2022

AN EVALUATION OF SUPPLY LEAD TIME IN THE NIGERIAN OIL DOWNSTREAM SECTOR: A SYSTEM DYNAMIC APPROACH

UHUKA, MAC-DANIEL

http://hdl.handle.net/10026.1/20061

http://dx.doi.org/10.24382/660
University of Plymouth

AN EVALUATION OF SUPPLY LEAD TIME IN THE NIGERIAN OIL DOWNSTREAM SECTOR: A SYSTEM DYNAMIC APPROACH

By

MAC DANIEL OFEKWE UHUKA

A thesis submitted to the University of Plymouth in
partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

Plymouth Business School

December 2022

ACKNOWLEDGEMENT

To all those who contributed in one way or the other to the completion of this research project I wish to express my profound gratitude.

First and foremost, my due appreciation goes to my research supervisors; Dr Jonathan Moizer for introducing me to system dynamics a fascinating area of simulation, Dr Chukwuneke Okorie for the invaluable technical guidance and advice and Dr Yi Wang for the time, effort and wealth of academic experience in carrying out this research.

Further appreciation goes to the academic and administrative staff at the Plymouth University for the help, support and making my stay a success.

I remain indebted to my parents Dr Daniel and Mrs Charity Uhuka for their relentless efforts and prayers through the period of my education. I pray that God will continue to provide and bless them.

I also want to thank my siblings, my colleagues for the support and exchange of ideas and advice.

Finally, to my beautiful wife Sarah and son for support, encouragement and motivation in carrying out this research, I love you.

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

Work submitted for this research degree at the University of Plymouth has not formed part of any other degree either at the University of Plymouth or at another establishment.

A programme of advanced study was undertaken, which included Post Graduate Certificate in Research Methodology.

Word count of main body of thesis: 52,773

Signed: MAC-DANIEL UHUKA

Date: 09/12/2022

MAC-DANIEL UHUKA

AN EVALUATION OF SUPPLY LEAD TIME IN THE NIGERIAN OIL DOWNSTREAM SECTOR: A SYSTEM DYNAMIC APPROACH.

ABSTRACT

This thesis presents a system dynamics (SD) approach for investigating the demand amplification problem, also known as the bullwhip effect, which has been studied extensively in the literature. The demand amplification occurs when supply chain moves upstream from the downstream. The problem of bullwhip effect can be costly and disruptive, and this is a problem supply chain managers normally seeks to minimise. The causes of bullwhip effect can be poor system design, poor policies, structure of the company and delays in material and information flow. The bullwhip effect has since been linked to exogenous factors like uncertainty in demand, supply, and distribution lead time, but these causes are not solely to blame, as academic and operational studies have demonstrated that orders and/or inventories can still show significant variability even when customer demand and lead time are deterministic. Consequently, this raises the likelihood that the cause may exhibit dynamic behaviour and point to a need for more research into the issue.

The Nigeria downstream petroleum industry is plagued with this problem of bullwhip effect such as long lead-times and customer order uncertainty. A system dynamics inventory model is built to identify the causes of these problems. The System dynamics (SD) inventory model of the downstream petroleum companies in Nigeria was developed in this research, to investigate uncertain customer order and the ability for the companies to manage their inventory to fulfil customer requirement at the same time reduce their overall total cost. The performance measure used for the simulation analysis is the total cost, oil distributor inventory, and retailer inventory storage.

Three ordering patterns (base case, high order and low order) is used for the simulation to represent the scenario of these companies in Nigeria and to investigate the instability of the Nigeria downstream petroleum companies and the impact on the companies' performance to ultimately reduce cost and increase profit for the companies. It was identified that the instabilities start from the downstream customers which makes the managers unable to effectively manage their inventory. The research findings provide more understanding how these instabilities occur and how it impacts supply chain companies using system dynamics modelling approach.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

ABBREVIATIONS

ABM	Agent Based Modelling
BAU	Business as Usual
BC	Base case
BDW	Behavioural Decomposition Weights
BDG	Beer Game Distribution
CR	Critical Realism
CLM	Contract Life-cycle Management
DH	Dynamic Hypothesis
EEA	Eigenvalue Elasticity Analysis
GDP	Gross Domestic Product
IT	Information Technology
MIT	Massachusetts Institute of Technology
MSE	Mean Square Error
ODI	Oil Distributor Inventory
POS	Point of Sale
RIS	Retailer Inventory Storage
RMSPE	Root Mean Square Percent Error
ROCT	Retailer Order cycle Time

SC	Supply Chain
SD	System Dynamics
SCM	System Chain Management
SSC	Safety Stock Coverage
TC	Total Cost

CHAPTER ONE: INTRODUCTION

1.0 Research overview

In today's commercial business' world competing organisational survival hinges mostly on shorter lead time, lower expenses and high customer satisfaction to excel (Ajit et al., 2015). In In the twentieth century organisations were solely concerned with customers, devoting resources into satisfying the requirements of customers (Prakash Mishra 2011). For instance, to effectively encourage client complete satisfaction in the worldwide market, a necessary provision by organisations are short lead times.

Organisations that focus on the use of Lead-time as an efficiency procedure have reported a lower delivery time, enhanced quality and lower expenses which produces more satisfied consumer. Lead-time can be defined as the lapse of time between when an order is placed and when the order is received into inventory, which can influence customer service and inventory costs (Silver et al 2013).

Globalization of product and services coupled with fast technological advancement have equally led to an increased in the level of customer demand uncertainty and a vibrant, fast paced market. Due to geographical augmentation between facilities operating worldwide, the procedure of handling and managing the supply chain has become somewhat complicated. Additionally, competitors are now on opposing sides of supply chains rather than business, that is to say competition is no longer between a business against another business but rather between one supply chain against other supply chains.

As an outcome of increasing worldwide organisation competitors, lots of organisations are trying to find methods to get competitive benefit. Vonderembse et al., (2006) observed that competitors in the oil market have moved to supply chain orientation and away from business orientation, hence, the enhancement of supply chains is crucial for a business to survive in the market.

One of the leading concerns in a tactical program for commercial and service organisation are constant environmental changes which can be tackled using Supply chain management (SCM). The goal of SCM activities is to present the best quality item better suited for a particular time. This is in an effort to control production, comprehend consumer demand, enhance responsiveness, manage service procedures, and assemble the goals of all participating partners in the supply chain. To accomplish this objective, businesses are required to possess the capabilities to provide policies for better management. These policies are to support the efficient and effective response during unanticipated occasions that may occur in the supply chain, possibly to rid the system of unfavourable results and decrease the effect of those that cannot be removed.

System dynamics simulation designs appropriate tools that essentially supports examination and decision-making on the effects of Supply chain characteristics. "System Dynamics is a method for the modelling and simulation of nonlinear vibrant systems that targets the understanding of a system's structure and the reduction of the behaviour from it. Therefore, to pay attention and mastery of this method will be an excellent benefit of the system dynamics approach as it is a requirement for the advancement of policies that result in the enhancement of the systems efficiency. The possibility to deduce the event of a particular model behaviour since the structure that causes system behaviour is made transparent is one of the essential benefits of system dynamics (Schieritz Größler 2003).

One method to hedge versus random changes of demand in supply chains is to keep inventory at numerous points in within the supply chain (Muharremoglu 2003). To give an example, consider a supply chain where items generally go through a storage facility, and after that it is offered to the last consumer by a retailer. If eventually the inventory level of the retailer reduces due to an unforeseen increase in demand, the retailer would need to put an order to meet the needed demand.

However, another commonly utilized technique for reacting to demand changes is to alter the lead-times in the system dynamically. Dealing with numerous suppliers, utilizing many transport choices, having the choice to expedite specific procedures, or having various possible paths for a system to go through the supply chain are all examples of having versatility in supply chain lead-times (John et.al. 2003).

This purpose of this research is to improve policy decision making in Nigeria's oil and gas supply chain downstream by developing quantitative models, indicating causal-structure and corresponding performance impact for selecting policy options. Testing alternative policy decisions over simulated or future time can reveal evidential insights for modellers that join policy changes across causal structure to enhance overall performance.

1.1 Statement of the problem

According to a study by Tianyuana et al (2018) on present and past issues in the supply chain identified bullwhip effect as a major issue in organisations. The emergence of bullwhip effect in the past attracted less attention to literature but phenomenon was known to economists. Demand amplification is one of the difficult issues to solve in the supply chain since its recognition by Forrester (1958). Price fluctuations, rationing, demand forecast updating and order batching are the 4 major factors contributing to the cause of bullwhip as identified by Lee, Padmanabhan and Wang (1979). An unfortunate but prominent feature in the Nigerian petroleum industry is the frequent shortages in products and uncertainities in the supply of petroleum over the years which disrupts the business activities leading to loss of revenue (Adelabu, 2012, Osuala 2013: Aminu and Olawore 2014).

The Nigeria downstream petroleum companies suffer the problem of bullwhip effect (Nsikan et al 2019). The downstream petroleum companies, retailers observe the needs of their customers' then make their orders to the distributors. The retailers make prediction of their needed inventory by forecasting their customer demand based on the inventory pattern of previous cycle and the next cycle and they then order to their partners in accordance with this standard. In the second phase the oil distributor adds their own judgment to that of the retailer then makes order from their supplier. This problem makes it difficult for managers to effectively manage their inventory at the same time meet their customer requirement as a result of bullwhip effect (Li, S. (2017).

1.2 System dynamics

System Dynamics (SD) as an idea first established by Jay W. Forrester in the 1950's at the M.I.T., Cambridge, MA. However, it has actually been utilized as an effective management tool for modelling complex real-world systems, comprehending their behaviour and carrying out tactical policies. Lertpattarapong (2002) argues that system dynamics can act as an effective technique to monitor the non-linear dynamic behaviour of a system and aiding the understanding of ways in which structure and specifications of the system determines behaviour patterns.

The conceptual idea fuelling system dynamics is the communication of all items within a particular system through casual relationships. Relationships such as these occur using feedback loops that manages the interactions in the system. System dynamics asserts that these relationships form the underlying structure for any system. The production of a total dynamic design of a system needs the recognition of causal relationships and referral modes that make up the feedback loops of the system. Feedback system discussed here describes the circumstance where variable A impacts variable B and B in turn impacts A through a series of causes and effect (Ribelo et al., 2004).

System dynamics differs to other methods employed to study systems that are complex. This is primarily because of its use of feedback loops extensively. The foundation of system dynamics models are Stocks and Flows, which best describes the connection formed by feedback loops. Following the creation of a model, a computerised software is adopted to stimulate this model in specific situations that are then studied. Performing simulation analysis termed "what-if" are carried out to examine several policies that significantly aids the understanding of changes in the system over time (Mohideen, 2004).

System dynamics has been utilized extensively in the design of complex supply chains, to understand behaviour patterns and design efficient policies. The supply chain design utilized in this thesis work has actually been solely designed utilizing system dynamics principles. The total description of the design and its analysis exist in Chapter 4.

1.3 Research scope and focus

The scope of a research refers to the boundaries with in research. During the early stages of developing this research, clarifying the extent and focus of this thesis was important in order to adopt an appropriate methodology. The rationale is that results and analysis of results can be applied in various context even though the research scope is limited to Nigeria. This limitation to Nigeria is because data such as case studies has been collated from the downstream oil industry in Nigeria. However, the informed conclusions from this research thesis can be applicable to other economies experiencing difficulties as they are heavily reliant on natural resources to support their economies.

Therefore, the challenges encountered by supply chain in the downstream sector of the Nigerian oil industry are the main focus of this research. The challenges are both practical and theoretical. Due to major events such as natural disasters, political instability and terrorism some supply chain vulnerability occur. Some examples include oil pipeline explosion by insurgent and militant groups in the Niger delta area of Nigeria, the oil workers' strike in 2016, fire disaster consuming tank farms, deports and pipelines, northeast blackout in 2003 and other acts of god. Other challenges include long queues at the filling stations, shortages and out of stock situations.

(Akanle, O., and Adebayo 2014) argued that supply chain disruptions in Nigerian downstream petroleum can be associated with poor management of information, poor decision making and inefficient management of internal and external process of the downstream petroleum supply chain. Theoretically, limited research have been conducted in the Nigerian petroleum sector using system dynamics to understand this phenomenon, and it merits investigation to help managers make good decisions and academics to understand the relevance and application of supply chain theory.

For the purpose of this research, the downstream gas sub-sector and upstream activities are excluded from this research completely. This research focuses on the Nigerian downstream oil (Petroleum) sector.

1.4 Research motivation

The motivation for this thesis is the detrimental effects of volatilities in a supply chain. In the economies dependent on their oil and gas sector, volatilities within the supply chain can result in erratic profits and oscillation of demand forecasts and inventory levels. These conditions increase capital cost and lower profits, intensifying overall risk.

However, contemporary managers can mitigate negative impacts by possessing the competency and innovative thinking to adapt quickly and develop new policies or series of activities. The identifying and testing of stable policies by the methodology proposed in this thesis will completely eradicate or curb behaviours that are unwanted. Policies would be gathered by redefining pertinent parameters and focused placed on combining strategies levels that coincides with amalgamated decisions of the supply chain.

System dynamics is an approach adopted to demonstrate current dynamic trends and sensitivity analysis is used to yield policies that would not be affected by oscillations easily. These approaches will present managers with a mechanism that engenders elimination of volatilities whilst creating policies that are robust.

Supply chain models are defined by their structure and parameters which traditionally sensitivity analysis was used to explore related structure and behaviour of the model in systems that are complex. There are certain objectives that have been accomplished after modifying the parameters of a system using the outcomes of simulation results. However, such objectives have to be clearly defined to match the system characteristics. This implies that for any given system, specific objectives and settings need to be drafted and adjusted.

Notwithstanding, though the identification of relevant parameters is made possible in a system's structure that results in specific behaviours, it is difficult to ascertain the most effective way to adjust these parameters concurrently to obtain a particular desired result. For the reasons just addressed, there is a need to employ a methodology that produces policies that are robust whilst actively eliminating or minimising the impact that instabilities can have within a generic supply chain model. Consequently, using such methodology, this research thesis hopes to provide simple but proficient tools in system dynamics for future academics and practitioners.

1.5 Research aims and objectives:

The improvement of policy decision making in Nigeria's supply chain downstream oil sector was achieved through developing quantitative models representing causal structure and corresponding performance impact for selecting between policy options. Testing various policy decisions over simulated or future time can reveal evidential understandings for modellers that join together policy changes across causal structure to enhance overall performance.

The process assists the researcher in designing models, gaining expertise, acquiring data from other sources and in-depth knowledge on modelled systems based on system dynamics (SD).

However, in this research the interaction between the individual component of a system following the design of a model is what is been evaluated within this system dynamics. Therefore, participants can easily identify where changes occur after different independent variables are regulated also highlighting the correlative response of the dependent variables.

Thus, this research hypothesis is based on system dynamics to improve insights gathered from problems within the oil supply chain downstream. Therefore, the postulation of this research thesis from system dynamics that have been chosen for investigating the dynamically complex case study could be a helpful tool for evaluating performance effectiveness and system sensitivity from policy intervention alternatives.

Therefore, the aim of this research is to build a system dynamic model for a downstream oil supply chain in Nigeria, using two case studies to analyse the effects of three ordering patterns to improve decision rule. This would be based on shared knowledge derived through specific objectives: -

- To analyse the effect of instability on the inventory level of Nigerian downstream petroleum companies model using different ordering patterns and the impact on cost.
- To adapt a well-established simulation model based on the system dynamics approach for analysing the bullwhip (instability) of downstream petroleum companies in Nigeria.
- To calibrate, validate and test the system dynamic model by using different customer ordering patterns of Nigerian downstream petroleum companies.
- To empirically test the model with real world data attained from the two case studies

1.6 Research questions

It is imperative that the researcher's decision-making hypothesis proposed to the energy industry managers should be able to improve the lead time policy alternatives in their various companies. Although, they may still retain some essential features within their preferred policy options that can add valuable innovative implementation in their organisation.

The research questions that flow from this hypothesis are: -

- What are the consequences of uncertainties in customer demand within downstream supply chain of the Nigerian oil industry?
- What are the best policies in reducing the costs under high level of uncertainties?

1.7 Thesis outline

Chapter 1 is a brief introduction of the research into the supply chain lead time of oil and gas management, justifying the importance of exploring such a topic. The problems are identified; the aims and objectives explained, research questions clearly outlined, and the research study overview are stated.

Chapter 2 contains the critical review of existing literatures exploring theories and concept by previous researchers. The review of literature in supply chain, oil industry and system dynamics encourages a better understanding of the areas that are facts-finding in the study providing an analysis on the research topic.

Chapter 3 identifies research methods, approaches, data collection and the reasons for adopting each approach.

Chapter 4 provides a bedrock of conceptual frameworks in current research, it involves formulation of the model, description and other activities involved in carrying out the research.

Chapter 5 is to analyse the system dynamics model. The discussion and results of this chapter involves case A and B using three different ordering patterns. The analysis would involve comparing the effects of the three ordering patterns: base case, high order and low order demand against the oil distributor inventory and retailer inventory storage and the effects on cost. Chapter 6 contains the discussion of findings, conclusions, recommendations, research contribution to existing knowledge as well as areas to consider supporting future research.

CHAPTER TWO: LITERATURE REVIEW

2. 0 Introduction

The fundamental themes of this research are system dynamics modelling, supply chain inventory management and the Bullwhip effect which this chapter will provide a synopsis of existing research on these themes. The focus of this chapter is the theorical and empirical research that attempts to provide definitions of supply chain management in order to carry out studies using quantitative research to arrive at an in-depth understanding of system dynamics in supply chain. Furthermore, this literature review will address the gaps that exist in previous research that inspired the research objectives and research questions. The initial parts of this section will provide definitions of terms frequently used in this thesis, followed closely by supply chain behaviour dynamics, causes of bullwhip effect and how to control bullwhip.

Furthermore, this chapter, will include research that has already explored the oil industry in Nigeria, the case study of this thesis. The role of system dynamics in the supply chain is examined. Finally, the history of system dynamics, the benefits of modelling and the modelling techniques will be addressed.

2.1 Supply chain management (SCM)

Kasi (2005), presents an explanation for this term defining supply chain management as the control and directing of a series of activities that are done in order to achieve a business objective or objectives. These activities could be the raw materials that go into manufacturing a product so its input; the manufacturing of a product; the finished products, the output and the distribution of that said finished product. These activities can affect business objectives by increasing or decreasing cost, improvement or deterioration of customer satisfaction. Another definition of supply chain is proposed by Christopher (2011) which explains it as a system deliveries and orders comprising of raw material suppliers, production equipment, services for distribution and customers who purchase finished product. In his previous paper in 2007 Christopher argues that the objective of a supply chain is the integration of various components to enhance strategic management. That is, measures to embellish the increase in profits, competitive advantage and efficiency of an organisation.

A network of businesses engaging in multiple techniques to increase the value of their product or services to meet the needs of the consumers and reduce costs is termed supply chain and supply chain management is a process-oriented method that is incorporated into the design, control of the supply chain (Chen and Paulraj 2004). Additionally, Lummus and Vokurka (1999) summarize SCM as activities leading up to the provision of items that customers require. This involves the procurement of raw materials, manufacturing, warehousing, stock-taking, entry of an order, shipping of an order and management of all other elements in the systems that are crucial to track and ensure success of all activities.

Li et al. (2006) contributes to understanding SCM by focusing on its double function that would engender efficiency of companies and the supply chain of an industry as whole. Customer Lifecycle Management (CLM) establishes that SCM is more developed than just being about the ‘logistics outside a company’ but rather the integration of both internal and external logistics (Lambert, 2004; Lambert et al., 1998, p. 2). This viewpoint is supported by studies that have be conducted recently because SCM is depicted as a tactical level idea that involves the relationship in companies, between companies and with other organizations (Stank et al., 2005). Additionally, according to Mentzer et al. (2001) SCM is a strategic collaboration of organizational functions within and between companies that are present in a supply chain, to optimize the efficiency of supply chains and private businesses in a sustainable manner.

Arguably, in the early stages of development SCM is a discipline (Gibson et al., 2005). It is a definitive form of ideas in a business ecosystem offering a structural process for institutions to co-exist instead of simply competing with each other (Bechtel and Jayaram, 1997).

Interestingly, business professionals introduced the term 'supply chain management' in 1982 and educators introduced its theories and structure in the 1990s (Cooper et al., 1997). The initial theoretical perspectives by educators clarified its distinction from prevalent names and techniques like logistics or production circulation handling. Cooper et al. (1997) are amongst the researchers who argue that logistics and SCM are very different by supplying an examination of 13 SCM meanings that were first proposed. Since the term SCM was proposed, research into this subject has grown exponentially in the past 20 years (Childhouse and Towill, 2003). An incorporation of a seamless flow of information and of goods between trading associates as a competitive defense that is reliable (Feldmann and Muller, 2003). Moreover, interests of academics, business managers, consultants and experts in SCM is ever increasing which is expected to match the business environment and knowledge that is constantly changing (Croom et al., 2000; Tan et al., 2002).

As seen, there are numerous definitions of supply chain management one reoccurring theme is the external factors that are environmental which affects companies (Croom, et al. 2000). Although the distribution of time and frequency can make up a simplistic supply chain structure most structure tend to be complicated because of the multiple functions, sovereign organisations and individuals within a progressive environment. (Van der Zee and Van der Vorst 2005). The focus of all definitions and perceptions of SCM is its goal to increase the value of goods and services for customers in a way that develops a unique advantage for companies (Stank et al., 2005). Facilitating responses to the demands of customers is a major challenge that companies are facing in a business environment that is customer focused (Christopher, 2011). For example, these demands pertain to pricing and differentiating finished products which impacts the competitive advantage of a company (Gunasekaran et al 2001). Another demand that companies are concerned with is shortening the time products are delivered (Ouyang et al., 2007; Ray and Jewkes, 2004). A short delivery time is paramount for customers who are eager to receive their ordered products instantaneously (Da Cunha et al., 2007, Ray and Jewkes, 2004). The capabilities of companies to deliver on these three dimensions is reliant on the lead-time customer orders are completed and how quickly suppliers replenish materials.

Satisfying customer requirements, enhancing competitive advantage and innovation of organisational processes are the core purposes of supply chain management (Childerhouse and Towill 2000). Consequently, research into supply chain management typically concentrate on ensuring efficiency and increasing competitive advantage of both suppliers and producers (Tan 2001). Furthermore, through upstream and downstream collaboration a network of organizations can employ various actions to provide good and services with the main intent of ensuring customer satisfaction (Christopher, 2005). Additionally, Lambert and Cooper (2000) stipulates that supply chains embodies interactions within and out of companies, whether between other companies, suppliers or customer directly and indirectly. These interactions are examined from the origin of a product or services down to the utilization of these services and goods. For instance, within a supply chain an oil distributor is responsible for the upstream elements of exploration and refinement of crude oil and the downstream elements of supplying and selling of finished product to customers. The dependence of organizations on one another is evident here, hence, all interlaced factors need to be coordinated in a manner than insures an agile supply chain system.

There are commercial advantages for organizations from the goods and services produced in a supply chain. For one, if expenses and time is reduced in the production of goods then an increase in value is a benefit companies can expect. In the realities of the oil industry, this would account for significant growth in the effectiveness of supply chain management in the future. Consequently, the perspectives on supply chain management take precedence over the perspectives of vertical integration. Notably, most companies concentrate on core competencies even choosing to outsource as a means of ensuring an agile and efficient supply chain is created rather than simply utilizing vertical combination which only improves the dimension of competitiveness. Inter-functional, intra-functional and inter-organizational are they three main types of supply chains that companies exploit (Ballou et al., 2000).

The three types of supply chain differ in scope, from a basic coordination in a single site production facility to a complex coordination of multi-corporations. This difference is the reason supply chain management weighs core competencies of a company against areas that should be prioritized for management. Subsequently, companies are involved in a supply chain, from sourcing raw materials to delivery of products to customers by specializing in activities with the capacity to provide some relative advantage. Besides, companies rarely adopt or are involved in just one supply chain. A company tends to emerge from multiple supply chains. Nevertheless, despite the increased attention on SCM, existing literature has failed to contribute substantially to the practice of SCM or focus on uncertainties in the demand and supply in a supply chain (Cigolini et al., 2004). Naturally, the foundation and development of SCM is an interdisciplinary theory thus no one specific definition is credited in literature (Feldmann and Muller, 2003).

2.2 Dynamic Supply chains

In a supply chain various elements function in relation to different sets of outlined objectives and limitations. Consequently, the performances of most, if not all of the elements within a supply chain are heavily reliant on the performance of other entity (Swaminatan et al 1998). The operational challenges experienced within and by a supply network is driven mainly by the dynamic behaviour of the supply chain meaning that interactions of various chain players have a causal effect on the whole system (Parunak, 1998). Moreover, the reference to dynamism of behaviours within the supply chain is a reflection of the evolution of the interactions of the various entities involved. Furthermore, interactions that evolve are the constant changes to product designs, market place demands and the need to employ cost-saving improvements (Haywood and Peck, 2004). These continuous improvements by institutions and the industry at large are the reasons why supply chains never reach a state considered stable or steady (Haywood and Peck, 2004). Fine (2000), further explained that the pace of the specific industry exerts influence on the vertical and horizontal forms in the structure of the cycle in the supply chain.

2.3 Complex supply chains

The impact of modernisation on supply chains can be seen in its complexity. This complexity is the constant flow of information and the varying parallel levels within the supply chain that needs to be considered to match the everchanging trends of modernisation. Moreover, the flow of information and the parallel levels ensure that desired products are produced at the designated time, are in fact cost-effective, the right amount and delivered to the right location (Chapman et al, 2002). Additionally, research carried out by Deloitte Touche Tohmatsu (2003) conclude that not only does modernisation affect a supply chain there are three critical trends that cause the supply chains to be complex and challenging to manage.

These include:

- The intransigent pressure from product conception to delivery to consciously and continually reduce the costs of and withing the supply chain
- The pursuit of avenues and markets deemed new, attractive of immensely profitable
- The increasing pace at which products are innovated

There are numerous research paper on the complexity of supply chain management that corroborate the statements made above and offer in-depth understanding of these complexities.

As mentioned above the result of the flow of information and material within supply chain networks is a complex set of activities that are interconnected and span across multiple factors like the distributing companies, the suppliers of goods and materials and manufactures of various elements that make up the product (Lee and Billington, 1993; Lee and Whang, 1998). Other factors that engender complexity in supply chain systems include: the bullwhip effect, completion date, cost, missing or inconclusive information, product priority and quality (Lee and Billington,1993; Davis, 1993, Lee and Whang, 1999; Lee et al, 1997, Taylor and Brunt, 2001; Geary et al, 2002, Arns et al 2002; Kouvelis and Milner, 2002). Subsequently, uncertainty within any of these parameters would propagate increased complexity of a supply chain network (Van der Vorst and Beulens, 2002).

Furthermore, Harland et al (2003) identifies that alternative path of design and delivery, customisation, novelty of technology, production and delivery feedback loops, scale, stakeholders, sub-system components quantities and the variety of knowledge bases are all active contribution to the complexity of the supply chain network. With all these characteristics operating within the complex system of supply networks an emergent behaviour can been seen, making it difficult to manage the supply network especially in cases where delays exist or inconsistencies persist (Chung et al., 2004 and Surana et al, 2005). This inherent complex nature of supply networks makes it tasking for one single entity to effectively and efficiently monitor or control the network as a whole Braithwaite and Hall (1999).

2.4 Supply chain vulnerability to disturbances

Having explored the complexity of supply chain if never toward that supply chains are constantly subjected to disturbances. Disturbances are referred to the unexpected events or occurrences that influence the ability of a supply chain to achieve its adverse objectives in regards to its performance. There are two main classifications of disturbances that have been outlined by Saad and Gindy (1998). These gained their classifications based on the origins of the disturbance, either, internal or external. Internal disturbances materialise when processes are faulty or companies have a considerable number of uncertainties within the supply chain. In some cases, processes employed to encourage sustainable improvement of the performances of a supply chain can in fact be origins of disturbances. This is an example of an internal disturbance, notably, the recent efforts using TQM and lean concepts to increase the efficiency of supply networks. These concepts call for companies to push for a near zero inventory system which leaves little room for the inventory in supply chain network to buffer future interruptions (Chapman et al, 2002). Moreover, the extent to which these disruptions are impactful is unmeasurable because of the close interconnected relationships between various supply chains coexisting in a supply network (Chapman et al, 2002). Additionally, in instances where critical disruptions occur, there are unavoidable hidden cost which can negatively affect the efficiency of estimated cost (Lee, 2004).

There are other casual factors that are considered internal disturbances even where the partnerships of logistics nodes are strong notably, the risk of conflicting areas such as ever competing local and global interest (Naish, 1994; Kahn, 1987). Equally, another factor is the excessive hesitancy to share common data within an organisation's supply network (McCullen and Towill, 2002; Loughman et al, 2000; O'Donnell et al, 2006). Moreover, supply chains in mundane realism are interfered with the effects of the bull-whip especially when companies begin to cooperate for a common goal (Van der Vorst et al, 1998). Ironically, findings of experiments carried out by likes of Wilding (1998) show that corrective actions such as the reduction of lead-times can be detrimental to the overall performance of the supply chain network.

On the other hand, according to Saad and Gindy (1998) there are two sub-categorical sources of external disturbances which are demand and supply. Demand disturbances are referred to as the time delays in expected orders, premature delivery of orders, sudden spikes in order numbers, variation of planned quantities compared to forecasted quantities and changes in the priorities of orders. Contrastingly, external disturbances that are related to supply encompass all delivery issues such as the untimely delivery of goods and the delivery of incorrect goods. Sheffi and Rice (2005) highlighted that the principal source of risks within a supply chain are uncertainties in product demands. These uncertainties are reinforced because of the growing global competition, product variety with shorter life cycle and the distorted expectations by customers.

Consequently, demand uncertainties could encourage under production or over production resulting in the incompetency to meet the needs of customers or production of surplus inventories respectfully. The dangers of excess inventory can be seen in the increased expenses in holding costs whilst inability to meet customers' needs incurs short-term losses of profits and long-term losses of loyal customers (Jung et al, 2004). Notwithstanding, these challenges are not the only challenges that supply chain managers have to deal with as these there are conventional in nature pertaining to quality, capacity and supply variability. Unconventional challenges that managers have to deal with include disruptions that are unwarranted such as strikes, accidents or devastations of natural disasters (Chapman et al, 2002; Mitroff and Alpasan, 2003).

Conversely, the most frequent external disturbances result in sales deviation form initial forecasts and contributing to colossal losses to the company that are long-term since the trust of customer may be lost and the effects of bullwhip being too costly which would adversely affect the performance of the supply chain network as a whole. Additionally, the magnitudes of some internal disturbances based on the rules and process of decision-making can be unfathomable and thus extremely difficult to effectively mitigate its effects on the supply chain. However, all other types of disturbances are less frequent in nature. Thus, we can summarise from the analysis made on supply chain management that in actuality the effective management of supply chain networks are progressively more difficult. The reasons for this increased difficulty are:

- The scale of the network with various organisational entities that are interconnected from manufactures to suppliers to distributors that span across the globe
- The conflicting objectives of all members actively and silently involved in the network
- The nature of the supply chain is uncertain and dynamic

As discussed, due the volatility of uncertainties, supply chains are prone to exhibit behaviours that are unpredictable, thus, restricting the ability to control them through top-down planning (Radjou 2002 and Lawrie, 2003). However, the adoption of a collaborative approach may facilitate the opportunities to control this volatility to an extent (McCarthy and Tan, 2000). This is so companies can reduce the risk of the system failing as a result of the increased dependence on complicated networks to encompass partners and global suppliers. This new proposed operating environment will encourage a model design for supply chain inventory that will carefully identify these problems listed above and effectively respond in a manner that limits uncertainties but promotes and restores the performance of the organisation (Rice and Caniato, 2003). Notably, this would be the development of a model deemed “robust” enough to not only identify but also reduce these risks (Sterman, 2000). The overall motivation to adopt these strategies is to aid any given organisation effectively improve the satisfaction of customers and efficiently reduce the overall cost. Furthermore, these same strategies will fortify sustainable operational systems within the organisation irrespectively of any uncertainties that may arise and better manage the aftermaths of these uncertainties.

2.5 Cost efficiency in supply chain

Total cost is a determinant of the financial performance of a supply chain. In a supply chain environment, a smooth flow of information and material is a strategy for cost (Wikner et al 1991). Meanwhile the cost in one part is affected by the cost in other parts, decision making becomes difficult as a result of different functional boundaries in the supply chain (Cavianto 1992). For instance, increasing inventory leads to an increase in cost. Gunasekaran et al (2001) established a supply chain structure for analysing the operational and tactical performance and evaluating the supply chain. Additionally, the key performance metrics in the supply chain were highlighted.

2.6 Ordering and supplier cost

The initial point of the supply chain of business activity is the acquisition of goods for any company. The performance of the downstream activities and inventory levels is determined by the way orders are propagated. According to Gunasekaran et al (2001) reducing the cycle time leads to a reduced response time in a supply chain. Competitive advantage is acquired resulting to a resilient system (Suri 1998, Christopher and Peck 2004, and Ponomarov and Holcomb 2009,). Contrastingly, placing an order requires a cost, cost is incurred by a company whenever a number of transaction are needed following the placement of an order. The cost include preparation of the order, liaising with the suppliers, payments and delivery (Slack et al 2010).

2.7 Production cost

After the placement of orders and products accepted, assembling the product is the next step. Some of the factors that affect the cost of production include demand variations, volume of the product, varieties, effective scheduling process, labour and raw material cost and the capacity utilised (Gunasekaran et al 2001). The supply chain production capacity fluctuates as high variations in the production rate result in cost increase. Resolving out of stock situations in supply chain is measure of resilience in the system (Towil 1982).

2.8 Asset cost and return on investments

Assets in supply chain consist of inventory, property, equipment and stocks (Stewart 1995). Measuring a firm's productivity in the supply chain, it is important to ascertain the cost related to assets, joint with revenue influences the overall flow of cash (Gunasekaran et al 2001).

The numbers of days required to convert revenue invested in possessions into revenue received from customer's aids measuring the productivity of a firm Stewart (1995). The inventory cost in the supply chain include finished goods, work in progress, raw materials, inventory in transit, service cost and buffer inventory (Callioni et al 2005).

2.9 Shipment cost

The shipment network, scheduling transportation and the location of warehouse play a vital role in delivery performance in the supply chain. Location policies, scheduling and a suitable network are a means of increasing performance of delivery (Gunasekaran et al 2001). Financial performance to improve the supply chain by reduction of lead time have been explored by numerous researchers (Disney et al 2003, Mason and Lalwani 2006, Wilson 2007, Blumenfeld et al 1985). The supply chain is resilient when lead time is reduced and flexibility is increased (Carvalho and Cruz Macdado 2011). The quantity of transit goods and work in progress are other elements of the shipping systems. For instance, a huge amount of transit goods results in low returns on inventory.

2.10 Customer service cost

Customer satisfaction is paramount in the supply chain, it is an indicator in measuring the loyalty of customers. Customer satisfaction is essential as retaining happy and satisfied customers is cheaper than acquiring new customers (Van Hoek et al 2001). In contemporary supply chain, customers are not bound by geographical boarders which company's need to cater for (Gunasekaran et al 2001). The unpredictability of the market and ever changing customer needs, the supply chain must be focused on satisfying customer demand (Van Hoek et al 2001). Losing customers can equate to the loss of sales, however dissatisfaction presents the company with an opportunity to improve (Slack et al 2010).

2.11 Supply Chains Behaviour Dynamics

In 1958, the study on the evaluation of supply chain performances was published by Jay Forrester, which was followed by another study on Industrial dynamics in 1961. This study covers two important concepts:

1. System dynamics simulation modelling as a means in analysing complex dynamic problems using feedback loops.
2. The focus on lead time, inventory behaviour and to assess the dynamics of supply chain performance.

The term Demand amplification by Jay Forrester in 1958 refers to the increase in variability of orders across an echelon within the supply chain, the over compensation in the supply chain by decision makers resulting to huge oscillatory behaviours that emanate from surplus inventories and out of stock situations.

The term Bullwhip effect was used by Lee, Padmanabhan and Wang (1979) after the study in Proctor and Gamble on the behaviour of disposable diapers.

In other to understand the supply chain concepts, computer based games, Beer Game and other board games were developed by Torres & Moran 2006 as a teaching tool to understand the supply chain concepts. The main areas which was the core focus was:

- Causes of the Bullwhip effect

- How to control the Bullwhip effect

2.12 Causes of Bullwhip Effect

Price fluctuations, rationing, demand forecast updating and order batching are the 4 major factors contributing to the cause of bullwhip as identified by Lee, Padmanabhan and Wang (1979). Sterman (2006) suggest that there are both operational and behavioural causes. Instability in the supply chain arises from the failure to account for feedback, time delays and unfilled orders in the system. The review of various causes of bullwhip effect by Bhattacharya & Bandyopadhyay (2011) includes inventory ordering policy and lead time.

Using case studies and the focus of beer game and the effects on supply chain chains, Lee and Whang (2006) concluded that different solutions addressing different drivers are required for different supply chains. This conclusion was further acknowledged by Gattorna 2010 in the design proposals.

Morán and Barrar (2006) identified various structural causes for the bullwhip effect. They evaluate the impact of alternative supply chain management strategies using system dynamics simulation modelling. The Advanced Forecast-sharing Coordination Model, which takes into account, expected future market conditions to place orders, showed the most promise. Further investigation of lean and agile supply chains was also recommended.

2.13 Controlling the Bullwhip Effect

There are various ways to control the bullwhip effect as suggested by Wikner et al (1991). These includes collaborative planning, collaborative transport management, forecast and replenishment, vendor managed inventory and joint managed inventory.

Improving replenishment policies to control the bullwhip effect were the main focus of Disney and Towill (2006). Disney and Towill concluded that depending on the demand pattern, a unique ordering policy should be set for each SKU. These conclusion was further supported by Gattoma (2010) which suggested supply chain designed for particular buying patterns.

The impacts of elements such as time compression, information transparency, echelon elimination and control system design as means to control the bullwhip effect in a supply chain over a period across numerous countries was studied by Towill et al (2006).

Using electronic versions of a custom developed game similar to the beer game, Botha (2007) echelon elimination had the most significant impact, time compressed was next and control system design had the less impact. The complexity of time delays and feedback loops cannot be solved manually. The propensity of inventory controllers to intervene and apply expertise to override control system decisions by adjusting orders also results in Control System Design being difficult to implement.

Ouyang, Lago and Daganzo (2006) focused on alternative ordering strategies. Using a Root Mean Square Error calculation, they demonstrated that "order-up-to" (ordering to a target) and "generalized kanban" will result in the bullwhip effect. A simple "order-based" (sell one-buy-one) policy will not result in the bullwhip effect for "any realization of demand and for chains with any number of stages." While this assertion suggests that sell-one buy-one is an ideal ordering policy, the analysis does not take into account the levels of service provided, does not assess stock-outs and would only be valid for very specific cases.

In addition, the analysis method relies on a static calculation of a set of variables, rather than the dynamic behaviour of a supply chain. Machua and Barajas (2006) discuss the impact of information technology and specifically Electronic Data Interchange, on controlling the bullwhip effect. This approach has the benefit that data is transferred faster and more accurately. The key is that all players must be integrated into the data transfer system and there should be no manual interference with the data. This thesis does not focus on improvements to the supply chain design, but rather focuses on the decision algorithms associated with inventory management

2.14 Stability analysis for bullwhip effect

In Stability analysis, the key objective is to understand if a system is moved away slightly from its state of equilibrium i.e. system variables tend not to change with time and will return to its original state. For any little distress or disruptions from the original balance state, the system would always stay within a controlled area surrounding that state, therefore the equilibrium state is said to be steady. Nonetheless, the system is said to be unsteady if a system continues to move further away from its original equilibrium state when disruptions occur. According to Sterman (2006), he opined that unrelenting and a long term attribute of market economies is a supply chain instability. The inventory level, projections in demand, the rate of employment reveal consistent and irregular variations in the supply chain as company indicators. Bad customer service, excessive inventories and stocks, and avoidable capital investment Instability in a supply chain to be expensive (Sterman, 2006). A slight discrepancy from a state of stability can initiate an out of proportion modifications in the behaviour of a system, such as an oscillating behaviour in which the magnitude tends to increase gradually in a complex dynamic supply chain system.

According to Lee et al (1997), the four primary contributing aspects to instability in a Supply chain are as follows: Forecast of demand: Forecast with the possible causes for information distortion when details about demand in a business is not shared throughout the supply chain. Batching of orders: this recommends businesses purchase a large amount of items in a period and not purchase items for other periods, will cause a distortion on the demand projection of other players in the supply chain, since it is centred on sales rather than orders. Short game: A manufacturer would tend to allocate items to its consumers, when the demand for an item goes higher than the supply, and this would trigger consumers to overestimate their demand to ensure they receive the adequate quantity they require. Change in Price: Consumers tend to purchase the item when the prices are reasonable and when there is a significant change in the cost of an item, thereby causing them to purchase goods in large quantities.

By applying the immense theory of linear and non-linear dynamic system control, the stability of supply chains can measured and evaluated. Disney et al. (2000) suggests an industrialised style inventory control system to enhance the efficiency of a process. By drawing attention to the classical control strategies used in a contemporary optimization treatment which is centred upon GA the five superior qualities of a production distribution system. They suggested that control system by fully understanding the compromise between factory orders and inventory levels and applying the procedure can improve efficiency of a production or distribution. According to Riddalls and Benneth (2002) opined that the Beer Distribution Game is the stability properties of a continuous time variation. They illustrated the significance of robust stability, for example, the effect of stock outs in lower tiers can trigger a sequence of unsteady impacts in the supply chain stability for a range of production and distribution hold ups.

Nagatani and Helbing (2004) research studied the management function which manages the speed of production in relation to the stock levels, numerous production methods to sustain a supply chain, this is revealed by many requirements. They carried out simulations for various techniques of control to derive stability linearly. Ortega and Lin (2004) divulged that control theory can be used in the production /inventory issue to solve the problems associated with the decrease of inventory variation, ordering rules and amplifying demands. The simplest and fastest method to understand the stability of an equilibrium point is linearization. Other techniques to ascertain stability conditions have been effectively incorporated with Control theory. Daganzo (2004) studied different stages of the supply chains under inconsistent demand conditions and decentralised stability. He also applied conservation laws to generate stable policies utilising mathematical analysis. The research searches for replenishment inventory policies, embrace all consumer demand processes and find policies with favourable properties. The prevention of bullwhip is recognised in terms of policy gain (Daganzo 2004) discovered the condition.

The minimum change in an average inventory is stipulated by gain, triggered by a policy where there is slight but continuous change in demand rate. Perea et al. (2000) suggests a method for SCM that is centred on dynamic modelling and control theory. Structural model analysis approach have been employed to curb out oscillatory behaviours in SC designs. Lertpattarapong (2002) and Gonçalves (2003), to reduce the oscillatory behaviour of inventory in the supply chain, EEA was functional to identify the loops. They also applied the perceptions about the result of feedback structures on behaviour of the system to recommend policies for supporting decision making. Inventory buffers or safety stock are dependent on these policies. Furthermore, Forrester (1982) stipulated various policies for stable dynamic system. The first 2 methods, increase in the rate decay of oscillations and decrease frequency of oscillation and represent a step in the behaviour of the whole system protected by the direct system control theory. Additional approaches such as gain and decrease in variation are focused on the stability of a particular variable of the system. Thus, they have to be extensive to implement stabilizing policies for the whole system.

