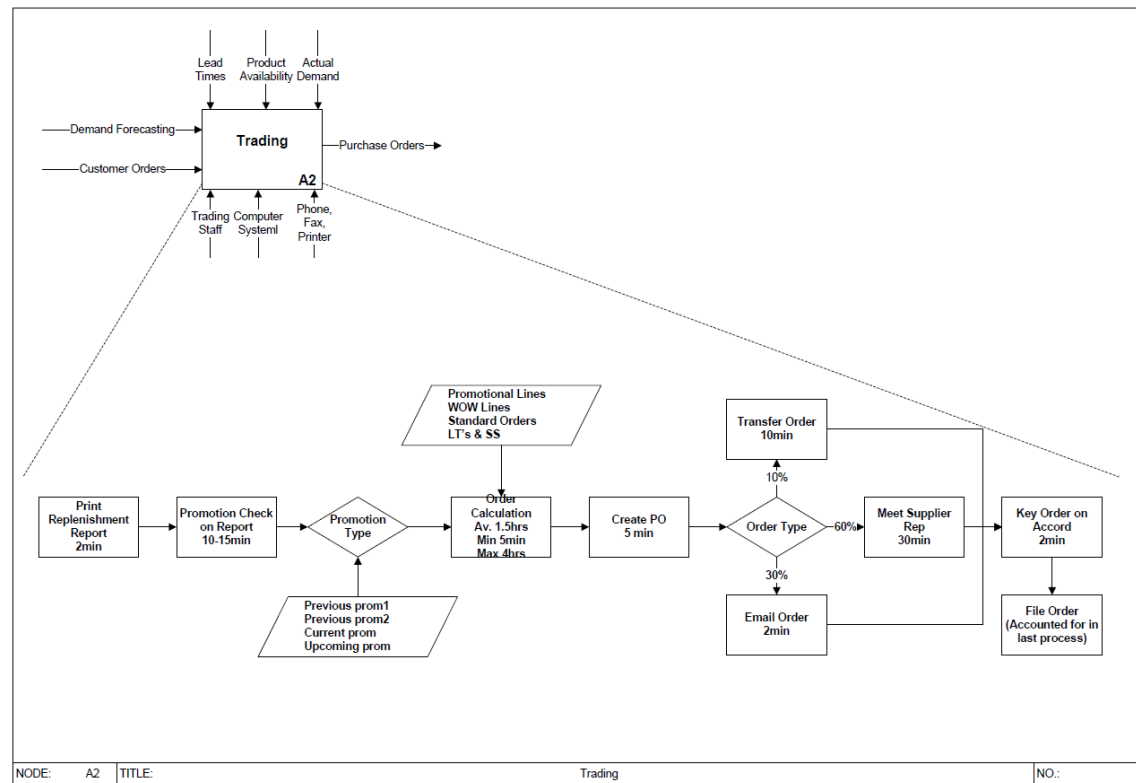
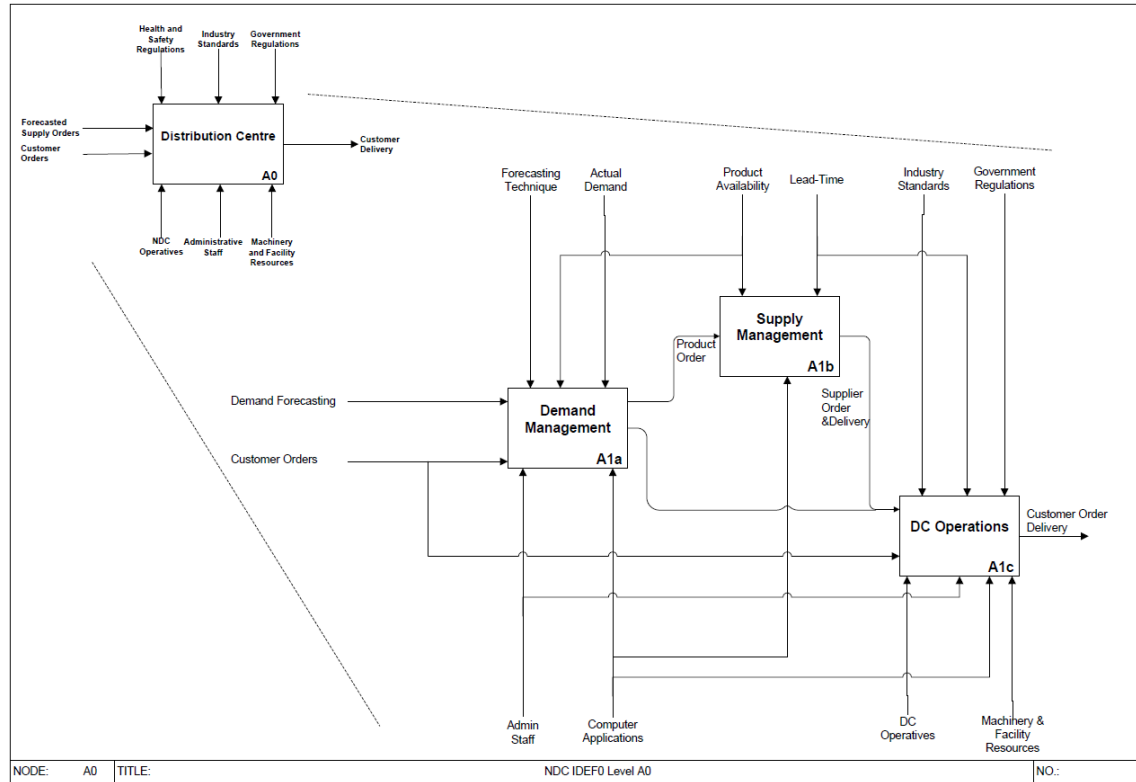
## NDC Employee and Finance Stock and Flow Map



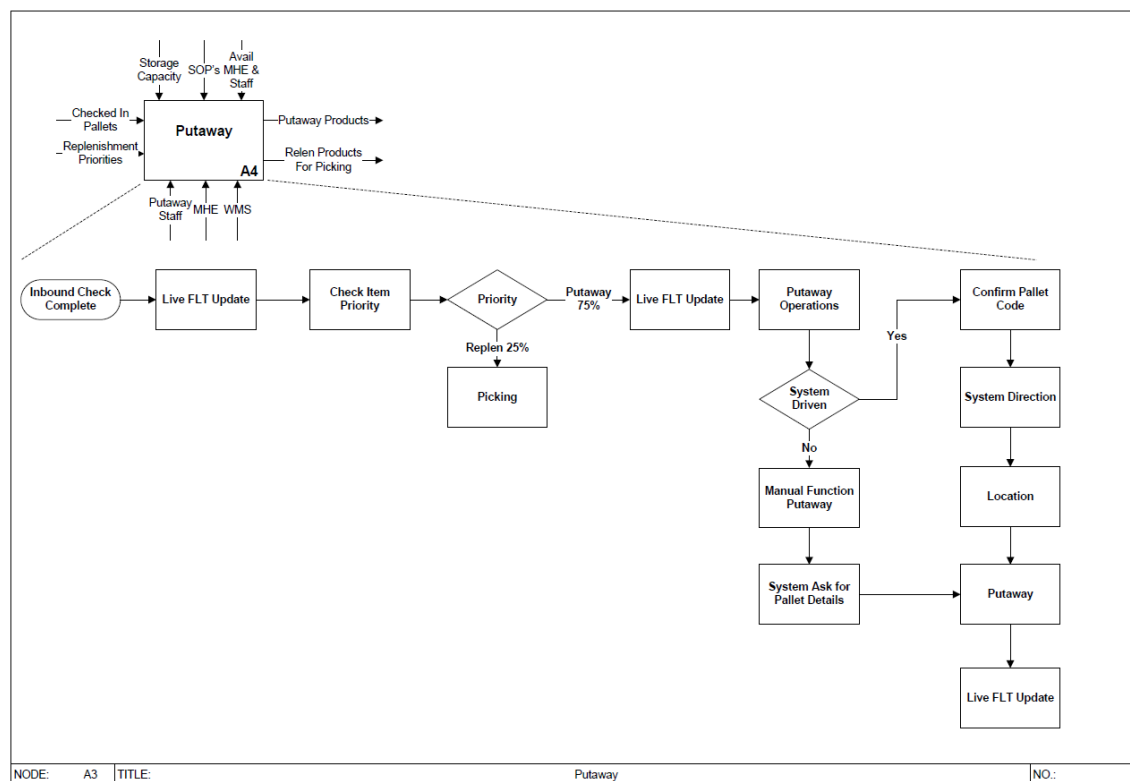
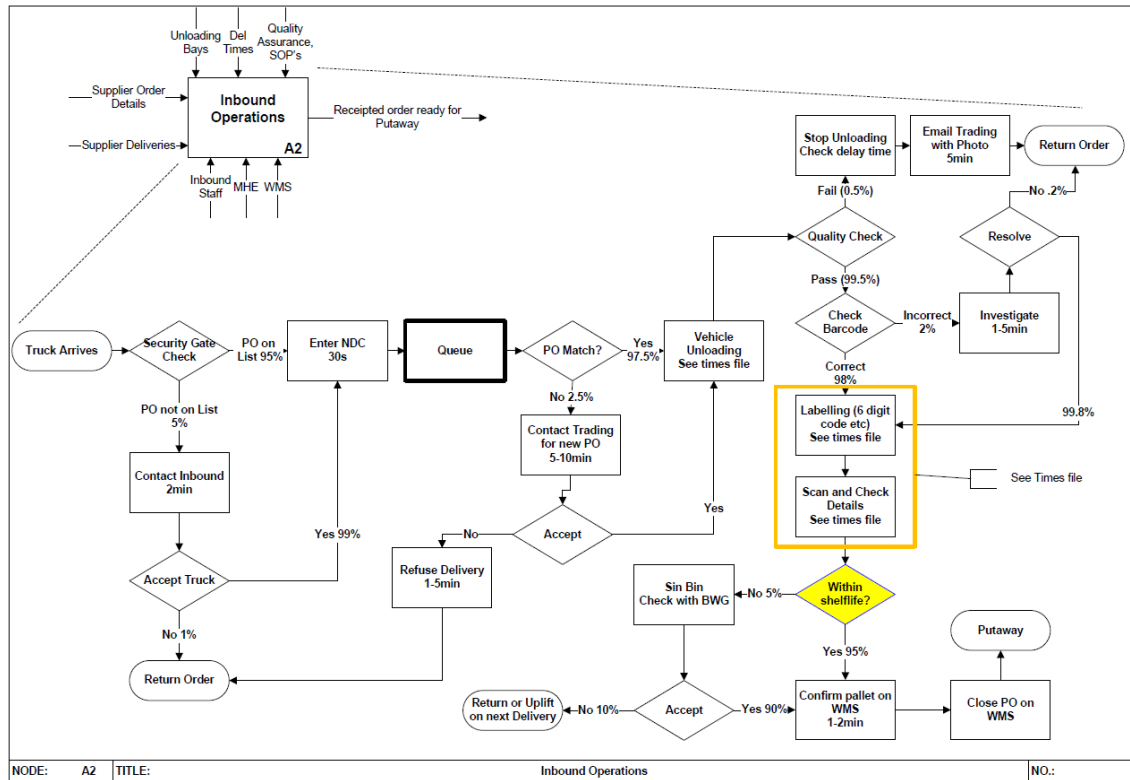
Appendix D – DES Study Conceptual Models

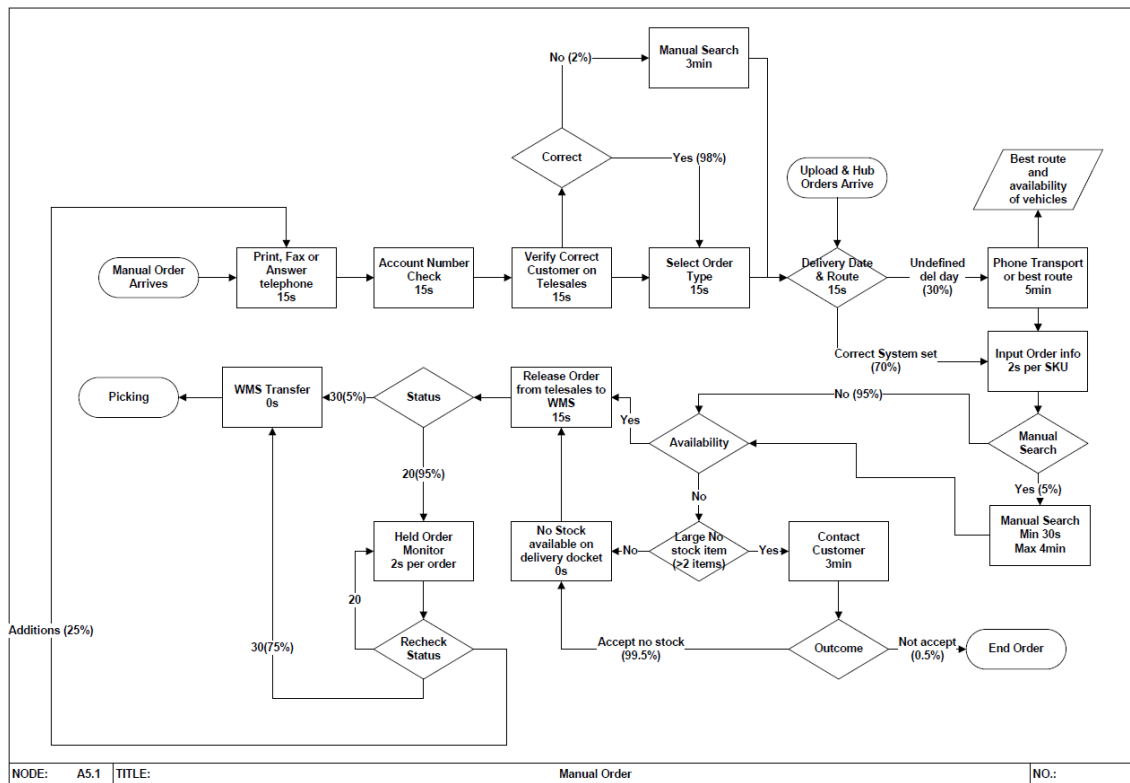
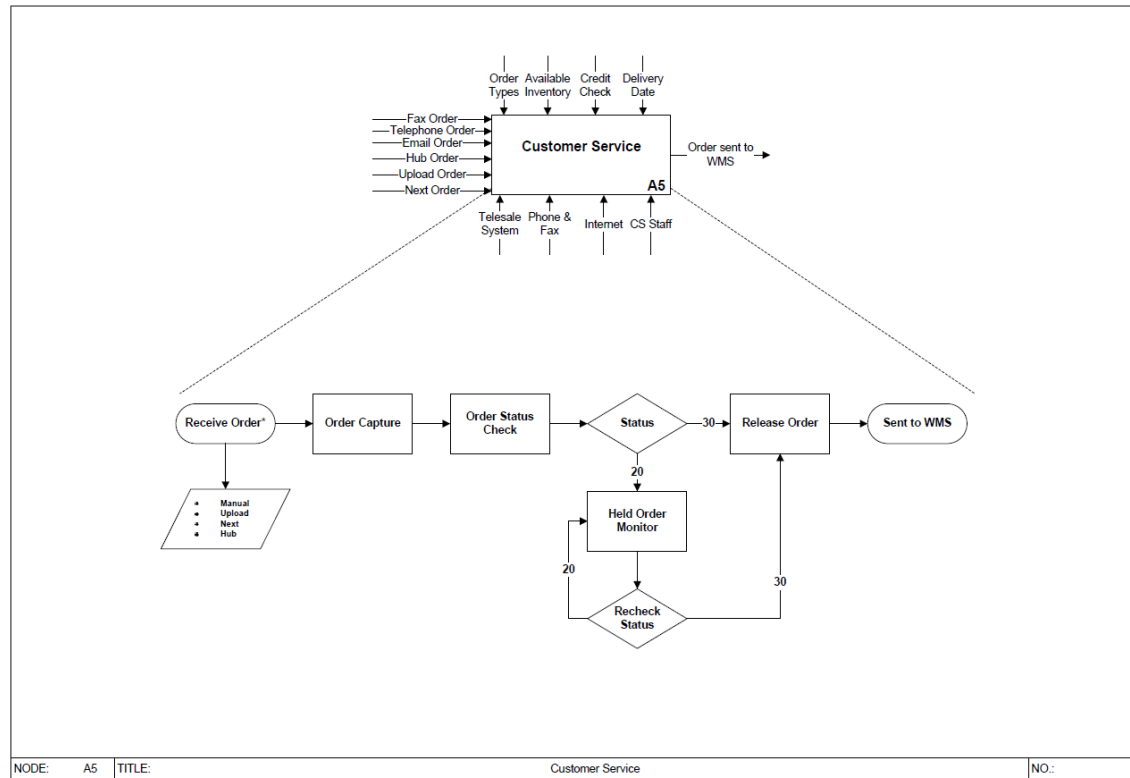