Evaluation of literature on stability analysis of the Supply chain discloses various strategies employed to ensure policy stabilization is created. Structural analysis of the model approach can propose an insight on how to tackle behaviours producing supply chain instability modelled as dynamic systems by recognizing the loops accountable for each variable. Nevertheless, these methodologies depend on the level of sensitivity analysis to produce the stabilization policies.

By applying the Control theory, stabilization approaches can supported by providing hypothetical ideas to support characteristics systems.

2.15 Supply chain uncertainty

Numerous business domain have explored the uncertainties and risk in a management perspective such as purchasing, finance, distribution, operations and supply chain management established that uncertainties can be observed as multidimensional (Yates and Stone 1992, Newman et al 1993, Ashton 1998, Lassar and Kerr 1996, Zsidisin 2003, Celly and Frazier 1996, Chow and Denning 1994, Yates and Stone 1992, Pagell and Krause 1999). Concept of supply chain uncertainty varies among managers and can be related to different variables within the system. The variables include safety stock, inventory levels and variations in customer demand (Juttner et al 2003). According to Sanchez et al (2008) argued that supply chain uncertainties occurs when the occurrence cannot be estimated based on the outcome and probability of it occurring. They argued that a major cause of this supply chain uncertainty in the supply chain is due to variation in customer demand, lack of information, supply side, control systems and material delays.

2.17 Causes of supply chain uncertainty

According to Towill and Mason (1998), uncertainties in the supply stems from the changes in customer demand, supply, control systems and the manufacturing processes. Consequently, Peck (2005) classified the uncertainty in supply chain into three and it includes: Uncertainties within the company, uncertainties outside the company but within the supply chain, and uncertainties outside the company.

One of the main causes of uncertainty in the supply chain is the unpredictability of customer demand which is external to the supply chain (Svenson 2000). Therefore, it is necessary for an effective supply chain management to ensure smooth distribution of goods and services, and information along the supply chain (Peck 2005; Christopher and Peck 2004; Colicchia et al 2010; Mason and Jones 1998).

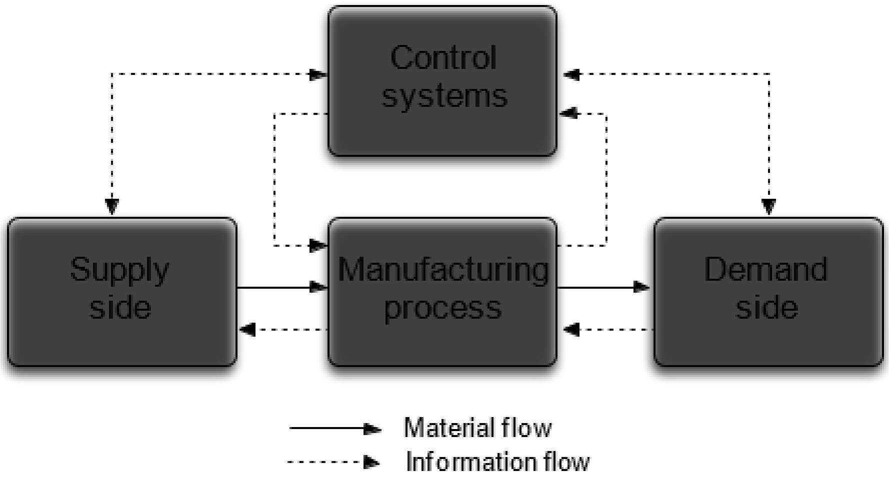


Figure 2.2: Causes of uncertainties in the supply chain

Figure 2. 2

Adapted from Mason-Jones and Towill (1998); Christopher and Peck (2004)

This research would concentrate on the ability of downstream oil supply chain to adapt to uncertainties employing system dynamics to reduce the long lead times in the supply chain and reducing the Safety stock coverage and retailer order cycle to impact policy decisions.

According to Zsidisin (2003), supply chain uncertainties external to a firm but internal to the supply chain arise from the disruptions in demand and supply. The sources of uncertainties and results in the system is classified by Zsidisin (2003). Due to the expensive cost of managing multiple suppliers, many firms decreased the number of suppliers in the late 1980s and early 1990s. Therefore cost of supply was increased which resulted in commitment uncertainties (Tang and Tomlin 2008).

Furthermore, a number of works provided unique way on adapting uncertainty in the supply chain (Boin et al (2010). Boin et al (2010) highlighted the truth about business. In spite of recent research concentrating on volatility arising from the supply side, disruptions in the system occurs due to demand variation and changes, when it increases or decreases. A sudden decline on purchases and customer demand, made businesses to hoard resources by lowering stocks, idle time, letting some members of staff leave, working out even more favourable deals with dealers as well as transportation suppliers, cost efficiency and outsourcing (Alsop and Armstrong, 2010). As result, makes them more exposed to variations. The variation in demand affects the forecast method, as demand changes due to uncertainties in the supply chain and changes in the demand pattern, the current forecasting policy might no longer be suitable to predict future events (Tang and Tomlin 2008).

2.18 System dynamics model

Forrester (1961) designed a system dynamic model for the analysing, modelling, simulation and understanding socio economic complex systems at the Massachusetts institute of technology. System dynamic model is a theoretical, logical and physical representation of reality (Acknoff and Sasinieni 1968). It is an imitation or substitute for a system that provides a unique understanding for interpreting and explanation (Forrester 1968, Saeed 1994). The opinion was supported by Richardson and Pugh (1981) describing an SD model as the part of reality simplified. This is because reality is complex with various elements interacting together which models cannot encompass or replicate in all its entireties. Therefore, models simply mimics reality (Forrester and Senge 1980). Modelling is more an art than a method as implied by Chick 2006, selecting the features in a model can be overwhelming and sometimes controversial. The model values arise as a result of the ability to understand and improve uncertain behaviour in the system effectively than observing the real system.

Ever since, system dynamics have been employed in solving dynamic problems, policy design and answering management and industrial issues (Erma et al 2010). Other studies in system dynamics followed with Sterman (2000) suggesting a case study approach to model issues in logistics using a system dynamic methodology. Minegishi and Thiel (2000) went further in applying system dynamics in the food industry to understand the complex logistics behaviour, the study laid emphasis on the coordination of variables in production of food. Furthermore, a system dynamic model for supply chain manufacturing system was developed by Ozbayrak et al (2007) to simulate the supply chain operations and gain an insight in the behaviour pattern.

2.19 Nonlinear system dynamics

In a nonlinear system, the concept of superposition is not the path followed by performance, indicating that variables identified should not depict linear and independent parts as a combined segment because outputs of a nonlinear system are not equivalent to inputs (Atherton, 1975). Supplementary to this, reality is nonlinear which makes recognition of a supply chain system a gruelling task (Rugh, 2002). Nonlinearities in a supply chain model can occur naturally as a result of economic and physical constrictions. For instance, hindrances to variable delays, controlling parameters of variables or fixed capacity and variable capacity in production and delivery methods (Naim et al. (2012). However, nonlinearities can boost the responses of outputs when introduced to the system deliberately.

2.19.1 Nonlinear system dynamics effects

According to Forrester, in his research on industrial dynamics, it drew attention to the significance of attempting to use non-linear models to show social and industrial processes. Forrester (1968) Opined that Nonlinearity can introduce unpredictable behaviour in a system which can lead to instability and uncertainties. Notwithstanding, the literature still lays emphasis on presumably linear models. Rugh (2002) suggested that although the theory for linear systems is well established, it lacks a unique non-linear theory that strives to generalize and make it applicable (Poles 2013, Shukla et al2009 Wikner et al 2007, Evans and Naim, 1994, Forrester 1961). There are still ongoing debates in the literature regarding nonlinear system dynamics in the domain for natural science, the absence of a clear focus has reflected in the research conducted in the social sciences. Therefore, the methods employed in the research and using predominantly sole simulation is a re-occurring problem in business systems dynamic studies.

Majority of the research and analytical work carried out on nonlinear systems dynamics appear to have been completed in the same period Forrester launched the Worls Dynamics model (Forrester, 1971). Using averaging techniques, Cuypers(1973) linearized discontinuous nonlinearities in Forrester's World dynamic model. The following year (Cuypers and Rademaker, 1974) explored numerical perturbation methods and model simplification by eliminating variables with slight variations. Ratnatunga and Sharp (1976) suggested using numerical analysis to linearize and lower the orders of a system based on the assumption that nonlinear associations can be estimated to a first order function. The importance of categorising various types of nonlinearities that occur frequently in business dynamics studies in order to apply appropriate techniques for each variable was established by Mohapatra in 1980. They include the tabl e functions, CLIP functions and product operators. A non-linear control theory method was also suggested which would include a small perturbation theory and linearization by applying the averaging technique; however, these techniques were not implemented in his paper.

A thorough analysis of the complex Forrester Industrial Dynamics model was carried out by Wikner et al (1992). By employing averaging techniques and manipulating the block diagram, they were able to simplify and linearize the original model and provide a detailed analytical insights into Forrester's simulation model. For example, they emphasized on the unavailability of feedback information added into the manufacturing rate and distinguish between 'safety' and 'real' orders. Naim et al (2012) applied the same steps for linearization and simplification and they achieved the same result for the discrete z-domain model, this enabled them to make comparison between Forrester's (1958) model and Burns and Sivazlian's (1978) model. In the Burns and Sivazlian model, they demonstrated the effect of the false order, which is as a result of combining between the 'real' and 'safety' orders and that can cause delays in the system. Using small perturbation theory Jeong et al (2000) found a state space illustration of three echelons in a variation of the industrial dynamics model. Nonetheless, no comparison was made between the original model and the linearized model, the simulation technique was used to analyse this model (Laugesen and Mosekilde, 2006; Shukla et al 2009; de souse et al 2000; Marques et al 2010, Hwarng and Xie, 2008). Due to innovation and cutting edge technology, majority of the research carried out has been through computer simulation. The Beer game which is a table top board simulation game created by Sterman in 1989 has been converted into a computer simulation model, various authors trying to understand a particular phenomenon such as stability, backlash, bullwhip have studied this model in order to improve systems performance.

In supply chains, other model of simulation have been employed to investigate the cause of batching and capacity constraints (Wikner et al 2007; Juntunen and Juga, 2009; Cannella et al 2008). By using the well-established inventory and order based production control system, Evans and Naim (1994) were able to simulate a total of eight different scenarios by inter-changing the combination of the capacity levels of each echelon in a three echelon supply chain system. They arrived at a conclusion that capacity constraints tend not to reduce the performance of an entire supply chain and they also discovered secondary dynamics can be affected by nonlinearities. Consequently, by solely using the simulation technique would prevent such behaviours from being analysed thoroughly because it is difficult for the modeller to ascertain fundamental relationships between variables. Forrester established in the early 1960s that in the dynamics of a complex system nonlinearities play a vital role. Although there were few exceptions, such as Holling(1959) the Lotka-Volterra predator-prey model in biological systems, economics, operational research, and other dynamic fields were dominated by linear models present in that period (Lane and Sterman, 2011). Forrester's background in servo mechanics enabled him to observe that economic, social and industrial systems were essentially nonlinear and estimating such complex linear systems could be exhaustive. However, engineering and mathematical sciences have carried out advanced research on nonlinear control theory and despite being a debateable area, new tools and methods to accommodate high orders, nonlinear systems with several loops have been developed further. Although various analytical techniques have been cited and recommendation given by dynamic scholars 30 years ago, they have been overlooked by recent studies, even though simulation techniques are still prevalent.

2.20 System dynamics systems and industry

SCM is a termed believed to be have been coined in the 20th century by Oliver and Webber (1982) for a new strategic logistics management. However, antecedent of supply chain management dates back to Forrester (1961) who applied it to transportation in industrial dynamics theory. The difference between these researchers is the field of study that system dynamic management is applied. Forester (1961) highlighted that the flow of information from downstream to upstream in a supply chain ends up distorted when capital or raw material are continually increased. This episode is referred to as the bullwhip effect titled by Lee et al. (1997a, b).

Following the publication made by Forrester, his work was applied from adjusting industrial issues was extended to researching concepts in economics, environmental science, management, public policy and many more. Hence, a more befitting term system dynamics rather than industrial dynamics was introduced to encompass its applicability to a breadth of fields (Richardson, 2008). The newly coined term endorses links to other systematic techniques in engineering systems, systems theory and thinking (Towill, 1992a). On the other hand, supply chain dynamics refers to the holistic analysis of system dynamics in the context of a supply chain to reveal demand for businesses to incorporate (Towill, 1992a). The characteristics of a supply chain system is the identification and understanding of boundaries between customers and supplier in all its complexity. Towill (1991) provides the aspects of a supply chain crucial for understanding its dynamism: forecasted demands for orders and sales, value procedures and importance of data on performance. Lagoudis et al., (2002) expands these aspects to include capacity schedule, current stocks, data or materials transmission delay, machinery, production rates, progress rates and status of procedures.

The presumption of supply chain dynamic is that improving one aspect in a supply does not inevitably translate into an increase in efficiency of the supply chain as a whole (Towill et al., 1992). Rather, supply chain dynamics is the development and implementation of an efficient system for production control based on recognisable dynamic behaviours of various components (Towill, 1982). Optimum control law can be created after identifying these dynamic behaviours to balance expensive alterations in production rates with the risk of overstocks (Towill, 1982). As attested by Hennet (2009) after observing cases in the real market, modelling, simulation of scenarios, supply chain dynamics have been employed in research into SCM to aid understanding of the implicit casual relationships and behaviours in the supply chain (Wolf, 2008).

2.21 Functions of system dynamics in supply chain performance

Dating back 50 years, supply chains were recognised as dynamic systems and this has brought a significant increase in the supply chain (Foresster 1958). To recommend mitigating solutions, the cause of dynamic behaviour in the system have been investigated by various researchers. The pioneering work of Forrester argued the irregularities in customer orders and production hinders the dynamic systems. Forrester went further to suggest the variability and demand amplification in the system are related to system delays (information and material), policy feedback loops and nonlinearities existing in the system. As a result, counter procedures for the issues in the system would be to reduce time, reduce echelons and understanding the feedback structure in the system (Wiker et al 1991). Furthermore, distortion of demand in the system and amplification is additional source of economic order quantity based on stock control (Burbidge 1961). Forrester's impacts in the supply chain is linked to dynamic structures and Burbidge's impact is linked to policies, operational decisions, and scheduling (Towill 1977). Burbidge 1961 suggested Synchronising the flow of orders and reducing batch sizes utilising ordering techniques to reduce material throughput time.

Through the Beer game simulator, the dynamic distortions in the system and supply chain demand amplification were observed and the feedback structure related to system delays was validated by Sterman (1989). He proposed solving the problem would improve awareness, education and communication. The bullwhip effect was a phenomenon of demand amplification experienced by Procter and Gamble (Lee et al 1997). Recently, more research have conducted in the transportation activities to understand and explain the distortions in the area (Holweg and Bicheno 2000). It was observed through the case study of a steel supply chain that a distorted and amplified pattern of supply is considered a reverse amplification. They argued that since order backlogs builds when there are supply constraints then the effect is caused by supply constraints (Holweg and Bicheno 2000). Furthermore, through simulation studies carried in an upstream company, it was deduced that even under constrained supply, deliveries are high. In addition, it was noted that as shipment move in the downstream, they are decreased in the supply chain (Shukla et al 2009). The backlash impact was a reflection of bullwhip effect and can lead to inefficient scheduling and high transportation cost. Various studies have been conducted to reduce and measure the variability in demand and the impacts on the supply chain performance such as financial performance, transportation and production operations (Chen et al 2000, Fransoo and Wouters 2000,Potter and Lalwani 2008, Torres and Maltz 2010, Canella et al 2008, Hamdouch 2011, Juntunen and Juga 2009, Lee and Wu 2006).

The effect of system dynamics on supply chain performance was also explored in some case studies such as automobile, food, grocery, electronics and toys industries (Kumar and Nigmatullin 2011, Hihuchi and Troutt 2004, Berry and Naim 1996, Edghill et 1988, Georgiadis et al 2005).

2.22 Discrete events simulation and system dynamics

Discrete modelling approaches depend on discrete events, an area of interest for social and management researcher (Forrester 1961). On the other hand, system dynamic modellers model constantly and utilise different equations. Experiments in system dynamics are an important function in computer models, to improve the system behaviour by developing structures and system strategies (Wolstenholme 1990). Developing the modelling technique is the next phase in order to analyse the issue. In this research particularly, Nigerian oil industry, the oil distribution supply chain and other problems such as long lead times which besets the industry. These problems are made complex, complicated, and interrelated, including many variables having causal relationships and feedback.

Therefore, a dynamic framework where the causal relationships and feedback of these variables in the system as they run in real world over a long period needs to be highlighted. It enables the understanding of the variables and how various policies affect the behaviour of the system. The system dynamics model helps in understanding the system through the feedback structures in the system and shows the relationship of each variables linked (Sterman 2000).

2.23 Research gap

A significant detrimental issue facing the downstream petroleum industries is the poor management of the supply chain dynamics (Li and Disney, 2017; Lin et al 2016), and whilst Geng and Jiang (2009) indicated other issues of uncertainties driven by unpredictable customer demand and long lead times in other parts of the world, it is important to highlight that Nigeria is not exempt from these experiences.

Given the relevance of the oil industry to the Nigerian economy and indeed the global economy, several studies have been conducted on this industry. Scheatzl (1969) steered the initial research in the Nigerian petroleum industry, with operational development being the main focus, taking into consideration the energy needs of the country and the importance of crude oil. Subsequently, the economic development and impact of the Nigerian petroleum industry was explored by Pearson (1970) and later by Ogunleye (2008). The early researchers focused on the economic and operational issues experienced in the industry, and not on the challenges encountered in the other segments of the Nigerian petroleum industry (Odofin, 1979; Onoh, 1983).

Furthermore, crude oil production shocks and effects to the nation was studied by Ayadi (2005) and Turner (1977), whilst Ihonyber and Shaw (1988) examined political influence in the oil industry, and Khan (1994) understudied its contributions to the Nigerian economy.

Using multivariate analysis, Aliyu (2011) assessed the impact of shocks in crude oil prices in Nigeria in relation to inflation, GDP and price, indicating that macroeconomic activities are affected by shocks in crude oil prices in Nigeria. SalaiMartin and Subramanian (2013), discussed the adverse result of mismanaging extractive resources on financial development. Recently, Musawa (2016) examined the challenges facing the Nigerian government's revenue from the oil industry using system dynamics but focused only on the upstream activities, to ascertain if the oil resource is a curse or a blessing, and concluded that certain factors such as political instabilities contributed to challenges.

As herein shown however, despite the numerous studies into the Nigerian oil industry, limited studies have been carried out to examine the effects of bullwhip on the downstream of the Nigerian petroleum industry's supply chain. This is a clear gap in the literature, given the supply chain uncertainties. In addition, there is a dearth of studies that have particularly employed the techniques of systems dynamics for an in-depth study of demand fluctuations in the downstream of the Nigerian oil industry.

Therefore, this study attempts to close this existing gap in literature by carrying out an in-depth examination of the impact of demand fluctuations or bullwhip on the downstream segment of the Nigerian petroleum industry's supply chain.

The significance of this research project is far-reaching, including the capacity to support policy making in industry and enriching the body of literature by closing the existing gap.

SUMMARY

In this chapter, the fundamental themes of this research are system dynamics and supply chain and Bullwhip effects was discussed, the research gap was identified. This chapter provided a synopsis of existing research on these themes. Also, the theory and empirical research that attempts to provide definitions of supply chain in order to carry out studies using quantitative research to arrive at an in-depth understanding of system dynamics in supply chain was discussed.

The chapter discussed research that has already explored the oil industry in Nigeria, the case study of this thesis, the role of system dynamics in the supply chain was examined.

Finally, supply chain behaviour dynamics was discussed, the effects of bullwhip and how to control the effects was also addressed.

CHAPTER 3 EXPLORING RESEARCH DESIGN AND METHODOLOGY

3.0 Introduction

The previous chapter highlighted the relevant gaps and also established the subject matter of this research that would be addressed taking into consideration the research questions. Further explanations on how the research was carried out would be addressed, the ontological and epistemological view points of the research would be explained, including the methods, research design and tools used. The outline of the ontological and epistemology grounds of supply chain management research would be considered first in this thesis and also the philosophical view point. This chapter would provide details on the tools and research methods including a review of system dynamics simulation.

Finally, the data collection process and the research design would be explained.

3.1. Research paradigm and philosophy

Blanche et al., 2007 refers to the involvement of an epistemology, ontology and methodology as a research paradigm. The researcher's perception regarding social reality represents the ontological position. Whether social reality naturally occurs or is constructed as a sequence of communications between people is a fundamental debate. The Epistemological position focuses on how the knowledge of social reality is constructed (Saunders 2009). As Saunders et al (2012) opined, whenever a research study is being conducted, the step-by-step approach to obtaining accurate data and drawing valid conclusion constitute the research methodology. The way the knowledge of reality is interpreted combining both the ontological and epistemological viewpoint is the methodological position. The credibility and rationality of a research study is largely reliant on the processes applied in carrying out the research study. In the initial stages of any research, a considerable amount and time and effort is dedicated to exploring numerous scientific approaches to use appropriate methodological methods to increase the accuracy of the research outcome (Selltiz et al 1959). The methods in research refer to a strategy for enquiry based on the assumptions, the research design, and also the data gathering process. According to Hair et al (2010) the options of the approach suitable for a research begins with the recognition and acknowledgement of issues to be examined, basic evaluation and assessments of the effects. Qualitative and quantitative method are the two basic approaches in a research despite the presence of other research methods. The Qualitative and quantitative method at a real-world level suggests a perspective of the world and the purpose of a critical research (Henry and Johnson 2009, Bernard and Bernard 2013). In other to determine the technique required for the research, the research methods suggest the manner in which the information is gathered, analysed, the type of representation of the target audience and way information is generalised (Eldabi et al (2002). Therefore, it is paramount to understand that there is no specific approach for a research method.

3.1.1. Research paradigms and philosophy in supply chain management

Supply chain management is an important research and business area since its acknowledgement, various debates to understand what constitutes the philosophical nature on this aspect of study. The debate in the supply chain management is limited based on the disciplinary, theoretic and definitive research (Wolf 2008).

Furthermore, in a vast area of supply chain management that consist of multiple concepts and theories such as the relationship within and outside the organisational construct, the logistics to run a business that employs supply chain management and the process of improving to match the global ever-changing environment (Burges et al 2006). The development of information systems, ensuring the goals of a business is achieved, ensuring a strategic management which refers to creating a competitive advantage in its sector, adapting to different fields and laws (Giannakis and Croom 2004).

There is a need to understand the various theories in the supply chain management. Arlbjorn and Halldorson (2002) opined that the various academic backgrounds of researchers in the supply chain would result in the several epistemological understanding of problems.

As Emmanuel et al 2012 suggested, the justification for this philosophical view point is that researchers design their supply chain on a preferred criteria such as cost, and its ontology are independent on social entities. Mathematical modelling, experiments and surveys are examples of quantitative methods common in the positivism epistemology due to the ontological perspectives of a supply chain research (Burges et al 2006 and Aastrup et al 2008). In order to conduct a qualitative research and understanding the subjective and inductive view, Naslund (2002) recommended a white space as a result of the dominance of positivist view. Based on this statement as supported by New (2004), flexibility of interpretation is constructed socially in supply chain and each interpretation is supported by power structures and specific interests. Researchers prefer interpretivist and qualitative methods such as interviews. The Abductive approach is a combination of inductive and deductive approach and the similarities and dissimilarities of these approaches (inductive and deductive) is shown in the figure below (Kova and Spens 2005). In the abductive approach, a link between real life observation and theoretical framework is created which makes it similar to the inductive approach and other part is similar to the deductive approach.

According to Johnson et al 2004, the mixed method approach has been the best approach in answering research questions used by various researchers. The practice has a long history in research, and researchers have adopted this method after understanding it offers more authenticity and validity to a research study.

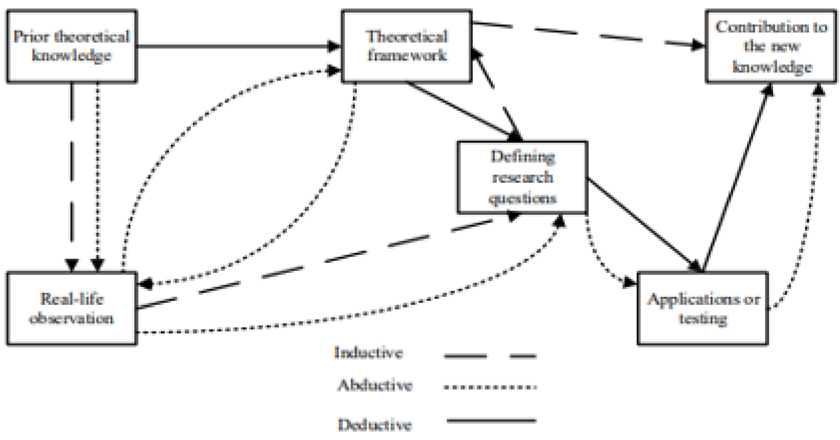


Figure 3. 1. The research process of deduction, induction and abduction. Source: Kovács and Spens (2005).

(Gammelgaard (2004) and Arbnor and Bjerke (1997) characterised supply chain research into 3 groups represented in the table below. They include analytical approach, system approach and actors approach within logistics research to correspond with the abductive approach, deductive approach and inductive approach.

	Analytical approach	System approach	Actor's approach
Theory type	1. determine causal effect 2. Explanation, prediction, universal laws	1.Models 2.recommendation 3.knowledge about concrete system	1.Interpretatin 2.Contextual knowledge understanding
Preferred methods	Quantitative (qualitative for validation)	Simulation and case study (mix methods)	Qualitative
Unit of analysis	Concept and their relations	Concept and their relations	People and their interaction
Data analysis	Description and hypothesis testing	Mapping and modelling	Interpretation
Position of research	outside	Preferably outside	Inside, as the part of process

Table 3. 1. Methodological framework for supply chain management research (Gammelgaard, 2004).

The analytical approach in supply chain is objective and researchers who agree to this approach believe in order to study the supply chain, it has to be broken down into smaller units and tested as reality is objective. Whist the researchers with the actors approach in supply chain management believe that reality is not objective but a result of social construct. Researchers who adopt the system approach are neutral, they study the links in the supply chain and feedbacks to improve the supply chain.

3.1.2. Ontological approach

Critical Realism is a philosophy of science that is based around several ontological principles. Forrester (1961) argued that variables in a system dynamic model should be equivalents in ideas of the actual system and corresponding quantities.

In the system dynamics perception, the primary ontological assumptions suggest that from patterns in physical constraints, the dynamic tendencies of some intricate social system may arise from the internal structure (Meadows and Robinson 1985).

There are various factors that influence the behaviours of people like societal pressures, goals and rewards. To understand the dominant tendencies of people these reasons must be cumulated to understand which are interrelated in complex pattern.

The levels, rates and feedback loops and flow of information are basically different from physical flows. The non-linearity and delays are essential elements in the system, behaviour arises from the structure of the system (Meadows 1989). The negative and positive feedback loops which consists of the delays, stock and flow explains the dynamic behaviour of the system (Mingers and Rosenhead 2001).

3.1.3. Epistemological approach

According to Mohammadreza et al (2013), the epistemological approach is concerned with essential and significant theoretical problems concerned with the limitations, nature and scope of knowledge.

Most arguments in the epistemological approach is focused on analysing the scope of knowledge, the justification, truth and beliefs are related to this perception. CR deals with the tools generating knowledge and uncertainty about different knowledge assertions.

Critical realism in epistemology offers concepts that can be used by researchers establishing theoretic descriptions about an occurrence worldwide. However, functions at a level comparable to that employed by Positivist and Interpretivist perspective. Critical Realist concepts are generally utilized to support the development of theoretic descriptions and considered a metatheory instead of a theory.

Our views and perspective concerning a series of cause and effect is replicated in a system dynamics model. Each model provides the modeller with an understanding of the problem who searches for validation of beliefs and truths in other to fully comprehend the problem Barlas (1996).

Forrester (1970) states that system dynamics analysis develops from an epistemological approach that is established based on the importance and understanding of mental models. CR recognizes the significance of a multi-level study e.g. the level of individuals and group.

3.1.3.1 The Positivist Paradigm

According to Bell and Bryman (2007), the positivist paradigm describes the study of social reality and beyond in natural sciences as the utilisation of techniques or methods with an epistemological perspective. The researcher is independent from reality under the positivist paradigm viewpoint. Thus, understanding acquired as a result of realities that agree with notion Collins and Hussey 2003). Developing hypothesis that can be tested, examined and validated is the essence of theory Bell and Bryman (2007).

The application of a deductive method is typically related to the positivist paradigm Saunders et al (2009). In this perspective, the theory and hypothesis are produced, the information gathered is used to test and evaluate the hypothesis. Gill and Johnson (2010) suggested that the advocates of positivist paradigm often use this approach as it helps in the validation of the research, and also research duplication.

3.1.3.2 The Critical Paradigm

According to Myers and Avison (2002), they argued that social reality in the critical paradigm is developed traditionally, for this reason designed and improved by people. Based on the assertions of researchers, actions to knowingly modify socio-economic events by individuals have been restricted by various situations such as governmental, traditional and societal dominance. The core objective of Critical paradigm is to help individuals develop an environment suitable for them Cavana et al (2001).

Researchers with the critical paradigm school of thought have a significant job in providing a review socially surrounded by the isolation and restricting situation within the exiting state of affairs. In other to achieve this, Myers and Avison (2002) argued that based on the assumptions of researchers, the people concerned might try to change the socio- economic situation, nevertheless are restricted by various situations such as governmental, traditional and societal dominance. One of the major qualities of a researcher in the Critical paradigm viewpoint is the thoughtfulness regarding assessment Cavana et al (2002).

According to Bernstein (1978), the positivist and the interpretivist research approach are the two main research approaches and are satisfied to discuss and anticipate the existing state of affairs. The researcher in a critical paradigm approach is more interested in analysing the social existing plans, pinpointing and identifying any disputes in the structure. While numerous similarities exist between the interpretivist approaches, Chua (1986) laid out three significant criticisms in the critical paradigm approach. The rationale for analysing results in agreements with the players is recognised as insubstantial as there is no room for assessment due to lack of consideration to details. Finally, the interpretivist researcher assumes that societal and physical reality is in accordance with interpretivist approach.

3.1.3.3 The Interpretive Paradigm

According to Bryman and Bell (2007), they argued that in the philosophy of interpretive paradigm, the researcher has to identify differences in relation to people, objects and materials requiring the researcher to embrace the biased nature of human activities.

Non-objective social reality is the ultimate expectation of this belief based on the perceptions presented by Collins and Hussey (2009). However, different to positivists, interpretivist argues that the intricacies of the human system cannot simply be theorised based on laws which natural science is founded on.

As expected the interpretivist approach employs interpretive analysis to understand the complex nature of a social phenomenon rather than simply exploring the significance of human phenomena usually carried out in the positivist approach (Hussey and Collins 2009). For the acknowledgement of incidents, rate of events and occurrences, a quantitative approach is adopted by positivist while the interpretivist analyse, explain and examine a phenomena using a set of processes (Collins and Hussey 2009). In theory development where data is gathered, the application of inductive method is a technique generally connected with the interpretivist paradigm (Saunders et al 2009). Bryman and Bell (2007) opined that philosophy is the introduction procedure and research results comprises of basic assumptions from the observation.

On the other hand, it is crucial to keep in mind that no perspective surpasses the other. The choice and adoption of one approach rest upon the research goals and issues relating to a specific area of research (Collins and Hussey 2009). The variables in the research are qualitative and quantitative thus a mixed method is needed for the findings to be valid, reasonable and authentic. Remenyi et al (1998) concluded that when both quantitative and qualitative methods is combined, the approach is complementary rather than two contrasting or different from each other. The improvement of policy decision making in Nigeria's supply chain downstream oil and gas sector are the main aims and objectives of this research

Furthermore, the quantitative analysis in this research study clarifies numerous steps for an unbiased investigation of the impacts of a range of strategy alternatives. The positivist paradigm is the ontological position of this research where the researcher is independent from reality. This technique though credible cannot fulfil the objectives of this thesis by itself, notably the tools employed to collate data because discussion on problems within supply chain would offer varying perspectives and analysis. Therefore, both positivists and interpretivist technique will be adopted as they display probable synergies. The integration of qualitative and quantitative is vital for the research design and modelling of this thesis. This will be established based on synergies of paradigms, perspectives and philosophies of both research technique.

Based on perspectives presented by Checkland (1981) and Lane and Oliva (1998) on ways to understand philosophical views of system dynamics this research study will develop a system dynamics models based on the main system players in Nigeria. This is so that data provided, will be reliable and appropriate as it is presented from those who have a first-hand experience with the system in Nigeria. Hence, utilising interviews system dynamics philosophy modelling was developed. The epistemological assumptions of this thesis involves the communications between the keys players in the Nigerian oil supply chain and the researcher. Knowledge was constructed socially as a result of the communication.

A stock and flow model was developed based on the interactions with key players and utilized mathematical information to estimate the model parameter values.

Additionally, the philosophy was tested deductively through various simulation tests relating to the scientific and experimental methods. The results are graphically represented and analysed within a positivist paradigm. The qualitative or quantitative approach is applied aims and objectives of the research, also positivist and interpretivist coexist in this research.

3.1.4 Methodological approach

The research objective and aim is to evaluate the dynamics affecting supply chain in terms of lead time in Nigerian downstream oil supply chain, seeking to reduce the lead time in supply chain by implementing lean and agile principles; therefore the output of this project should be applicable in improving the current situation. As Saunders et al (2012) opined, whenever a research study is being conducted, the step-by-step approach to obtaining accurate data and drawing valid conclusion constitute the research methodology.

Mingers (2000) suggested that models in System dynamics are dependent on time, a background, and are developed based on the interactions with key players in the supply chain and thus a visual representation of information or data. Simulation is carried out in a quantitative manner and interpreted in a qualitative method because the methodology for system dynamics is both quantitative and qualitative. In other to enhance the knowledge of system dynamics, the results are interpreted this way Erik (2006)

Critical realists argue that the image of things in the world are not things directly but feelings is what we experience and in system dynamics, causality is of prehistoric value, due to the fact that it permits one to connect aspects together in holistic structures which produce model behaviour through simulation which in turn might be connected to truth.

Therefore, as the social world is changing constantly, critical realists argue that the purpose of research in business is to understand the causes of such changes and provide adequate solutions to the change.

3.2. Research Methods and Tools

The research tools and method in conducting this thesis would be highlighted below. Wolf (2008) developed a hierarchy for a research methodology. The methods in research refer to a strategy for enquiry based on the assumptions, the research design, and also the data gathering process. According to Hair et al (2010) the options of the approach suitable for a research begins with the recognition and acknowledgement of issues to be examined, basic evaluation and assessments of the effects.

The conceptual research strategy employed in the thesis has been emphasised in earlier sections and the strategy could be empirical or conceptual depending on the data gathered. A conceptual strategy as purported by Bowen and Sparks (1998) supports a theoretical argument and further encourages an empirical research. The concepts used to increase validity and reliability does not depend on data gathered but also the tool. For example, to make a theoretical model more precise in a research analysis, simulations, mathematical modelling and experiments can be used to create artificial data (Wolf 2008). Exploratory research is used to ask questions, gain proper insights into an occurrence with a different perspective, this can be done by reviewing literature. Figure 3.2 below is methodological hierarchy depicting the research strategy and research analysis.

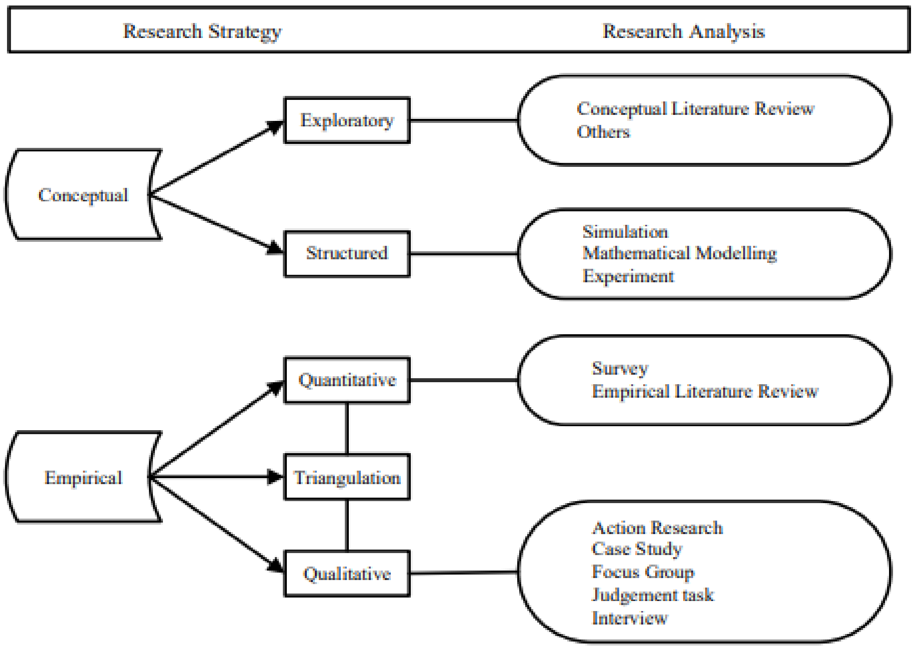


Figure 3. 2. Wolf (2008) Methodological Hierarchy

In a conceptual research, the research analysis commences with a conceptualised review of literature, simulation, mathematical modelling and experiments as depicted in the Figure 3.2 above. In order to conceptualise models, a conceptual literature review aims to outline information in an area or field of study. The models are additional tested empirically and in a structured conceptualised analysis (Denver 2006). Cameron and Price (2009) progressively concluded that Mathematical modelling techniques uses mathematical concepts to analyse the behaviour of the system.

3.2.1 System thinking

According to Senge (1990), research methods based on system thinking have exhibited positive results in human resources and services and technology industries. One of the main importance of system thinking is dealing effectively with complex problems. System thinking presents a holistic view of the system, the dynamics behaviours, stochastic behaviour, also integrating individuals, processes, relationship of the system and feedbacks in the model, provides suggestions for improvements of the system and compatibility of adapting the mental model to a computer model. In other to solve multi-dimensional problems, system thinking adopts both quantitative and qualitative methods. Qualitative methods in system thinking are used in model conceptualisation while Quantitative methods in system thinking approach are used in simulation. Examples of research methods in system thinking includes:

- Interviews
- Focus groups
- Field observation
- Experimental approach
- Case studies.

3.2.2. Mathematical models

Using mathematical concepts, mathematical modelling creates models to imitate reality. This concepts includes Control theory, different equations, feedback systems and time constraints. According to Leigh (2004), the connection of elements through information and links is referred to as a system. Control theory is used to study the inventory and supply chain systems and it’s a mathematical model of the relationship of the input and output based on the feedback systems, links and different equations(Lin et al 2017 and Naim et al 2017).

3.2.3 Model Assessment

Additional research into the literature has been done to create the system dynamics inventory model for calculating the effects of instability and bullwhips on the company's performance. The perspective of the customers and main objectives of the supply chain has been considered.

The causes of bullwhip and how to control the bullwhip have been discussed in Chapter Two and the measures the instability in the supply chain and testing carried out in chapter 5.

3.2.4 Model simulation

(Sterman 2000) inventory model was adapted by the researcher to address issues such as instability in downstream sector of the Nigerian oil supply chain and to address issues such as uncertainty and instability in supply chain, the model is required to represent the inventory processes. The primary benefit of employing Sterman model is that it comprises a large number of variables and equations that accurately depict the common supply chain system needed for decision- and policy-making.

The inventory model seeks to provide and extend the SD method of managing inventory that is capable of investigating the issue of bullwhip in the two companies.

The system dynamic inventory model comprises all the variables involved in a downstream flow chain that represents the movement of products between the oil distributor inventory and retailer inventory storage and finally delivered to consumers in Nigeria.

3.2.5 Simulation Software

Early software application service was released in 1958 and was based on the DYNAMO recognised SIMPLE compiler (Forrester, 1995). Even while DYNAMO was created and used for continuous simulation, it also served as a catalyst for the advancement of discrete event simulations (Nance, 1993). Although EXCITED BEAVER was innovative for about 30 years, as a result of technology development, particularly the widespread use of Windows, new software application options were developed (Clark Jr. and Kurono, 1995). STELLA existed 1985 and provided a visual programs basic, that is utilized nowadays too. There are various software application packages providing equivalent basic functions, nevertheless vary in the area and handling, such as iThink R, ModelMaker R, Powersim R Studio, Vensim R and much more. In addition to the theoretical part, a qualitative and a quantitative model of the oil supply chain was produced. Vensim PLE is a discrete event simulation software used in developing feedback loops, stock-flow diagrams and simulation models and it was used in carrying out this research.

However, the limitations of the vensim software included the software version which was available in carrying out this study. The version available was a student version and not the full version as such, certain functions was restricted such as user configurable tools to limit potential for human error and making changes faster.

3.2.6 Modelling Tools in System Dynamics

Many modelling tools in system dynamics are created particularly to assist in the development of models reliable, dependable and effective to serve as a computer based environment to aid in learning and decision making. The various tools includes:

3.2.7 A Causal Loop Diagram (CLD)

The feedback structure in a system is emphasized through causal loops, it is a visual diagram showing the various relationships in dynamic system (Sterman 2000). As stated by Sherwood (2002), in a causal loop diagram, the relationships between the cause and effects can be visualised in manner to capture all aspects of the systems, thus understanding the connection between the problems in the system. In a research study, system dynamists concentrate on behaviours that are dynamic and structures of the system that are founded on a varied number of feedback loop. This is to aid the conceptualizations of the system to better serve the research (Richardson and Push 1981). The relationships are closely related between causes and effects, information and actions. Figure 2.3 shows a causal loop diagram.

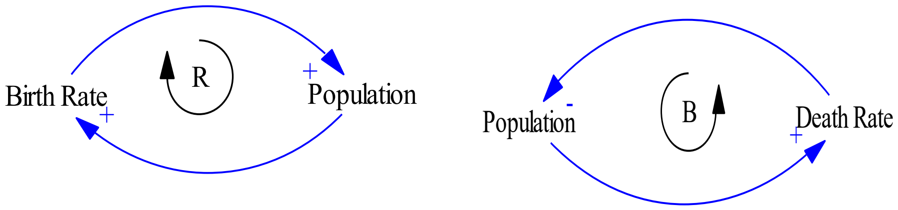


Figure 3.3: Causal Loop Diagram adopted from Sterman 2000

A system dynamic tool used for visual representation in the system showing the various feedback is a causal loop diagram. Figure 2.3 above depicts the CLD where the loop refers to a series of variables and causality in a closed system. The relationships in casual loop diagram is depicted using arrows and signs such as (+) and (-), the feedback loop in the structure is a means of conceptualising the model in CLD (Sherwood 2002).

Variables in the system are affected simultaneously, the variable at the top affects the variable below (Sterman 2000).

When the sign is positive (+) it means causal relationship and effects in the system is resulting to variables moving the same way.

When the sign is positive (-) it means causal relationship and effects in the system is resulting to variables moving in the opposite way.

Finally, the inflow and outflow of information in the system is represented by a feedback loop Sterman (2000).

3.2.8 Feedback loop

In a system, the feedback constitutes the main structure, the feedback could balancing feedback or reinforcing feedback (Forrester 1969). The positive feedback is reinforcing while the negative feedback is balancing (Senge 2006). The feedback loop is represented with the following signs below. Counting the minus sign is way to determine the feedback loops (balancing or reinforcing), the links in the system are represented by the sign Sherwood(2000).

Or

The reinforcing feedback loop is represented by the sign above.

Or

The balancing feedback loop is represented by the sign above.

3.2.9 Stock and Flow Diagram

The structure of feedback in a system is emphasized through causal loops while the physical system of the system is emphasised through stock and flow diagrams (Sterman 2000). The stock is a part of the system where the value at any time depends on past events in the system while the Flow in the system represent the rate which the stock changes at any time.

In a stock and flow diagram, the level and rate monitor the accumulations of processes, product and inventories as they progress in the system. The stocks consist of inventories, people, monetary products and money while the flows consist of the rate to increase or reduce stocks, it could be the rate of increase or decrease in births, deaths, delivery, inventory and production (Sterman 2000). In this reseach, there are two main stocks namely: Oil distributor inventory and Retailer inventory storage.

Figure 2.4 shows the stock and flow diagram, highlighting one of stocks in the research. However, there are various parts of the stock and flow in model namely: (1) flows, (2) stocks, (3) variables, (4) connectors, (5) valves and (6) clouds. Figure 2 below shows a stock and flow structure.

Figure 3.4 Typical stock flow diagram Authors work

From the above, the stock called Oil distributor inventory is increased by an inflow called Distributor order rate, and depleted by the outflow, Retailer order rate. The cloud in the diagram represents the model boundary and the valves are a base for increasing or reducing the flow. Flow in the system represent the rate which the stock changes at any time variables. Stock are state variables. The Converters are intermediate variables for calculations, and are represented by general variables. Lastly, connectors are similar to causal loops, they emphasise the link within each part in the system through arrows.

3.2.10 Benefits of modelling

Davies (2001) suggests within a research, modelling allows the integration of processes, information, systems, details and organisation. It also helps with analysing the various perspectives and relationship in the system to enhance policy makers to select the suitable and best techniques when exploring alternatives (Bennett 1992). Modelling provides an understanding of the system by establishing a natural depiction of the system (Bonabeau 2002). With reference to Daves (2001) modelling uses a perfect opportunity for the assessment of "what if" situations. In system dynamics modelling, it is significantly thought about as a suitable method of assisting in the interpretation of choices into plan by policy makers. There are five important benefits of system dynamics modelling, it includes: documenting process, focus on problems, the framework enhances the participation of the public and serves as a means for learning and policy design (Stave 2002).

Decision makers can use system dynamics model as practice environment which helps in experimenting and understanding the dynamic system and how it operates. Experimenting helps the decision makers practice such as flight simulators (Sterman 2000). Stake holders are involved in the processes of a model based research in system dynamics and the incorporation of results in their input (Voinov and Bousquet 2010). However, modelling complex system can be challenging when defining each components, data availability and understanding the system and system uncertainties can be time consuming (Wilson, 2001).

3.3 Research Design

A deductive research methodology is used to address the study issues. Reading the literature was the first step in the inquiry. The bullwhip effect, inventory management, supply chain management, and system dynamics modelling were all rigorously examined in this thesis. Figure 3.4 shows how this study's research was conducted. The primary research questions are formed, the gaps in the literature regarding supply chain inventory theory and the system dynamics model in this study are acknowledged, and the downstream oil supply chain is used to test their performance. In this chapter, the choice of approaches and frameworks for researching system dynamics is taken into account. The model conceptualisation and design would be discussed in chapter 4 and chapter 5 would focus on the analysis of the system dynamic inventory model specifically the downstream oil supply chain in Nigeria. The primary data would be collected from the two case study companies involved in this research.

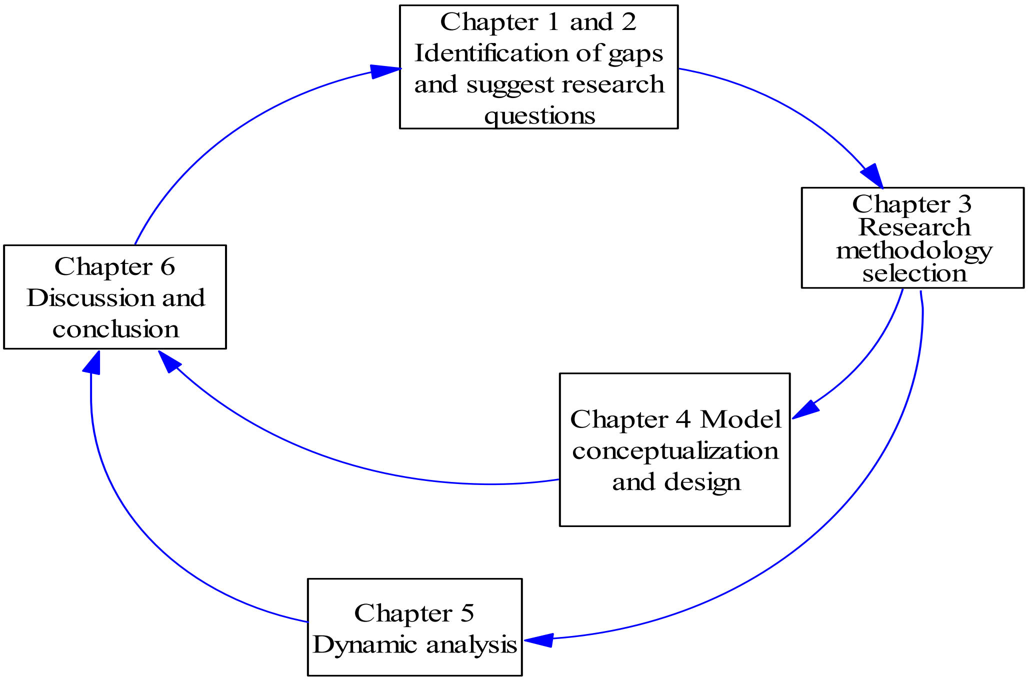


Figure 3.5 Research design for this thesis

3.3.1 Process of literature review

To start the literature review process, various search engines and databases were used to run numerous keyword searches. Various database such as Emerald, Science direct, Scopus, Global, Google, Ebscohost and abi/inform were explored using an exploratory literature review process. The process began by searching for keywords such as supply chain, Nigerian downstream oil sector activities, bullwhip effects, instability in oil industry and system dynamics. As the research progressed, the searches were focused on the problems encountered in the downstream sector, supply chains and causes and effects of bullwhip. The same methodology was utilised to comprehend the numerous research methodologies used as well as the techniques frequently employed in supply chain and system dynamics. The results of the searches showed that supply chain management frequently uses numerical and simulation techniques.

In addition, it was clear from the methodical studies that were found during the search that neither the theories used nor the research techniques were discussed.

In parallel, the keywords system dynamics, ‘inventory management’ and ‘supply chain management’ were examined independently to determine the different fields using these principles. Subsequently, the researcher gathered all the qualitative and quantitative research that were relevant to developing the system dynamics inventory model. Lastly, the researcher used textbooks because the entire description of procedures cannot be added in research articles in this field due to page number restrictions.

3.4 Supply chains occurring problems

Based on the researcher’s perspective, information on the instabilities in any company’s supply chain arouses an interest in having access into the organisation and trying to understand the causes of the problem. These problems in the supply chain are real life events and the cases are apparent. A very strong empirical reality stems from the establishment of a good theory and validation of the theory is important and observing real life cases is necessary to complete the research.

The case studies contribution to this field of research is not limited to being a conceptual one. The existing industrial problems and importance of the proposed model is equally relevant. To answer the research questions theoretically and practical, case study approach is the most research method for this research.

According to Siggelkow (2007), motivation, illustration and inspiration are the primary reasons for using a case study method. Some studies can combine motivation, illustration and inspiration when carrying out a case study research while some may employ one or two reasons mentioned above. Siggelkow further purported that, motivation is a great way to carry out a case study research questions. Therefore, understanding the relationship between variables and organisation structure based on the observations of the downstream oil company in Nigeria contributed to the development of a research question. To understand the company policies and structure based on real life events, case study research is appropriate.

3.5 Data Collection

Case studies will be utilised in this thesis to validate the model created for the inventory system for the Nigerian downstream oil supply chain and to support the study findings. The case studies in this thesis will be used to evaluate the study findings gained through model simulation and analysis.

Additionally, data collected and some information sourced from the case companies would be effective in the selection of variables and the relationships among them to be used in the model development. Based on that reason, the researcher gathered data and information through company records and interviews with twelve company representatives of the two companies of the Nigeria downstream oil supply chain. However, due to the company privacy policies some specific data and other relevant information required were not available to the researcher or were not recorded by the companies.

The case companies were selected based on their involvement in sales of oil products in Nigeria. Due to the nature of the data and information collected from the companies, the choice for specific company data for analysis.

Specifically, to capture and understand the reason for the bullwhip, it is required to apply an approach involving the use of qualitative methods to gather and examine the variables that causes bullwhip, literature search was conducted to identify the important variables with the confirmation of the managers. A detailed explanation and the validation of the system dynamics inventory model and data analysis is provided in the next chapter.

3.5.1 Location of the Research

The location and accessibility to the case companies are crucial for the effective completion of an empirical research project involving the collection of primary data, as Saunders et al. (2009) recommended. This research involves two companies in the downstream sector of the Nigerian oil and gas industry. In order to conduct this research, these businesses would supply pertinent data, and the researcher made contact with them in order to obtain access to the company's operations and to facilitate the data collection process. The researcher faced some challenges as the information were not readily available and access was a bit restricted.

3.5.2 Interview

Data collection methods such as interviews was very essential in carrying out this research, it offered the researcher a mental opinion of the managers. Mental opinion is a visual representation of events in the dynamic system, it involves the assumptions, generalisation, ideas and views, the information and decisions are made and thus understanding the connection between the problems in the system (Vennix 1990). Interviews can be divided into three aspects as categorised by (Saunders et al 2009) and it includes unstructured interviews, structured interviews and semi structured interviews.

Structured interviews are also known as formal interviews and it's a quantitative research method where participants are given the same set of questions, they are predetermined (Bernard and Bernard 2013). Unstructured interview on the other hand is an informal interview, it mostly feels like a normal conversation which is guided by the researcher. The questions are not prearranged which allows for spontaneity and allows for more questions during the process of data gathering (Yin 2009). Finally, semi structured interview is described as an interview process where the researcher does not strictly follow a pattern of questions, it involves open ended questions (Bryman and Bell 2007). This method of interview is mostly associated with social sciences.

The participants in this research included the managers, supervisors and salespersons in order to gain proper insight and not only from a single source e.g. supervisors only. The purpose was to gather relevant information from various participants and to answer the questions on how and why social events occur, understanding the causes of uncertainty and instabilities in the supply chain of the Nigerian downstream oil industry.

Semi structured interviews was employed in this research as it allows the researcher to ask questions depending on the role of the participant in the company. The flexibility of the interview enabled the researcher understand the causes of instabilities and uncertainty in the industry from the perspective of the various participants, questions could be added or removed to suit the participant. The data gathered from the interview were important in validating the results of the research.

3.5.3 Procedure for Interview

The researcher made sure the questions weren't overly precise, as claimed by Bryman and Bell (2007), in order to find areas of inquiry that may occur during the interview process. The procedure for interview involves expressing the purpose of the interview clearly, ensuring the questions were clear, short and easily understandable by the participants. The majority of the inquiries started out by asking what and why a certain phenomena or social event occurred as well as how social actors interacted with the events to create social reality. The interviews comprised of twelve participants in the downstream sector of the Nigerian oil supply chain, it includes managers, supervisors and sales persons. The table below highlights the participants and the reasons for selection.

No of Participants (twelve)	Reasons for selection
Managers (Two)	As overseers of every single stage within the supply chain they are responsible for providing in-depth record of people involve with the institution process. This includes communication, control of inventory to anticipate instabilities.
Supervisors (Four)	They oversee the sales and distribution of oil in the supply chain, they also ensure the company has enough to meet customer demand.
Salesperson (Six)	To provide understanding of the downstream oil supply chain.

Table 3.2. Reasons for participant's selection

3.5.4 Ethical Consideration

Some codes of ethics would be adhered to in the course of this inquiry. The researcher would avoid plagiarism by acknowledging quoted works using the appropriate citations (Dawson 2009).

The names of the participants would be anonymous and their personal bio-data would not be stated. Also, the researcher will ensure that both interest of the respondents and the research community would be protected. See appendix for ethics approval form.

3.5.5 Additional sources of data collection

The company records provided by the managers from the two case companies was used in the development of data, information available on the company's website and observing the company directly were sources for data collection. In order to understand the causes of instability and the implications it has on both case company's financial performance, Other sources such as cost of carrying inventory, number of inventories, sales lists and cost of units, time parameters for ordering and receiving orders would be used. This is known as

Triangulation and it's a method of data collection (Todd 1979). As stated by Steman (2000), a modeller should draw from personal experience and observation to suggest the links when some crucial feedback connections are absent. See appendix for elements of data.

3.6. Summary

The process of carrying out this research based on the research methods, research design, epistemological positions, ontological positions and techniques utilised in this study was detailed in this chapter. The three essential measurements according to Saunders et al 2009 include ontological, epistemological and the methodological approach was also emphasised. The view point of the researcher is objective, value free ontological perspective for analysing and modelling in the downstream oil system dynamics inventory model. A deductive logic of reasoning was adopted by the researcher based on critical realism, conceptual epistemological research and systems. The various methods of research was also discussed, philosophies used in the research was highlighted, and the reason for system dynamics simulation and how it offers analytical and robust insights into Nigerian downstream oil system dynamics was justified. Finally, the research approach taken to address the study questions has been thoroughly described, including the literature review procedure, model selection consisting of existing system dynamics model of inventory system. The next Chapter describes the modelling process and validation of the system dynamics model used for this study.

CHAPTER 4: MODELLING THE SYSTEM DYNAMICS INVENTORY MODEL

4.0 Introduction

The basis for conceptual framework in this thesis is discussed in this chapter. Drawing from system dynamics intellectual integrity which explores non-linear and control theory characteristics, a model will be developed investigate the instability in the downstream oil companies in Nigeria that serves to mitigate problems in a mechanical and industrial system. Specifically, the system dynamics inventory model will be modelled using several elements which influence the models performance and these problems are pertaining to delays, feedbacks, flows and stock that influence systems.

Consequently, to insure the creation of an advantage for complex system and ability to successfully analyse system the methodological objective is presenting a strong analysis of simulation methods in system dynamics. This method culminates a system of interest that is not only dynamic in perspectives but is also holistic. Additionally, system dynamics modelling will be employed to comprehend the supply chain uncertainties in the Nigerian oil industry. In order to identify the main variables or factors important in the system and the relationships between them, a mental model is developed. Through the mental model, a quantitative model or stock and flow achieved, the mental model helps to classify the stocks and flow, identify the variables, relationship between the variables to create mathematical equations to represent the dynamic behaviour of the system. In order to evaluate and investigate effect of the uncertain customer order on the downstream oil companies in Nigeria aimed at improving the performance of the companies, the model would be used to simulate scenarios with emphasis on the inventory system of the case companies. The robustness of the model, validation of the model would be discussed in this chapter taking into consideration two case companies in Nigeria directly involved in sales of oil to their customers.

4.1 Model building process

In system dynamics, the modelling process is characterised by iterative activities and phases that require changes and continuous revisions in its system. Sterman (2000) defined the modelling process as a continual process of iteration between the articulations of the problem, data collection, hypothesis generation, formulation of the model, analysis and testing. The final results of the iterative process which leads to building the inventory model for Nigerian downstream oil companies are presented in this section.

First a brief introduction of the SD inventory model is presented, factors considered that affect the inventory system and the main assumptions about the system. Followed by explanations on the development of the quantitative model and mental model

4.2 Problem definition

In a supply chain inventory system, providing an inventory analysis method that employs a unique quantitative and qualitative data to manage unstable inventory system is challenging with consideration to complex interactions between the effect of uncertain customer order and changes associated to their behaviour in the system. In order to investigate this problem, a system dynamic modelling approach is used to examine the effects that bring about the instability in the behaviour of the system.

The SD inventory model used for this study has been adapted from a well-known SD model to investigate the downstream oil companies in Nigeria. Following the rigorous approaches in building the system dynamics modelling the first step was to identify the problem faced by the case companies. This steps offers questions on which variables or parameters would contribute to those concerns and what the major concerns in modelling activities of companies (Sterman 2000). As suggested by Sterman, the steps involves defining the purpose of the system, listing the variables and determine the system boundaries.

The problem definition stage for this study starts with purpose identification and system boundary classification (Peterson and Eberlein, 1994; Mashayekhi and Ghili, 2012). The aim of carrying out this step in the modelling process is to understand the structural causes that trigger the changes of system performance arising from unpredictability of customer order. The inventory model seeks to provide and extend the SD method of managing inventory that is capable of investigating the issue of bullwhip in the two companies. In this research, a well-known system dynamics inventory model is adapted which represents the system boundaries that represents the impact of customer order uncertainty on the companies' performance respectively. The system dynamic inventory model comprises all the variables involved in a downstream flow chain that represents the movement of products between the oil distributor inventory and retailer inventory storage and finally delivered to consumers in Nigeria. The structure provided in Figure 4.1 in the next section presents the mental model which depicts an integration of distributors, retailers and customers in one system which is significant to investigate the issues understudy.

4.3 Mental model and assumptions

All of the assumptions considered in relation to the Nigeria downstream oil inventory system is presented in Figure 4.1, this mental model will be used to model and develop the full system dynamics inventory simulation model of the system, focusing particularly on the effect of the uncertain customer order on the companies' performance. The assumptions and mental model are summarised as follows: customer order is assumed, the inventory system of the distributor and retailer is assumed. Figure 4.1 represent the mental model that shows the important elements of the inventory system under study.

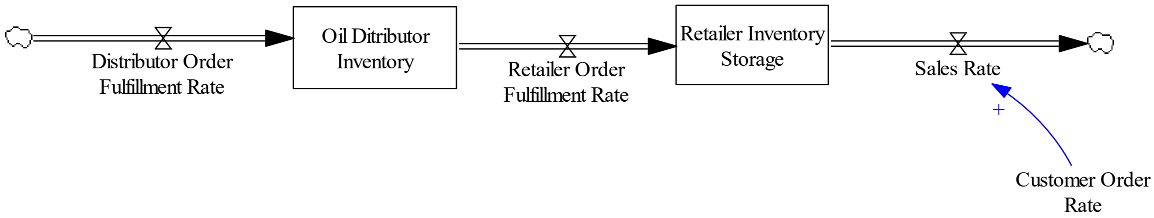


Figure 4.1: Mental Model (Authors work)

As previously explained that when designing or building system dynamics model, the most important and initial step is identifying the problem that is being investigated. This step has been undertaken to serve as a possibility that could be realistic to the real life scenarios and policies (Saeed 1994). Forrester (1961), in his study also identified the importance in the problem identification asserting that the main phase of conducting a study is the clear and concise identification of issues been investigated. Thus, a research should concentrate on issues that are actual in models and not systems of modelling (Vennix 1996). The simulation settings and initialisation settings in building the SD inventory model for further investigation and analysis are discussed in the next section..

4.4 Model settings and time step

Before the start of building the SD model, the duration and the time step needs to be defined as this is one of the most important things to carry out. Different simulation settings could provide different answer therefore it is important to be mindful of these effects and possibilities. Stocks and all numbers are numerically calculated and approximated since system dynamics functions involving nonlinear ordinary differential equations are typically not resolved analytically, stocks and all other values are computed numerically and approximated. The time step used for the experiment is shown in Figure 4.2 with time step 0.125.

4.5 Time horizon

Forrester (1961) asserted that time horizon must involve the existing issue under study showing the start of the problem and future trajectory in order to understand the impact on likely policies and delays both direct and indirectly. He also suggested that time horizon need to be examined for a short period of time to investigate its effects and the possible implications of the decision chosen. A time horizon of five years at maximum was stipulated by Barringer and Bluedorn (1999) which can be optimal as companies usually compete in uncertain business environment with short service life cycles thus market conditions will change during a long period of time and the present assumptions may not be valid any longer. Therefore for this reason, this study uses a time horizon of less than five years for the investigation. Figure 4.2 presents the time horizon used for the investigation of effect of customer order uncertainty on the two case company performance with initial time 0 to final time 100 weeks.

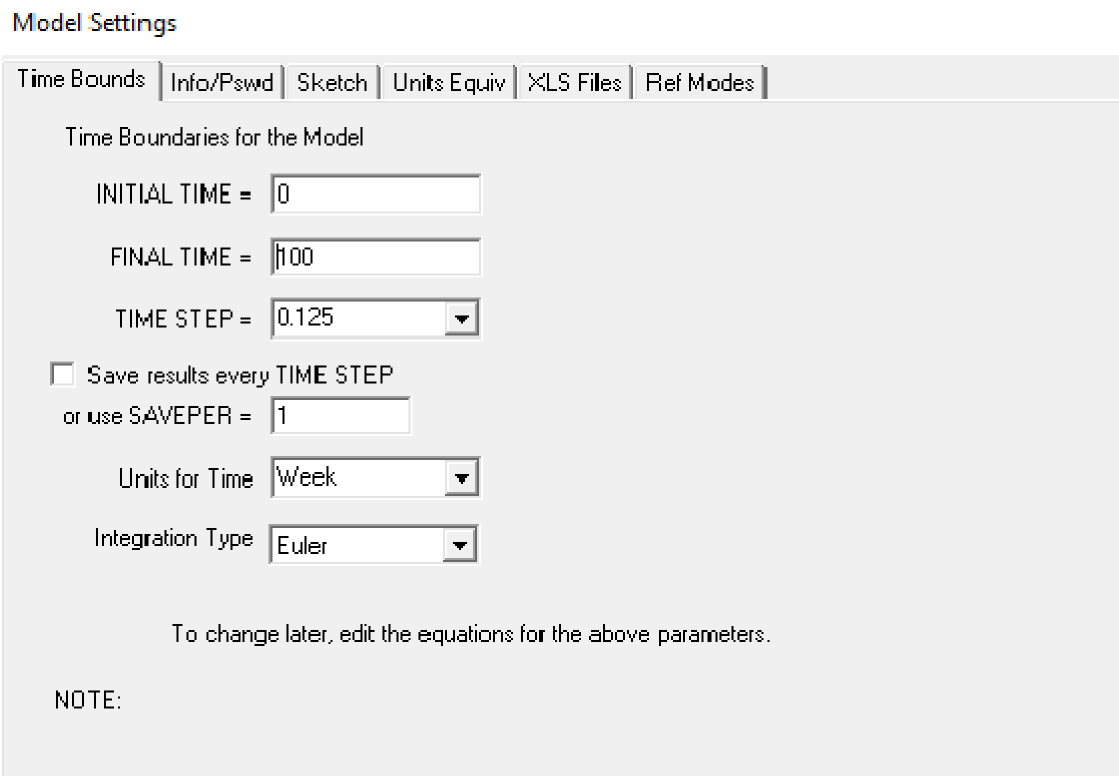


Figure 4.2: Time horizon and time step

4.6 Parameter testing

System dynamics model parameter values are a specific and important test to carry out during model building phase (Sterman, 2000). Testing parameter values in a model can be tested in a straightforward way like using historical data. Although, in a real world scenario for conducting the dynamic simulation models the required data may be unavailable, may be in an inappropriate form, or may be incorrect. There may be components that cannot be quantified, but are very important to the system being modelled. These elements should be added in the model even if the data is unavailable. In this study, data and descriptions relating to the parameters from the case companies has been provided by the managers based on the company records and to support these data literatures have been conducted in regards to parameter values. The point is that model parameter values for dynamic simulation from whatsoever source they have been collected are subject to rigorous testing. These parameter values significantly contribute to the model confidence when the identified parameter values are consistent and reasonable with whatever supporting data might exist and it representation in a real world scenario. In accordance with this concept, the model parameter values were examined by contrasting the variables and equations with the body of current knowledge, the facts at hand, and the expertise of the experts. The parameter values utilised for this investigation are summarised in Table 4.1.

PARAMETER	VALUE	UNITS
Retailer order cycle time	10	Weeks
Distributor adjustment time	2	Weeks
Min sales Processing time	2	Weeks
Safety stock	2	Weeks

Retailer adjustment time	8	Weeks
Time to average expected order	6	Weeks

Table 4.1: Parameter values for BAU

4.7 Structural test

Structural tests for this study helped to examine the developed system dynamic inventory model to know if it represents the real-world processes and problems being investigated. Sterman (2000) proposes processes for carrying out structure verification tests which includes causal loop diagrams, stock and flow diagrams, partial model tests of the rationality of decision rules. It therefore takes into consideration the practicability of aggregation level, if the model corresponds to the basic physical facts such as the behaviours of experts in decision rules and the preservation laws. In this research, the structural testing has been verified using the Vensim software and with the knowledge of the case managers Figure 4.3 presents the validation of the structural test.

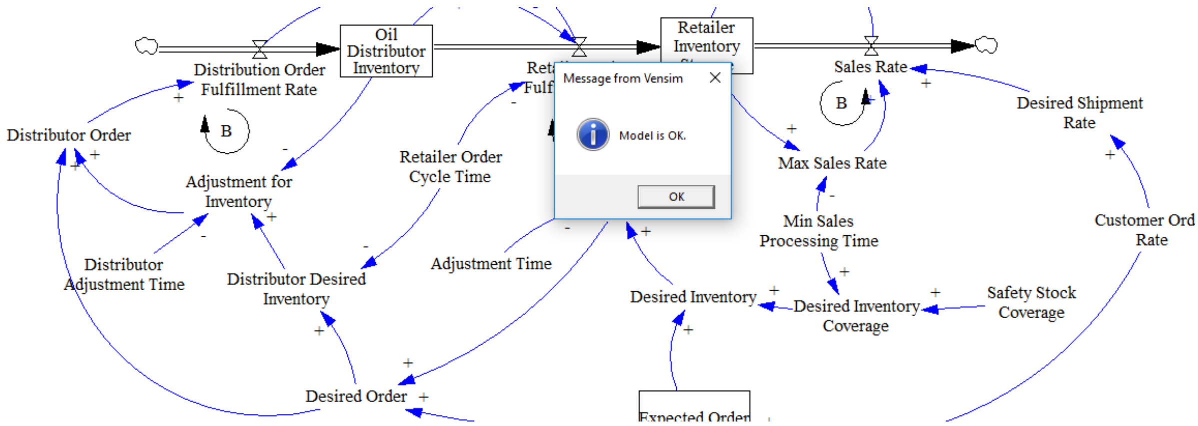


Figure 4.3: Structural test

4.8 Dimensional consistency

The dimension consistency test was carried out using the vensim software to check whether the dimension and equations of each variable is correct and accurately represents the issues under study. The applied software provides a powerful dimensional calculation function which helped to verify and ensure that the dimensions are accurate and consistent Figure 4.4 provides the results of dimensional consistency test.

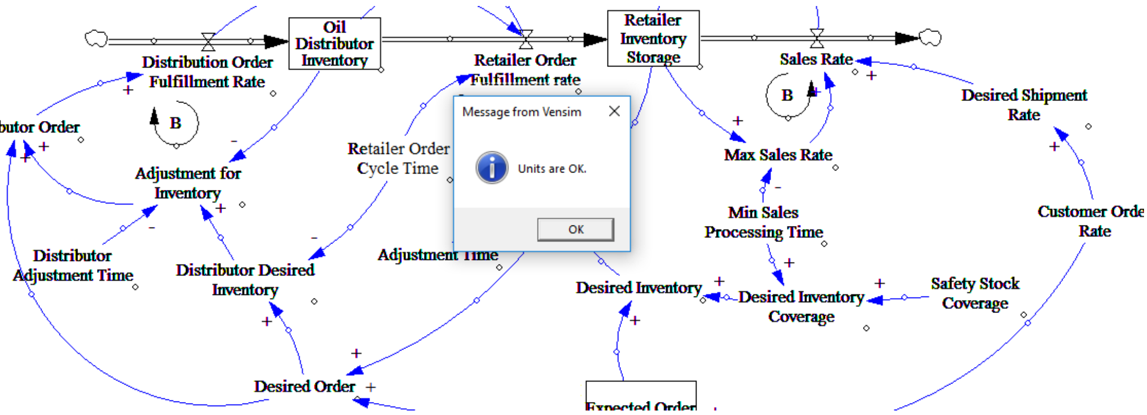


Figure 4.4 Dimensional consistency test

As discussed in previous sections, based on the interactions with the supply chain experts the system dynamics inventory model was developed. Therefore, to logically and rationally examine the dimensions of the variables created, the dimensional consistency tests are carried out. Based on defined causal relations, the strong dimensional computation tool provided by Vensim software allows for an automated verification of the created model's dimensional consistency. Regarding the specified verification technique in a system dynamic model, the model may be checked and all the relevant variables are evaluated to ensure the model's dependability by confirming whether the system behaviour matches the anticipated outcomes. As a result, the dimensions of the model might likewise be determined using the specified mathematical formulae.

4.9 Model description

Figure 4.5 shows the system dynamics inventory model for the oil distributor inventory and retailer inventory storage describing the relationship of the variables, which is explained in detail later. It further details the major components described in previous section Figure 4.1, specified in the mental model and assumptions. The system dynamics model has been adapted from a well-known model by Sterman (2000) and aims to represent and implement the inventory management model on actual issues affecting the case companies in Nigeria. Many studies have applied the use of this inventory model in several research areas. Therefore, the SD inventory model presented in Figure 4.5 examines how the performance of the companies is impacted by the influence of customer order uncertainty. It is based on the idea of an established stock management model but reflects the internal inventory management process of a downstream oil company in Nigeria.

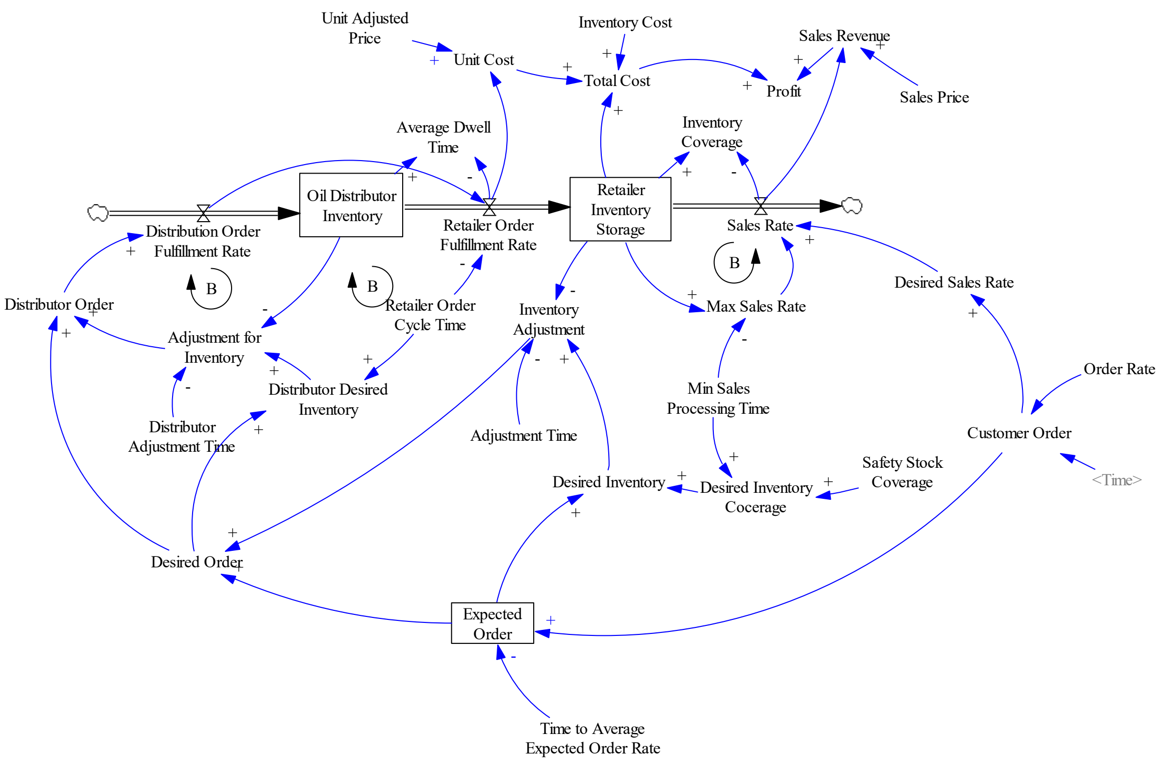


Figure 4.5: Stock and flow diagram of the inventory model

The pace at which distributor orders are filled increases the oil distributor inventory, while the rate at which retailer orders are filled decreases it. The retailer has learned that he sells a specific volume of oil each week. However, the retailer is only permitted to sell what is on hand. Therefore, the retailer may only sell the lesser of these quantities, the quantity he has available, if the sales rate or demand for petrol at any particular moment is greater than the amount of oil distributor inventory. Before choosing the quantity of inventory to order, oil retailers and distributors must account for the reduction of their inventory according to this model. Additionally, the duration of the inventory they currently have in stock must also be determined.

When customers make purchases from the retailer, the latter must update its current inventory level in order to determine the gap between its actual and intended stocks. Both the distributor and the oil retailer maintain distinct policies and stock stockpiles of oil. Both the seller and the oil distributor use the model-illustrated exponential smoothing techniques for their order forecasting procedures. The feedback loops and various variables represent the dynamic and intricate relationships between customer orders, the desired inventory level, order fulfilment rates, the distributor's capacity to fill orders, the distributor's own capacity to fill orders, and the time to fill these capacity levels. The oil supply chain's stock and flow structure in this study takes into account the time it takes to satisfy orders. The structure contains the unfilled orders from distributors that have been placed but have not yet been fulfilled. The current firm decision rule is the order fulfilment rate. The percentage of orders that are filled relies on the oil distributor's or retailer's stock of barrels that have been ordered but have not yet been delivered. Distributor and retailer continue to ask for replacement of the anticipated flow from their inventories and a reduction in the gap between intended and actual inventory. The company aims to keep a sufficient inventory of unfulfilled orders during fulfilment delays to adjust it so that delivery to the client is near to the desired condition.

The expenses of having too little or too much inventory is minimised by maintaining an effective inventory level. Both the oil distributor and the retailer keep safety stock due to the unpredictability of demand as a safeguard against delivery issues or to lessen the likelihood of stock-out incidents. The stock quantity that minimises stock-out and carrying costs is the ideal safety stock level. The retailer projects a specific volume of litres to be sold each week based on past performance. It often takes a few weeks to see a shift in sales rather than merely random variations if the demand for oil changes. The projected order rate average time is modelled by this time constant. Additionally, the retailer wants to have product accessible well in advance. The amount of oil the merchant wishes to have available for safety stock coverage is the number of weeks' worth. If the store stops ordering oil at week 4, for instance, with a safety stock coverage of two weeks, the seller will still be able to sell all of the remaining oil by week six, assuming that the demand for oil stays the same throughout this time.

The desired amount of oil is therefore determined by safety stock coverage. The retailer will then compare the intended quantity to the actual amount and will require some time to adjust the oil amount to make up for the shortfall. The weekly adjustment in the quantity is equal to the difference between the desired and actual amounts of oil, divided by the time required to update the amounts. The retailer then adjusts the anticipated oil sales amount and produces the necessary number of litres of oil. This figure represents the stock's weekly inflow. The distributor order rate obviously cannot be zero. The retailer won't order any oil until the total of the correction and expectations is positive again if the correction is negative (if the targeted quantity is less than the actual amount) and if the sum of the correction and expectations is still negative.

4.10 Model Equations

Adjustment for Inventory: Adjustment for inventory are adjustments made to inventory, increase or decrease in inventory to preferred state.

(Distributor Desired Inventory - Oil Distributor Inventory)/Distributor Adjustment Time (1)

Units: Litres/Week

Adjustment Time: The adjustment time is the time it takes to adjust the inventory. The time is set at 8 weeks. (2)

Units: Weeks

Average Dwell Time: The time is takes for the distributor to satisfy customer demand is determined by the total dwell time.

ZIDZ (Retailer Order Fulfilment Rate, Oil Distributor Inventory) (3)

Units: Week

Customer Order: Customers issue orders to buy goods or services from upstream members, which makes the consumer demand rate an exogenous variable. However, supply chain operations are uncertain due to competition and shifting consumer preferences. In order to deal with uncertainties, managers must establish an awareness of the nature of the market and provide a strong and flexible supply chain network.

Order rates (Time) (4)

Units: Litres/Weeks

Desired Inventory: The retailer chooses the desired inventory coverage. This offers an inventory level that, given the current merchant order cycle time, will provide the appropriate pace of orders. This is the quantity of inventory that the company deems suitable.

Expected Order * Desired Inventory Coverage (5)

Units: Litres

Desired Inventory Coverage: Enough inventories are kept on hand to protect against unanticipated variations in demand, according to the required inventory coverage.

Safety Stock Coverage + Min Sales Processing Time (6)

Units: Week

Desired Order: The intended order serves as an anchor, and an amount is subsequently added to it in order to bring the oil distributor's inventory of unfulfilled orders into compliance with its objective.

MAX (0, Expected Order + Inventory Adjustment) (7)

Units: Litres/Week

Desired Sales Rate: The firm can sell what it wants or what it can sell if it achieves the required sales rate. The consumer buy rate is equal to the desired sales rate. In this scenario, unfulfilled orders are lost rather than building up as a backlog.

Desired Sales Rate = Customer Order (8)

Units: Litres/Week

Distributor Order fulfilment Rate: The distributor order is intended to replenish their stock once it has been used up. The distributor order fulfilment rate serves as a supplementary variable that gauges the effectiveness of the system. In order to describe the dependability of transportation service providers, this variable provides the percentages of orders completed in each simulation phase.

MAX (0, Distributor Order) (9)

Units: Litres/Week

Distributor Adjustment Time: The distributor adjustment period is the length of time needed to update the distributor's records so that they agree with the results of the actual inventory. It starts out at two weeks. (10)

Units: Week

Distributor Desired Inventory: Given the present retailer order cycle time, the distributor's intended inventory gives a level of inventory to produce the desired rate of orders. This is the quantity of inventory that the company deems suitable.

Retailer Order Cycle Time * Desired Order (11)

Units: Litres

Distributor Order : The adjustment process is expressed as the distributor order.

Adjustment for Inventory + Desired Order (12)

Units: Litres/Week

Expected Order: The expected order demand suggests that there is a delay for the company in reacting to change in demand, so the retailer is on the opinion that the value of demand slowly gets used to the real value of demand when it detects gaps by smoothing actual customer demand. It stands as the value of the order rate in this model.

SMOOTH (Customer Order, Time to Average Expected Order Rate) (13)

Units: Litres

FINAL TIME: The final time 100weeks for simulation. (14)

Units: Weeks

INITIAL TIME: For the simulation the initial time starts at week 0 (15)

Units: Week

Inventory Adjustment: Inventory adjustment modifies the rate at which distributor orders are fulfilled in order to maintain the distributor inventory at the desired level.

(Desired Inventory-Retailer Inventory Storage)/Adjustment Time (16)

Units: Litres/Week

Inventory Cost: The inventory cost includes all cost associated with holding or storing inventory for sale. (17)

Units: NGN

Inventory Coverage: The amount of time which the distributor can fulfil customer orders is the Inventory storage

ZIDZ (Sales Rate, Retailer Inventory Storage) (18)

Units: Week

Max Sales Rate: The Company's maximum sales rate reveals the retailer inventory storage level at the moment and the shortest possible sales processing time.

Retailer Inventory Storage/Min Sales Processing Time (19)

Units: Litres/Week

Min Sales Processing Time: The minimum sales processing time is the minimum time required by the company to process and sell customer order. This is set 2 weeks. (20)

Units: Week

Oil Distributor Inventory: The oil distributor inventory is the current amount of inventory the distributor has in stock ready for delivery to retailer inventory storage

INTEG (Distribution Order fulfilment Rate-Retailer Order fulfilment Rate, Distributor Desired Inventory) (21)

Units: Litres

Order rates for company A: The order rates represent the order cycle for a given time for company A. The values are derived from the record of the case company. (22)

Units: Litres/week

Order rates for company B: The order rates represent the order cycle for a given time for company B. The values are derived from the record of the case company. (23)

Units: Litres/week

Profit: Is the financial gain, the difference between the amounts earned against the amount invested by the companies.

Total Cost-Sales Revenue (24)

Units: NGN

Retailer Inventory Storage: The retailer inventory storage is the amount of oil the retailer has in stock to sell to their customers.

INTEG (Retailer Order Fulfilment Rate - Sales Rate, Desired Inventory) (25)

Units: Litres

Retailer Order Cycle Time: The cycle time represents the average transit time for all items aggregated together. The retailer order cycle time is set at 10 weeks. (26)

Units: Weeks

Retailer Order fulfilment Rate: Retailer order fulfilment rate is a third order delay of the distributor order fulfilment rate, with the delay time determined by the retailer order fulfilment cycle time.

DELAY3 (Distribution Order Fulfilment Rate, Retailer Order Cycle Time) (27)

Units: Litres/Week

Safety Stock Coverage: Describes the extra stock built to minimize the risk of supply and demand deficits due to inaccurate demand forecast, it is one way to prevent out of stock, is also called buffer stock. It can also be referred to as the coverage of extra inventory that is maintained to mitigate risks of stock out due to uncertainties in demand and sales. The safety stock coverage is set at 2 weeks. (28)

Units: Week

Sales Price: sales price is the discounted price of an item from the regular selling price. It is the price the retailer is offering for the product. The sales price is 145. (29)

Units: NGN/Week

Sales Rate: The sales rate is the rate at which oil are sold to customers. When the company is determining how much to sell to customers, they take into consideration the amount of orders from the customers and the amount of goods available in the inventory. The orders from customers set the desired amount of deliveries the company would like to have in the given week.

MIN (Max Sales Rate, Desired Sales Rate) (30)

Units: Litres/Week

Sales Revenue: Sales revenue is the amount received by the company or organisation from the sale of goods or services.

Sales Price*Sales Rate (31)

Units: NGN/Week

SAVEPER: The frequency with which output is stored. The frequency is 1 (32)

Units: Week

TIME STEP: The time step for the simulation. The time step is 0.25 (33)

Units: Week

Time to Average Expected Order Rate: The time to average expected order rate is an average estimated over a period of time. In this case, it is the average time it takes to complete the process. The time to average expected order is set at 6 weeks. (34)

Units: Week

Total Cost: The total cost is the aggregate of all expenses.

Unit Cost + (Inventory Cost*Retailer Inventory Storage) (35)

Units: Litres/Week

Unit Adjusted Price: Unit adjusted price indicates the business adjusts its unit prices to account for differences in customers' demand. The unit adjusted price is 100000. (36)

Units: NGN

Unit Cost: Unit cost is the total expenditure incurred by the company to store and sell one unit of a product or service.

Retailer Order fulfilment Rate*Unit Adjusted Price (37)

Units: NGN/Week

4.11 Extreme condition test

Under the extreme condition test, the robustness of the model is tested under extreme circumstance. The extreme condition test suggests the behaviour of the model to be realistic despite the various polices or inputs in the model. The extreme test improves the validation process of the model by examining the beyond the initial boundaries. Despite the size of model, all the concerned variables such as zero can be tested to verify whether the system behaviour matches the expected results. Inventory should never be zero no matter the size of demand. This test has been carried out utilizing Vensim software application by simulation using large and small numbers of parameter values to understand the effect on the model behaviour. The reliability of the developed SD inventory model was verified through comparing the system performance under an extreme condition against the anticipated behaviour of the real system (Qudrat-Ullah and Seong, 2010). Figure 4.6 shows the result derived from conducting the extreme condition test. Despite the size of model and the assigned parameter, the model response to these inputs and the expectations of the model behaviour matches the expected results.