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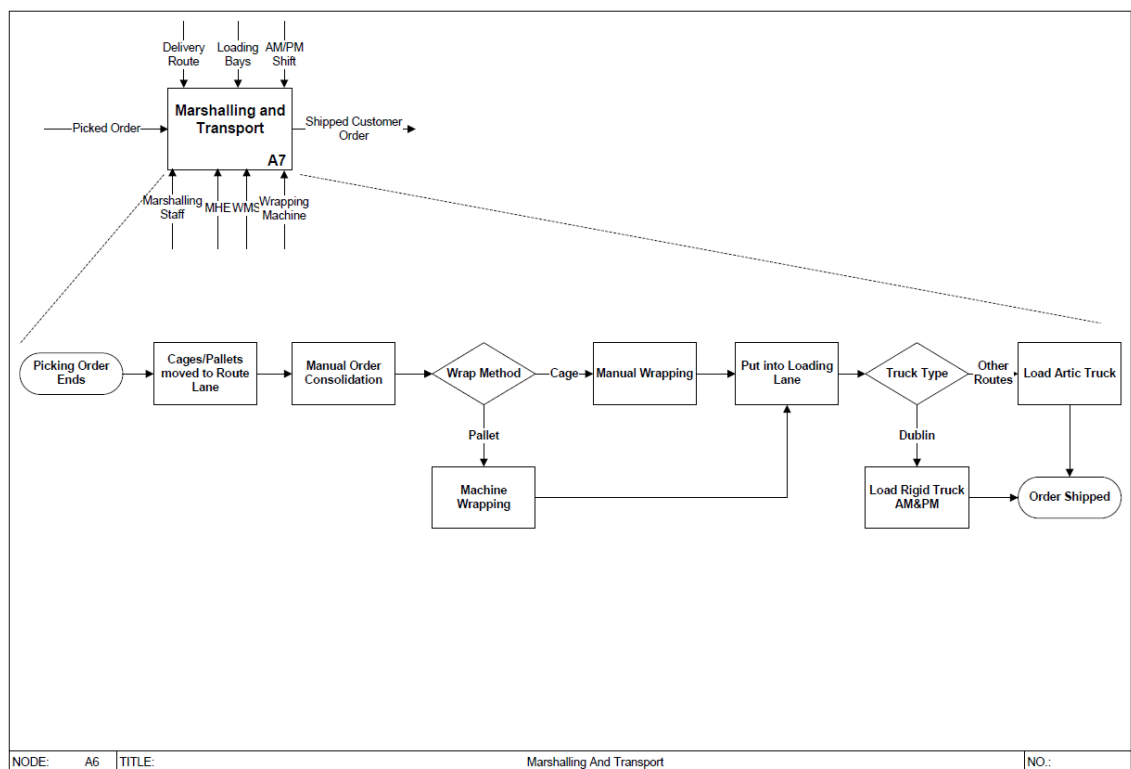
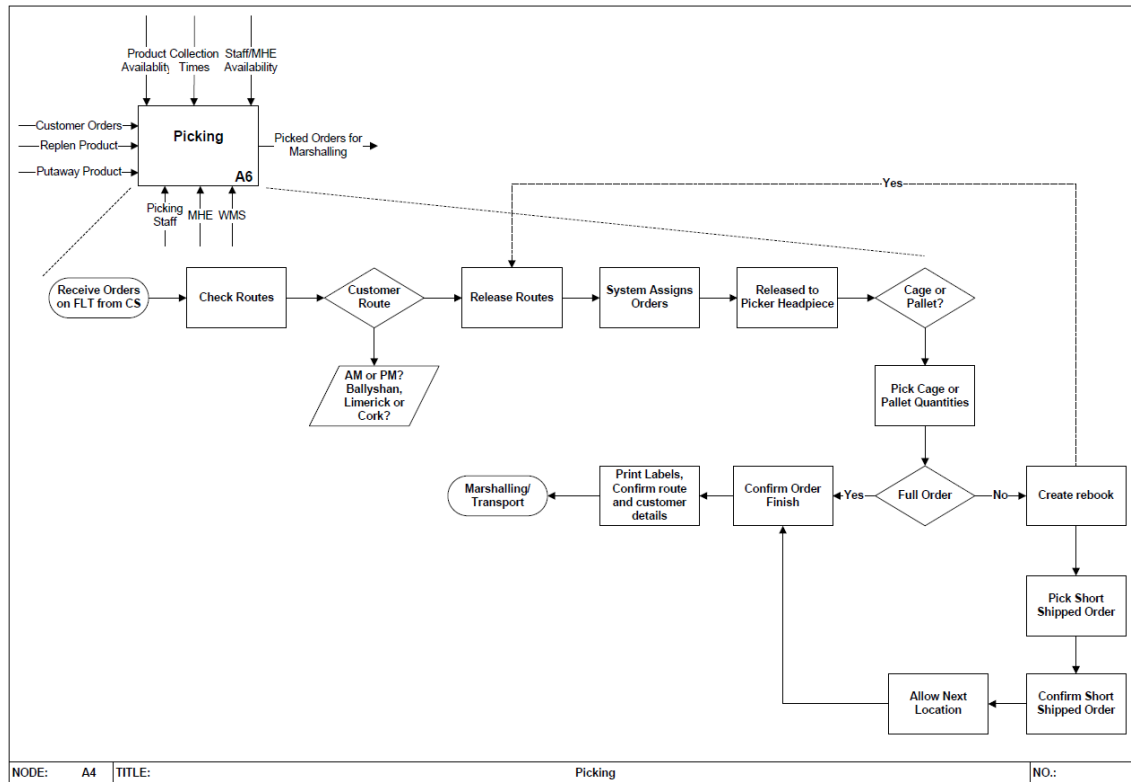


## APPENDICES





## APPENDICES





## LIST OF PUBLICATIONS - FRONT PAGES

TOWARDS LEANER HEALTHCARE FACILITY: APPLICATION OF SIMULATION  
MODELLING AND VALUE STREAM MAPPING

Waleed Abo Hamad, John Crowe, Amr Arisha

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Aungier Street, Dublin2, Ireland**ABSTRACT**

Recently, the application of lean thinking in healthcare has grown significantly in response to rising demand caused by population growth, ageing and high expectations of service quality. However, insufficient justifications and lack of quantifiable evidence are the main obstacles to convince healthcare executives to adopt lean. Therefore, this paper presents a methodology that integrates lean tools with simulation to enhance the quality of patient care in healthcare facilities. This enables healthcare organisations to dedicate more time and effort to patient care without extra cost to the organisation or to the patient. Value stream mapping is used to identify value-added and non-value-added activities. Then, a comprehensive simulation model is developed to account for the variability and complexity of healthcare processes and to assess the gains of proposed improvement strategies. An extensive analysis of results is provided and presented to managers to illustrate the potential benefits of adapting lean practices.