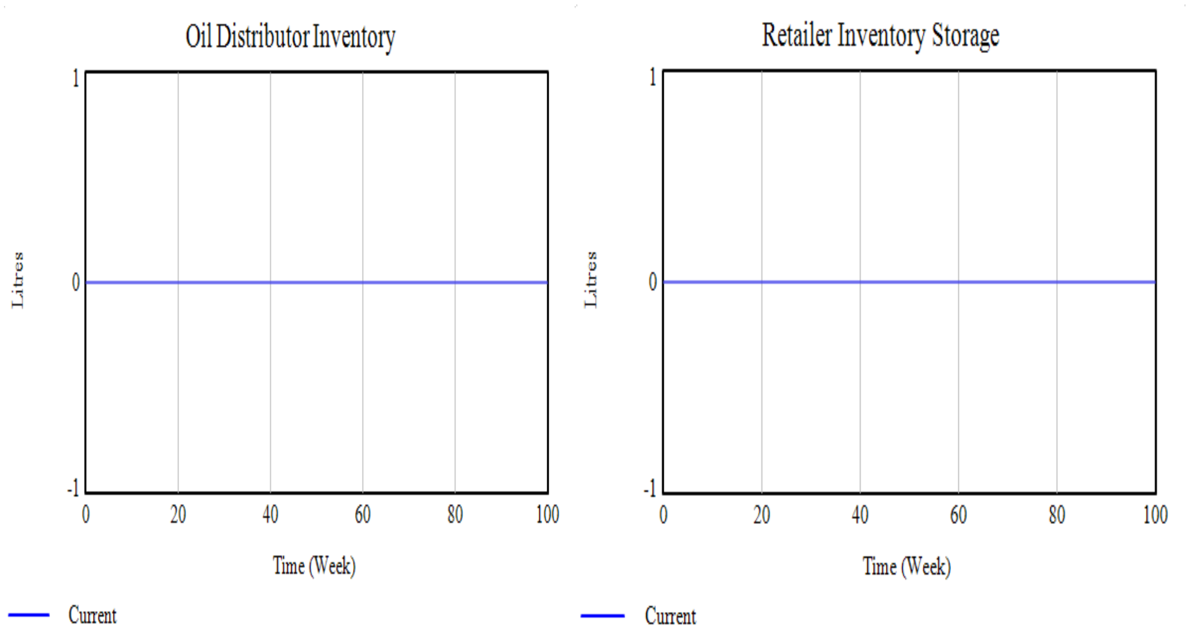


Figure 4.6: Extreme condition test

4.12 Sensitivity test

Sensitivity testing will be used in this study to determine which model parameters are more critical and sensitive to the results of the simulation. More study and research would be done to reduce the uncertainty in the parameter value when the model is sensitive to any parameter. According to Forrester (1969), system dynamic output behaviour is generally unaffected by changes in most variables, but that the factors that have a substantial impact on how the model behaves should be found during the model construction and model validation phases. The sensitivity behavioural test enables the modeller to determine whether a little change in the model's parameters has a large impact on the behaviour of the system or the model (Forrester, 1969; Moffatt, 1991). Regardless of the model size and the results of the sensitivity test, all model variables can be tested in accordance with either historical or hypothetical patterns to enable a typical depiction of the model behaviours, which can be used for the calibration of the developed model to fit the real-world scenario Christopher and Patil (2002)

In the meantime, sensitivity testing and analysis have been done in this study to lessen the instability in the inventory level and lower overall cost by adjusting the input of the model parameter values to evaluate the output on system behaviour. To identify the parameter that has the greatest impact on the performance of the model, sensitivity testing makes use of the impacts of various parameters. The values of retailer order cycle time and safety stock coverage are shown to have the biggest effects on the model's performance after several simulations are completed. The researcher was able to identify the sensitive variable's location in the specific effect of the uncertain customer order by using this approach while doing the sensitivity simulation test of modifying the variable value and the parameters. The results derived from these test provide a suggestion for the potential solutions for the reduction of the instability for further investigation.

4.13 Model calibration

Model calibration in system dynamics is the process of estimating model parameters to make sure that there is agreement between the observed behaviour and simulated behaviour (Graham 1980; Peterson and Eberlein 1994; Barlas 1996; Oliva 2003). In order word, the estimation of the model parameters is carried out to attain an equivalent between the simulated behaviour and observed behaviour (Randers, 1976; Olivia 1995). Barlas (1996) stipulates that when the actual behaviour does not correspond to the observed behaviour, the model calibration cannot be used. Homer and Homer (1997) assert that model calibration solves the problem in the model equations and modifies the observed behaviour to match the parameters of the model. Therefore, the suitability of the model equations should include the assessment of the structure and behaviour Kennedy (1992), by comparing the output of the model to the real-world behaviour and any discrepancy in the model behaviours would lead to inaccurate results despite time and effort invested.

This research defines model calibration as a process of adjusting the model parameters to obtain the model representation of the case companies that satisfy pre-agreed measures (goodness-of-fit) by using data collected from the actual case study companies. The calibration process for this study has been carried out through the following set of steps which includes: Defining the calibration reference variable, identify and list the auxiliary variables and their estimated values from the actual data, in order to use these values as known input for the calibration problem, identify and select the model's parameters for calibration, check the result from the calibration, finally statistical and graphical evaluation of calibrated fit to the actual time series (Lyneis and Pugh 1996). Moizer (1999) asserts that statistical and graphical evaluation is an important process in validating system dynamics as it's tends to identify whether the value of the parameter is estimated with sufficient accuracy.

	Distributor	Retailer	Sales
Calibration reference variable	Oil Distributor Inventory	Retailer Inventory Storage	Sales Rate

Table 4.2: calibration reference variable for this study

Table 4.2 presents the reference variable for the model calibration for this study. The calibration variable used for this research is the oil distributor inventory, retailer inventory storage, and sales rate. The reason for selecting these variables for selection is because of the inconsistency present in the historical context of the real system and also for its strategic relevance as these variables will be used to measure performance of the companies and for further investigations which is the causes of the bullwhip effect and instability.

<u>Company A</u>

Company A is a Nigeria leading energy company which is involved in the marketing and sales of oil and petroleum products to the downstream customers in Nigeria. The operation of the company encompasses the chain of more than 550 distribution and retail outlets spread in the whole of Nigeria with major storage of oil and petroleum products in four states of Nigeria. The focus of the company is offering quality products and good services to their customers at the right place and right time. However, the problem of meeting their customer order has significant negative effect as a result of long lead time in the supply chains from the upstream partners and the ability to correctly forecast orders resulting to out of stock situations thereby prompting the company to hold large number of products to guard against out of stock situations which causes poor performance for the company causing high total cost and less profit.

Company B

Company B is also one of the leading oil and petroleum companies in Nigeria, it operates in the land and swamp areas in Nigeria. It was founded in the mid-1900s, and the Headquarters is in Lagos, Nigeria. It has concessions in the Niger-Delta area of Nigeria and has various agreements with other oil companies in Nigeria. The successful growth of the company has been achieved by constantly and consistently finding and developing world class assets. The business is focused on safely exploring and producing from conventional offshore and onshore activities. The entire energy supply chain, size and capability create a competitive advantage that ensures they deliver long term value. The strategy is to safely and sustainably develop high quality portfolio to deliver oil and gas for everyone. However just like company A, company B also has the same problem of meeting their customer order that usually impact the company performance negatively due to long lead time in the supply chains and the ability to also forecast customer orders accurately resulting to out of stock situations and most at times holding large number of products resulting in high total cost.

4.14 Model Error Decomposition with Behaviour Reproduction

Mean Square Error (MSE) Test

The mean-square-error (MSE)**,** is the process of measuring forecast error, this is defined as:

$$\frac{1}{n} = \sum_{t=1}^{n} (s_t - A_t)^2 \tag{1}$$

Where

n = Number of observations (t = 1,.., n)

St = Simulated value at time t

At = Actual value at time t

The simulated variable from the actual value over a given period of time is determined by the MSE deviation. The benefits of this measure are that large errors are weighted more heavily than small ones and that error of opposite indication do not cancel each other out (Sterman 1984).

By taking the square root of the MSE, the forecast error can be put into the very same systems as the variable in question. This measure is described as the root mean square (RMS) simulation error (Pindyck and Rubenfield 1991).

Root Mean Square Percent Error (RMSPE) Test

This is a measure of forecast error is the root mean square percent error (RMSPE), which gives a stabilized variation of the error and is specified as:

$$\sqrt{\frac{1}{n}\Sigma_{t-1}^{n}\left(\frac{(s_t - A_t)}{A_t^{-}}\right)^2} \tag{2}$$

It also measures the simulated variable and measures the deviation from the real value over a given period, but puts it into percentage terms (Pindyck and Rubenfield 1991).

4.15 Theil Inequalities Statistics Test

The size of the total error between the actual data and simulated data is measured through the MSE and the RMSPE. Theil statistics can also be used to decompose the MSE, to enable understanding the source of errors to help in revealing the sources of the error. The errors are represented in variance, covariance and bias (Pindyck and Rubenfield 1991, Sterman 1984). The MSE was decomposed into Theil statistics in this research below:

$$\frac{1}{n} = \sum_{t=1}^{n}(s_t - A_t)^2 = \left(\tilde{s} - \widetilde{A}\right)^2 + (s_s - s_A)^2 + s(1 - r)s_s \cdot S_A$$

Where *S* and *A* are the means of S and A, i.e.

$$\frac{1}{n}\sum S_t \ and \ \frac{1}{n}\sum A_{t,}$$

The standard deviations of S and A, SS and SA and the correlation coefficient between actual and the simulated equals R.

$$\frac{\frac{1}{n}\Sigma(s_t - \tilde{s})(A_z - \tilde{A})}{s_S \cdot s_A}$$

The inequality proportions are derived is derived by dividing the Total mean square error MSE by each component of errors.

$$U^M = \frac{(s-A)^2}{\frac{1}{n}\Sigma(s_t-A_t)^2}$$

$$U^S = \frac{(s_S-s_A)^2}{\frac{1}{n}\Sigma(s_t-A_t)^2}$$

$$U^C = \frac{2(1-r)s_S s_A}{\frac{1}{n}\Sigma(s_t-A_t)^2}$$

The amount of errors in MSE due to bias, covariance and variance is represented through the proportions of U^M, U^S and U^C. Therefore, the three proportion of errors must be equal to 1, $U^M + U^S + U^C = 1$. The bias determines the variation between the actual values and the simulated values.

4.16 Calibration for both case studies

To understand how the inequality statistics apply to decompose model error, each term of U^M, U^S, and U^C has been considered. Bias shown by a large U^M and U^S and U^C has been used as a translation of the error by constant amount at all points in time. Error due to unequal variance may be systematic if the error (U^S) unequal variation dominates the error with the small U^M and U^C then the two series match on average and are highly correlated but the magnitude of the variation in the two around their common mean differs. Alternatively, if the U^S is large but both series have the same mean (U^M =0) and if at least one variable is nearly constant U^C will be small because standard deviation will be small. When most of the errors is focused on unequal covariation U^C, and U^M and U^S are less, the model shows the point-by-point values of actual data and simulated case study data do not even match even though the model captures the average value and dominant trends in the actual data.

4.17 Summary result of Company A

Table 4.3 summarizes the result of case study A. The sales rate variable displays RMSPE at 16.15% for sales rate, 18.03% for retailer inventory storage, and 6.23% for oil distributor inventory. The inequality statistics also indicates that the error is concentrated in one source unequal covariance (U^C) 0.92 for sales rate, 0.97 for retailer inventory storage and 0.99 for oil distributor inventory meaning they are all unsystematic error in nature. In this scenario, the model trend coincides with the actual data precisely. Figures 4.7, 4.8, and 4.9 present the result of the model calibration of case study A.

Variable	**RMSPE (%)**	**MSE**	**U^M**	**U^S**	**U^C**
Oil Distributor Inventory	6.23%	20833	2.98752E-05	0.02	0.99
Retailer Inventory storage	18.03%	174945.4	2.14897E-06	0.04	0.97
Sales Rate	16.15%	8446.7	2.42E-06	0.08	0.92

Table 4.3: Summary statistics for the historical fit of Company A

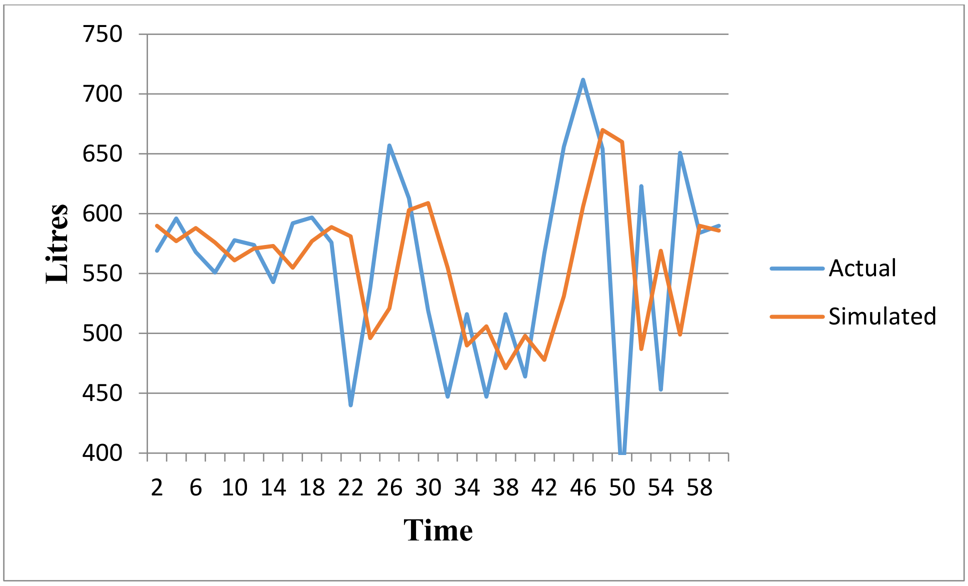


Figure 4.7: Sales rate analysis

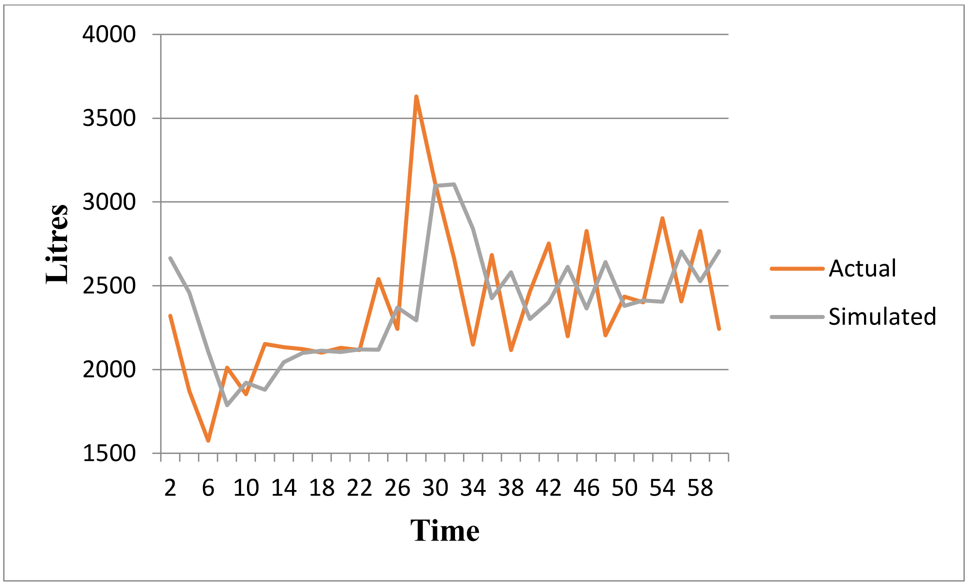


Figure 4.8: Retailer inventory storage

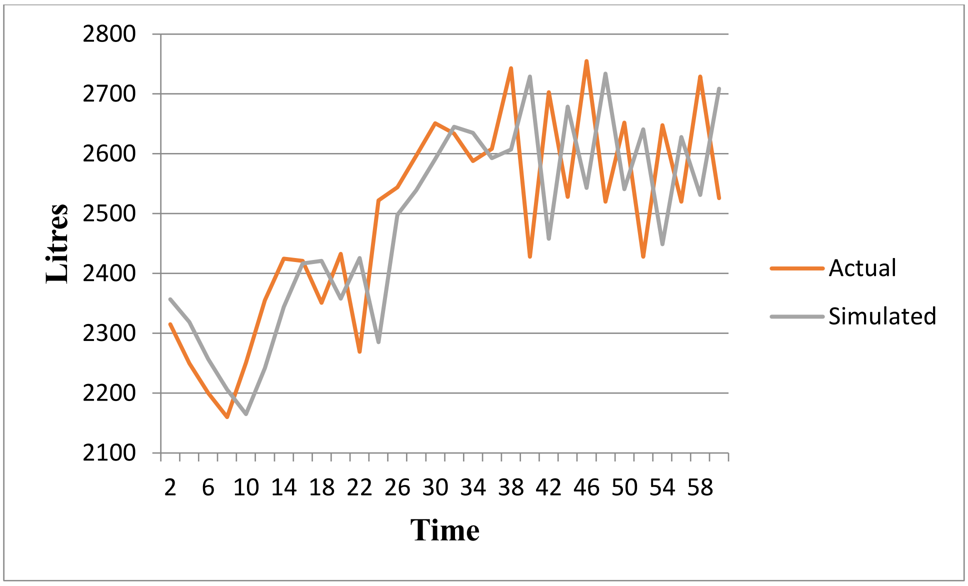


Figure 4.9: Oil distributor inventory

4.18 Summary result of Company B

Table 4.4 summarizes the result of case study B. The sales rate variable displays RMSPE at 4.20% for sales rate, 0.94% for retailer inventory storage, and 0.60% for oil distributor inventory. The inequality statistics also indicates that the error is concentrated in one source unequal covariance (U^C) 0.99 for sales rate, 0.96 for retailer inventory storage and 0.90 for oil distributor inventory meaning they are all unsystematic error in nature. In this scenario, the model trend coincides with the actual data precisely. Figures 4.10, 4.11, and 4.12 present the result of model calibration of case study B.

Variable	**RMSPE (%)**	**MSE**	**U^M**	**U^S**	**U^C**
Oil Distributor Inventory	0.60%	85645.4	6.48544E-06	0.007	0.99
Retailer Inventory storage	0.94%	29,009	6.45813E-06	0.04	0.96

Sales Rate	4.20%	16963.2	6.447E-06	0.09	0.90

Table 4.4: Summary statistics for the historical fit of company B

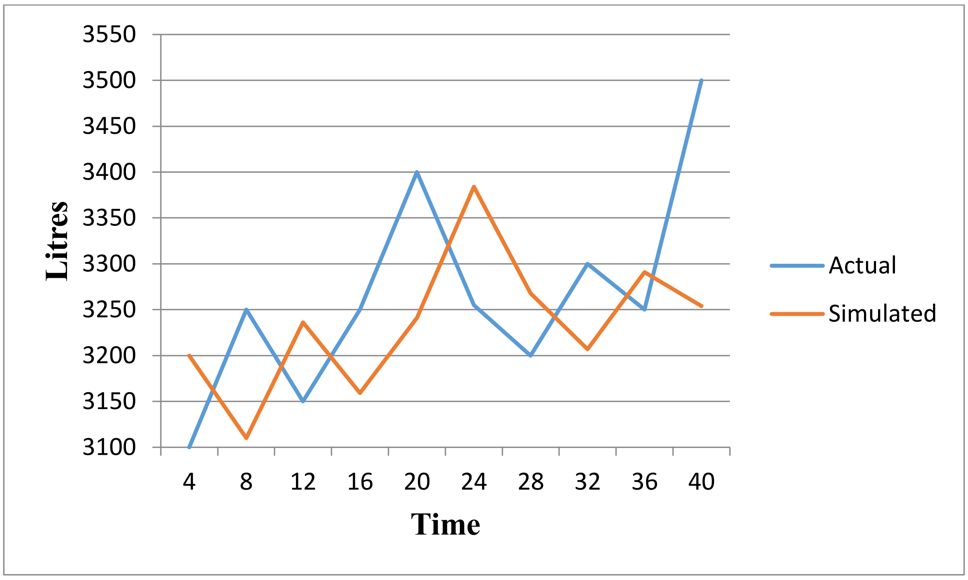


Figure 4.10: Sales rate analysis for company B

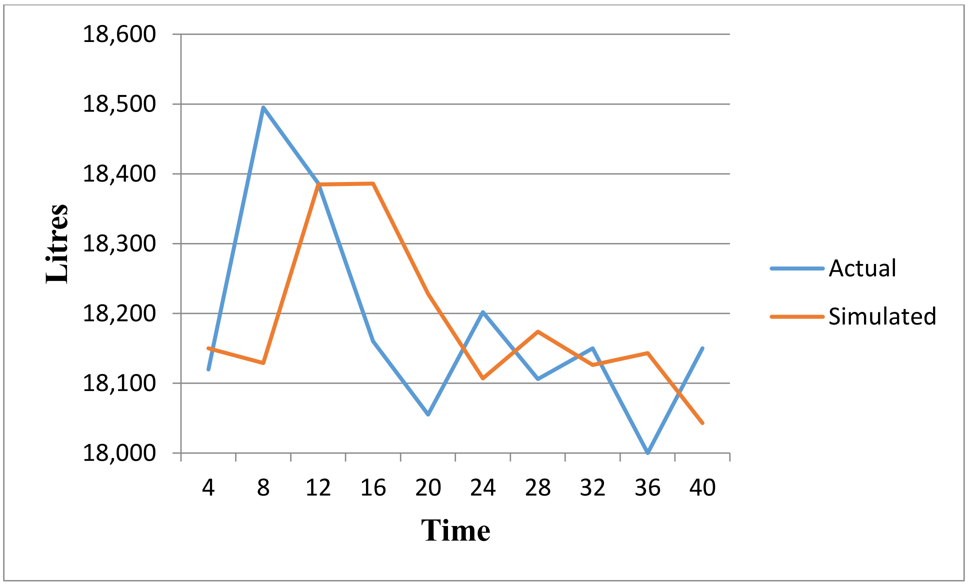


Figure 4.11: Retailer inventory storage

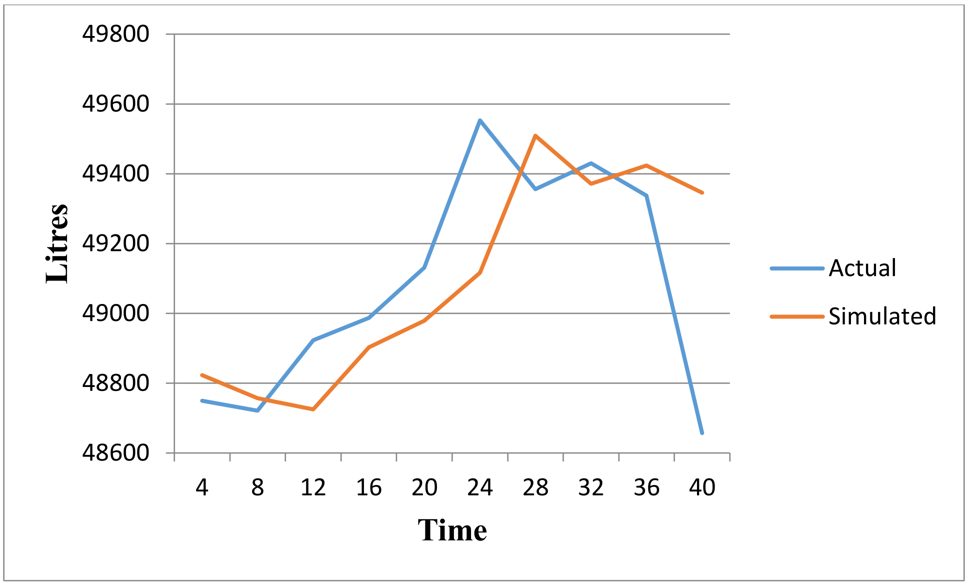


Figure 4.12: Oil distributor inventory

Summary

This chapter established a well-known SD simulation inventory model with an emphasis on the inventory level for Nigeria's downstream oil companies. The goal was to discuss and comprehend how the dynamics of distributor inventory and retailer are produced by the interaction of physical flow, information flow, and company procedures.

In particular, the effect of customer order on the company performance and the model parameters. To the process outlined in this Chapter, a mental model was first developed to identify the boundary of this model as this study aim to investigate the downstream oil companies in Nigeria. A stock and flow diagram (SFD) was then developed by adapting a well-known inventory model in which the variables and their relationships were formulated and discussed using mathematical equations and the meaning in the real world processes. The obtained inventory model was validated through different test as suggested by Sterman 2000 namely; boundary adequacy testing, parameter testing, dimensional consistency testing, extreme condition testing, and sensitivity testing and a related method to the behaviour pattern prediction testing which involved the use and calibration through decomposition of error of the two case study presented in this chapter.

Following the sensitivity test, the simulation of various parameters involved in the management of the inventory level by the companies was carried out. The purpose of carrying out the test is to understand and identify the parameters with the most effect on the model performance for further investigation. During the course of carrying out the sensitivity test it was discovered that the model performance is significantly sensitive to both parameters of the retailer order cycle time and safety stock coverage and less sensitive to other parameters. Such observations were obtained by constantly simulating the model with different parameter numbers analysing the total cost involved. The next Chapter will conduct more investigation and analysis that would allow the simulation of more scenarios, through sensitivity simulation analysis to find out the effect of uncertain customer order on the company performance using different ordering patterns upon expected system behaviours.

CHAPTER 5 SIMULATION ANALYSIS

5.0 Introduction

Case A and B using different ordering patterns is discussed in this chapter. The analysis would involve comparing the effects of the three ordering patterns: base case, high order and low order against the oil distributor inventory and retailer inventory storage and the effects on cost. Sections 5.1 analyses the oil distributor inventory, retailer inventory storage and cost measures through increasing and reducing retailer order cycle time and safety stock on a single parameter testing. It goes further for policy improvement by running double parameters policy testing by changing the values of safety stock (SSC) and retailer cycle time (ROCT) simultaneously to understand the effect of bullwhip on the level of inventories and cost measures.

5.1 Simulation of scenario and analysis

The uncertainties of customer of order have been recognised and discussed in earlier chapters. Customer order uncertainty and its effect in the downstream oil company using the system dynamics inventory model adapted in the previous chapter to analyse the effect on the financial performance of case companies. This study was conducted to investigate the costs associated with the instabilities, as well as the impacts of dynamics on the inventory level of the inventory model employing distinctive demand patterns, the Nigerian downstream oil supply chain inventory (Base case, High demand pattern and Low demand pattern).

Base case, High and Low ordering patterns were chosen to appropriately illustrate the various future ordering estimates. Figures 5.1 through 5.3 provide illustrations of the ordering patterns. The managers have given their approval for the use of the future order prediction reflected in these data. The Base case ordering pattern, the high-demand pattern, and the low-demand pattern were recommended by the case companies. In the simulation used in this study, the actual ordering patterns are used to deconstruct the patterns across them based on policy decisions and when demand shifts in order to provide some knowledge of the model's responses to each trend.

In order to evaluate strategies designed to improve the performance of the system of inventory in Nigeria, the simulation of scenarios regarding the modelled downstream oil supply chain was developed.

5.1.1 Reducing the bullwhip effect through Sensitivity Analysis

The process of enhancing the desired behaviour produced by the model, such as maximising profits and minimising or avoiding delivery delays, may be characterised as the parameters used for the model enhancement. The literature and case company managers for both case firms are used to set the parameter values and ranges for each parameter for these tests as the first phase of the sensitivity test. Typically, the simulation run uses around 20% of the parameter value (Sterman, 2000). Through Vensim, significant analysis of these parameter sensitivity has been done to determine the ideal results in terms of profit, overall cost, and inventory level. The sensitivity test results demonstrate which parameter values successfully change the model's behaviour. Retailer order cycle time (ROCT) and safety stock (SSC) were determined to have the most effects on the behaviour of the model in continuous sensitivity testing. One week at the least, and no more than four weeks of (SSC) are established as the value range for the safety stock coverage. Based on conversations with a plant expert, Morecroft (2008) estimated that safety stock coverage would last four weeks in his production control model. As a result, the maximum safety stock coverage allowed by the model is four weeks. The cycle time is the typical amount of time it takes to fill an order.

5.2 Performance Measure

Total cost, oil distributor inventory, and retailer inventory storage are the performance indicators used for the simulation study of Nigeria's modelled downstream oil supply chain. In particular, this extra cost was calculated by adding a number of costs, as the model in Chapter 4 illustrates. These are the inventory cost as well as the holding cost. Since Forrester developed the approach in 1956, system dynamics model validation has been the subject of vigorous debate. The basic justification for system dynamics (SD) and other models comes from a different angle. System dynamics modelling illustrates the relationships between the inventory and customer orders with the corresponding changes in the system behaviours in addition to verifying the model. It is a scenario-based analytical technique in which the model is fed either an increased or decreased client order. The SD model may reflect the generating process of all the relevant schemes by creating distinct situations and specialised random requests.

There has been a lot of discussion about this procedure. To increase the trust in system dynamics models, Forrester and Senge (1980) proposed a number of tests and experiments. The approaches used in their study to rigorously evaluate a system dynamics model are broken down into three categories: the model's behaviour, structure, and potential policy consequences are all tested.

As mentioned, it is necessary to confirm the model's resilience and structural correspondence under both normal and extreme circumstances. Confidence in the model is increased by comparing the simulated system behaviours with the expected behaviours. It may be used to look at the behaviours of a dynamic system in a variety of high-demand, demand-reduction, and other demand scenarios. The management requested that the researcher do a test utilising a real parameter provided by the company in order to comprehend the typical business as usual scenario and its impact on the firm's performance (time to average customer demand).The outcomes of the simulation runs are contrasted with the modeller's analytical conclusions, which are founded on information gleaned from the literature.

Three actual tests using both quantitative and qualitative methodologies are recommended for the system dynamic model validation process: parameter verification and structure verification, system testing under severe situations and dimensional consistency assessment (Barlas, 1994). The possibility of using statistical methods in the system dynamics validation process is demonstrated by Barlas (1996) under the condition that tests be pattern-oriented rather than point-oriented. A statistical test may be useful for evaluating the behaviour outcomes and applicability of simulation games.

As (Moizer, 1999) suggested, the SD model validation procedure depends heavily on the "statistical significance" testing. It seeks to determine whether or not the parameter's value is calculated accurately enough. Surprisingly, the model's designers may decide on the parameter values for extreme situations to see if the time-dependent performance reflects the system's actual behaviour. The idea that "if input A has had an influence on the system, then behaviour B must have ensued" is employed (Peterson & Eberlein, 1994). The "Reality Check" feature of the Vensim software programme provides the extreme-condition test implementation. (Owen, Love and Albores 2008) argued it akes use of a system performance that is substantially greater than that of humans in order to predict dynamic and complicated behaviours under the premise of an independent variable input value.

However, it is crucial to remember that rather than providing an in-depth mathematical explanation of a certain value, a range of behaviour reproduced in the simulation must be assessed in patterns, frequencies, and variations of system behaviour (Das and Dutta, 2013). To show that the model structure is suitable regardless of the different demand patterns, it is crucial to verify the models under various demand patterns. In their study, Barlas and Carpenter (1990a) distinguish between statistical/correlation and theory-like mathematical models. To prove the validity of the system dynamics model, the paper shows how and why it differs from a non-causal mathematical model. Despite objections to the system dynamics model validation, several system dynamics researchers have made additional efforts to formalise system dynamics modelling verification.

SD uses simulation and modelling based on scenarios to predict system behaviour. Therefore, only under certain circumstances can the model validation be carried out. The analysis that is described in the next part carries on the models' validation procedures.

5.3 Supply chain scenario design

Towill 1996b specified that the main obstacles in the modern supply chain are quick, reliable and effective action to changes in the market. Compression of time for that reason is a response to the problems. In other to improve forecast in the performance of the supply chain, Senge 1980 suggested time compression techniques based on simulation. To improve systems performance a model devised by Forrester (1961) can be utilised which provides easy way to rank re-designing systems in a supply chain.

This section explains this performance metric, comprising the 4 components oil distributor inventory, retailer inventory storage, total cost, and profit. The inclusion of weighting relatively allows for changes to make these components match various choice options. According to Towill (1996b) decreased lead time will positively contribute to the three ordering patterns and argument based the archetype of cycle time compression. Although lead-time is significant in ensuring stability of a supply chain, time compressing largely contributes to improving the detection of problems, forecasting for demands and restrict the flow of dissociated points to the customers. Following the results from simulations advice on how to utilize re-designing models are proposed:

(1) Reducing product information cash flows in all lead-times

(2) Eliminating factors that cause delays

(3) Informing upstream decision making by providing crucial information.

Alternatively, Cakravastia and Diawati (1999) provide an alternative system dynamics model based on the Indonesian shipbuilding market. Their model allows the identification of probable bottlenecks and prediction of the logistical performance in the shipment industry. There are three indicators proposed by them to gauge performance logistics, cost time, quality and shipment of finished product. Traditionally, focused was placed on controlling and directing information and physical flow. However, based on the literature review presented in this thesis neglecting financial flow would only be detrimental to the supply chain. Thus, restricting logistical performance. Therefore, Cakravastia and Diawati (1999) proposes the integration of information, physical and financial flows in a system dynamics model.

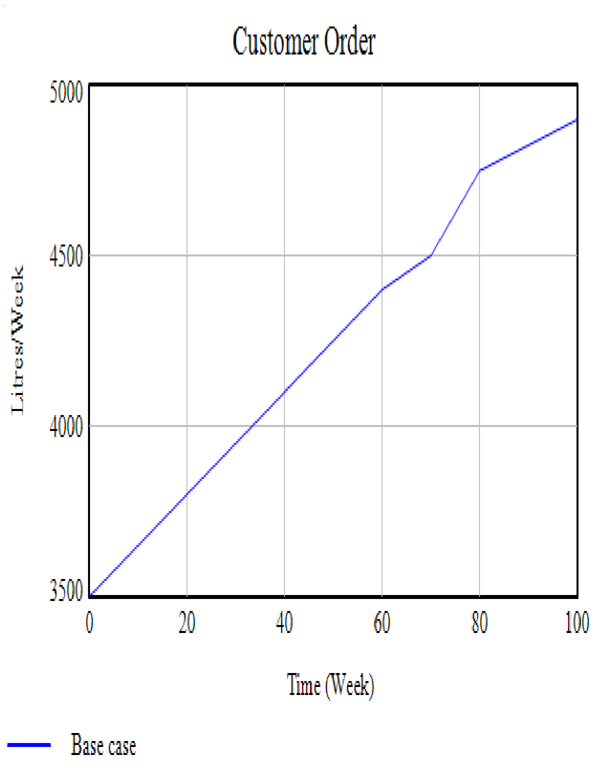
To incorporate this integration the structure in this research is captured in a flow diagram that shows the flow of inventory and information pointing outwards; the financial flow matching a causal diagram that also shows the flow of products. Additionally, simulation model was generated based on completed primary analysis on system dynamics. Hence, the model presents operational developments, orders, time behaviour of crucial signs, shipping, delays in delivery total number of sales and profits.

The models in this research have been developed on the basis to compare the different customer order patterns. The "what if" analysis would focus on the dynamics of the order pattern from the start of the simulation to the end, when each of the three alternative order patterns would have the same policy for addressing time delays and safety stock coverage to address the diverse customer ordering patterns. The study attempts to highlight any variations in the model's overall cost, profit, and oil distributor inventories during the simulation period.

Janamanchi, (2011) in the research argued that companies regularly have challenges in dealing with uncertainty order from their customers and reducing product life cycles. Therefore, demand at a reduced instability can be defined as the most a preferred demand pattern that most companies thrive to pursue is to reduce instability in their supply chain and also dampen the dynamic conditions. Thus, the assumption in this analysis is that the model will continue showing effects from the dynamic patterns during the simulation. The results are defined in the subsequent sections.

5.4 Analysis of Oil Distributor Inventory and Retailer Inventory Storage of Company A

The three demand pattern selected for the test represents the ordering projections. The ordering patterns are presented in Figures **5** a, b, and **c**. These patterns were chosen based on interactions with the company. After sensitivity test these model parameters have been chosen to explore further and to be used for policy design to enhance stability and reduce unsteadiness. (ROCT) and (SSC) as model is more sensitive to these set of parameters.



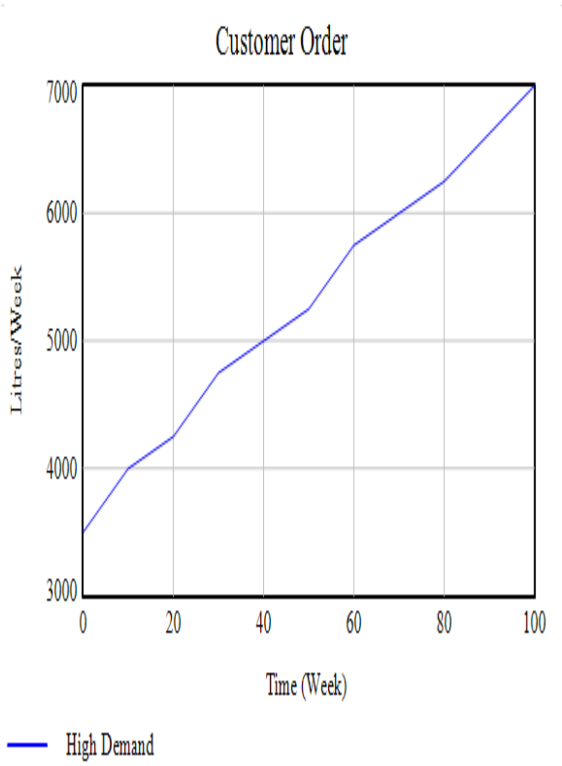


figure 5.1 (a) Business as usual

figure 5.1 (b) High demand

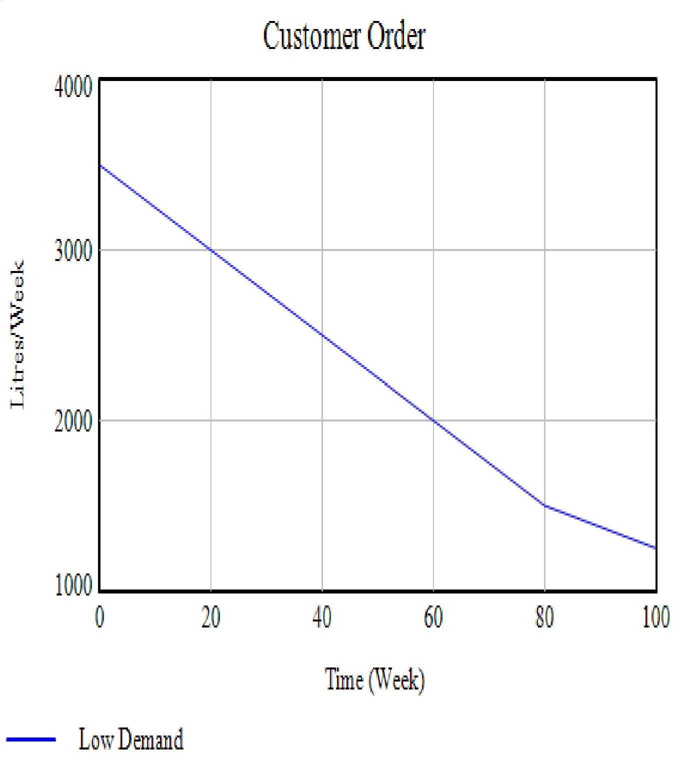


Figure 5.1 (c) Low demand

The ordering patterns as displayed in Figures **5 a, b** and **c** starts from week **0** and ends at the final simulation run of week 100. The first Figure displays the base case where the customer order follows the normal business process. Figure **5.1 b** displays the high order where the customer order keeps increasing from week **0** to the final simulation time of week **100**. Figure **5.1 (c)** displays the low ordering pattern which signifies the customer order decreasing from the initial time of week **0** to the final simulation time of week **100**.

To understand the model response to each demand pattern, the ordering patterns was analysed to show the demand patterns across various policy choices. The purpose is to generate an insight to the problem in the company's supply chain.

5.5 Effect of Base Case Ordering Pattern on Inventory Oil Distributor Inventory, Retailer Inventory Storage, Total Cost and Profit

The instabilities in the oil distributor inventory and retailer inventory storage patterns, which are a dysfunctional occurrence in the company's supply chains, are shown in Figures 5.2 (a) and (b); Figures 5.2 (c) and (d) give the overall cost and profit for these ordering patterns. The lead-time delays in the supply chain, lack of coordination, and gaps between echelon-level ordering and actual consumption at the customers' end are the main causes of the instabilities in the inventory pattern. Like seen in the graphs, customer demand uncertainty results in the transmission of demand fluctuations upstream that eventually amplify as tidal waves. Due to inventory accumulation, stock waste, and obsolescence, this impact may result in considerable losses of the overall cost with a decreased profit. These demand uncertainties are a critical marker of supply chain inefficiencies for the organisation.

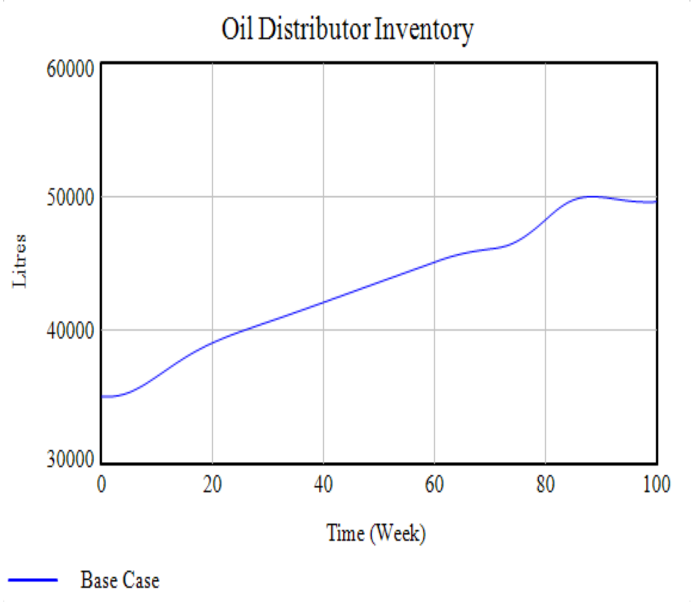


Figure 5.2 (a) Oil Distributor Inventory

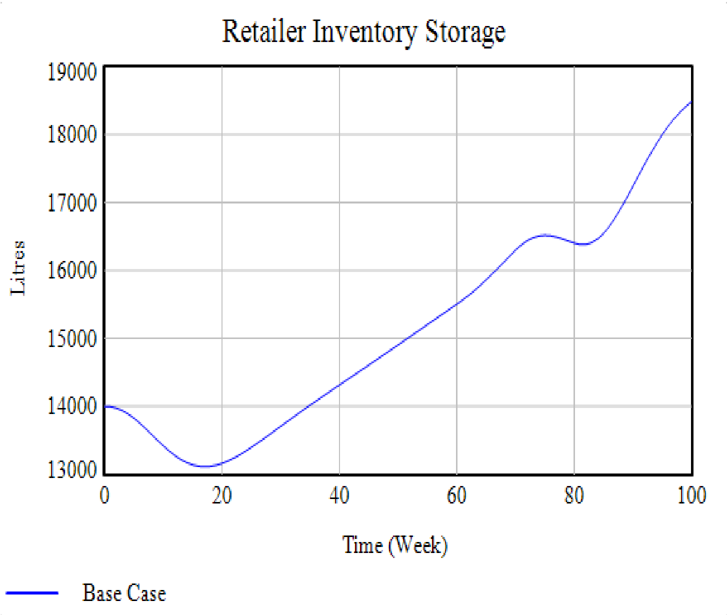


Figure 5.2 (b) Retailer Inventory Storage

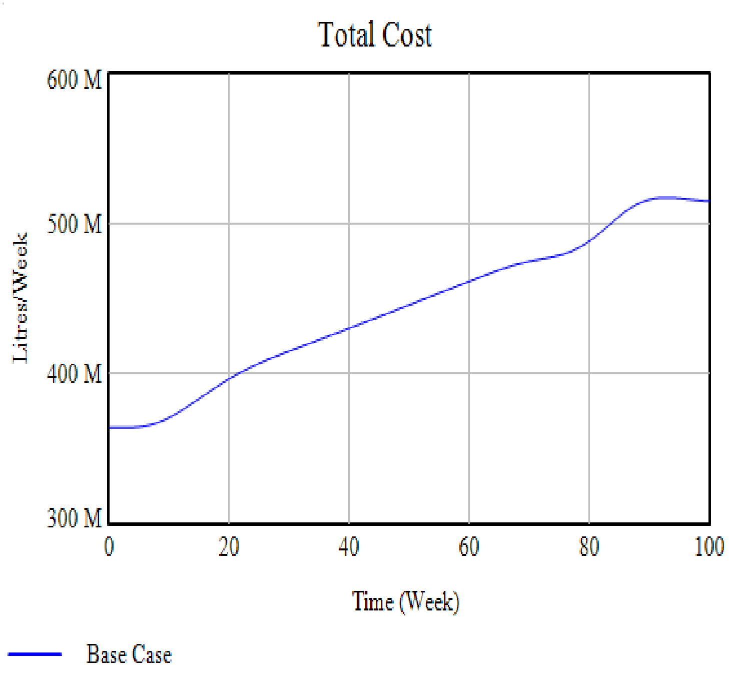


Figure 5.2 (c) Total Cost

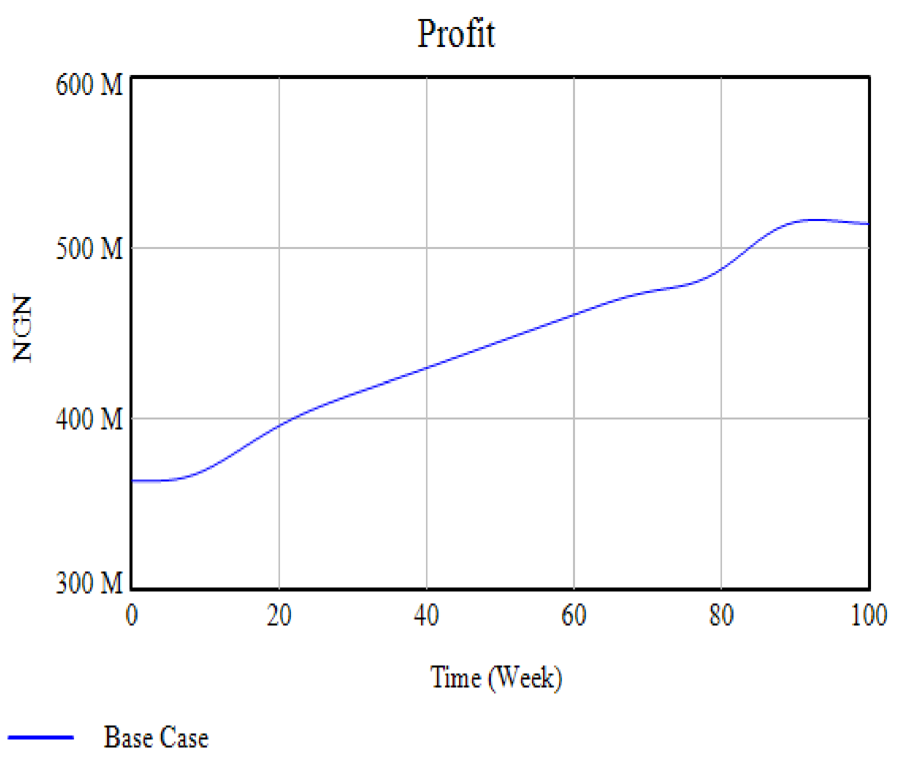


Figure 5.2 (d) Profit

5.6 Effect of Retailer Order Cycle Time on Base Case

By modelling system operations under the original operating state, the supply chain system behaviour was established as the basis case. It was utilised to benchmark the cost and inventory levels in this situation.

The base case scenario determines the model parameters that was initially used to test the model under the future ordering projection situations. This first simulation run has been carried out by changing the values of retailer order cycle time at the same time leaving other parameter values as base case. The purpose is to gain insight on the Retailer Order Cycle Time (ROCT) on the inventory level and cost. Figures 5.3 a, b, c and d shows the effect of oil distributor inventory, retailer inventory storage, cost and profit.

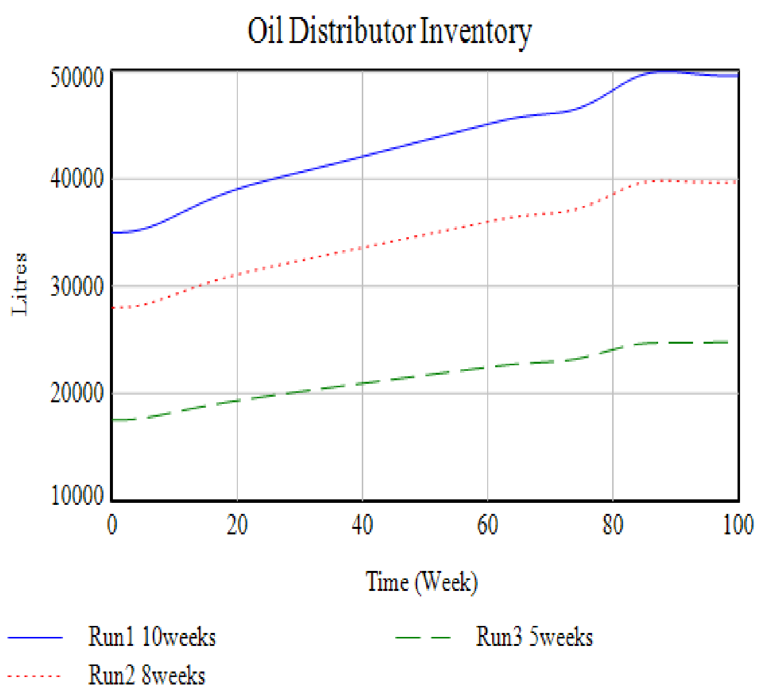


Figure 5.3 (a) Effect of ROCT on Oil distributor inventory

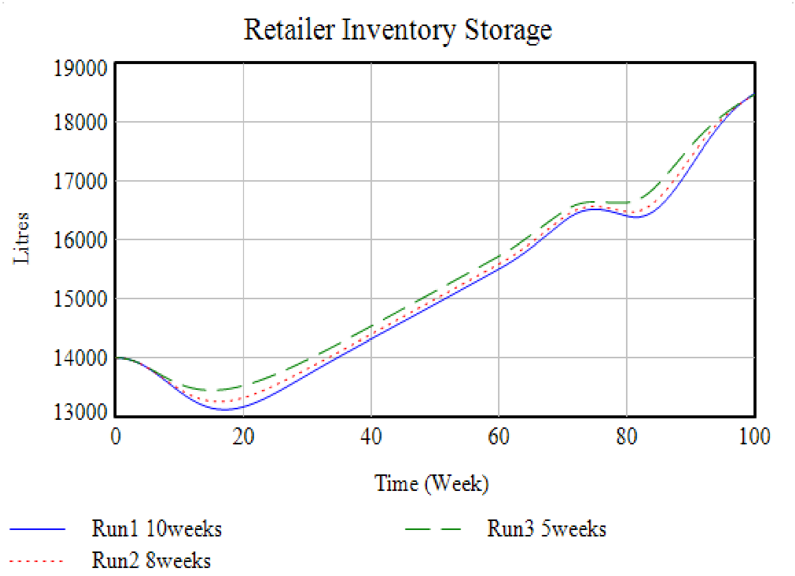


Figure 5.3 (b) Effect of ROCT on Retailer inventory storage

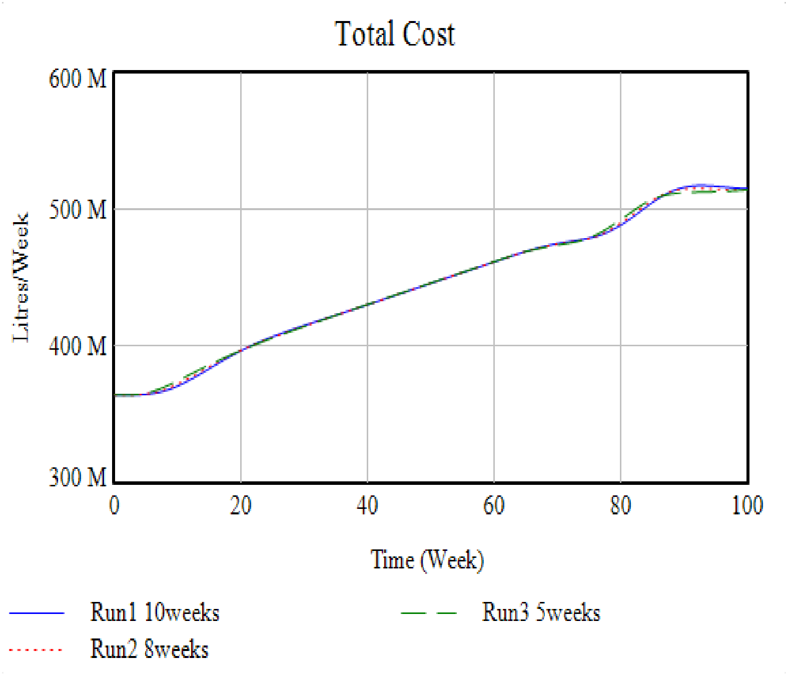


Figure 5.3 (c) Effect of ROCT on Total cost

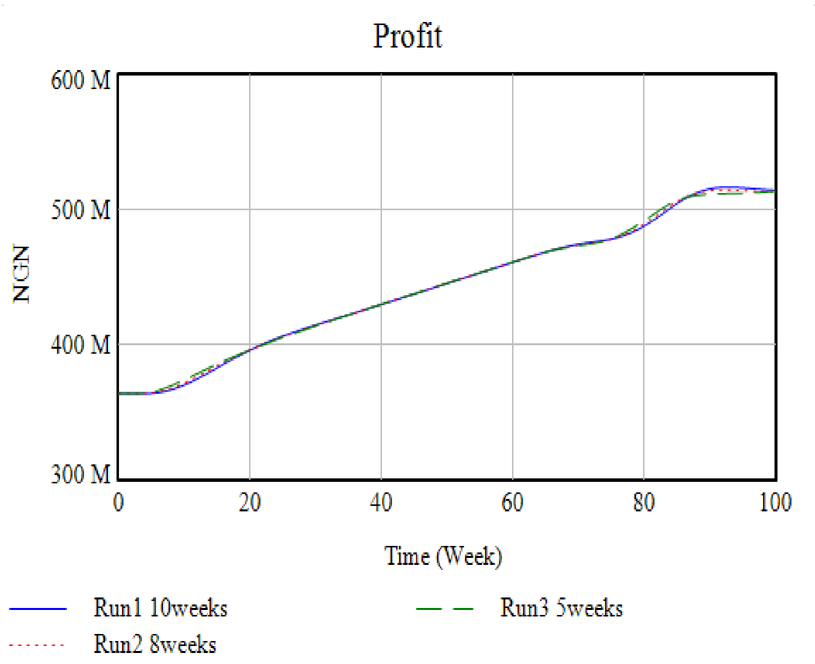


Figure 5.3 (d) Effect of ROCT on Profit

As the Figures suggest the effect of retailer order cycle time has a significant impact on oil distributor inventory but with less or vague impact on retailer inventory storage when this parameter value is reduced. The total cost remains high and a minimal profit after the parameter changes. **Table 5.1** summarises the result of these runs. Retailer order cycle time has less effect on the model output when conducted with a single parameter testing.

Run 1: ROCT = 10 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	49626	18487	51509400	51438400
Run 2: ROCT = 8 weeks				
SD Inventory Model	39717	18466	51439600	51368500
Run 3: ROCT = 5 weeks				
SD Inventory Model	24825	18469	51434800	51363700

Table 5.1 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

Effect of Safety Stock Coverage on Base Case

The parameter safety stock coverage determines how many weeks the worth of inventory the manager would like to hold available in stock. This particular test is conducted to gain insight or understand the effects of carrying more or less inventory. In other to access the number of inventories in the model, this test has been subjected to the base case demand pattern. Figures **5.4 a, b, c**, and **d** shows the effect of oil distributor inventory, retailer inventory storage, cost and profit.

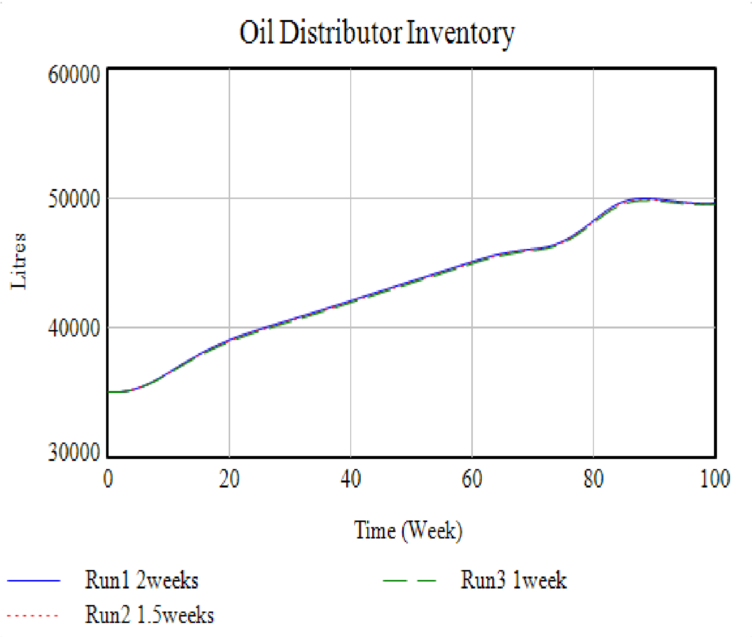


Figure 5.4 (a) Effect of SSC on Oil distributor inventory

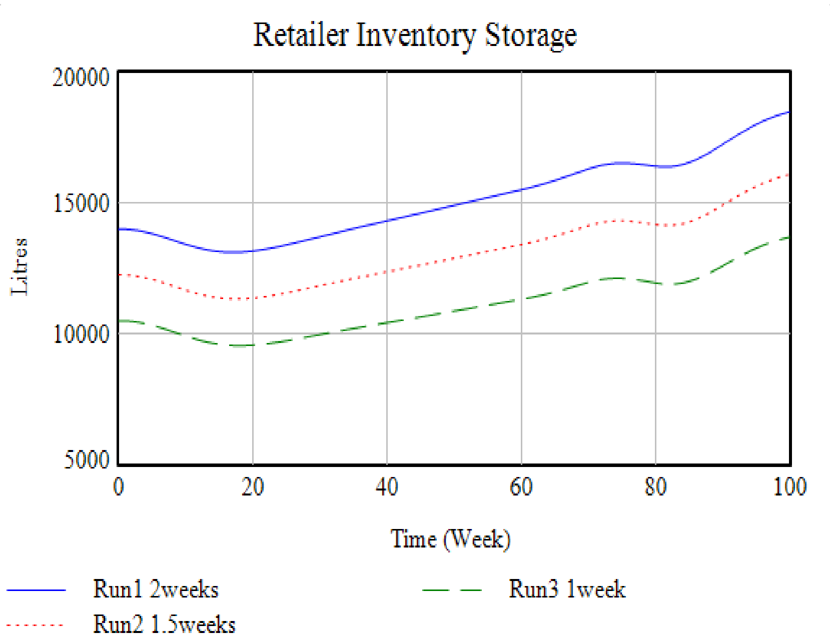


Figure 5.4 (b) Effect of SSC on Retailer inventory storage

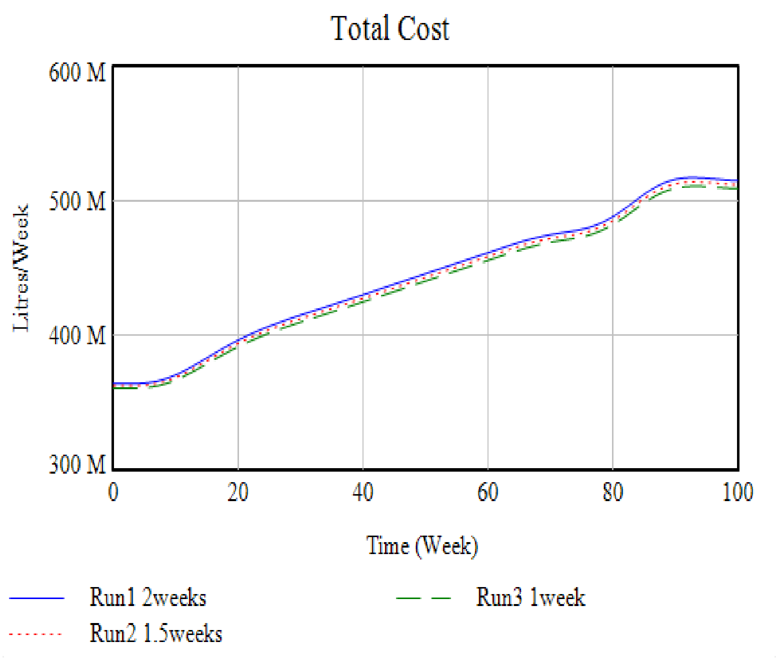


Figure 5.4 (c) Effect of SSC on Total cost

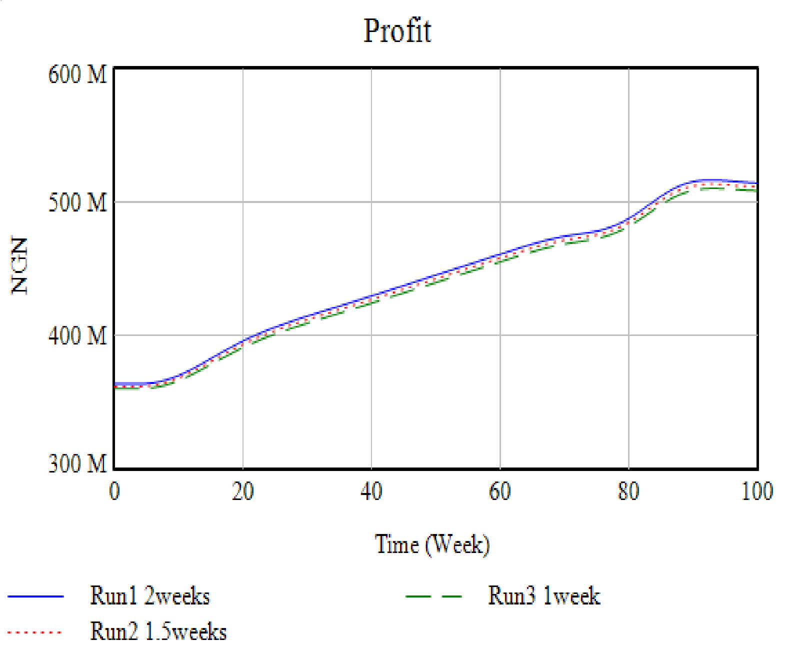


Figure 5.4 (d) Effect of SSC on Profit

As the Figure **5.4a** and **b** suggests, the effect of safety stock coverage has a significant impact on retailer inventory storage but with less or vague impact on oil distributor inventory when this parameter value is reduced. The total cost and profit slightly reduces after the parameter changes. **Table 5.2** summarises the result of these runs. Safety stock coverage has less effect on the model output when conducted with a single parameter testing.

Run 1: SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	49626	18487	51509400	51438400
Run 2: SSC = 1.5 weeks				
SD Inventory Model	49595	16571	51278800	51207800
Run 3: SSC = 1 week				
SD Inventory Model	24825	18469	50932800	50861800

Table 5.2 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

5.7 Effect of ROCT and SSC on Base Case

After running different single parameters test to ascertain which parameters helps to reduce the unsteady pattern, the result deduce that single parameter testing does not have a huge influence in reducing the oscillation and instabilities hence the need for multiple parameter testing. The first observation suggests that a reduction in retailer order cycle time and safety stock coverage leads to lower discrepancy and inventory level on both the oil distributor and retailer inventory storage as **figure 5.5 (a)** and **(b)** depicts.

According to the results, the oil distributor's inventory significantly drops when ROCT =10 weeks, 8 weeks and 5weeks and SSC = 2 weeks, 1.5week and 1 week. **Figure 5.5 (c)** and **(d)** depicts that when the ROCT and SSC are changed simultaneously the total cost is reduced.

These two parameter values have the capability of reducing total cost thereby increasing the profit for the company. **Table 5.3** summarises the inventory levels, total cost and profits.

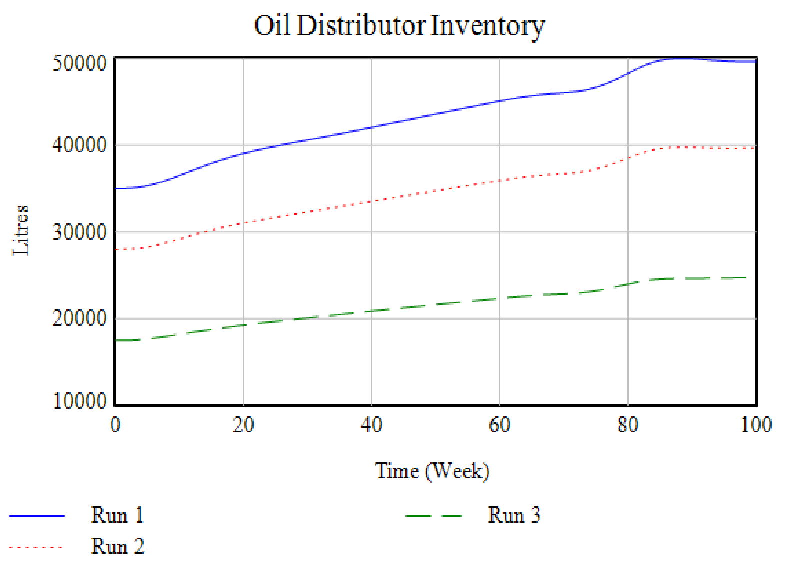


Figure 5.5 (a) Effect of ROCT and SSC on Oil distributor inventory

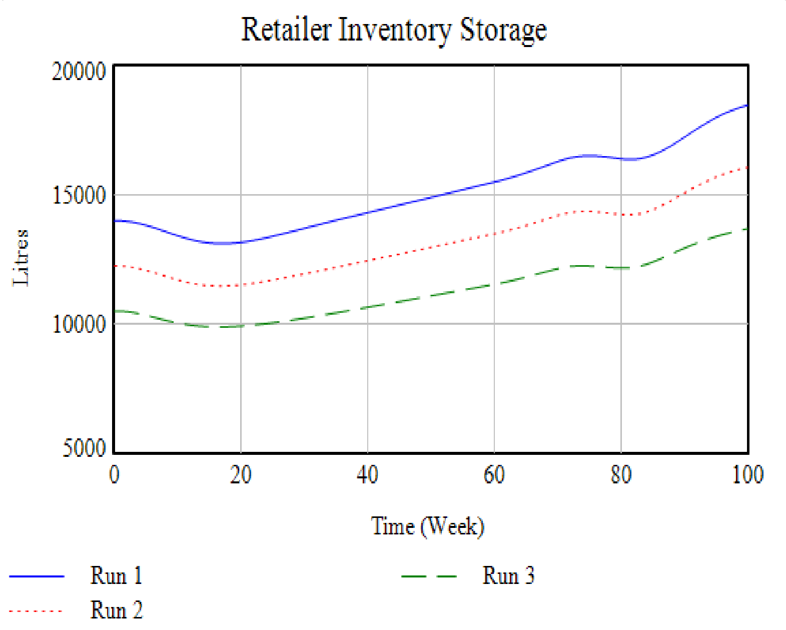


Figure 5.5 (b) Effect of ROCT and SSC on Retailer Inventory Storage

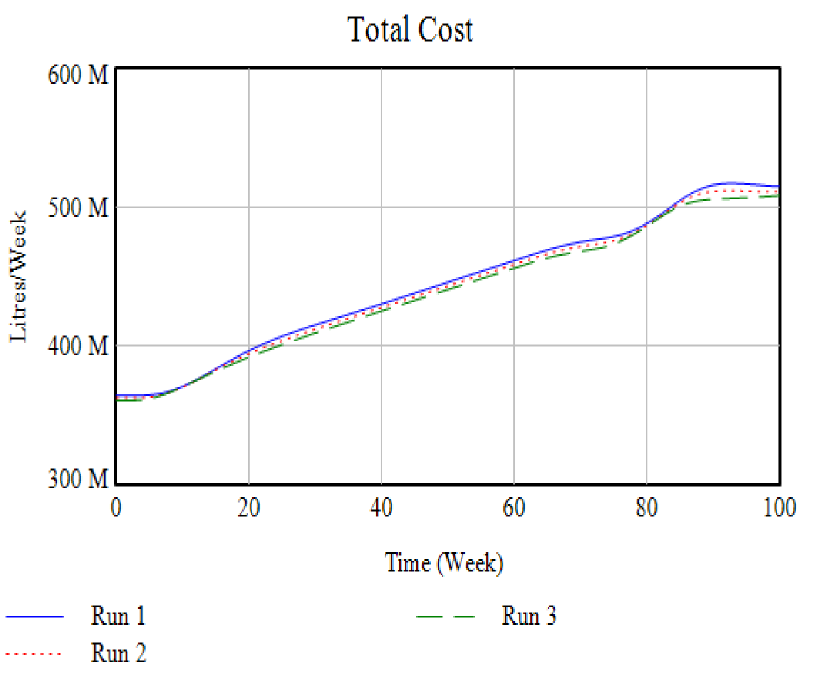


Figure 5.5 (c) effect of ROCT and SSC on Total cost

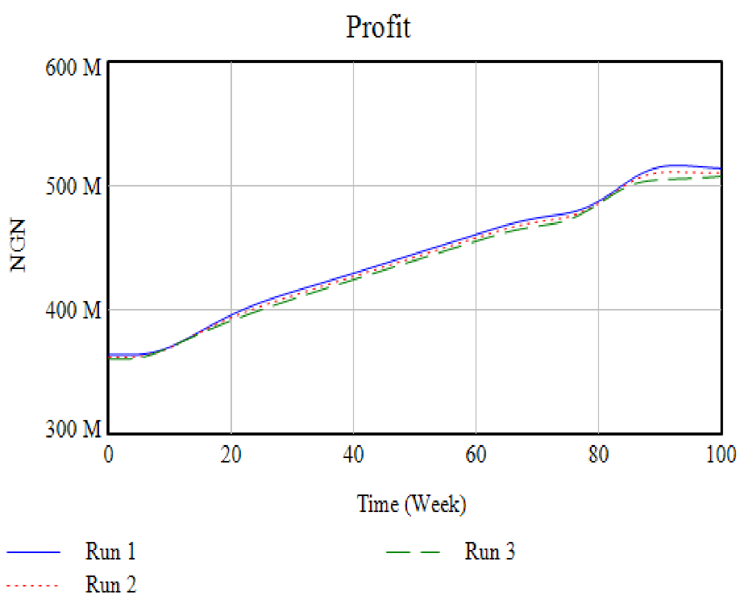


Figure 5.5 (d) effect of ROCT and SSC on Profit

Run 1: ROCT = 10 weeks and SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	49626	18487	51509400	51438400

Run 2: ROCT = 8 weeks and SSC = 1.5 weeks				
SD Inventory Model	39690	16552	51209400	51138400
Run 3: ROCT = 5 weeks and SSC = 1 week				
SD Inventory Model	24778	13690	50856700	50785600

Table 5.3 Effect of ROCT and SSC on ODI, RIS, TOTAL COST AND PROFIT

In addition, reducing the safety stock coverage without reducing the retailer order cycle time the model has less effect on the model behaviour. As the **table 5.4** suggests, when the retailer order cycle time is left as the base value, the customer orders cannot be met due to additional discrepancy between the desired and actual inventory required to satisfy customer order therefore safety stock coverage might not be enough. For that reason, the outcome is that the seller is not able to meet client need if there is any kind of disruption or delay in the distribution channel.

5.8 High Demand Pattern on Inventory Oil Distributor Inventory and Retailer Inventory Storage, Total Cost, and Profit

The effect of high order pattern is presented in **Fig. 5.6 (a), (b), (c),** and **(d).** Oil distributor inventory increases with an unsteady pattern from the start of the simulation till the end of the simulation. This is a result of the high demand coming from the customer the distributor tends to keep excess stocks to fulfil customer requirements. Retailer inventory storage drops for about 15 weeks before increasing with an unsteady pattern. This is a result of the system's undesirable feedback. Because of this, we can see how supply chains may be managed without having to deal with delays and interruptions; even little changes in demand can cause each supply chain member's inventory to be more volatile and cause demand to continuously rise in a variety of everyday market demand conditions.

Figures 5.6 (c) and **(d)** present the graphs of the total cost and profit. As the graph suggests the total costs and profit remains high as a result of the high inventory level.

The customer order rate is significant and crucial to the model; hence, it is essential to understand the effect that a sharp increase in the order rate will have on the model's performance. Further simulations are carried out in the next sections as part of this tests involves changing the values of ROCT and SSC to investigate the impact on oil distributor inventory, retailer inventory storage, total cost, and profit.

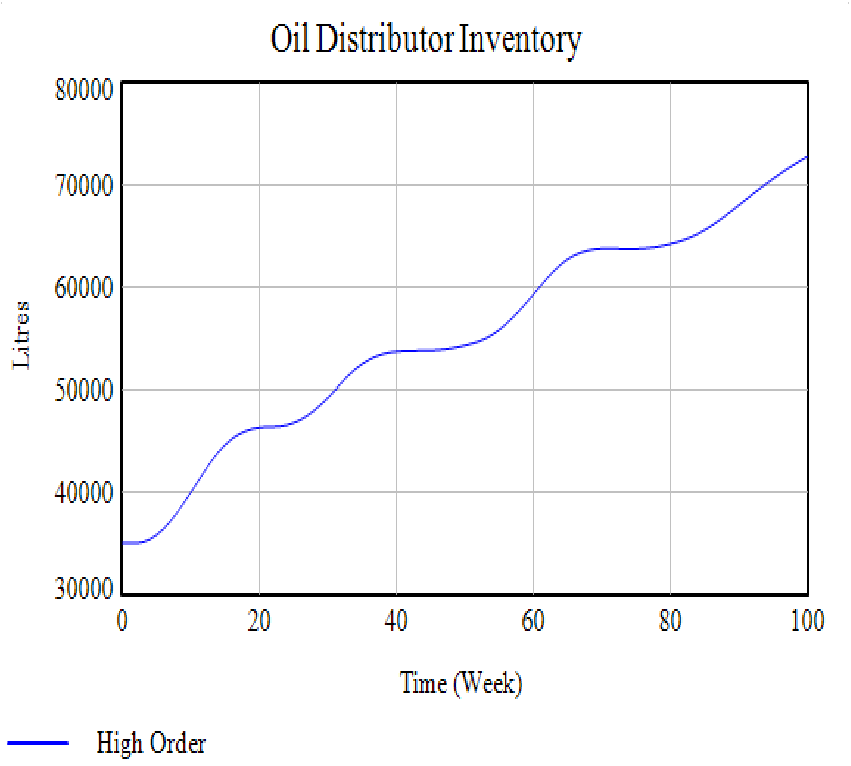


Figure 5.6 (a) Effect of High Order on Oil Distributor Inventory

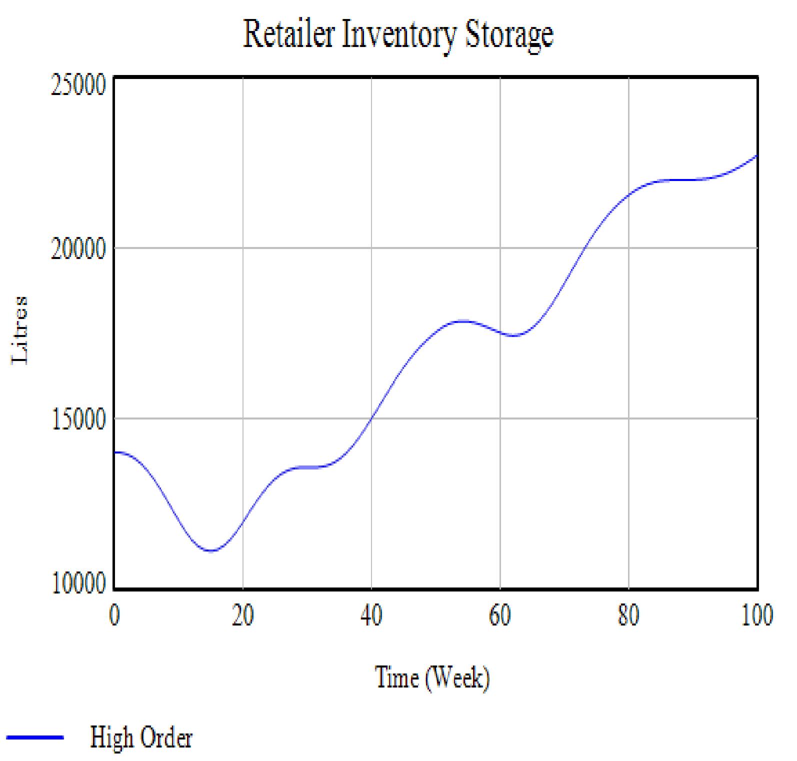


Figure 5.6 (b) Effect of High Order on Retailer Inventory Storage

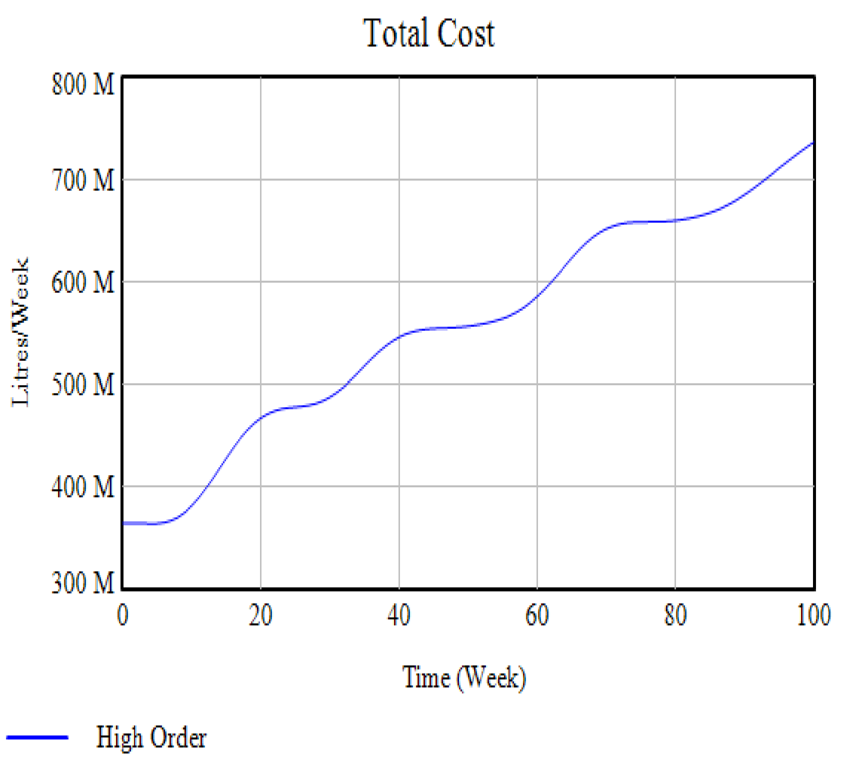


Figure 5. 6 (c) Effect of High Order on Total Cost

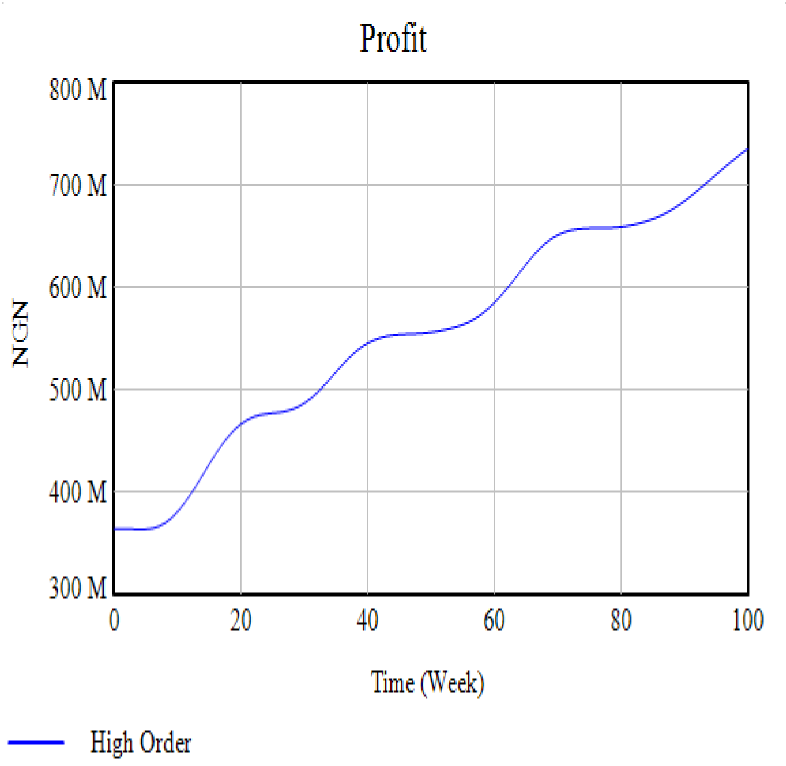


Figure 5.6 (d) Effect of High Order on Profit

5.9 Effects of Retailer Order Cycle Time on High Demand Pattern

By modelling system operations under high-demand operating conditions, the supply chain system behaviour was achieved as high order. The inventory levels and cost were then benchmarked using this scenario. In this initial simulation run, the retailer order cycle time values have been altered but the values for other parameters have been left as-is. The demand risk is brought on by downstream operations, particularly the potential for an unanticipated change in the orders (Gonvales et al., 2005). Order forecasting is important to operations because it helps distributors and retailers plan their purchases, deliveries, and other tasks around anticipated orders. However, the discrepancy between expected and actual orders causes the firm to fluctuate and prevents it from keeping up with consumer demands or raising the inventory level. The simulation is run to address the effects of demand volatility and to continually enhance the supply chain.

The simulation is carried out to investigate the effect of changes in demand and to improve the supply chain continuously. The purpose is to gain insight on the Retailer Order Cycle (ROCT) Time on the inventory level of distributor, retailer, total cost and profit. **Figures 5.7 a, b, c,** and d shows the effect of oil distributor inventory, retailer inventory storage, cost and profit.

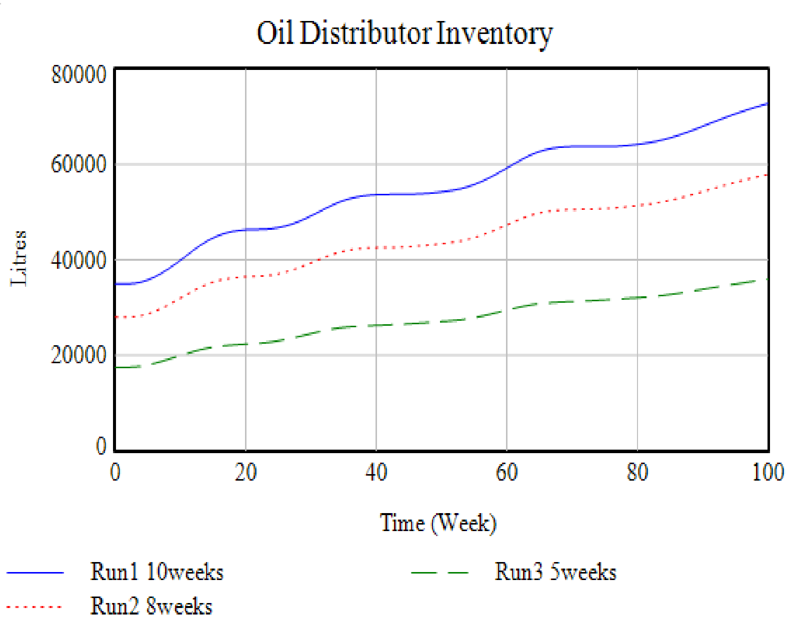


Figure 5.7 (a) Effect of ROCT on Oil Distributor Inventory

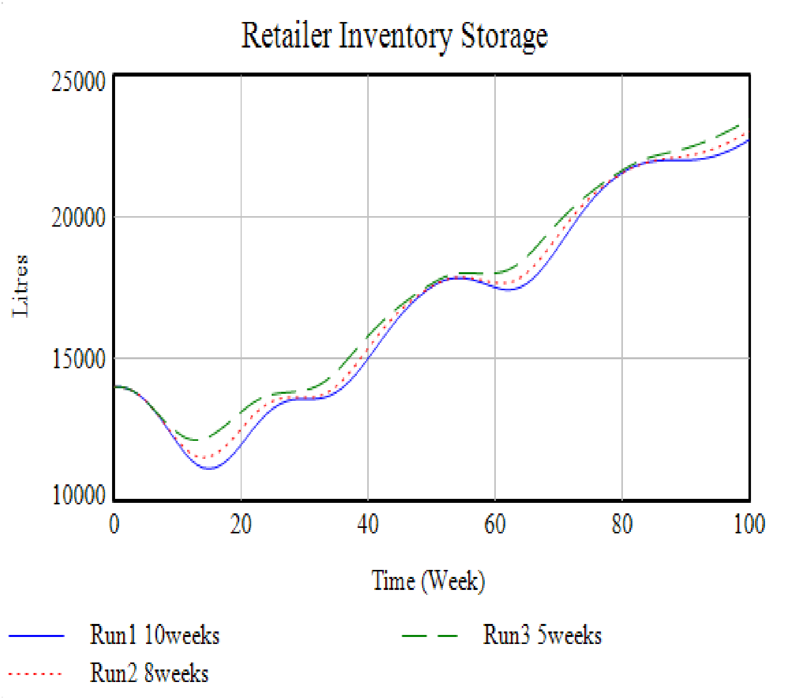


Figure 5.7 (b) Effect of ROCT on Retailer Inventory storage

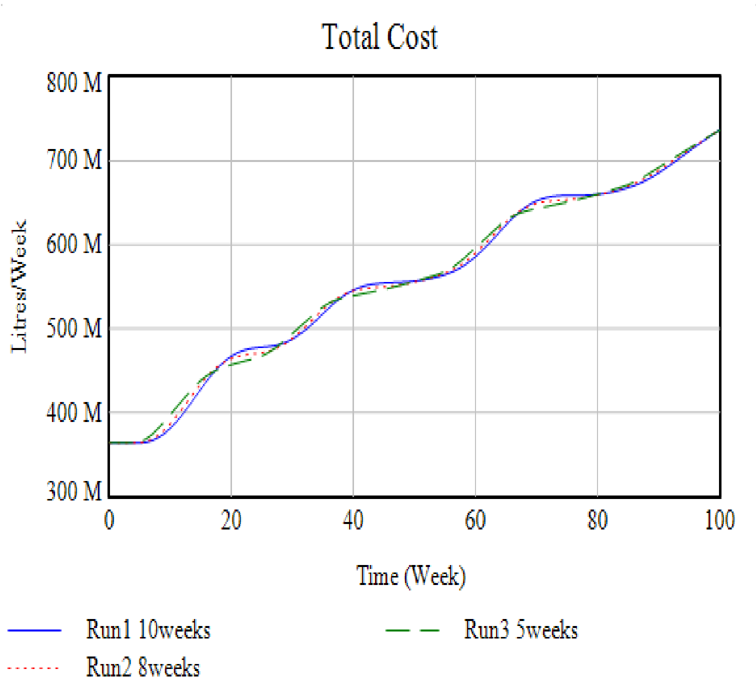


Figure 5.7 (c) Effect of ROCT on Total Cost

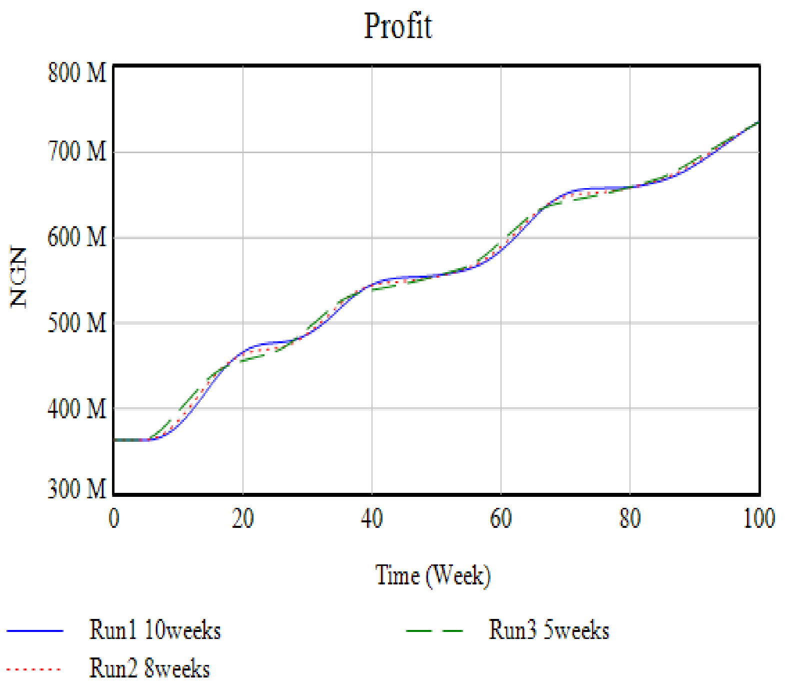


Figure 5.7 (d) effect of ROCT on Profit

In this scenario, the analysis is focused on the fluctuation in terms of increase in customer order. As customer order uncertainty increases there is a need to hold more inventory levels to avoid out of stock situations this would result to high total cost and lower profit. The effect of the increase in customer order is summarised in **Table 5.4**.