Keywords: lean thinking, modelling and simulation, value stream mapping, healthcare management

**1. INTRODUCTION**

Science and technology are advancing at a rapid pace; however, the healthcare delivery systems world-wide struggle to cope, especially in their ability to provide high-quality service levels consistently. Healthcare systems are in need of fundamental changes in the way care services are managed. Many patients, doctors, nurses, and healthcare providers are concerned that the care delivered is not, essentially, the care that should be received. The frustration levels of both patients and clinicians have probably never been higher. Policy makers, healthcare providers and managers should provide the quality of care that meets people's needs while improving the efficiency of their business processes based on the best scientific knowledge available. Yet there is strong evidence that this frequently is not the case. Large numbers of disciplined review bodies have reported the scale and gravity in healthcare problems world-wide. More systematic and sophisticated approaches are needed to analyse and manage healthcare processes and to support decision makers and healthcare managers in the provision of

informed decisions and strategies for delivering safe and effective care.

Accordingly, many healthcare organisations have recently adopted Lean management as the performance improvement approach for their systems (Poksinska, 2010). The Lean approach seeks improvements within the existing processes of an organisation without substantial reorganisation requiring high investments (Bahensky et al., 2005). (Mahfouz et al., 2011) The main step in Lean healthcare thinking is to put the patient in the foreground and include time and comfort as key performance measures of the system (Womack and Jones, 2003). Lean strategies eliminate process steps that do not add value for patient care, while enhancing those that are valuable and essential. As a result, staff members feel empowered to improve care processes (Spear, 2005). However, insufficient justifications and lack of quantifiable evidence are the main obstacles to convince healthcare executives to adopt lean management. Therefore, this paper presents a framework that integrates lean techniques with simulation to enhance the quality of patient care in healthcare facilities.

**2. PROPOSED FRAMEWORK**

The proposed framework is a simulation-based lean decision support model for healthcare application. There are three distinct phases to the framework; (1) identification, (2) development and (3) assessment, as illustrated in Figure 1. The framework phases will be discussed in detail in Section 3. The remainder of this section will introduce the core domains that are the foundations of the framework. They are; value stream mapping (VSM), Simulation-based VSM and Healthcare Application.

**2.1. Value Stream Mapping**

The logic behind lean thinking is pursuing the optimization of value streams from the consumption point of view by eliminating waste and non-value added activities. In order to identify the sources of waste, non-value added activities and opportunities of improvement, value added activities have to be mapped using systematic tools and techniques – VSM technique (Rother and Shook, 1998). A value stream can be defined as the collection of activities (value added and non-value added) that are operated to produce a product or service or a combination of both to a customer



## Increasing Value Generation using a Hierarchical Simulation-Based SCOR Framework

John Crowe<sup>1</sup> and Amr Arisha<sup>2</sup>

### Abstract

We are part of extraordinary times, global recession coupled with increased competition; high costs and decreasing demand have changed the dynamics of supply chain management (SCM). In response, many organizations have fast-tracked changes to corporate-level strategies to reduce costs and maintain profit margins and have not considered the long-term impact these decisions have on more operational-level SCM activities. This has resulted in a renewed focus on customer value and the economic and behavioral systems of the supply chain, or more accurately, the value chain. The Supply Chain Operations Reference (SCOR) model increases the integration organizations have within their supply chains and increases alignment between different hierarchical strategies. Simulation techniques, in particular discrete-event simulation (DES) and system dynamics (SD) are proven techniques in improving SCM corporate and operational decision making processes. This paper presents a framework that integrates SCOR with DES-SD modeling approaches in order to improve the performance of inventory management in a leading tire distribution center in Ireland. This integration shows an effective method to evaluate order strategies, enhance throughput and increase value generation within supply chain networks.

**Keywords:** Supply Chain Management, Value Chain, SCOR, Simulation, System Dynamics

### 1. Introduction

This is an era marked by an unprecedented global recession and a high level of uncertainty within markets. Coupled with cost reduction pressures and rapidly changing customer requirements, strategic management has evolved requiring more agile planning and lean control techniques. Through this evolution, there is recognition of the need for decision-making tools and new approaches to the arrangement of the supply chain (SC) that optimizes value, both for the customer and supply chain partners. The variations in product-orders, multi-suppliers, and parallel processes have increased the level of risk in SC's and make SC management (SCM) a major challenge. To complicate planning activities further, increased global competitiveness and innovations in technology have decreased the life cycle of many products. Demand uncertainty, in particular, has become an increasingly important factor. To accurately hedge against demand uncertainty, efficient inventory management controls are needed in SC operations.

SCM is a vast management concept, with many interpretations and definitions. Although the concept itself was only introduced in early 1980 by Oliver and Webber, cited in Jüttner et al. (2007), it was not until the mid 1990's that it came to prominence globally. SCM can be defined as the strategic management of upstream (suppliers) and downstream (customers) relationships in order to create enhanced value to the final consumer at less cost to the SC as a whole (Christopher, 1998). At its basic level, a SC is made up of multiple actors, multiple flows of items, information, and finances, and is sometimes described as looking like an 'uprooted tree' (Lambert and Pohlen, 2001). The end goal of SCM is value creation, both for end consumers; in the form of reliable high quality products and pre/after-sales services, and for SC partners; in the form of increased turnover and profits (Mentzer et al., 2001, Mentzer, 2004, Murman, 2002). Such value creation in the SC is more commonly known as the value chain (VC).

#### 1.1 Value Chain Improvement

In recent years, decision makers have realized that competition is no longer enterprise versus enterprise, but SC versus SC (Li et al., 2005, Christopher, 2000), or more appropriately, VC versus VC. In addition, the global recession has disturbed the fundamental concepts of international business. To keep competitive, organizations have had to drastically revise and implement cost cutting strategies to their VC operations to sustain profits. This is not an easy task. VCs are very dynamic, and each network node has its own customers' and suppliers' management strategies, partnerships, demand arrival process and demand forecast methods,

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20<sup>th</sup> European Operations Management Association (EurOMA) Conference 2013, Dublin

## **An integrated decision support framework for assessing food supply chain risk management processes: A food retail case study**

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College of Business  
Dublin Institute of Technology*

*Amr Arisha  
College of Business  
Dublin Institute of Technology*

### **Abstract**

Global confidence and reliability in Irish food supply chains are essential elements to overall competitiveness and future growth. The complex nature of food supply chains make them vulnerable to many sources of risk, both internal and external. Integrating the SCOR11 model with system dynamics and discrete-event simulation modelling is effective decision support integration, reducing the risks decision makers have to manage daily. At GRD, using the integrated framework to assess the risks associated with lean initiatives helped management in understanding both the risk scenario, likelihood and impact factor of their decisions on operations performance measures.

**Keywords:** Food Supply Chain Risk Management, Simulation, Optimisation

### **Introduction**

The dynamic nature of food supply chains (FSC) and their complexity make them vulnerable to many different kinds of internal and external risk. FSC vulnerability has been heightened by the relentless drive for cost cutting and implementation of lean techniques such as JIT, which have left very little room for error in decision making processes. To complicate this further, risk within a FSC has the added elements of food safety and short product life cycles to manage.