Run 1: ROCT = 10 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	72828	22728	73690800	73589300
Run 2: ROCT = 8 weeks				
SD Inventory Model	57954	23039	73665800	73564300
Run 3: ROCT = 5 weeks				
SD Inventory Model	35984	23444	73643400	73541900

Table 5.4 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

The effect of retailer order cycle time has a significant impact on oil distributor inventory but with less or vague impact on retailer inventory storage when this parameter value is reduced. The total cost remains high and a minimal profit after the parameter changes as seen in the Table above. Retailer order cycle time has less effect on the model output when conducted with a single parameter testing. The table above also shows the slight changes in total and profit as ROCT is reduced from 10weeks, 8 weeks and 5 weeks respectively.

Effect of Safety Stock Coverage on High Order

The **figure 5.8 (a)** suggests that while reducing the safety stock coverage leads to a lower instability and unsteady behaviours especially the retailer inventory storage in the system, as **Figure 5.8 (b)** suggest the graph of the inventory is less unstable by setting the value of this particular parameter to a low value. This model's sensitivity simulations are carried out under the presumption that the parameter values are increased or decreased by a range of 20% (Sterman, 2000) from the base values. Morecroft 2008 argues that safety stock coverage should be between the range of 1 to 4 weeks based on his production and control model. The result of the sensitivity analysis in the previous paragraph suggests that when one of the parameters is changed for example retailer order cycle time the sensitivity of the output significantly affects the distributor inventory and less sensitive to the retailer inventory and when the safety stock coverage is changed the retailer inventory is more sensitive to this parameter the resulting behaviour is depicted in **Figure 5.18 (b).** According to the previous figures, SSC and ROCT are the most significant parameters for instability and oscillation because the rest of the parameters are less sensitive to the output of the model.

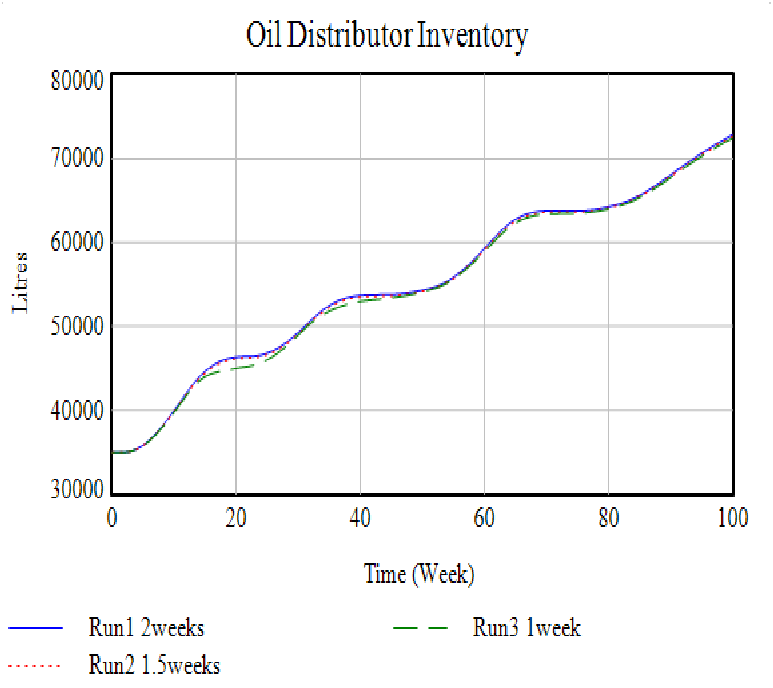


Figure 5.8 (a) Effect of SSC on Oil distributor Inventory

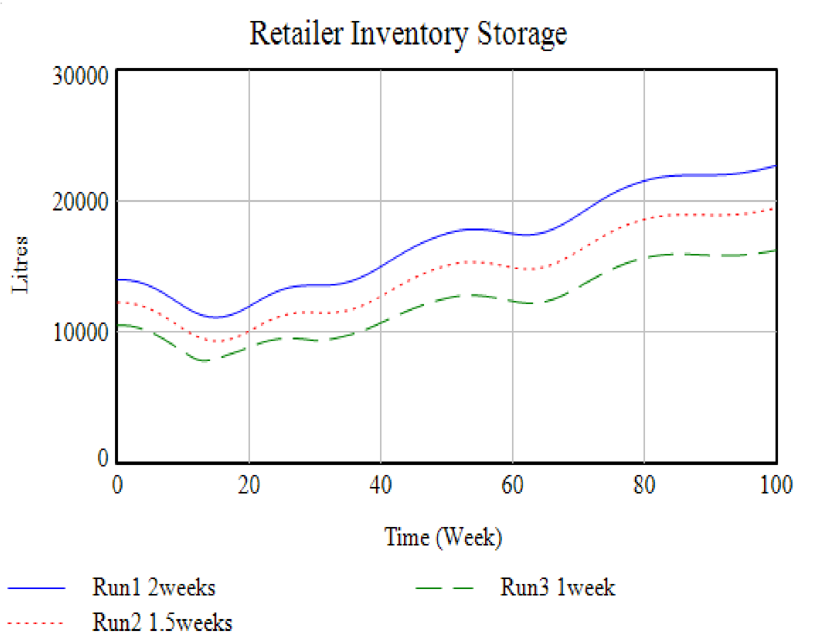


Figure 5.8 (b) Effect of SSC on Retailer Inventory Storage

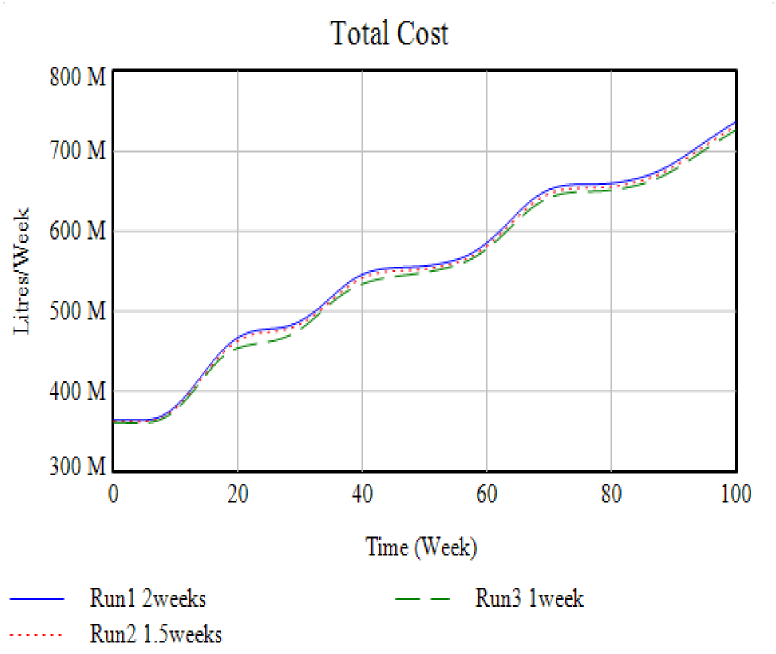


Figure 5.8 (c) Effect of Safety stock on Total Cost

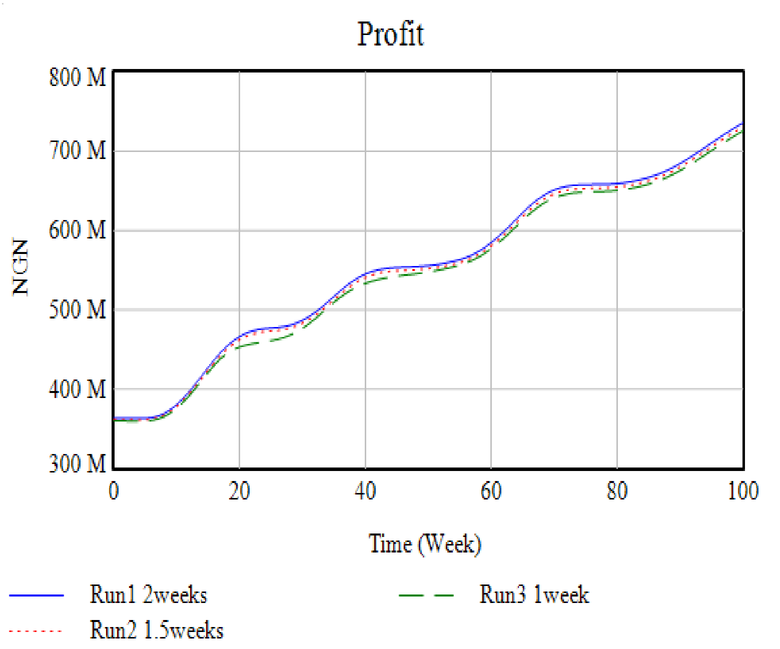


Figure 5.8 (d) Effect of Safety stock on Profit

Lesser values of these parameters lead to reduced response to the customer order input, so more stability emerge. In other words, increasing time makes the system more unstable. Therefore, the manager managing the supply chain including inherent delays should keep the delay times as small as possible in order to avoid instability and unsteady behaviours. Like other behaviour measures, ROCT and SSC are concluded as the most significant parameters.

Run 1: SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	72828	22728	73690800	73589300
Run 2: SSC = 1.5 weeks				
SD Inventory Model	72638	19492	73181400	73079900
Run 3: SSC = 1 week				
SD Inventory Model	72448	16255	72671700	7.2570200

Table 5.5 Effect of SSC on ODI, RIS, TOTAL COST AND PROFIT

As the table depicts the effect of safety stock coverage has a significant impact on retailer inventory storage but with less or vague impact on oil distributor inventory when this parameter value is reduced. The total cost vaguely reduces and a minimal profit after the parameter changes. **Table 5.5** summarises the result of these runs. Safety stock coverage has less effect on the model output when conducted with a single parameter testing.

5.9 Effect of ROCT and SSC on High Customer Order Pattern

After running different single parameters test to determine which parameters helps to reduce the unsteady pattern, we can assume that single parameter testing does not have a huge influence in reducing the unsteady pattern hence the need for multiple parameter testing. The first observation suggests that a reduction in retailer order cycle time and safety stock coverage leads to lower discrepancy and inventory level on both the oil distributor and retailer inventory storage as **figure 5.9 (a)** and **(b)** depicts. The results shows that there is a significant decrease in inventory when the ROCT =10 weeks, 8 weeks and 5weeks and SSC = 2 weeks, 1.5week and 1 week.

Figure 5.9 (c) and **(d)** depicts that when the ROCT and SSC are changed simultaneously the total cost is slightly reduced. These two parameter values have the capability of reducing total cost thereby increasing the profit for the company. **Table 5.7** summarises the inventory levels of oil distributor, retailer storage, total cost and profits.

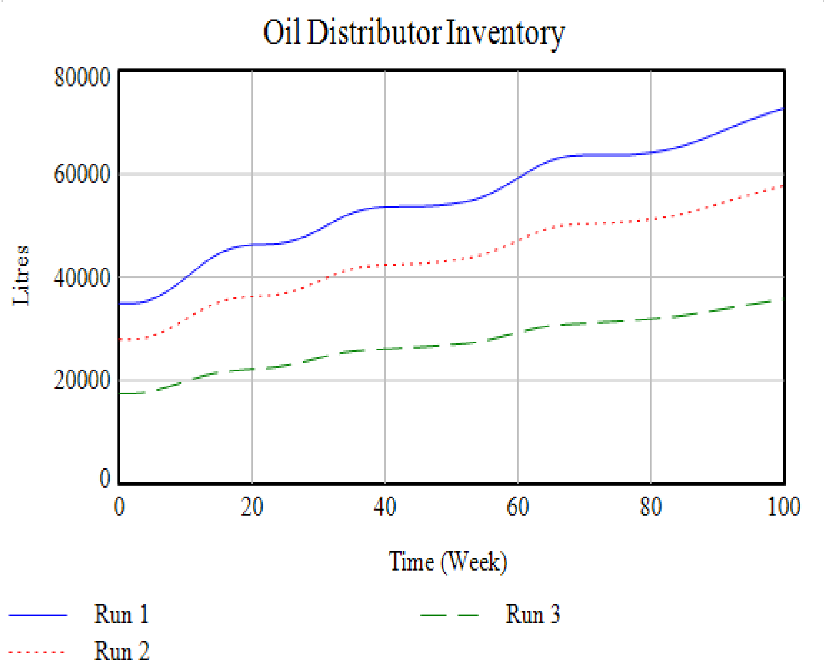


Figure 5.9 above depicts, there is an oscillation in the system that corresponds to a bullwhip, where there is a high demand which disequilibrate the system. Safety stock was changed as a single policy intervention but had little impact on the behaviour of the system, Retailer order cycle time when reduced as a single policy intervention had little impact on reducing the oscillation or bullwhip. However, simultaneous policy intervention safety stock and retailer order cycle time are capable of dampening down the bullwhip effect.

Figure 5.9 (a) Effect of ROCT and SSC on Oil distributor inventory

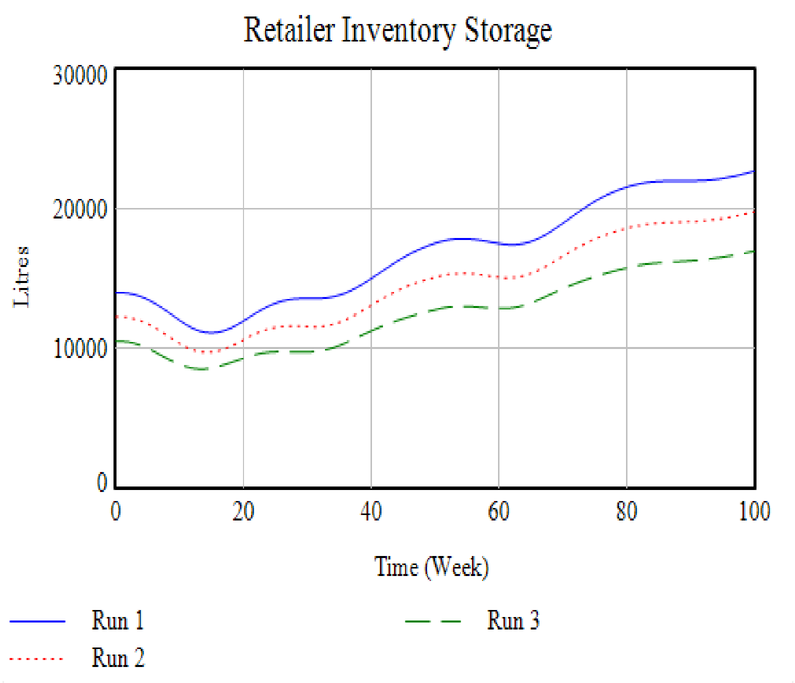


Figure 5.9 (b) Effect of ROCT and SSC on Retailer inventory storage

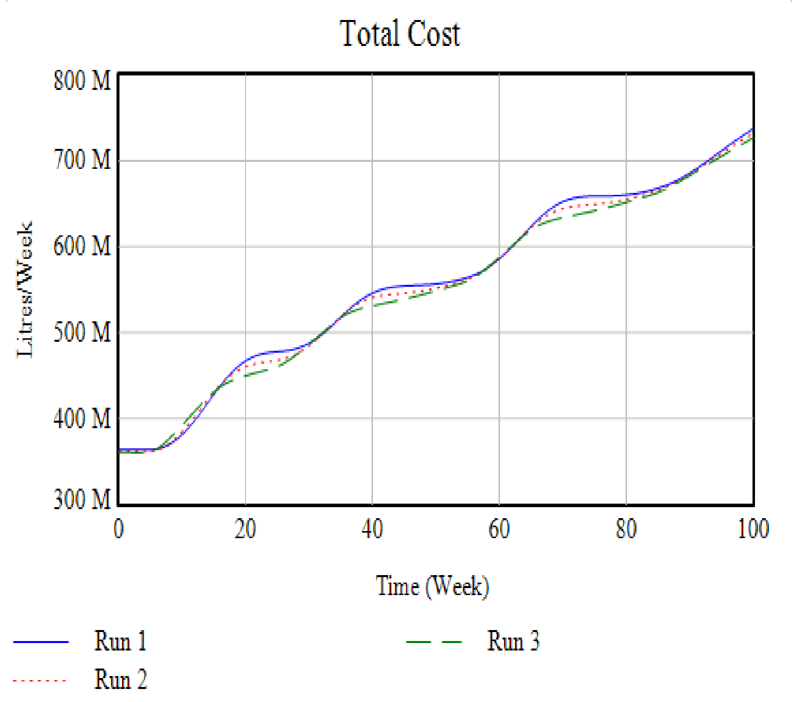


Figure 5.9 (c) Effect of ROCT and SSC on Total Cost

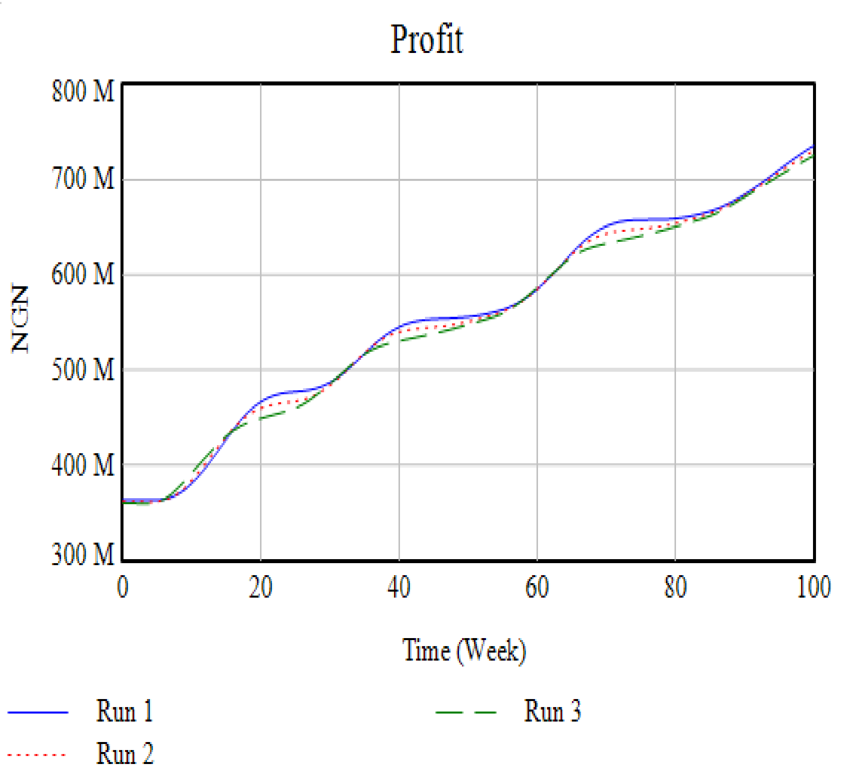


Figure 5.9 (d) Effect of ROCT and SSC on Profit

Run 1: ROCT = 10 weeks and SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	72828	22728	73690800	73589300
Run 2: ROCT = 8 weeks and SSC = 1.5 weeks				
SD Inventory Model	57806	19799	73159500	73058000
Run 3: ROCT = 5 weeks and SSC = 1 week				
SD Inventory Model	35804	16958	72637100	72535600

Table 5.6 Effect of ROCT and SSC on ODI, RIS, Total Cost and Profit

According to the analysis, increasing retailer order cycle time makes the model more unstable and unsteady. Like other behaviour measures, safety stock coverage (SSC) and retailer order cycle time (ROCT)is concluded as the most significant parameters that improves the policy. Furthermore, lesser value of the parameter of retailer order cycle time indicates that systems, which have smaller retailer order cycle time, are more robust to the incoming shocks. These results are also verified with smaller size sensitivity simulations in **Table 5.6.**

5.10 Effect of Low Order on Oil Distributor Inventory, Retailer Inventory Storage, Total Cost, and Profit

As customer order is highly unpredictable, low customer order rate explores the effect of the opposite case of high customer order rate, i.e., order rate falls rapidly. The results are exactly the opposite of those obtained by testing with high order rate; lower order results in low inventory levels as depicted in **Figures 5.10 (a) and (b).** These results confirm the fact that there is an invert relationship between customer order and inventory levels. **Figure 5.10 (c**) and **(d)** presents the total cost and profit, the total cost is low as a result of low inventory level with low profit. There is always a risk when reducing the customer order in the system, the effects of these changes in the level of inventory is realised in later periods. The risk of ending up holding obsolete inventory is increased, therefore, it is essential that the inventory levels are set as low as possible to maintain maximum customer fulfilment.

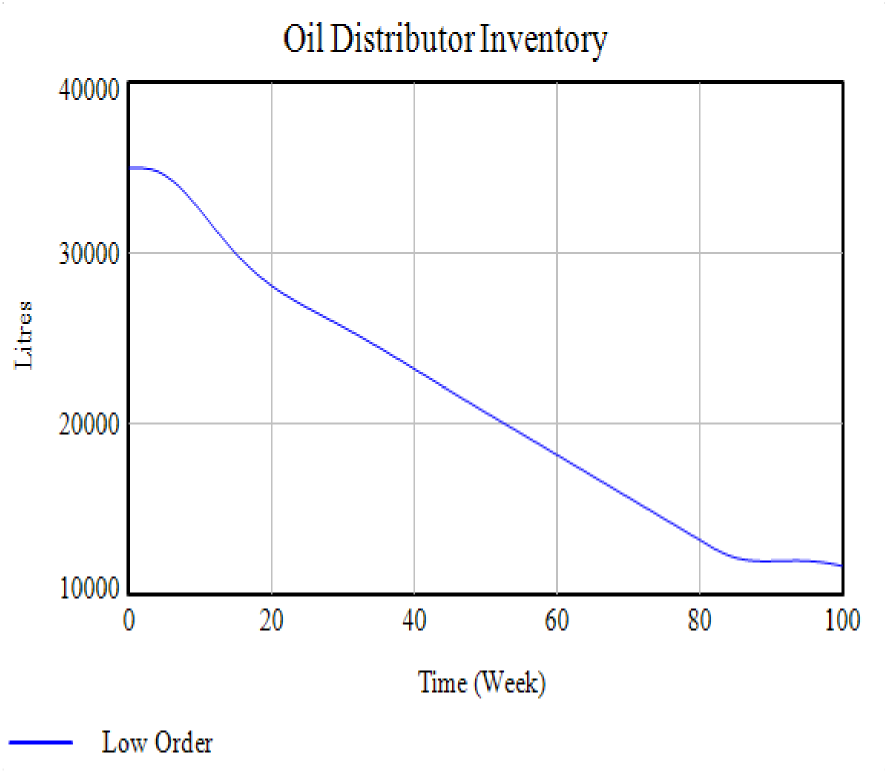


Figure 5.10 (a) Effect of Low Order on Oil Distributor Inventory

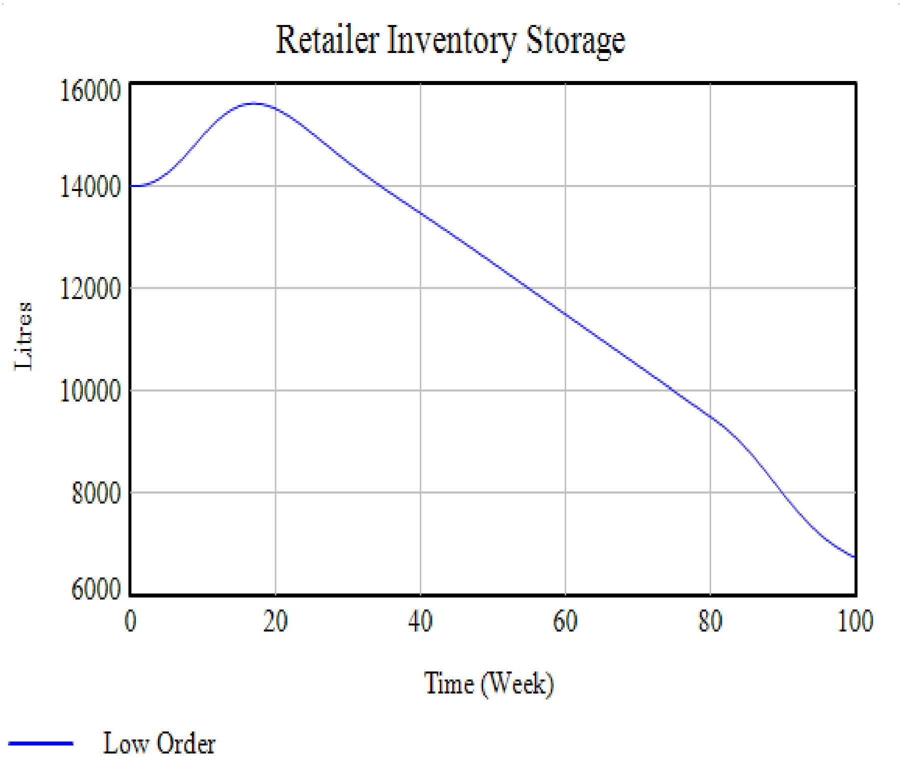


Figure 5.10 (b) Effect of Low Order on Retailer Inventory Storage

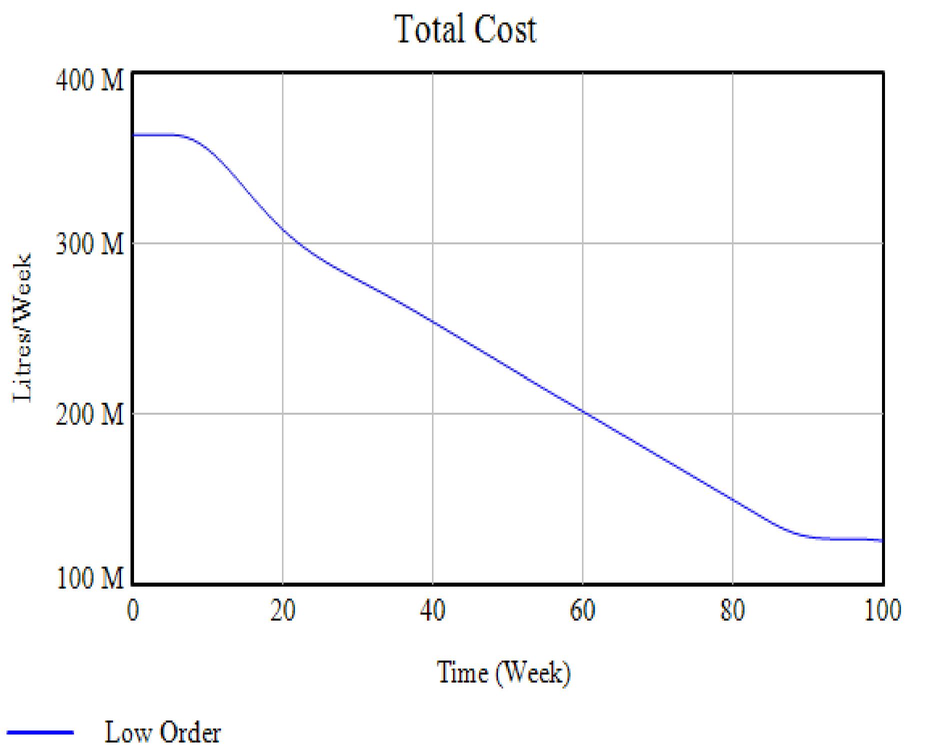


Figure 5.10 (c) Effect of Low Order on Total Cost

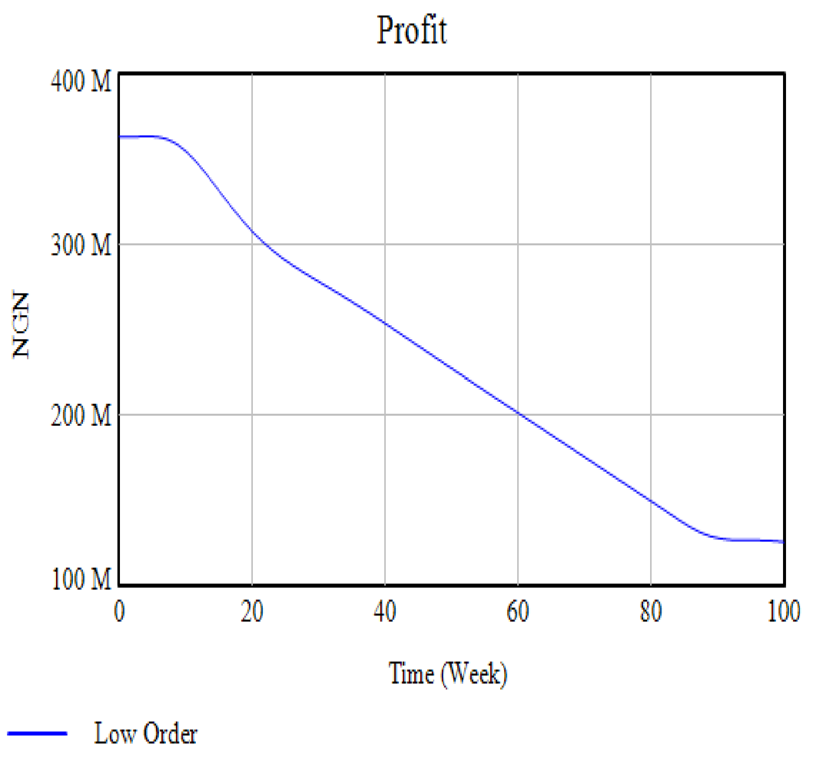


Figure 5.10 (d) Effect of Low Order on Profit

5.11 Effect of Retailer Order Cycle Time on Low Customer Order Pattern

This test explores the effect of retailer order cycle time on low customer order. As shown in **Figure 5.11 (a).** Reduction in retailer order cycle time reduces the instabilities in the oil distributor inventory but less sensitive in the retailer inventory storage as seen in **Figure 5.11 (b),** as the graph depicts, the instability in the oil distributor inventory dampens. In **Figures 5.11 (c) and (d),** total cost and profit are vaguely affected by reducing these parameters.

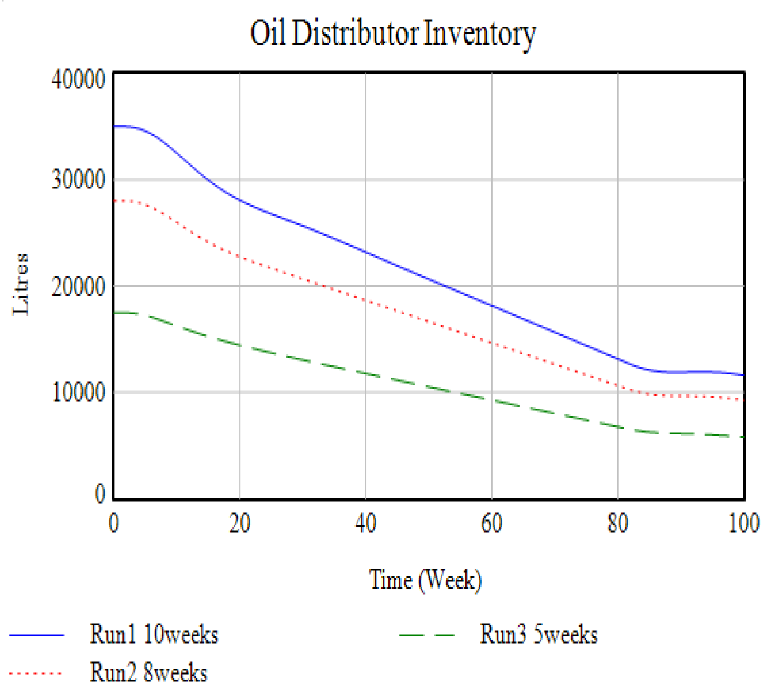


Figure 5.11 (a) Effect of ROCT on Oil Distributor Inventory

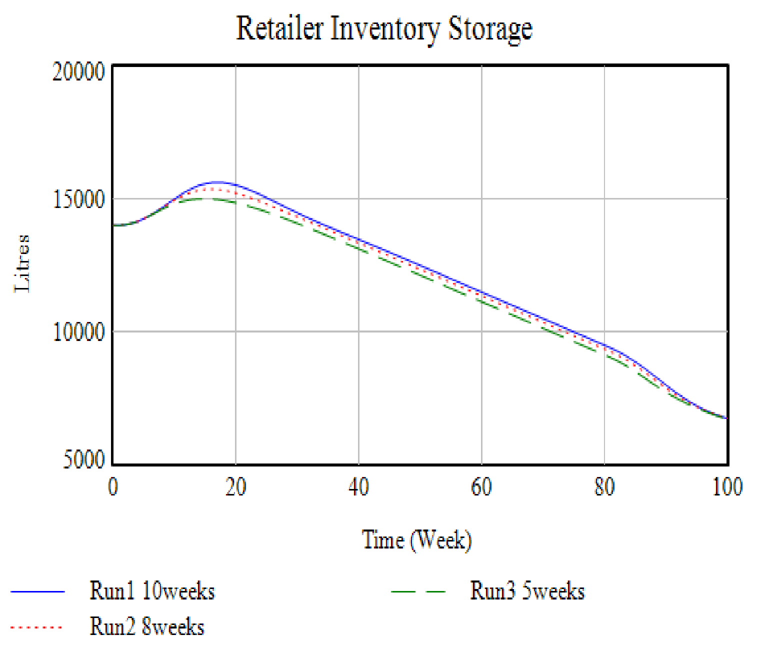


Figure 5.11 (b) Effect of ROCT on Retailer Inventory storage

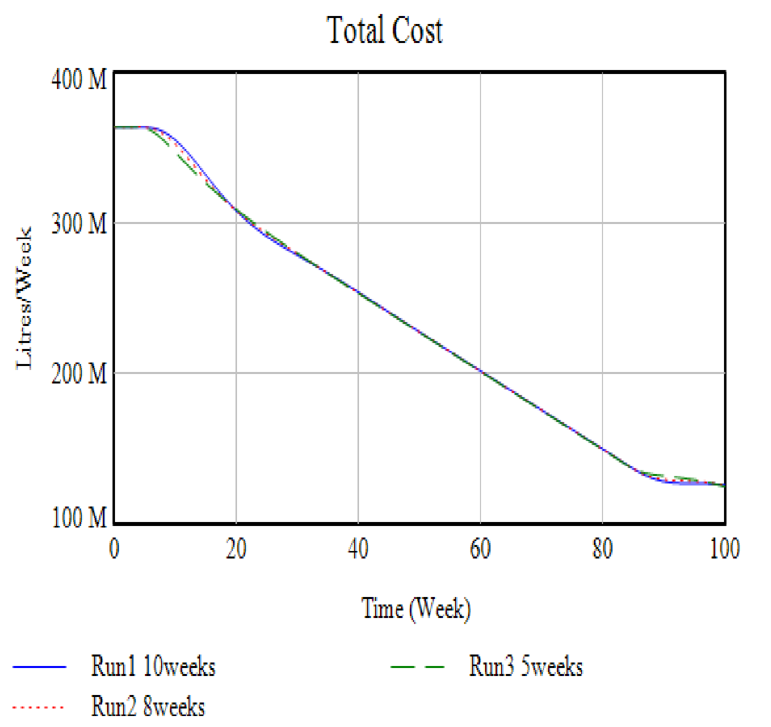


Figure 5.11 (c) Effect of ROCT on Total Cost

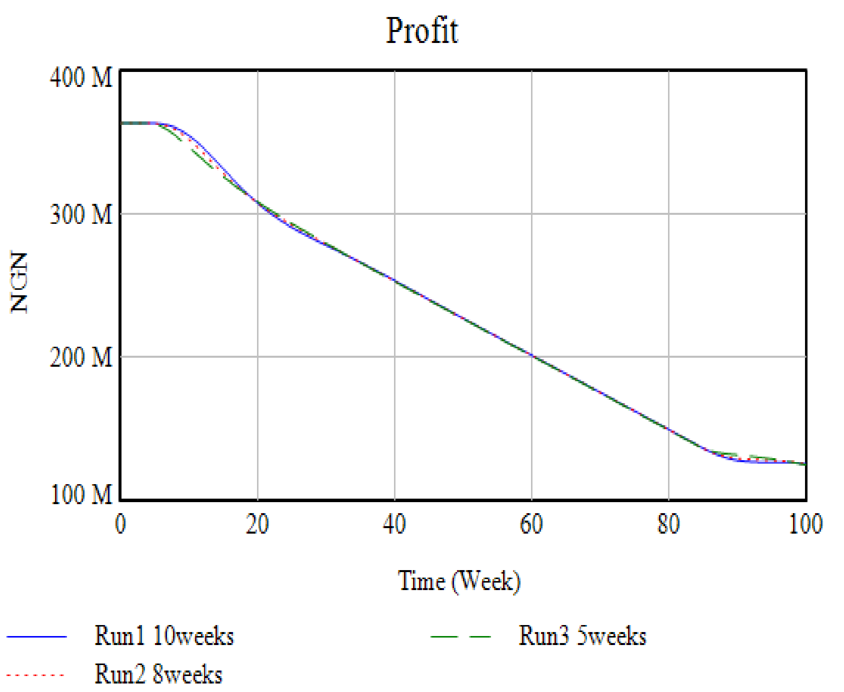


Figure 5.11 (d) Effect of ROCT on Profit

.

Run 1: ROCT = 10 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	11626	6728	12541300	12523200
Run 2: ROCT = 8 weeks				
SD Inventory Model	9283	6736	12525900	12507800
Run 3: ROCT = 5 weeks				
SD Inventory Model	5813	6699	12457500	12439300

Table 5.7 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

Table 5.7 summarises the result of these runs. Effect of retailer order cycle time has a significant impact on oil distributor inventory but with less or vague impact on retailer inventory storage when this parameter value is reduced. The total cost remains high and a minimal profit after the parameter changes.

5.12 Effect of Safety Stock Coverage on Low Order Pattern

The parameter safety stock coverage determines how many weeks the worth of inventory the manager would like to hold available in stock. **Figures 5.12 a, b, c** and **d** shows the effect of safety stock coverage on oil distributor inventory, retailer inventory storage, cost and profit. The decrease in this parameter reduces the retailer inventory storage but less effect on oil distributor inventory. This particular test is conducted to gain insight or understand the effects of carrying more or less inventory.