This papers overall purpose is to investigate the requirements for developing an integrated decision support framework for managing the complex aspects of FSC risk management. Strong analytical tools such as discrete-event simulation (DES), system dynamics (SD) and optimisation; and reference models such as the Supply Chain Operations Reference (SCOR11) model are successful risk assessment tools for complex business systems. Individually, they have been proven to be cost efficient, improve risk mitigation and give organisations a better understanding of their FSC network. Although several of these techniques have been successfully integrated, especially DES and optimisation (Abo-Hamad and Arisha, 2011), there is no literature available to suggest that the strengths of all techniques have been integrated into one working framework. The remainder of the paper will introduce the different phases in

## Customer Management Analysis of Irish Plumbing & Heating Distribution System: A Simulation Study

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[amr.mahfouz@dit.ie](mailto:amr.mahfouz@dit.ie), and [amr.arisha@dit.ie](mailto:amr.arisha@dit.ie)

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**Abstract**— The sudden burst of the property bubble, coupled with current global economic conditions has resulted in a huge decrease in demand for plumbing and heating fixtures in the Irish construction industry. Moreover, inefficient supply chain management policies have imposed further pressures on companies resulting in more system bottlenecks and unnecessary costs. Inventory management is seen as a functional area that can ease such bottlenecks and in turn increase supply chain efficiency, decrease costs and increase customer satisfaction. The challenge is to predict the balance of on-hand inventory and order quantity to optimise customer satisfaction and minimise inventory cost. It is also essential that managers clearly understand the cost effect stock-outs have on different groups of customer, i.e. customer segmentation policy. Traditional inventory mathematical techniques are inadequate in investigating the influence of customer segmentation policy on performance. To investigate this further, conceptual modelling using flowcharts and data flow diagrams in conjunction with simulation modelling and design of experiments have been developed to characterise the inventory management process of a plumbing and heating distribution centre. Significant process parameters were identified and examined with and without segmented customer management policies, aiming to achieve a high level of customer satisfaction rate at the lowest possible total cost.

**Keywords:** *Simulation Modelling; Inventory Management; Business Process Analysis; Customer Segmentation*

### I. INTRODUCTION

The unprecedented fall of the Irish economy into recession during the current global economic crisis has been partly caused by the dependency on an oversized domestic construction industry [8]. The sudden collapse in the property boom has led to a decrease in construction output volume of 36.9% between 2008 and 2009 [5]. As a result of this collapse, the plumbing and heating (P&H) materials distribution system has been affected greatly due to losing a considerable number of their customers and a remarkable decline in sales figures. Therefore, the application of economic management strategies for the P&H distribution industry has become crucial to survive these extraordinary circumstances. One of the biggest challenges the P&H distribution industry faces is the need

to sustain a competitive advantage, by satisfying customer demands and fulfilling orders at the lowest cost. Without an efficient supply chain and strong inventory management strategies, it is becoming more difficult to achieve this target and gain a competitive advantage [6]. Improved inventory management contributes to lower costs, increased revenue and greater customer satisfaction [17].

P&H Distribution firm has about 3,000 different items that are stored in a large dedicated P&H warehouse. Many suppliers around the world (e.g. China, UK, France... etc.) are listed in the P&H supplier list. Monthly forecasts for all items based on twelve month sales historical data is the main source of input for that system. Due to the uncertainty of suppliers lead time, demand fluctuation, changeable prices and high shortage costs, the strategy of keeping safe inventory levels for fulfilling unexpected demand is currently applied. The high cost of on-hand inventory versus the cost of a stock out and late delivery drove the inventory manager to target the balance between minimizing the inventory level and keeping on time service level at an optimum point. The result of changes in this balance and its impact on customer satisfaction level has to be predicted and investigated. To model such systems that contain a large number of entities with a stochastic nature for all its processes, a simulation modelling technique is recommended [4]. This is due to its capability in modelling the dynamic nature of the systems as well as their variability. Data flow diagram (DFD) and flow charts are integrated before the development of simulation to conceptually model the system. This integration provided synergies by merging the information and object flow in one conceptual model. Finally a design of experiments has been developed to investigate the significance of process parameters and examine various customer management scenarios.

The purpose of this study is to investigate two customer management scenarios, customer equality (no segmentation) policy and customer segmentation policy. In order to identify the best policy that achieves high levels of customer satisfaction, two performance indicators will be used to represent customer satisfaction level – delivery time and total cost. The study also aims to analyse the influence of the changes in the selected scenarios and

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*L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.*

# UNDERSTANDING THE DYNAMIC BEHAVIOUR OF THREE ECHELON RETAIL SUPPLY CHAIN DISRUPTIONS

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## ABSTRACT

It is often taken for granted that the right products will be available to buy in retail outlets 7 days a week, 52 weeks a year. Challenges in achieving this continued on-shelf availability range from recession hit demand patterns to cost reduction driven strategies. Irish government initiatives to brand the country as a sustainable, reliable provider of food retail supply chains has resulted in increased importance on decision maker accuracy. The vulnerability of retail supply chain's (RSC) to disruption is another catalyst in the complexity of the decision making process and a more robust understanding of disruption behavior is needed. The aim of this paper is to illustrate the advantages of integrating balanced scorecard system thinking to system dynamic modeling of an extended retail supply chain. With this approach, decision makers can gain a better understanding of disruptions within their own organization and the partners within their extended RSC.

## 1 INTRODUCTION

The food industry in Ireland is at the core of government strategic plans for growth during such extraordinary economic difficulties over the past 8 years. From "farm to fork" traceability to an *Bord Bia's* (Irish Food Board) current (2012) initiative, "Pathways for Growth", never has been there a more influential time for Ireland to become a world leader in the supply of sustainable, reliable and safe food products. To achieve this, global confidence and reliability in Irish fast moving consumer goods (FMCG) and grocery retail supply chains (RSC) are essential elements to overall competitiveness.

The sectors that make up Irelands RSC network create a very strategic industry in relation to the overall success of the Irish economy. The retail sector alone employs just over 11% of the total workforce and the entire RSC industry was worth nearly €30 billion in sales to end consumers in 2013 (Bia 2013). Retail in Ireland is a very competitive market, where the top 5 companies: Musgrave Group Plc., Tesco Plc., Dunnes Stores Ltd, International Spar Centrale BV, and BWG Ltd hold over 40% share of the market. Apart from the strong competition between the top 5 in becoming market leaders, there are many other barriers to sustaining growth within this market. They include but are not limited to:

- Recession has increased consumer demand for price cuts and promotions.
- Competition from low-cost focused alternatives.
- Sterling strength against Euro increasing competition with Northern Ireland competitors.
- Decreasing demand, 4.5% decrease 2006-2011, has led to a drive for cost driven strategic plans and increased urgency in operational efficiencies.
- Rising operation costs and pressures to reduce them has increased tension between RSC partners.
- Demand uncertainty and forecast accuracy.
- Food safety standard level consistencies along the entire RSC.

## Integrating Current State and Future State Value Stream Mapping with Discrete Event Simulation: A Lean Distribution Case Study

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**Abstract:** In response to global recession and increased competition, organizations have tried to become more efficient by decreasing costs and streamlining operations. To achieve this, the philosophy of lean management has gained in popularity. The main obstacle organizations face when implementing lean is deciding which activities to implement lean principals on. A well known lean practice, value stream mapping, is a very effective tool in mapping the current and future state of an organizations lean activities. Limitations in calculating variability information that describe system variations and uncertainty means more powerful analytical tools are needed. Simulation offers a more thorough analysis of a system's data, including the examination of variability and has the ability to change certain parameters and measure key lean performance indicators. Using a tire distribution company as a case study, this paper has developed a framework that uses discrete event simulation as an integrative layer between current and future value stream mapping. The framework maps current state value and non-value activities in the company and through simulation has highlighted the activities that should be used when developing the future state map. This paper has highlighted simulation as a crucial middle layer in value stream mapping that will generate more accurate future state maps than the more common practices of using random estimates and experience alone.

**Keywords:** Value stream mapping; distribution center; lean management; discrete event simulation

### I. INTRODUCTION

The theory behind lean philosophy is to create more value with less. Over the last decade, competition between organizations has become a matter of not only productivity, but also of overall supply chain performance [1]. Delivering the right quantity of products to the right place and at the right time has become a necessity for supply chain survival in an ever-more-acutely competitive atmosphere [2]. The quest to offer high levels of service to customers, while keeping a worthwhile profit margin, has forced managers to think of new ways to eliminate waste from their internal operations. Lean thinking is one of the most effective techniques managers can use in this ambition.

The 'lean' strategy represents a holistic attack on all negative aspects of resource consumption, and seeks to achieve streamlined and waste-free

operations [3]. While the focus of lean thinking literature has essentially been on production systems, the notion can also be stretched to cover every management activity. Recent research [4], [5] attention was directed into the use of simulation modeling in lean implementation and assessment processes due to many reasons including:

1. Identifying the factors and parameters involved in the manufacturing process.
2. Exploring the various opportunities of process improvement.
3. Predicting the impacts of the proposed changes before implementation.
4. Reducing the risks associated with lean implementation process.
5. Mapping the future state of organizations' – value stream mapping.
6. Assessing the interaction influence between system's components and parameters.

Based on the above reasons, primarily 1,3 and 5, and through case study application, this paper has developed a framework (Fig. 1) that uses simulation and modelling as an integrated layer between current and future state value stream maps. To achieve this, Section II will give a background overview of lean management, generally and from the case study perspective of distribution. This is followed by a detailed profile of the case study industry, tire distribution, and the case study tire distribution company (hereafter to be known as TDC) in relation to lean implementation in Section III. Section IV will develop a current value stream map of TDC using data collected through extensive field work in the industry. This map will then be used in Section V to build an accurate simulation model of the TDC system that can be analysed in Section VI to aid in a future state value stream map before conclusions and future work are discussed in Section VII.

### II. LEAN MANAGEMENT

Lean management as a philosophy, rather than a stand-alone practice, aims to create a streamlined, high quality system that can achieve a high level of customer service with minimum cost with little or no waste. Originating from Toyota Production System (TPS), lean thinking has become one of the most effective management concepts in the world [6]. Lean processes encompass a wide variety of



**SUPPLY CHAIN SIMULATION: EXPERIMENTATION WITHOUT PAIN**

**ABSTRACT**

Bridging the gap between theory and practice has always been a key issue for students and graduates. The magnitude and scope of subject areas that students at third level institutions have to learn in theory means that visualising them without any practical experience can be very difficult. Understanding the complexity of supply chain networks and how to manage them create a considerable level of difficulty for students and professionals. Theories and applications included in supply chain management subjects are the key to empathise the real challenges. Nevertheless, teaching these theories needs substantial efforts and new innovative approaches to deliver the concepts and assure successful transfer of the learning outcomes.

To complicate things more, the levels of uncertainty and risk within an entire supply chain are still not fully recognised or understood even by industry professionals. Research studies showed the need for more transparency and collaborative approaches to take place among supply chain partners in order to achieve more sustainable operations. Making sure students comprehend the scale of activities and stochastic nature of a supply chain before they carry on their industrial careers is therefore crucial.

Using computer simulation integrated with structured modelling techniques, a detailed, animated and generic supply chain simulation-based learning framework can be developed to incorporate many areas of learning undertaken by students in relation to the supply chain management. Experimenting on the simulation models allow the students to examine quantitatively the impact of changing critical factors (e.g. inventory level, demand, suppliers' lead time) on the performance of supply chain. This paper demonstrates the impact of using interactive simulation technologies in teaching third level education with special reference to supply chain management and discusses the benefits of learning through such a level of immersion.



## WEB-BASED SUPPLY CHAIN SIMULATION: AN INTEGRATED APPROACH

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### Abstract

This is an era marked by rapid technology development in all different educational arenas. Alongside this growing demand of technology, learning process is getting new forms and hence traditional teaching approaches tend to struggle and lack the requisite qualities to meet new generation expectations. In third level education, this problem is increasing in magnitude and new dimensions, especially when it comes to teaching difficult subjects such as supply chain management. Understanding the complexity of supply chain networks and how to manage them create a considerable level of difficulty for students and professionals. Collaboration between supply chain members is now recognised as an important strategic factor in creating a solution to the complexity of the supply chain system. New technologies are beginning to bring a huge transformation into teaching delivery methods. This paper presents an integrated web-based simulation framework that supports learning supply chain concepts and challenges. Simulation-based learning environment allow participants to examine various management strategies without real disruptions to the current system. Using supply chain simulation creates a vibrant experience and a better understanding to the impact of uncertainty and risks within supply chains. Integrating web technologies to simulation has added an edge to the learning environment with the friendly graphical user interface.

**Keywords:** Simulation-based learning, web-based technologies, supply chain management.

### 1 INTRODUCTION

Never has there been a better time for educational institutes to exploit the advances in information communication technologies and other technological breakthroughs. Especially the relationship between teaching and learning and the bridging of the theory/practice gap for college graduates entering the workplace. Instructional technologies such as; overhead transparencies, slides, videotapes and computer programmes play an important role in the bridge between learning and teaching [1]. However, over the past few decades, these technologies have matured and individually they are not a recognised stimulant for today's more digitally orientated students [2, 3]. To help stimulate this new era of virtual students, there is huge scope for the use of simulation as an aid to these learning techniques, although there are few if any examples in literature. Apart from maybe in medical [4], engineering [5] and science schools, simulation modelling is one technological advancement in recent years that has still to be embraced by educational institutes [6].

There has been an increased development of simulation software packages that have increased simulation capabilities [7]. Business modules, including supply chain management, are one area that these enhanced capabilities can be most effectively utilised. Understanding the magnitude and complexity of supply chain networks and how to manage them creates a considerable amount of difficulty for students and practitioners alike. Supply chain experimentation and decision making in the real world can have detrimental effects (such as distorted and amplified supply and demand) on companies when they go wrong [8]. Collaboration between supply chain members is now recognised as an important strategic factor in decreasing the impact of poor supply chain decisions. In the academic world, visualising and understanding the size and complexity of supply chains has always been an issue. Using computer simulation coupled with web-enabling technologies, a detailed, animated and generic supply chain simulation framework can be developed to incorporate many areas of learning undertaken by students in relation to the supply chain management. Experimenting/playing on the simulation models allow the students to examine quantitatively the impact of changing critical factors such as capacity utilisation and queuing times on the performance measures within the supply chain. Web enabling applications also allow students to access online versions of the simulations without the necessity of purchasing expensive simulation software.

## **DISTRIBUTED SUPPLY CHAIN SIMULATION PORTAL: DESIGN AND IMPLEMENTATION**

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### **Abstract**

The emerging paradigm of eLearning is becoming increasingly in evidence across many academic disciplines acknowledging the concept that learning processes no longer support traditional teaching methods alone. It can be argued that today's third level education students are part of a new virtual era where the blackboard has been replaced with an interactive whiteboard. To assist in the transition from traditional learning to eLearning, more interactive and virtually orientated teaching aids are needed. A simulation-based learning framework that integrates web-based simulation and a web content management hierarchy model is the key objective of this paper. Using the highly complex subject of supply chain management as a case study, the new framework allows users to examine various management strategies of real-life scenarios, encourages group work and has remote access capabilities for distance learning. Interactive learning is facilitated using the web-based simulation portal, enabling instructors to demonstrate the complexity of decisions in multiple criteria environment and also show the users the impact of strategies on performance. Supply chain simulation creates an animated experience and better understanding of the system dynamics including risks. The portal interface is friendly and hence there is a potential to be applied in other subject areas.