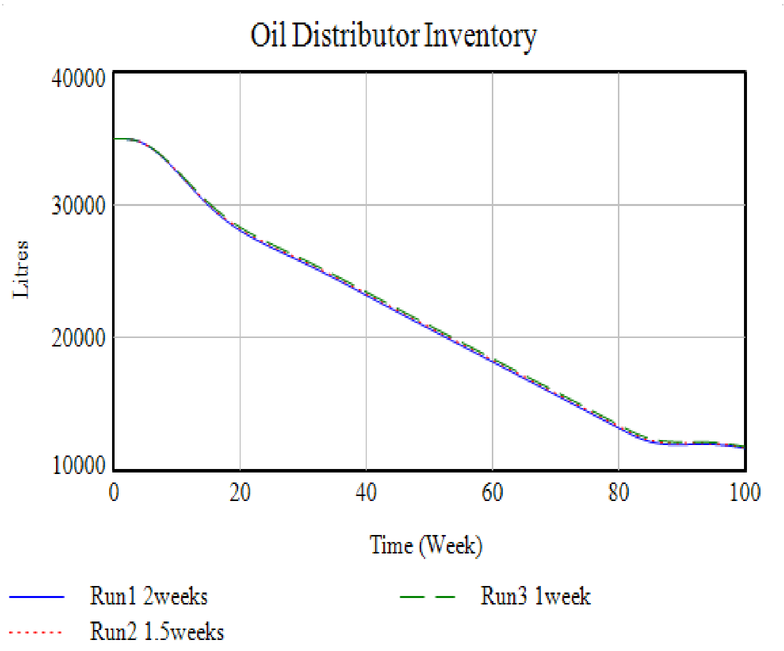


Figure 5.12 (a) Effect of SSC on Oil distributor inventory

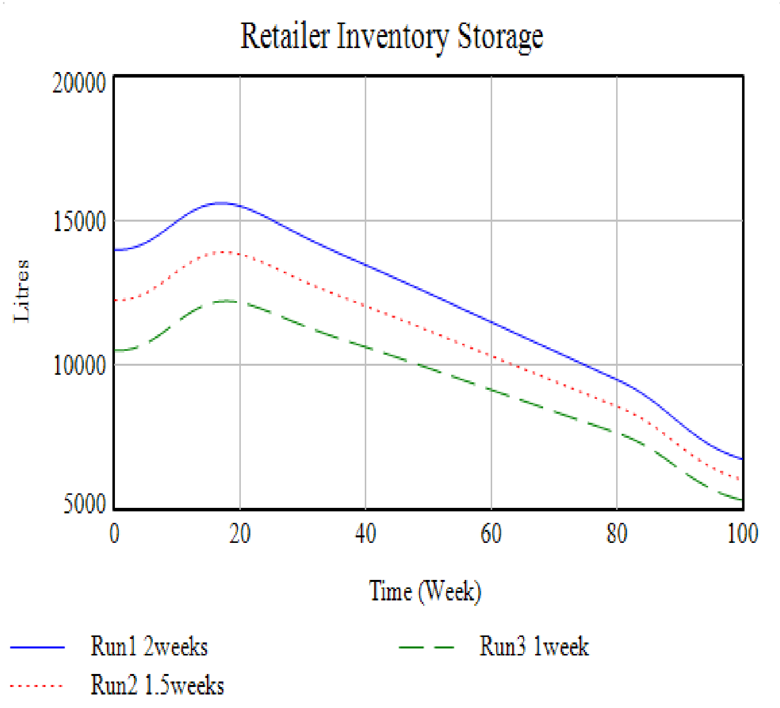


Figure 5.12 (b) Effect of SSC on Retailer inventory Storage

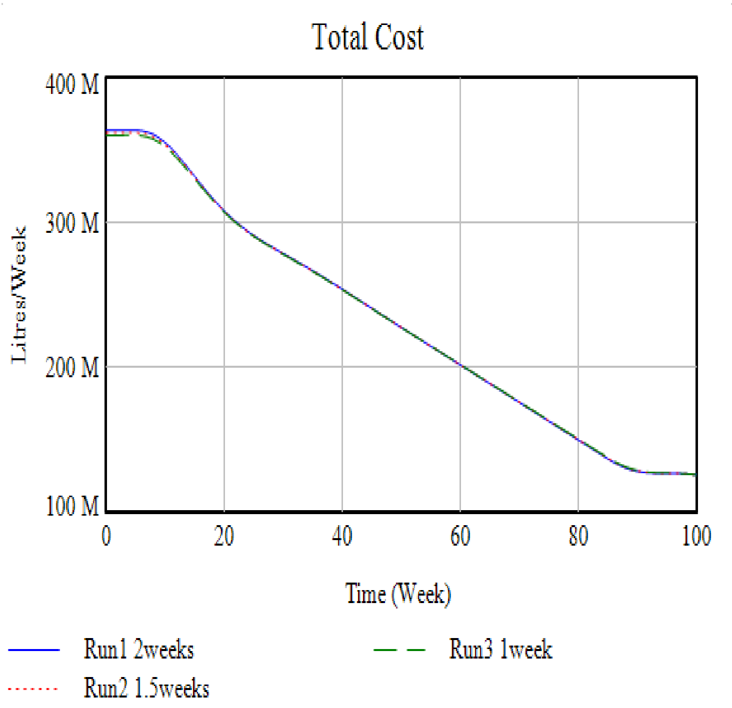


Figure 5.12 (c) Effect of SSC on Total cost

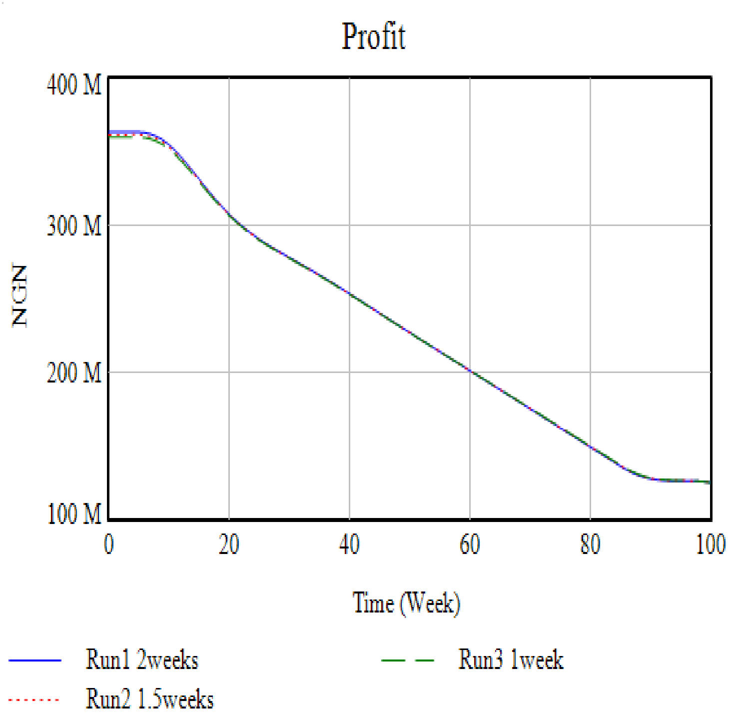


Figure 5.12 (d) Effect of SSC on Profit

Run 1: SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	11626	6728	12541300	12523200
Run 2: SSC = 1.5 weeks				
SD Inventory Model	11687	6016	12536100	12518000
Run 3: SSC = 1 week				
SD Inventory Model	11748	5304	12530900	12512800

Table 5.8 Effect of SSC on ODI, RIS, Total Cost, and Profit

Table 5.8 summarises the result of these runs. Safety stock coverage has less effect on the model output when conducted with a single parameter testing. As seen in the table above, the effect of safety stock coverage has a significant impact on retailer inventory storage but with less or vague impact on oil distributor inventory when this parameter value is reduced. The total cost slightly reduces and little effect on profit after the parameter changes.

5.13 Effect of ROCT and SSC on Low Customer Order Pattern

After running different single parameters test to determine which parameters helps to reduce the unsteady pattern, it was observed during the simulation testing that single parameter testing have a slight influence in reducing the instability in the oil distributor inventory and retailer inventory storage hence, the need for multiple parameter testing. The first observation suggest that a reduction in retailer order cycle time and safety stock coverage leads to lower discrepancy in inventory level on both the oil distributor and retailer inventory storage as **Figures 5.13 (a)** and **(b)** depicts. The results shows that there is a significant decrease in inventory when retailer order cycle time is reduced from 10 weeks, to 8 weeks and 5weeks and SSC is reduced from 2 weeks to 1.5week and 1 week respectively.

Figure 5.13 (c) and **(d)** depicts that when the ROCT and SSC are changed simultaneously the total cost is significantly reduced. This two parameter values have the capability of reducing total cost thereby increasing the profit for the company. **Table 5.9** summarises the oil distributor inventory, retailer inventory storage, total cost and profits.

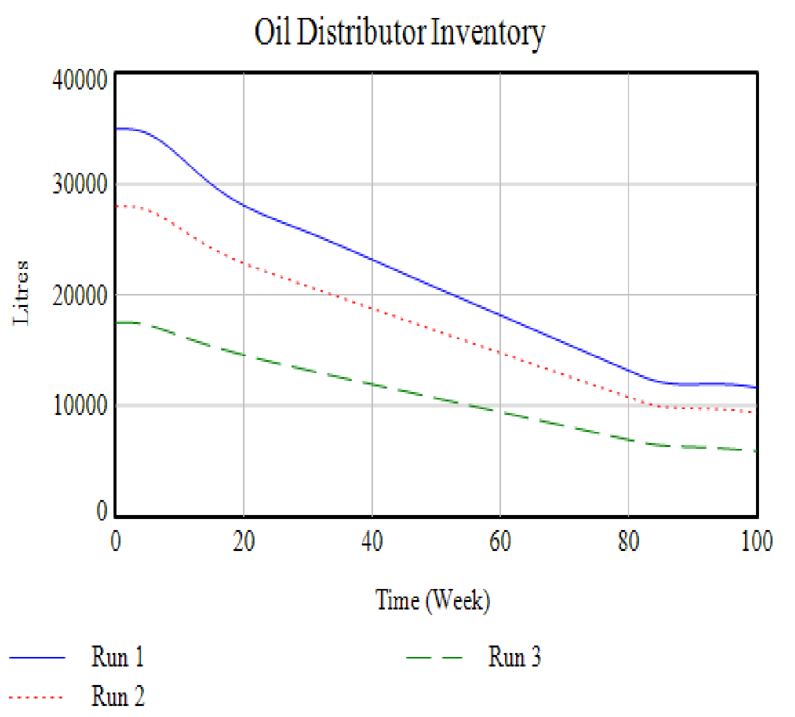


Figure 5.13 (a) Effect of ROCT and SSC on Oil distributor inventory

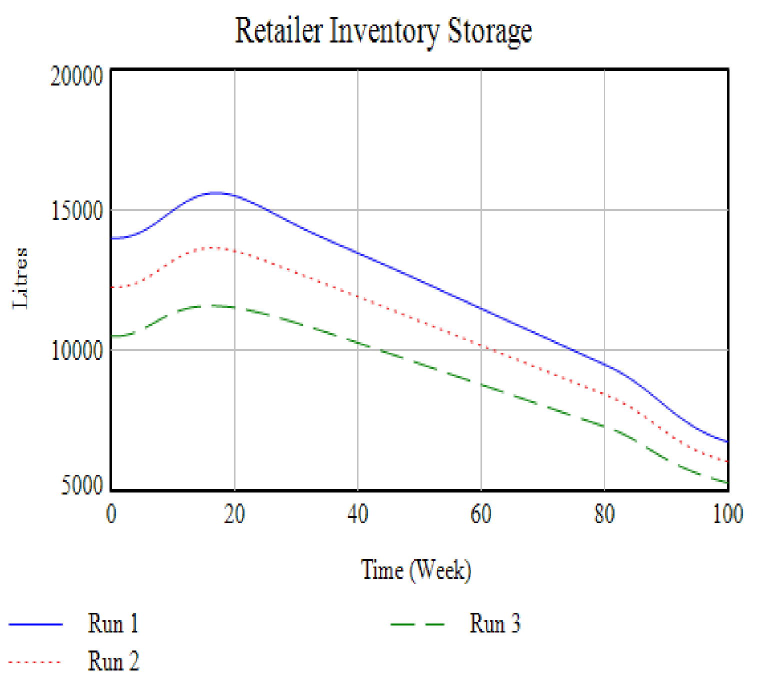


Figure 5.13 (b) Effect of ROCT and SSC on Retailer Inventory storage

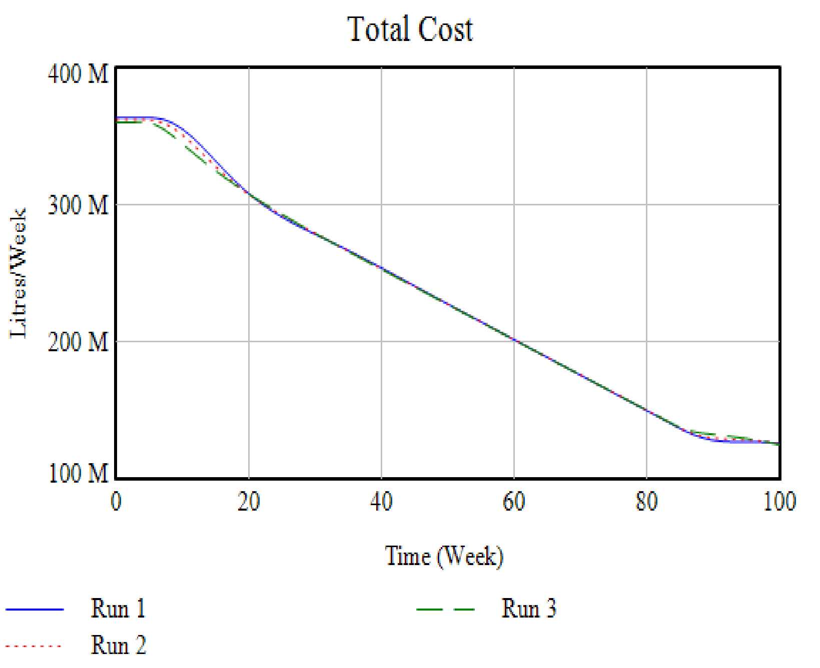


Figure 5.13 (c) effect of ROCT and SSC on Total cost

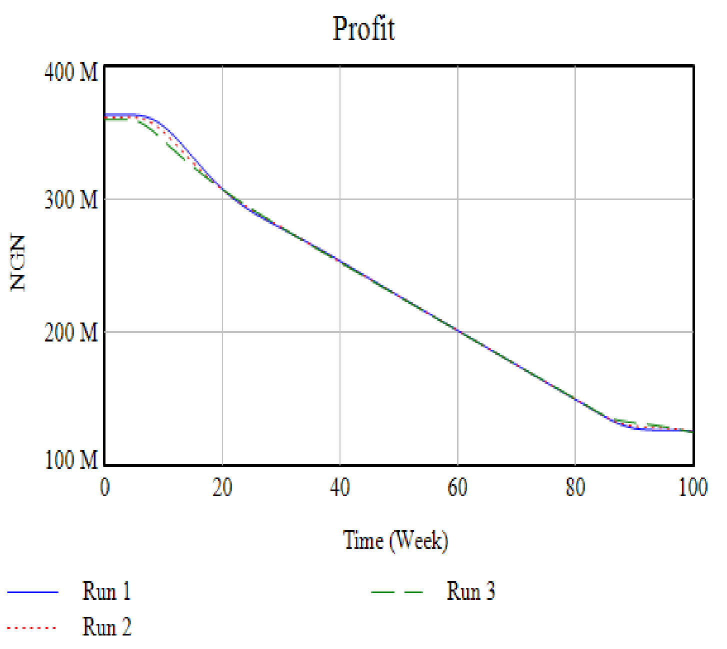


Figure 5.13 (d) effect of ROCT and SSC on Profit

Run 1: ROCT = 10 weeks and SSC = 2 weeks				
	ODI	RIS	Total Cost	Profit

SD Inventory Model	11626	6728	12541300	12523200
Run 2: ROCT = 8 weeks and SSC = 1.5 weeks				
SD Inventory Model	9335	6021	12522500	12504400
Run 3: ROCT = 5 weeks and SSC = 1 week				
SD Inventory Model	5883	5262	12457100	12439000

Table 5.9 Effect of ROCT and SSC on ODI, RIS, TOTAL COST AND PROFIT

Smaller values of these parameters lead to reduced response to the demand input, so more stability emerge.

In other words, the system becomes more unstable as time passes. In order to prevent unstable behaviours, the manager who designed the system with inherent delays should maintain the delay times as short as possible. Another interesting result of sensitivity analysis is retailer order cycle time parameter. Like other behaviour measures, safety stock coverage (SSC) and retailer order cycle time (ROCT) is found as the most significant parameters.

Furthermore, lesser value of the parameter of retailer order cycle time indicates that systems, which have smaller retailer order cycle time are more robust to uncertainties in the system. Smaller size sensitivity simulations are used to also verify the results.in **Table 5.9.**

5.14 ANALYSIS OF COMPANY B

The three demand pattern selected for the test represents the ordering projections. The ordering patterns are presented in **figures 5.14 a, b and c**.

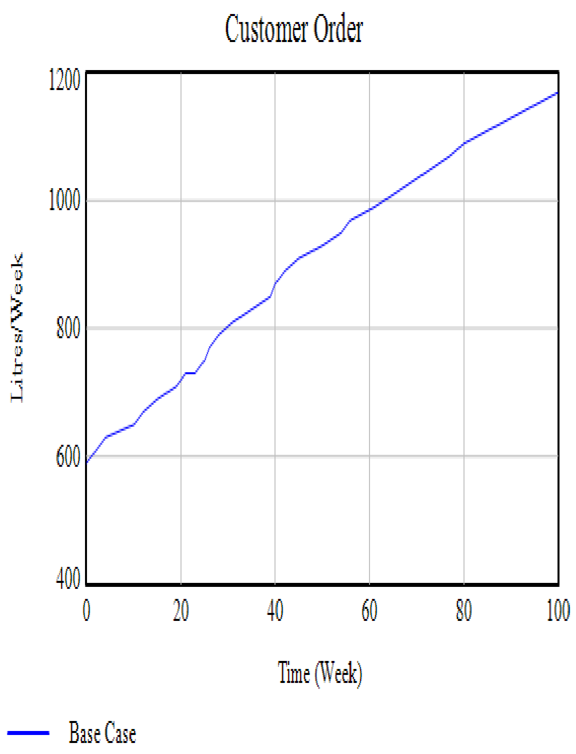


Figure 5.14 (a) Business as usual

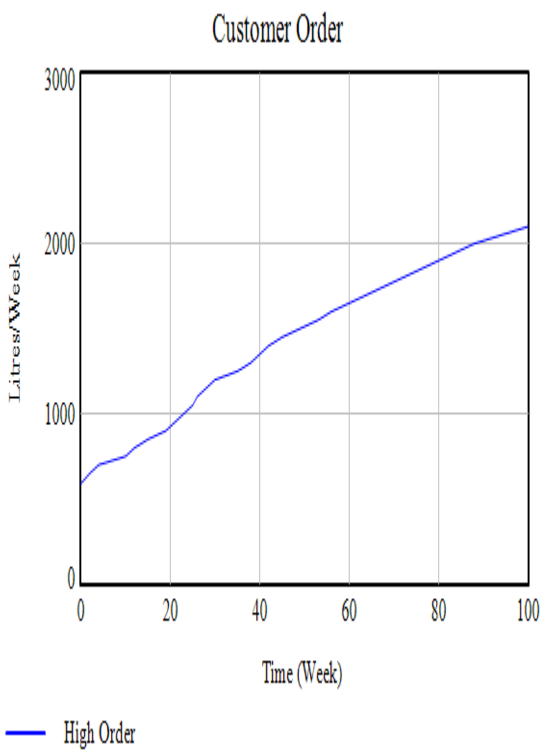


Figure 5.14 (b) High order

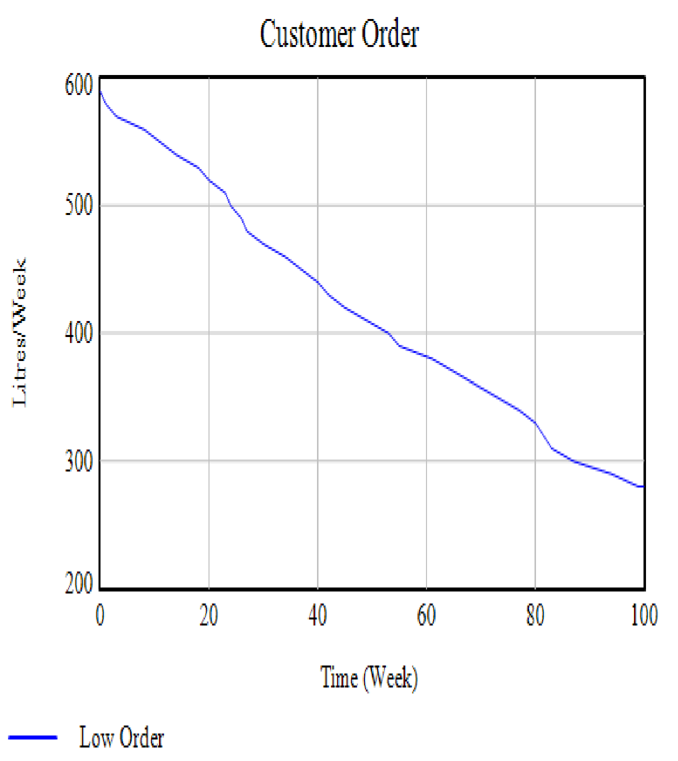


Figure 5.14 (c) Low orders

The ordering patterns as displayed in **Figures 5.14 a, b and c** starts from week **0** and ends at the final simulation run of week **100**. The first Figure displays the base case where the customer order follows the normal business process. **Figure 5.14b** displays the high order where the customer order keeps increasing from week **0** to the final simulation time of week 100. **Figure 5.14c** displays the low ordering pattern which signifies the customer order decreasing from the initial time of week **0** to the final simulation time of week **100.**

This investigation used different ordering patterns to show trends across the policy options and determine how each pattern affected the model's response. The purpose is to generate an insight and understanding to the problem in the company's supply chain.

5.15 Effect of Base Case Ordering Pattern on Inventory Oil Distributor Inventory, Retailer Inventory Storage, Total Cost and Profit

Figures 5.15 (a), and (b), shows variabilities in the patterns of the oil distributor inventory and retailer inventory storage which is a dysfunctional occurrence in company's supply chains, **Figures 5.15 (c) and (d)** presents the total cost and profit for these ordering patterns. The lead-time interferences, supply chain delays, lack of coordination, actual customer consumption, and gaps in echelon-level ordering are the main causes of the uncertainty in the inventory pattern. As shown in the graphs, customer demand uncertainty results in upstream demand variations that eventually intensify as tidal waves. Due to inventory accumulation, waste, and obsolescence, this effect may result in significant increases in total cost with a decreased profit. One of the key signs of supply chain inefficiencies in the organisation is these demand uncertainties.

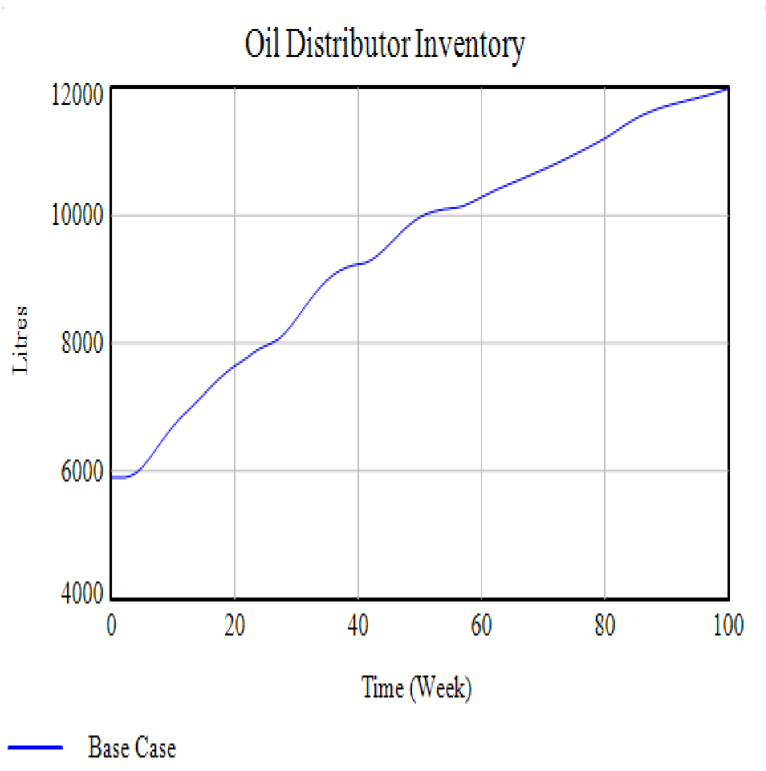


Figure 5.15(a) Oil Distributor Inventory

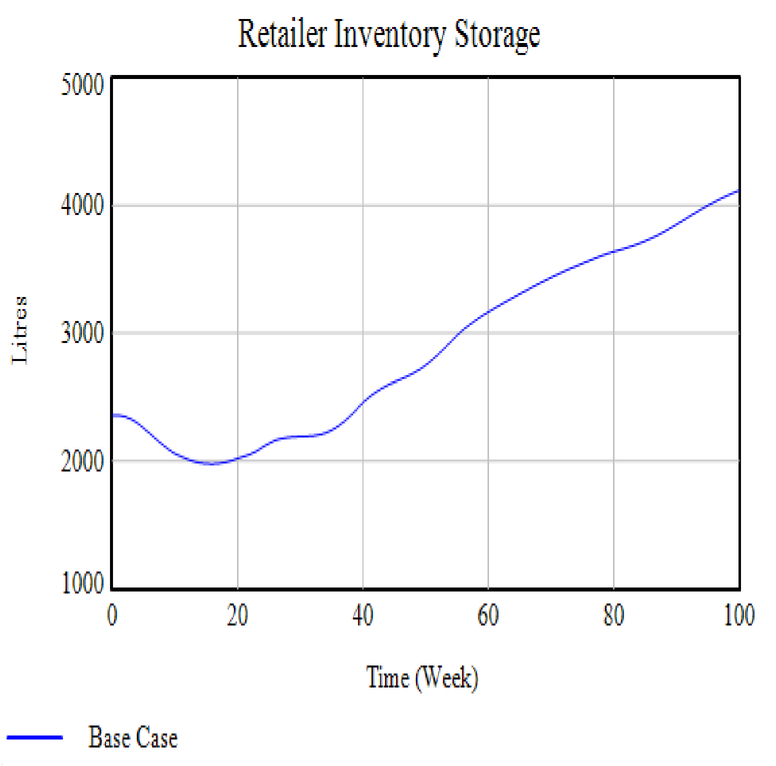


Figure 5.15 (b) Retailer Inventory Storage

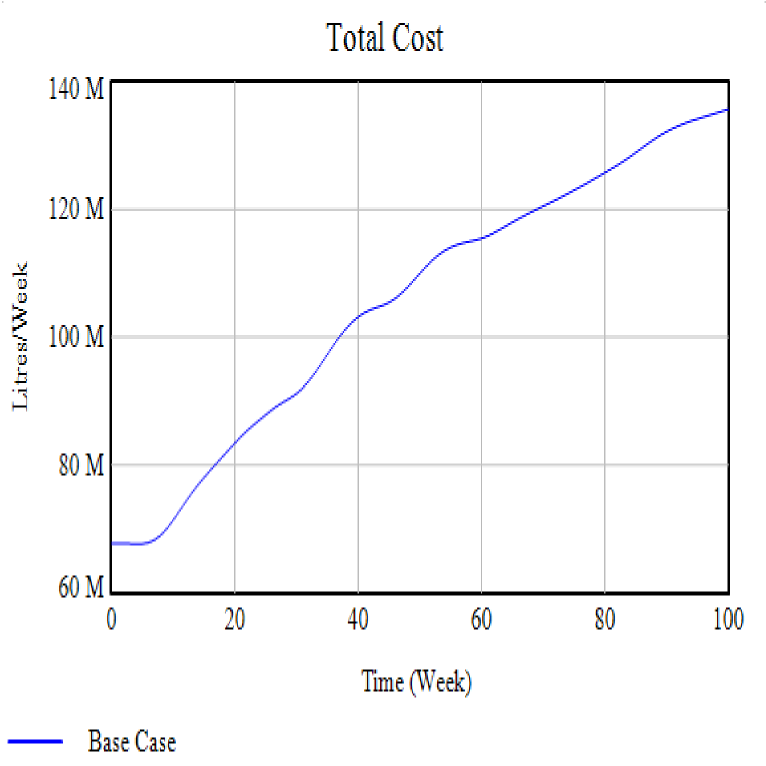


Figure 5.15 (c) Total Cost

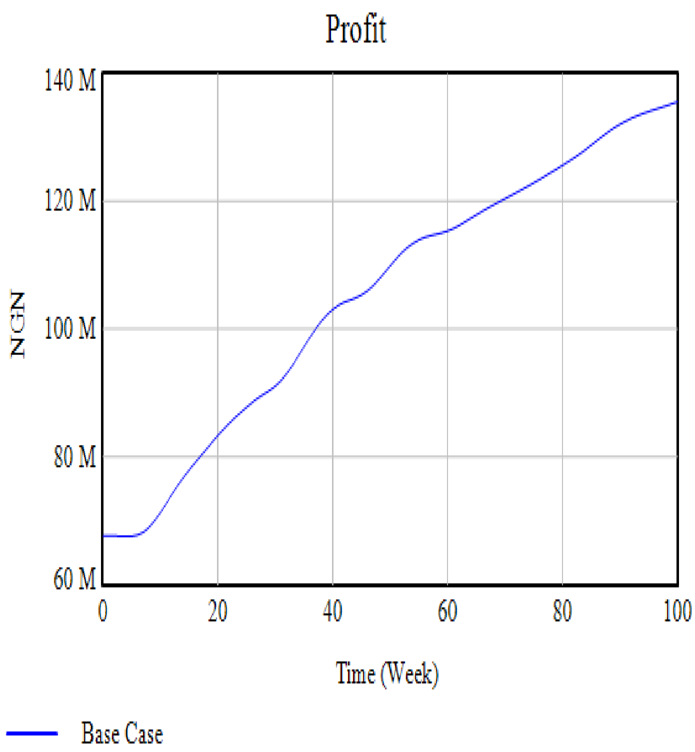


Figure 5.15 (d) Profit

5.16 Effect of Retailer Order Cycle Time on Base Case

The model parameters that was initially used to test the model under the future ordering projection situations is known as the Base case. The supply chain system behaviour was obtained as the base case through simulating the system operations under the business-as-usual conditions. It was then used for the comparison of the inventory levels and cost under this scenario. This first simulation run has been carried out by changing the values of retailer order cycle time at the same time leaving other parameter values as base case. The aim is to gain a proper perception and understanding on the Retailer Order Cycle Time (ROCT) on the inventory level and cost. **Figures 5.16 a, b, c** and d shows the effect of oil distributor inventory, retailer inventory storage, cost and profit.

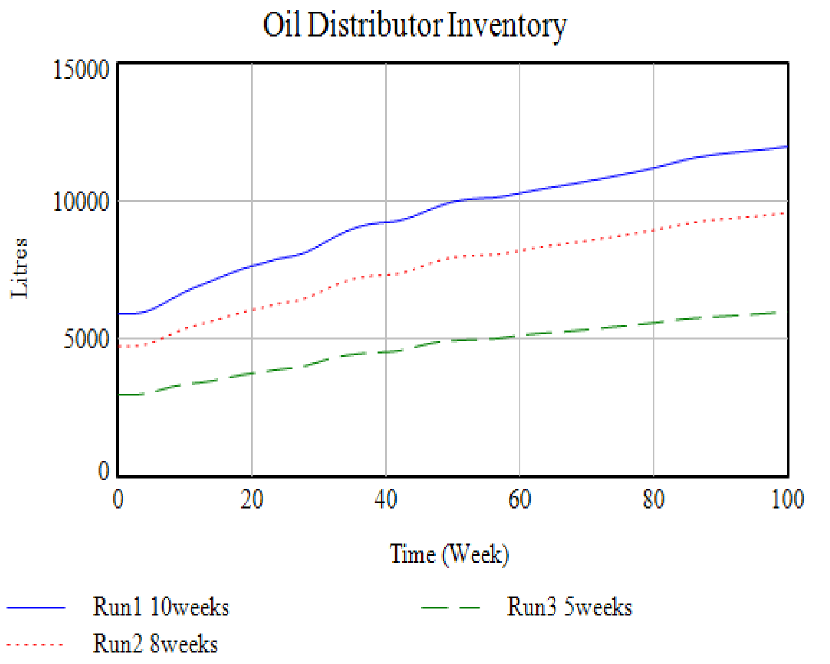


Figure 5.16 (a) effect of ROCT on Oil distributor inventory

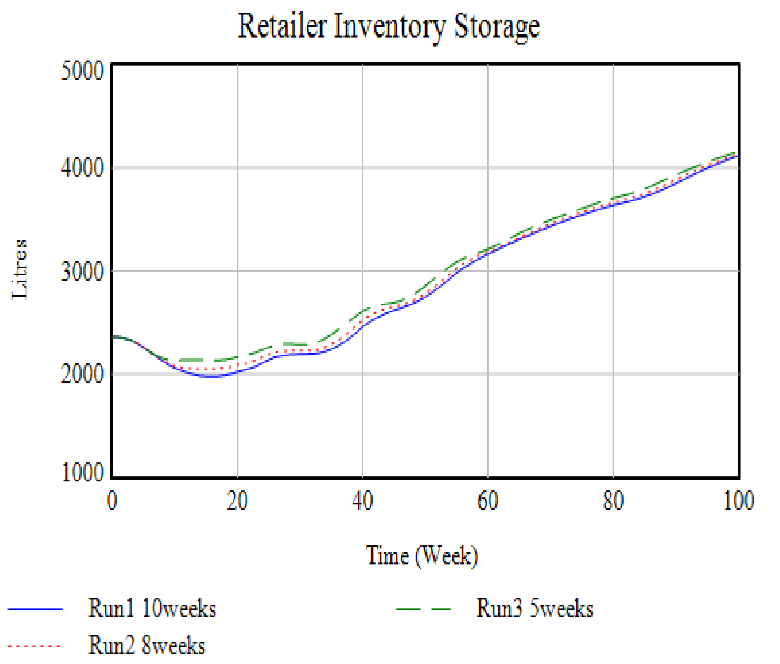


Figure 5.16 (b) Effect of ROCT on Retailer inventory storage

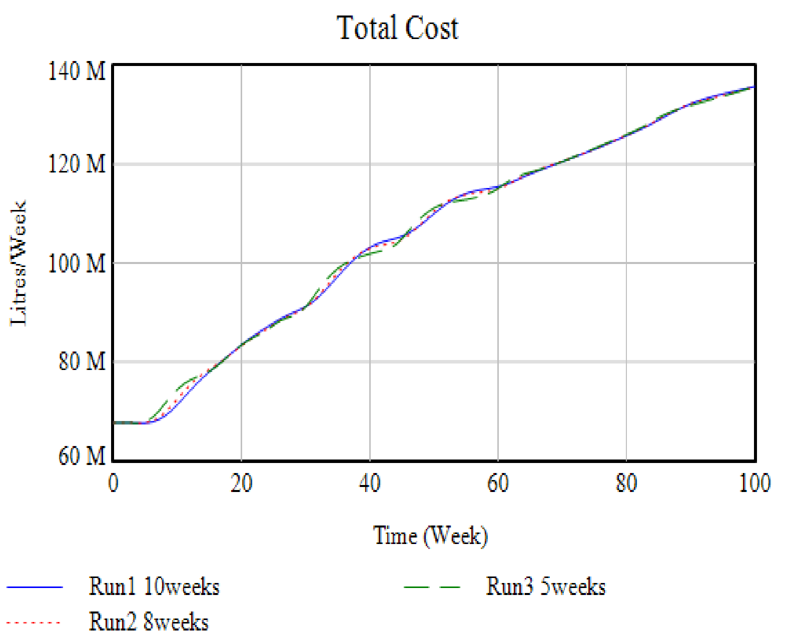


Figure 5.16 (c) Effect of ROCT on Total cost

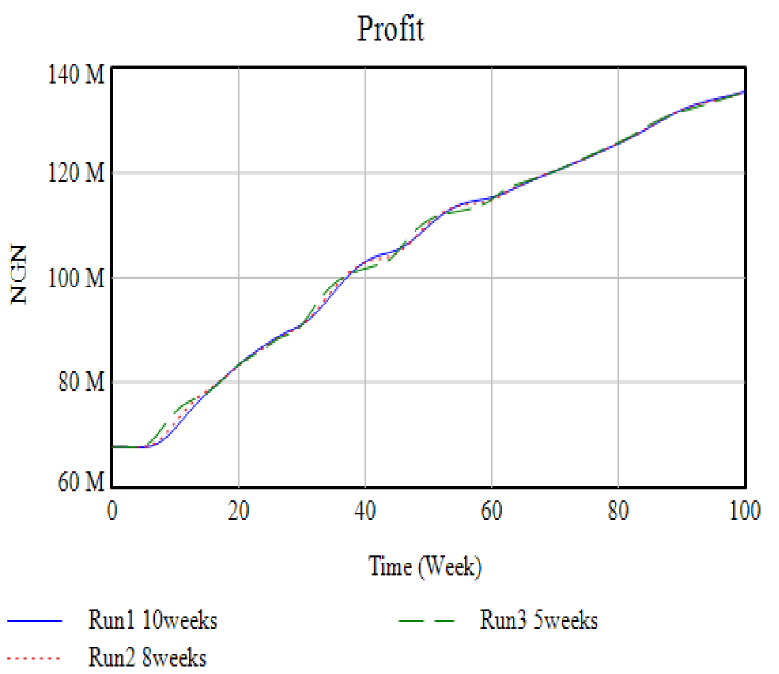


Figure 5.16 (d) Effect of ROCT on Profit

As **Figures 5.16** suggests, the effect of retailer order cycle time has an important impact on oil distributor inventory but with less impact on retailer inventory storage when this parameter

ROCT value is reduced. The total cost remains high and a minimal profit after the parameter changes. **Table 5.10** summarises the result of these runs. Retailer order cycle time has less effect on the model output when conducted with a single parameter testing.

Run 1: ROCT = 10 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	11994	4120	13576600	13559600
Run 2: ROCT = 8 weeks				
SD Inventory Model	9581	4135	13569200	13552200
Run 3: ROCT = 5 weeks				
SD Inventory Model	5974	4161	13576200	135559300

Table 5.10 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

5.17 Effect of Safety Stock Coverage on Base Case

The safety stock coverage parameter determines how many weeks the worth of inventory the manager would like to hold available in stock. This simulation is conducted to understand the effects of carrying more or less inventory. In other to access the number of inventories in the model, this test has been subjected to the base case demand pattern. This first simulation run has been carried out by changing the values of safety stock coverage at the same time leaving other parameter values as base case. The base case value of safety stock is 2 weeks. **Figures 5.17 a, b, c, and d** shows the effect of oil distributor inventory, retailer inventory storage, cost and profit.

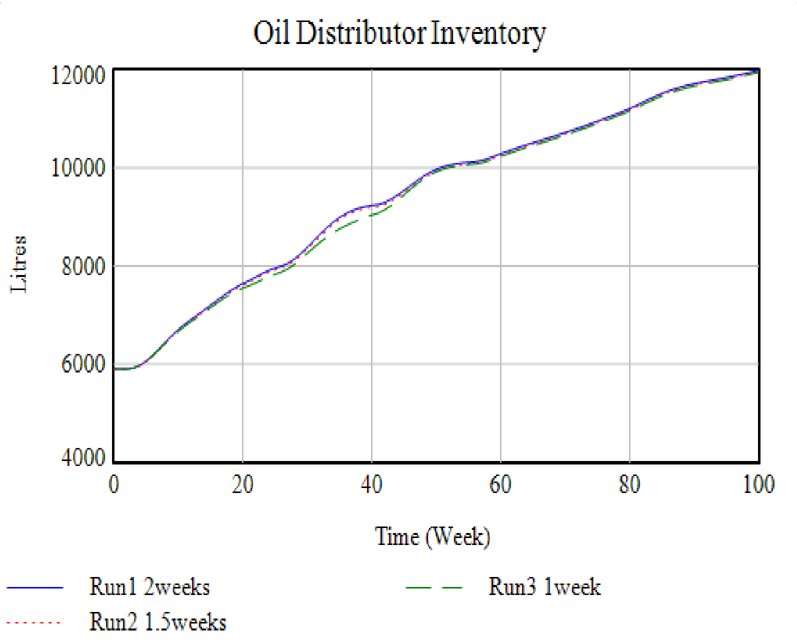


Figure 5.17 (a) Effect of SSC on Oil distributor inventory

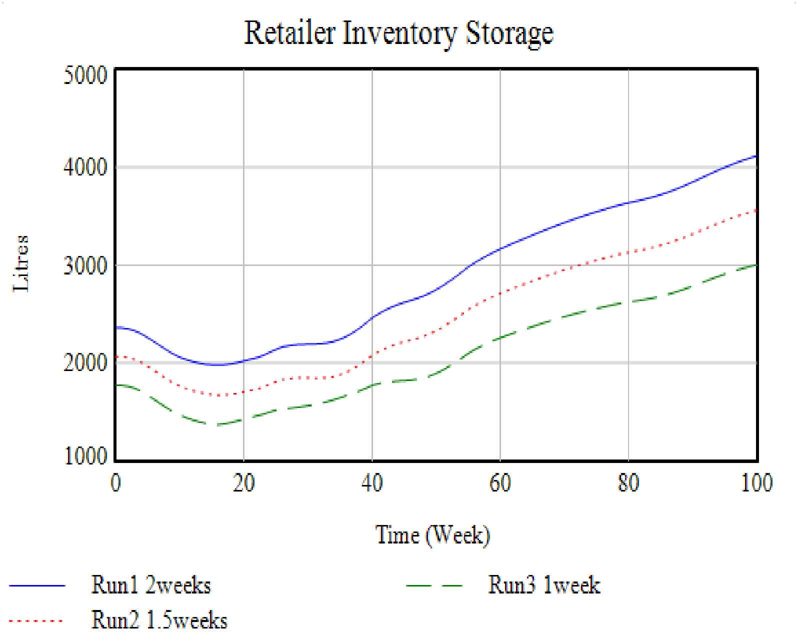


Figure 5.17 (b) effect of SSC on Retailer inventory storage

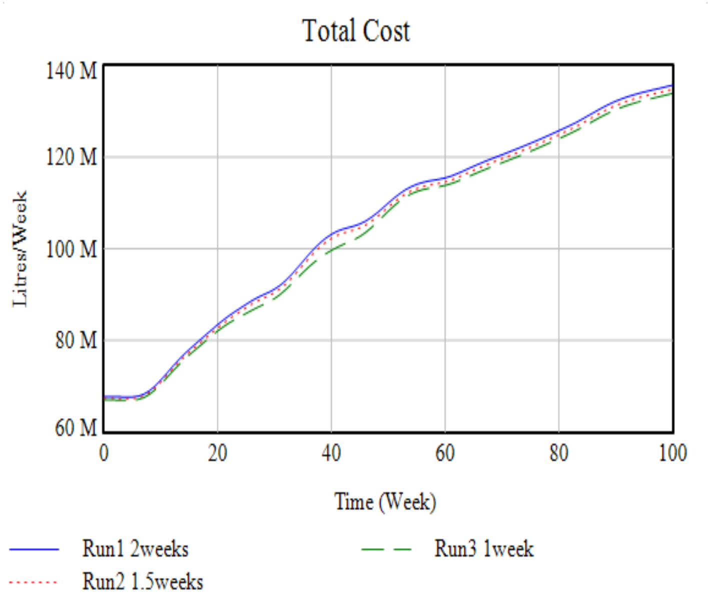


Figure 5.17 (c) Effect of SSC on Total cost

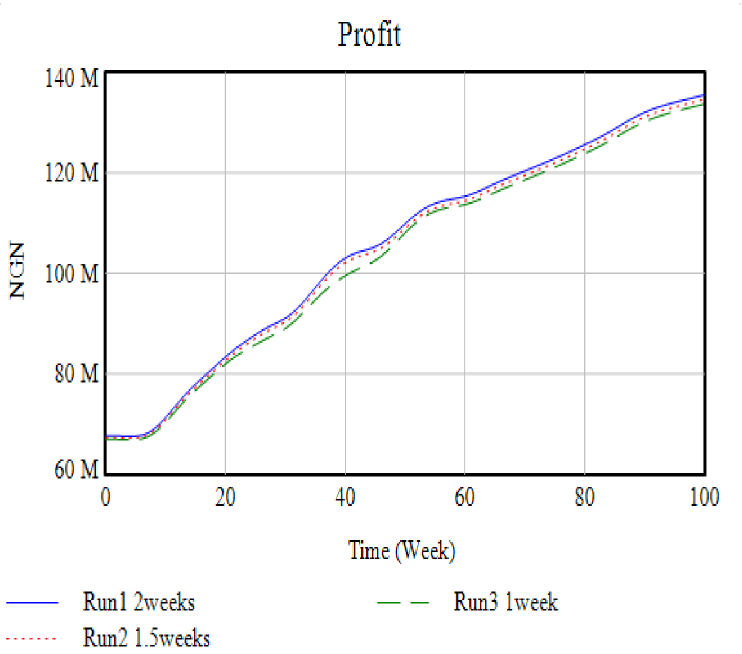


Figure 5.17 (d) effect of SSC on Profit

As **Figures 5.17** suggests, the effect of safety stock coverage has a substantial influence on retailer inventory storage but with less or vague influence on oil distributor inventory when this parameter value is reduced. The total cost slightly reduces after the parameter changes. **Table 5.11** summarises the result of these runs. Safety stock coverage has less effect on the model output when conducted with a single parameter testing.