### **Keywords**

Web-based Simulation - Distributed Simulation - Supply Chain Management

### **Introduction**

The ability to learn has always been the foundations of any successful society. Learning can be defined as the acquisition of knowledge through cognitive processes that translate into new understandings, behaviors and skills (Moore et al., 2009). In today's knowledge driven society, gaining such valuable understandings through education is a very important resource (Schleicher, 2003). The advances made in computer technology, coupled with educations drive to take advantage of such advances have given rise to eLearning.

The emerging paradigm of eLearning is becoming increasingly in evidence across many academic disciplines and provides further support for the concept that learning processes no longer support traditional teaching methods alone. It can

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## LEARNING BY GAMING: SUPPLY CHAIN APPLICATION

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### ABSTRACT

Today's third level students are of a virtual generation, where online interactive multi-player games, virtual reality and simulations are a part of everyday life, making gaming and simulation a very important catalyst in the learning process. Teaching methods have to be more innovative to help students understand the complexity of decisions within dynamic supply chain environment. Interactive simulation games have the potential to be an efficient and enjoyable means of learning. A serious interactive business game, Automobile Supply Chain Management Game (AUSUM), has been introduced in this paper. Using theories learnt in class as a knowledge base, participants have to develop effective supply chain partnership strategy to enhance their supply chain networks. Deploying the game over the web encourages student interaction and group work. Most importantly the game will enable students to fundamentally grasp the impact of strategic decisions on other parts and players of the supply chain network.

### 1 INTRODUCTION

Ever since the introduction of a Simulation and Process Modeling module to the B.Sc. in supply chain management (SCM) at Dublin Institute of Technology (DIT) in 2008, there has been very positive feedback from students relating to how effective simulation modeling was in helping them get a better understanding of the dynamic nature of supply chains. The central theme of this paper is to develop an interactive supply chain serious game that can aid in teaching and training various concepts in SCM.

As a management philosophy, SCM is a vast concept, with many interpretations and definitions. Although the management concept itself was only introduced in early 1980 by Oliver and Webber, cited in Jüttner et al. (2007), it was not until the mid-1990's that it came to prominence on a global basis. SCM can be defined as the strategic management of upstream (suppliers) and downstream (customers) relationships in order to create enhanced value to the final consumer at less cost to the supply chain as a whole (Christopher 1998). At its basic level a supply chain is made up of multiple actors, multiple flows of items, information and finances and is sometimes described as looking like an 'uprooted tree' (Lambert and Pohlen 2001). Supply chains are very dynamic, each network node has its own customers' and suppliers' management strategies, partnerships, demand arrival process and demand forecast methods, inventory control policies and items mixture (Longo and Mirabelli 2008), with many challenges to overcome including: complexity, uncertainty, risk, visibility, collaboration, cost and sustainability to name a few. Most importantly, educating both SCM professionals and SCM students alike to fully understand the dynamics of the supply chain can be difficult. Textbooks, case studies and the traditional class lecture alone are an adequate foundation in helping students understand the fundamental concepts of SCM, but fail in highlighting the bigger picture of the supply chain and the strategic decisions that need to be made. In this environment it is hard for students to see things from a manager's perspective, where decisions made

## SERIOUS GAMING LEARNING: SUPPLY CHAIN MULTI-AGENT WEB-BASED SIMULATION GAME

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### Abstract

High levels of complexity and uncertainty, and various sources of risks, create challenges for supply chain networks in achieving satisfactory performance, but advances in Information Technology can help supply chain decision makers predict the magnitude and impact of the risks related to their decisions. The framework proposed in this paper offers a solution that integrates intelligent-agents, simulation modelling, and optimisation. Its friendly, animated, interactive web-based interface is especially designed to engage the user in a 'serious game' environment. Each user plays a specific role in the supply chain network, and encounters the consequences of their decisions. The optimisation engine embedded in the framework advises users about the optimum decisions and their anticipated performance outcomes. Genetics Algorithm (GA) and Case-Based Reasoning (CBR) are used to enhance the decision quality. A high-level communication protocol has been designed, developed and implemented to facilitate client/server communications, and allow intelligent-agents to inter-communicate easily and efficiently. The tool we develop offers equal value in supporting management decision-making, or in educating trainees in the realities of supply chain management.

Keywords: Serious Gaming, Multi-Agents, Web-Based Simulation.

### 1 INTRODUCTION

When the business world thinks of risk, they are generally financial, and refer to areas such as insurance, investments, futures, options and swaps [1]. But, since major disruptions to global supply - such as the 9/11 terrorist attacks and Hurricane Katrina in the US, foot and mouth disease in the UK, the SARS and bird flu outbreaks in Eastern Asia, the volcanic ash clouds over Iceland and the tsunami that hit Japan in 2011 - supply chain risk has received ever-greater attention from both academic and industry experts [2-4]. The high level of complexity and uncertainty across supply chain (SC) networks, and the variety in the sources of risk, create challenges for supply chain partners and customers in achieving and sustaining satisfactory performance.

One of the barriers to implement a successful SC risk management plan is the varying levels of awareness and overall knowledge held by different managers and actors throughout the SC network, and the lack of recognition of common terminologies across SCs [5]. Numerous tools are now available to analyse risks and assist in their management, but the supply chain sector lacks interactive educational tools that can give trainees an understanding of a complete SC environment, and develop their ability to identify, assess, manage and control the various processes along the SC network. Many theories and techniques have already been adapted for SC risk management (SCRM), which has opened the door for the development of more tools to computerise the process, helping advance the use of IT within the SCM field. The platform for SCRM advancement is the concept of supply chain collaboration. SCRM research at Cranfield University [6] finds that "the underlying principle of collaboration in the supply chain is that the exchange of information and application of shared knowledge can reduce uncertainty" (pp.47). Knowledge is a very important resource in managing and understanding supply chains,[7] and the transfer and sharing of knowledge along chain is commonly known as Supply Chain Knowledge Management [8].





DUBLIN INSTITUTE OF TECHNOLOGY

# SERIOUS GAMING LEARNING: SUPPLY CHAIN MULTI-AGENTS WEB-BASED SIMULATION GAME

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3S GROUP – SUSTAINABLE SMART  
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## 1. ABSTRACT

High levels of complexity and uncertainty, and various sources of risks, create challenges for supply chain managers in achieving satisfactory performance. In this paper, an integrated framework for supply chain simulation is proposed. The framework is based on a multi-agent system (MAS) and a web-based simulation environment. The MAS is designed to model the supply chain dynamics and the web-based simulation environment is designed to provide a user-friendly interface for the supply chain simulation. The framework is designed to be a multi-agent system (MAS) and a web-based simulation environment. The MAS is designed to model the supply chain dynamics and the web-based simulation environment is designed to provide a user-friendly interface for the supply chain simulation. The framework is designed to be a multi-agent system (MAS) and a web-based simulation environment. The MAS is designed to model the supply chain dynamics and the web-based simulation environment is designed to provide a user-friendly interface for the supply chain simulation.

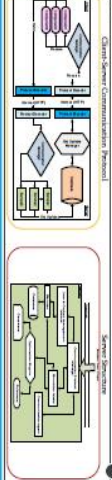
## 2. PROJECT MOTIVE

Simulation tools provide a means to model and analyze complex systems. They are used to study the behavior of systems under different conditions and to evaluate the impact of different decisions. Simulation tools are used to study the behavior of systems under different conditions and to evaluate the impact of different decisions. Simulation tools are used to study the behavior of systems under different conditions and to evaluate the impact of different decisions.

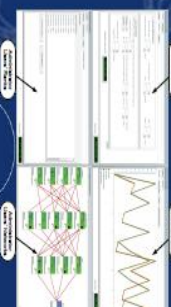
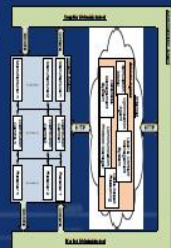
## 4. SUPPLY CHAIN MANAGEMENT

The supply chain is a network of organizations that are involved in the production and distribution of goods and services. It includes the flow of materials, information, and financial resources. The supply chain is a network of organizations that are involved in the production and distribution of goods and services. It includes the flow of materials, information, and financial resources. The supply chain is a network of organizations that are involved in the production and distribution of goods and services. It includes the flow of materials, information, and financial resources.

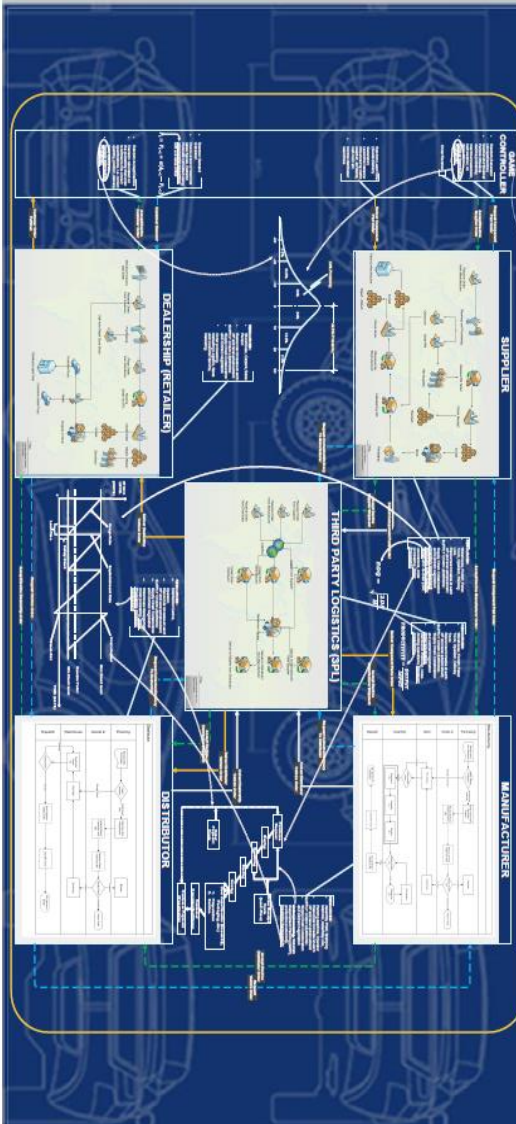
## 5. SERVER STRUCTURE



## 3. INTEGRATED FRAMEWORK



## The Game Process and Theory



## 6. GAME RULES AND FEATURES

**Business Manager:** A mathematical engine has been developed to reflect the player performance in some logical indicators (Figure 1). **Business Manager:** A mathematical engine has been developed to reflect the player performance in some logical indicators (Figure 1). **Business Manager:** A mathematical engine has been developed to reflect the player performance in some logical indicators (Figure 1). **Business Manager:** A mathematical engine has been developed to reflect the player performance in some logical indicators (Figure 1). **Business Manager:** A mathematical engine has been developed to reflect the player performance in some logical indicators (Figure 1).

Figure 1



Figure 2



Figure 3



## 7. CONCLUSION

The developed model aims to:   
 • Provide a user-friendly interface for the supply chain simulation.   
 • Provide a user-friendly interface for the supply chain simulation.   
 • Provide a user-friendly interface for the supply chain simulation.   
 • Provide a user-friendly interface for the supply chain simulation.   
 • Provide a user-friendly interface for the supply chain simulation.



Fifth International Conference of Education, Research and Innovation 2012, Madrid

<p>Analytics</p> <p><b>THE INTERNATIONAL HANDBOOK OF CULTURES OF TEACHER EDUCATION COMPARATIVE INTERNATIONAL ISSUES IN CURRICULUM AND PEDAGOGY</b></p> <p>Béatrice Boufroy-Bastick</p>	<p><b>CHAPTER 8</b></p> <p><b>INTERACTIVE WEB-BASED SIMULATION FOR SUPPLY CHAIN EDUCATION</b></p> <p>Ayman Tobail, John Crowe &amp; Amr Arisha</p> <p>Dublin Institute of Technology, Ireland</p> <p><a href="mailto:ayman.tobail@dit.ie">ayman.tobail@dit.ie</a> <a href="mailto:john.crowe@dit.ie">john.crowe@dit.ie</a> <a href="mailto:amr.arisha@dit.ie">amr.arisha@dit.ie</a></p> <p><b>Abstract</b></p> <p>Knowledge economies are based on the concept of knowledge transfer between education institutes and stakeholders. In response, the significant move away from traditional teaching methods to the emerging paradigm of elearning has become increasingly in evidence across many academic disciplines. To assist in the transition from traditional learning to elearning, more interactive and virtually orientated teaching aids are needed. This chapter introduces a simulation-based learning framework that integrates web-based simulation and a web content management hierarchy model. Using the complex subject of supply chain management as a case study, the new</p>
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## Interactive Learning: Developing an eSimulation Portal Framework

Research Article

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**Abstract:** The emerging eLearning paradigm is becoming increasingly used in many academic disciplines. The concept acknowledges learning processes that no longer deploy only traditional teaching methods. It can be argued that today's third level education students are part of a new virtual era where the blackboard has been replaced by the interactive whiteboard, so more interactive and virtually orientated teaching aids are required to assist in the transition from traditional learning to eLearning. The key objective of this paper is to propose a simulation-based learning framework that integrates web-based simulation and a web content management hierarchy model. Using the highly complex subject of supply chain management as a field of study, the newly developed eSimulation tool allows users to examine various management strategies in real-life scenarios, encourages group work and offers remote access capabilities for distance learning. Interactive learning is facilitated using a web-based portal, enabling instructors to demonstrate the complexity of decisions in multiple criteria environments and also demonstrate the impact of various strategies on performance to the users. eSimulation creates an animated experience and better understanding of the system dynamics of decision-making processes. The portal interface is friendly and, hence, has the potential to be applied in other subject areas.

**Keywords:** eLearning • simulation • supply chain management education

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### Introduction

The ability to learn, which can be defined as the acquisition of knowledge through cognitive processes that translate into new understandings, behaviours and skills (Moore et al., 2009), has always been the foundation of any successful society. In today's knowledge-driven society, such valuable understandings, which can be gained through education, are very important resources (Schleicher, 2003). The advances made in computer technology, coupled with the education sector's drive to take advantage of such advances, have given rise to the emerging eLearning paradigm, which is becoming increasingly evident across many academic disciplines, providing further support for the notion that learning processes are no longer only supported by traditional teaching methods. It can be argued that today's third level education (TLE) students are part of a new virtual generation, where blackboards and refill pads have been replaced by interactive white boards and laptops, as more interactive, animated and virtually orientated teaching aids assist the transition from traditional learning to eLearning.

The main contribution of this paper is to create a framework to enable the examination of different innovative teaching technologies such as simulation through a web-based portal accessible from anywhere. First, we give an overview of TLE and its challenges from an Irish perspective. Second, we discuss innovations in teaching/learning processes, with particular emphasis on simulation-based applications, using the complex field of supply chain management as our study field of knowledge. The advantages of utilising web-based technologies are then reviewed before the methodology of our portal framework is introduced and discussed in detail. The paper concludes with a conceptual overview of the portal framework, and outlines its potential future development into a serious working TLE game.

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