Run 1: SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	11994	4120	13576600	13559600
Run 2: SSC = 1.5 weeks				
SD Inventory Model	11974	3563	13486700	13469800
Run 3: SSC = 1 week				
SD Inventory Model	11954	3006	13396800	1.3379800

Table 5.11 Effect of SSC on ODI, RIS, TOTAL COST AND PROFIT

5.18 Effect of ROCT and SSC on Base Case

As carried out in the first case company, after carrying out different single parameters test to determine which parameters helps to reduce the unsteady pattern of the model, the results suggests that single parameter testing does not have a huge effect in reducing the unsteadiness and instabilities hence the need to carry out multiple parameter testing. The first observation suggests that a reduction in retailer order cycle time and safety stock coverage leads to lower discrepancy and inventory level on both the oil distributor and retailer inventory storage as **figure 5.18 (a) and (b)** depicts.

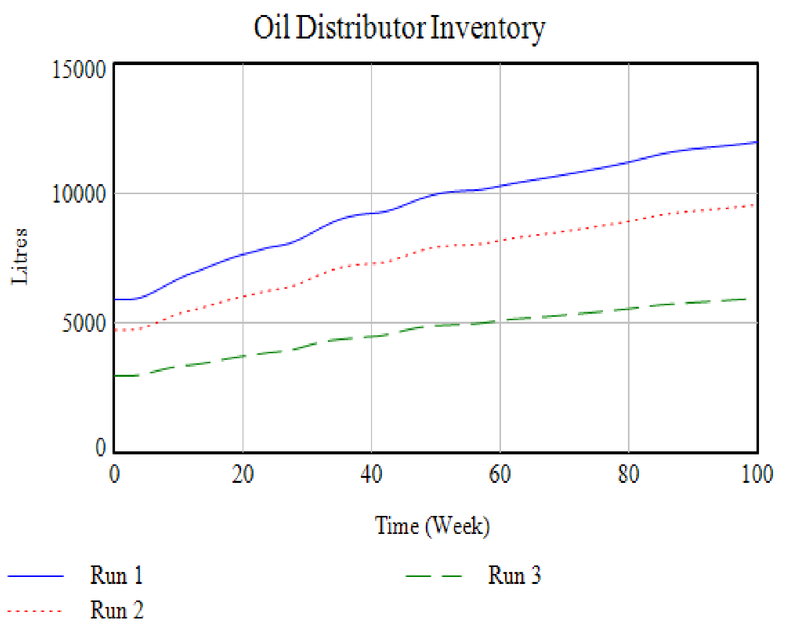


Figure 5.18 (a) Effect of ROCT and SSC on Oil distributor inventory

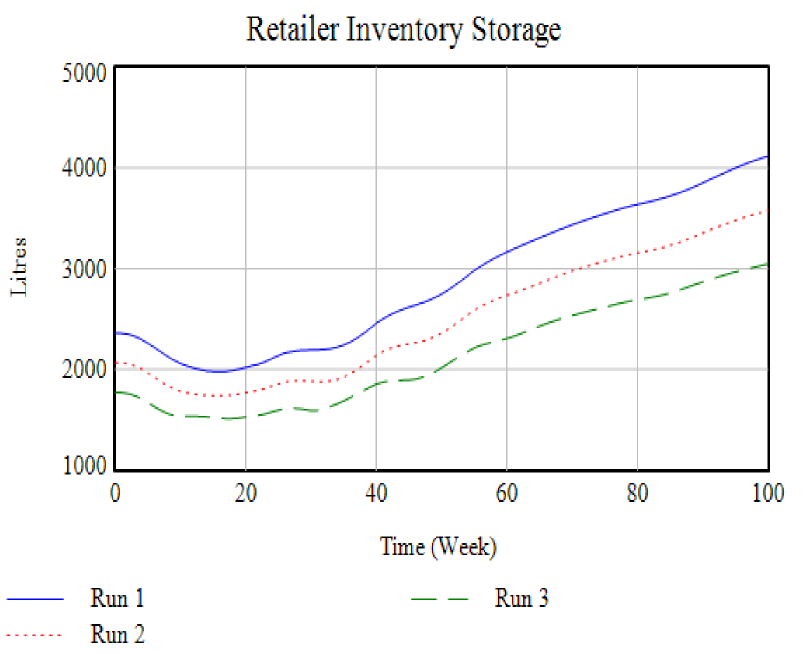


Figure 5.18 (b) Effect of ROCT and SSC on Retailer Inventory Storage

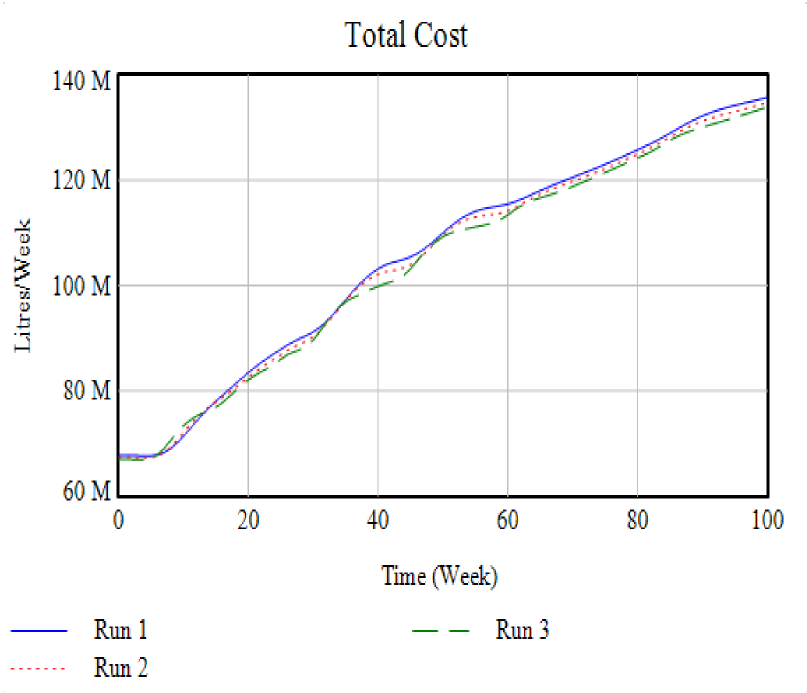


Figure 5.18 (c) Effect of ROCT and SSC on Total cost

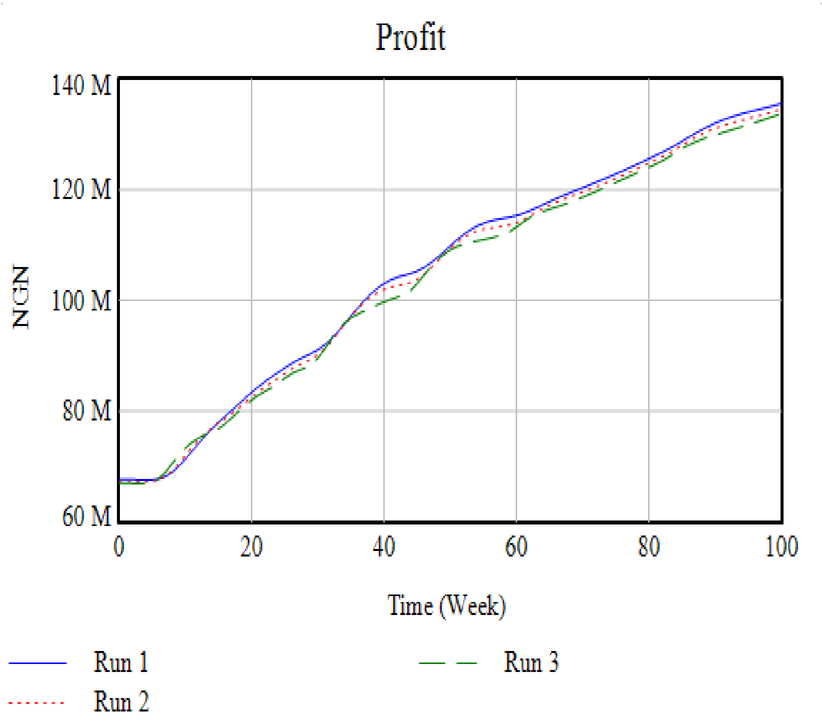


Figure 5.18 (d) Effect of ROCT and SSC on Profit

Run 1: ROCT = 10 weeks and SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	11994	4120	13576600	13559600
Run 2: ROCT = 8 weeks and SSC = 1.5 weeks				
SD Inventory Model	9565	3578	13479400	13462400
Run 3: ROCT = 5 weeks and SSC = 1 week				
SD Inventory Model	5953	3049	13396100	13379100

Table 5.12 Effect of ROCT and SSC on ODI, RIS, TOTAL COST AND PROFIT

The results shows that there is a significant decrease in oil distributor inventory when the ROCT =10 weeks, 8 weeks and 5weeks and SSC = 2 weeks, 1.5week and 1 week. **Figure 5.18 (c) and (d)** depicts that when the ROCT and SSC are changed simultaneously the total cost is reduced. These two parameter values have the capability of reducing total cost thereby increasing the profit for the company. **Table 5.12** summarises the inventory levels, total cost and profits.

In addition, when reducing the safety stock coverage without reducing the retailer order cycle time, the model has less effect on the model behaviour. If the retailer order cycle time is left as the base value, the customer orders cannot be met due to additional difference between the desired and actual inventory required to satisfy customer order therefore, safety stock coverage might not be enough, the outcome is that the seller is not able to meet client need if there is any kind of disruption or delay in the distribution channel.

5.19 Effect of High Order Pattern on Inventory Oil Distributor Inventory and Retailer Inventory Storage, Total Cost, and Profit

The effect of high order pattern is presented in **Fig. 5.19 (a), (b), (c),** and **(d).** Oil distributor inventory increases with an unsteady pattern from the start of the simulation till the end of the test. This is as a result of the high demand coming from the customer; the distributor tends to keep excess stocks to fulfil customer requirements. Retailer inventory storage drops for about 12 weeks before increasing with an unsteady pattern. The system's unfavourable feedback is what led to this. As a result, from this perspective, we may view supply chain management approaches without controlling delays and disruptions; small variations in demand may cause each supply chain member's inventory to be more volatile, and demand may continue to rise in a variety of everyday market demand conditions. **Figures 5.19 (c) and (d)** present the graphs of the total cost and profit. As the graph suggests the total costs and profit remains high as a result of the high inventory level.

The customer order rate is very significant and crucial to the model; hence, it is essential to understand the effect that a sharp increase in the order rate will have on the model's performance. Further simulations is carried out in the next sections as part of this tests involves changing the values of retailer order cycle time and safety stock coverage to see the effect on oil distributor inventory, retailer inventory storage, total cost, and profit.

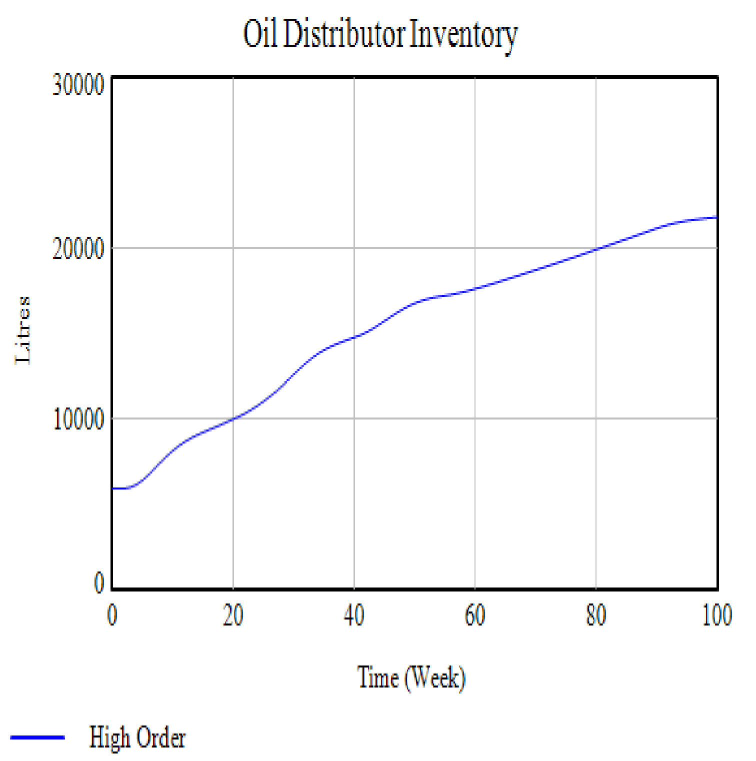


Figure 5.19 (a) Effect of High Order on Oil Distributor Inventory

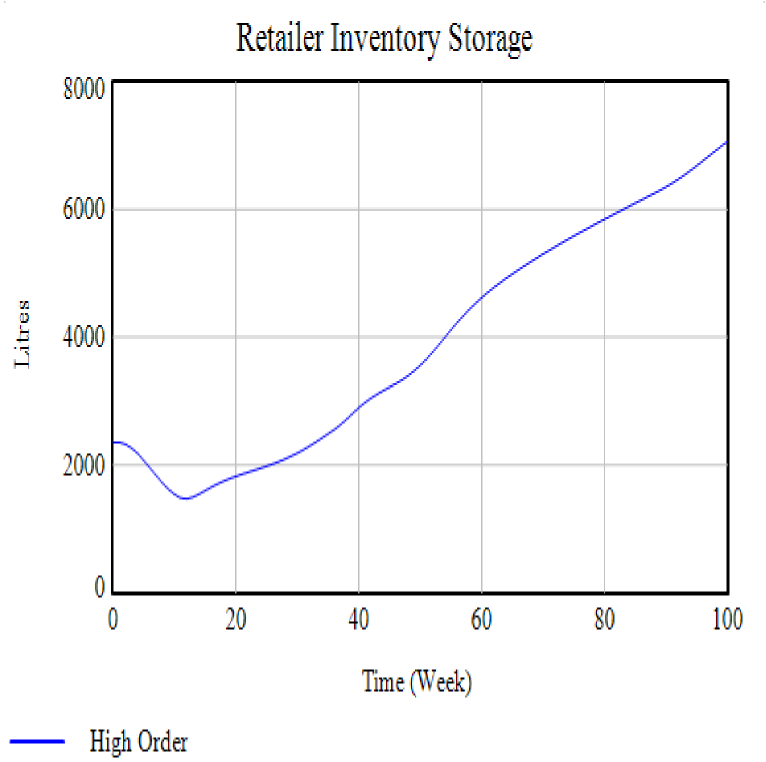


Figure 5.19 (b) Effect of High Order on Retailer Inventory Storage

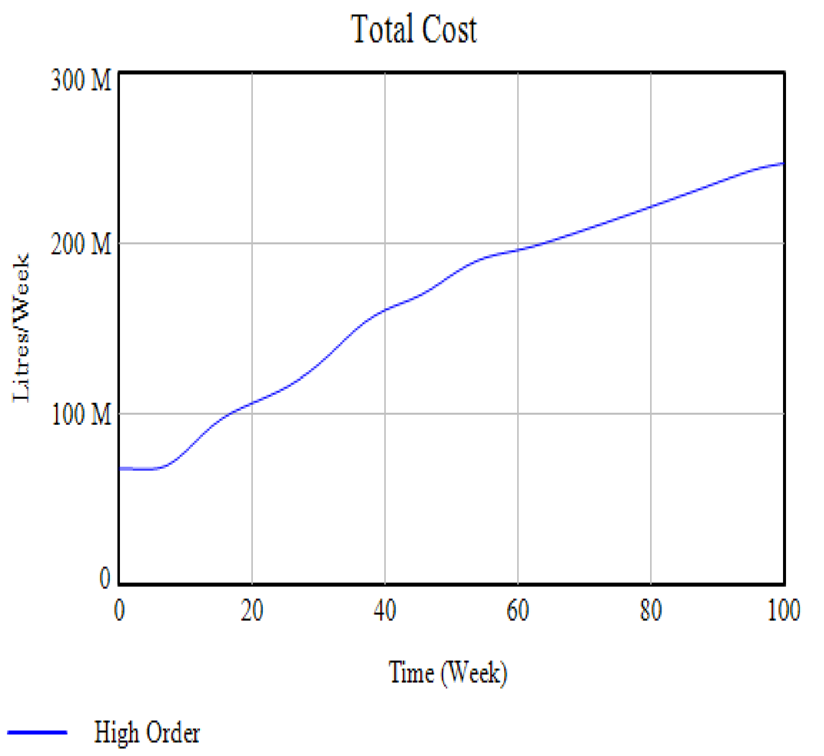


Figure 5.19 (c) Effect of High Order on Total Cost

Figure 5.19 (d) Effect of High Order on Profit

5.20 Effects of Retailer Order Cycle Time on High Order Pattern

The supply chain system behaviour was obtained as high order through simulating the system operations under high order operating condition. It was then used for as a benchmark for the comparison of the inventory levels and cost under this scenario. This first simulation run have been carried out by changing the values of retailer order cycle time at the same time leaving other parameter values as base case. The downstream processes that give rise to the demand risk specifically involve the potential for an unanticipated change in the orders (Gonvales et al., 2005). Order forecasting is important to operations because it helps distributors and retailers plan their purchases, deliveries, and other tasks around anticipated orders. But the discrepancy between anticipated demand and actual orders prevents the business from keeping up with consumer demands or raising the inventory level, and it fluctuates.

The simulation is carried out to address the impact of demand fluctuation and to continuously improve the supply chain. The purpose is to gain insight on the ROCT on the inventory level of distributor, retailer, total cost and profit. **Figures 5.20 a, b, c,** and d shows the effect of oil distributor inventory, retailer inventory storage, cost and profit.

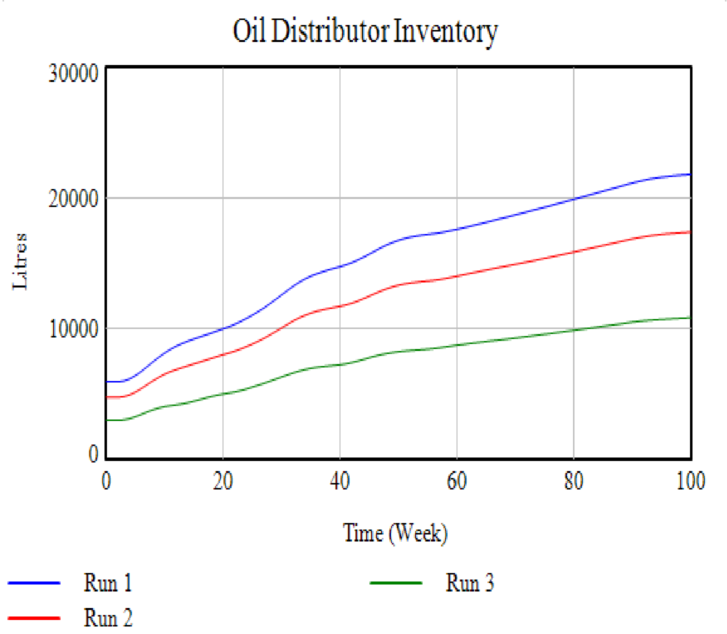


Figure 5.20 (a) effect of ROCT on Oil Distributor Inventory

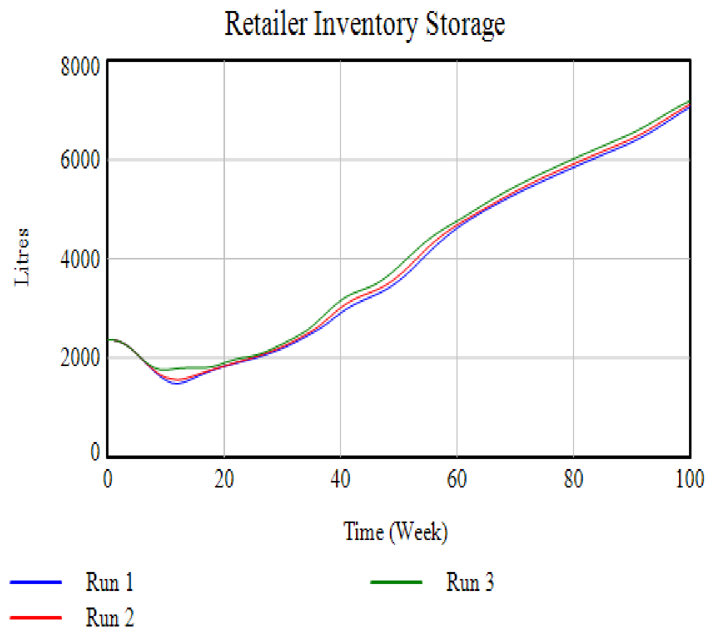


Figure 5.20 (b) effect of ROCT on Retailer Inventory storage

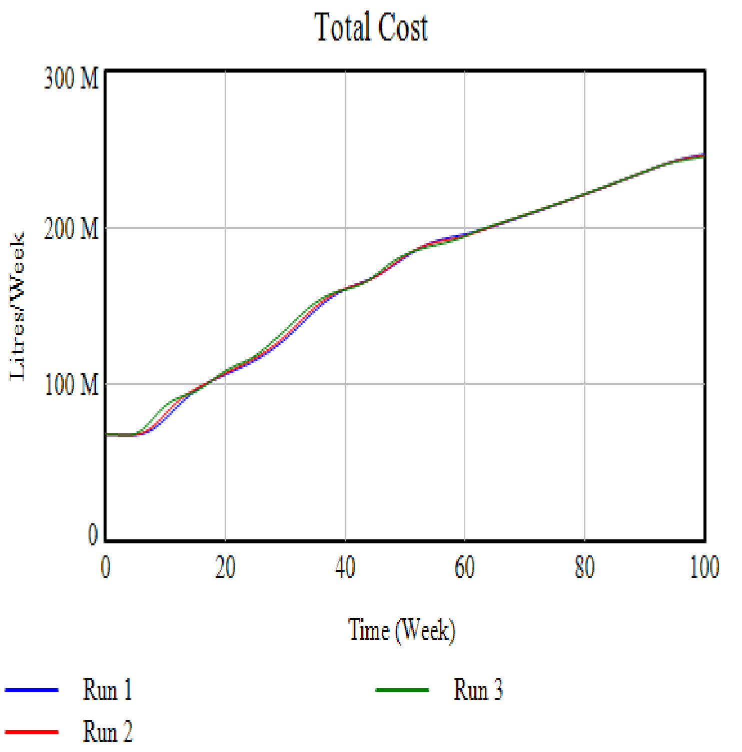


Figure 5.20 (c) effect of ROCT on Total Cost

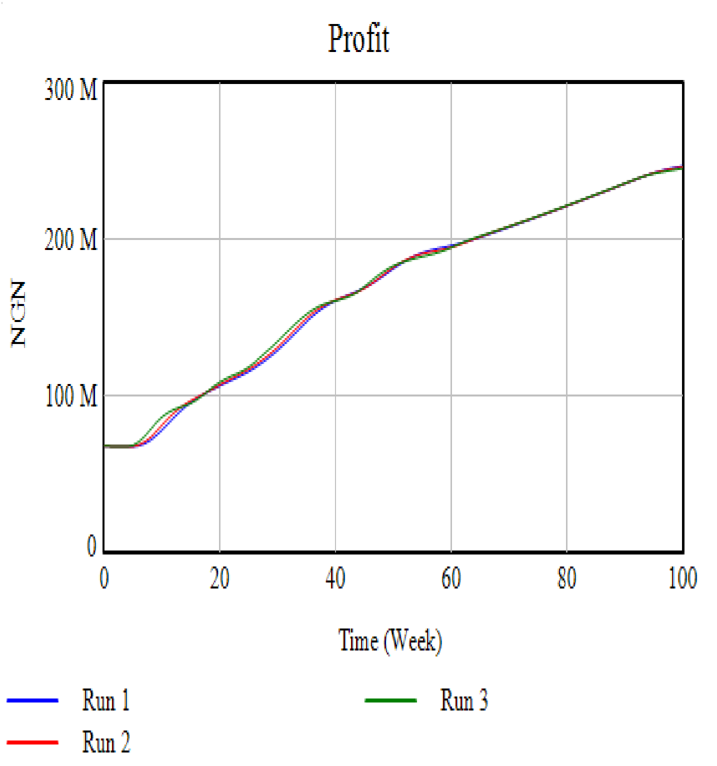


Figure 5.20 (d) effect of ROCT on Profit

In this scenario, the analysis is focused on the fluctuation in terms of increase in customer order. As customer order uncertainty increases there is a need to hold more inventory levels to avoid out of stock situations this would result to high total cost and lower profit. The effect of the increase in customer order is summarised in **Table 5.13**.

Run 1: ROCT = 10 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	21826	7070	2.47162e+08	2.46858e+08
Run 2: ROCT = 8 weeks				
SD Inventory Model	17400	7123	2.46575e+08	2.4627e+08
Run 3: ROCT = 5 weeks				
SD Inventory Model	10828	7193	2.45818e+08	2.45513e+08

Table 5.13 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

The effect of retailer order cycle time has a significant impact on oil distributor inventory but with less or vague impact on retailer inventory storage when this parameter value is reduced. The total cost remains high and a minimal profit after the parameter changes as seen in the **Table 5.13.** Retailer order cycle time has less effect on the model output when conducted with a single parameter testing.

5.21 Effect of Safety Stock Coverage on High Order

The figure suggests that while reducing the safety stock coverage between leads to a lower instability and unsteady behaviours especially the retailer inventory storage in the system, as **Figure 5.21 (b)** suggest The graph of the inventory is less unstable by setting the value of this particular parameter to a low value. This model's sensitivity simulations are carried out under the presumption that the parameter values are increased or decreased by a range of 20% (Sterman, 2000) from the base values. Morecroft 2008 argues that safety stock coverage should be between the range of 1 to 4 weeks based on his production and control model. After sensitivity test these model parameters have been chosen to explore further and to be used for policy design to enhance stability and reduce oscillations safety stock coverage (SSC) and retailer order cycle time (ROCT) as the model is more sensitive to these set of parameters.

The result of the sensitivity analysis in the previous paragraph suggests that when one of the parameters is changed for example retailer order cycle time the sensitivity of the output significantly affects the distributor inventory and less sensitive to the retailer inventory storage and when the safety stock coverage is changed the retailer inventory is more sensitive to this parameter the resulting behaviour is depicted in **Figure 5.21 (b).** According to the previous figures, (SSC) and (ROCT) are the most significant parameters for instability and oscillation why the rest of the parameters are less sensitive to the output of the model.

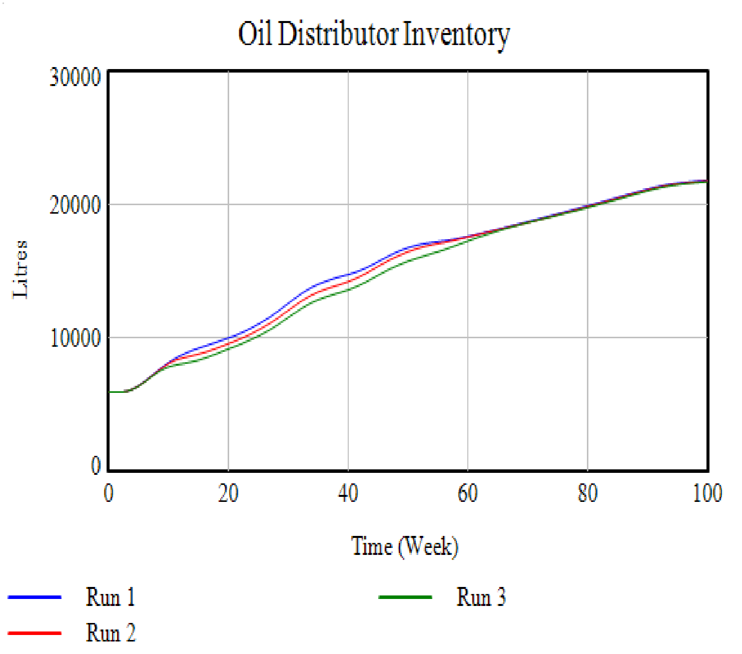


Figure 5.21 (a) Effect of SSC on Oil distributor Inventory

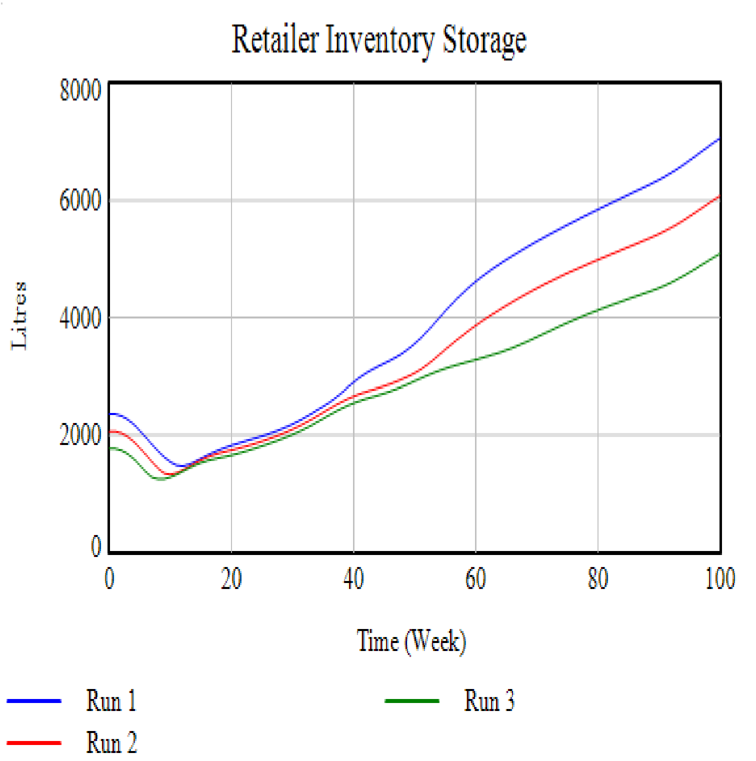


Figure 5.21 (b) Effect of SSC on Retailer Inventory Storage

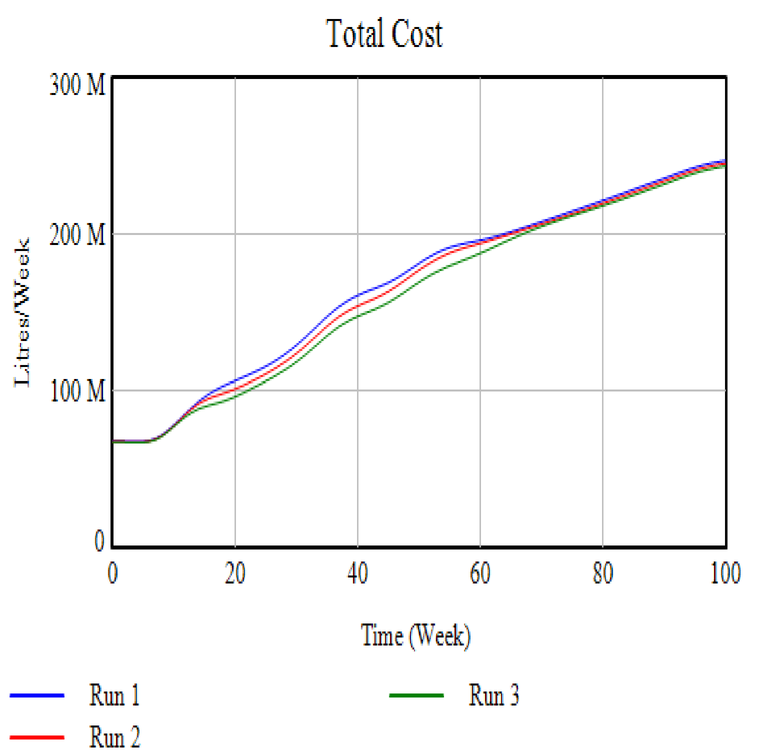


Figure 5.21 (c) Effect of SSC on Total Cost

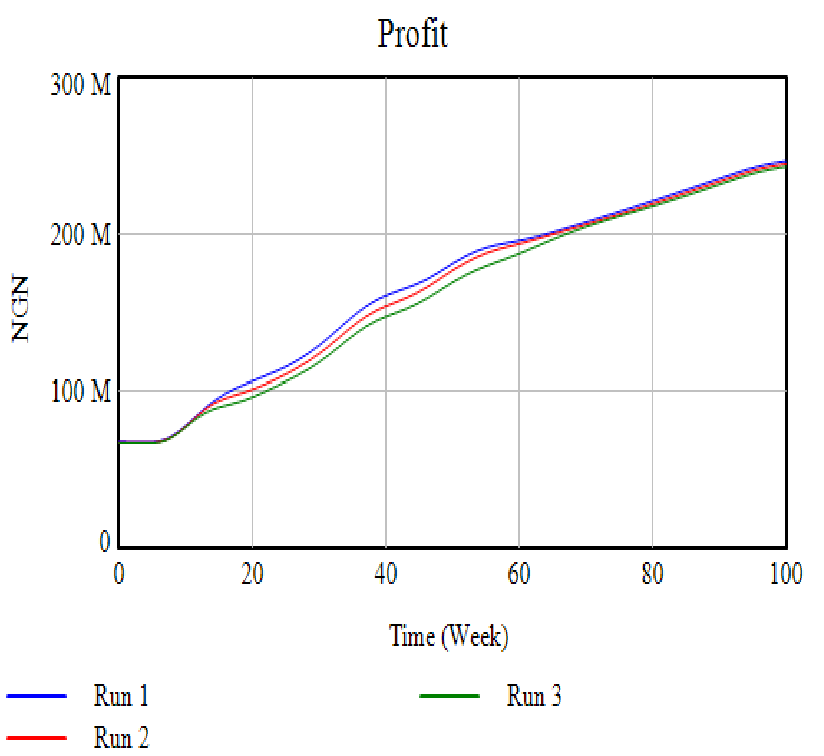


Figure 5.21 (d) Effect of SSC on Profit

Smaller values of these parameters lead to reduced response to the customer order input, so more stability arise. Increasing time makes the system more unstable. Therefore, the manager managing the supply chain including essential delays should keep the delay times as small as possible in order to avoid instability and unsteady behaviours. Like other behaviour measures, retailer order cycle time and safety stock coverage is concluded as the most significant parameters.

Table 5.14 Effect of SSC on ODI, RIS, TOTAL COST AND PROFIT

Run 1: SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	21826	7070	2.47162e+08	2.46858e+08
Run 2: SSC = 1.5 weeks				
SD Inventory Model	21777	6084	2.45379e+08	2.45075e+08
Run 3: SSC = 1 week				
SD Inventory Model	21730	5097	2.43605e+08	2.433e+08

As the table depicts the effect of safety stock coverage has a significant impact on retailer inventory storage but with less or vague impact on oil distributor inventory when this parameter value is reduced. The total cost vaguely reduces and a minimal profit after the parameter changes. **Table 5.14** summarises the result of these runs. Safety stock coverage has less effect on the model output when conducted with a single parameter testing.

5.22 Effect of ROCT and SSC on High Customer Order Pattern

After running different single parameters test to determine which parameters helps to reduce the unsteady pattern, we can assume that single parameter testing does not have a huge influence in reducing the oscillation hence the need for multiple parameter testing. The first observation suggests that a reduction in retailer order cycle time and safety stock coverage leads to lower discrepancy and inventory level on both the oil distributor and retailer inventory storage as **figure 5.22 (a) and (b)** depicts. The results shows that there is a significant decrease in inventory when the ROCT =10 weeks, 8 weeks and 5weeks and SSC = 2 weeks, 1.5week and 1 week.

Figure 5.22 (c) and (d) depicts that when the ROCT and SSC are changed simultaneously the total cost is reduced. These two parameter values have the capability of reducing total cost thereby increasing the profit for the company. **Table 5.15** summarises the inventory levels of oil distributor, retailer storage, total cost and profits.

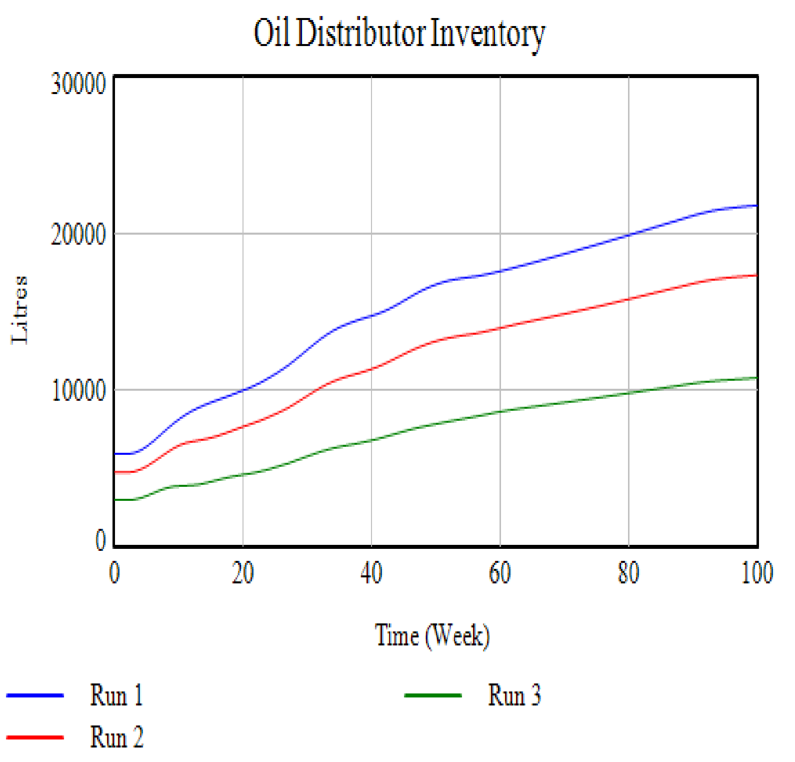


Figure 5.22 (a) Effect of ROCT and SSC on Oil distributor inventory

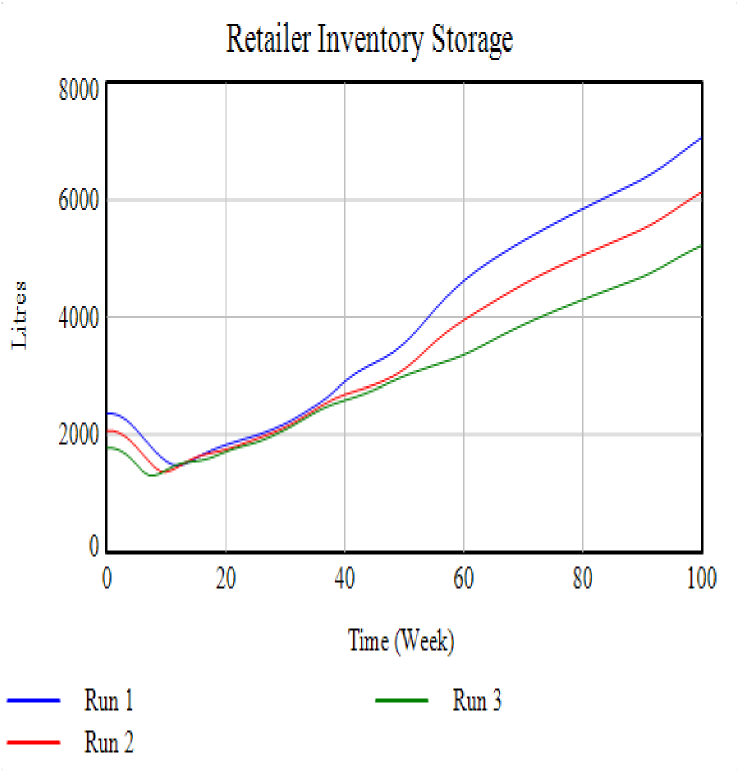


Figure 5.22 (b) Effect of ROCT and SSC on Retailer inventory storage

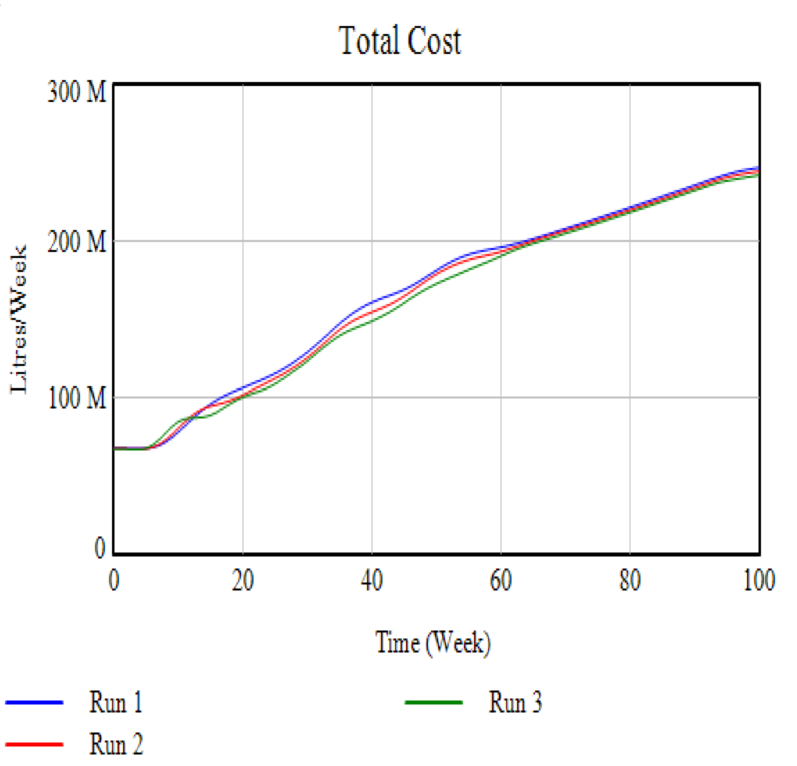


Figure 5.22 (c) Effect of ROCT and SSC on Total Cost

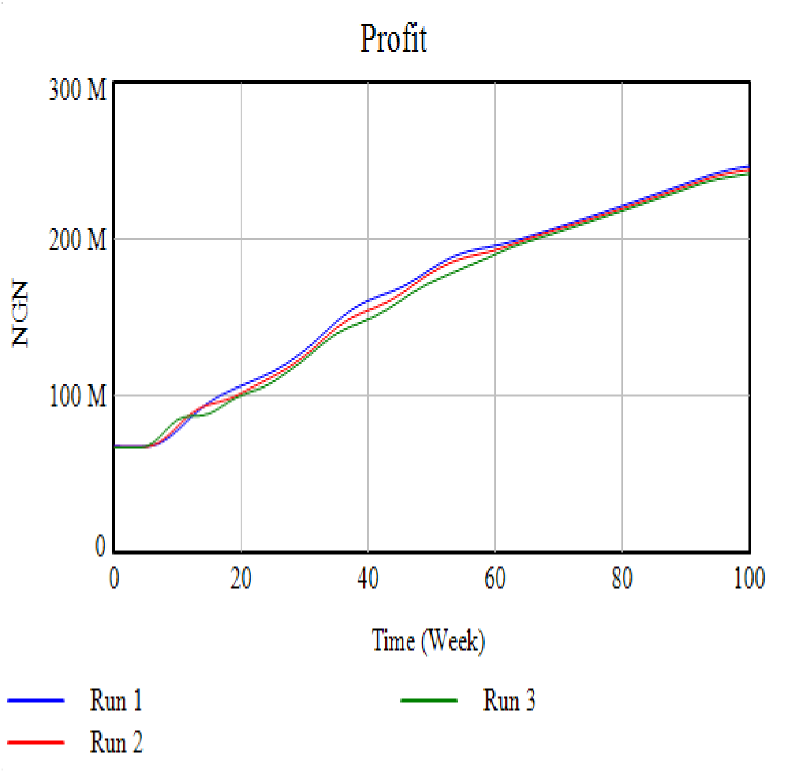


Figure 5.22 (d) Effect of ROCT and SSC on Profit

Run 1: ROCT = 10 weeks and SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	21826	7070	2.47162e+08	2.46858e+08
Run 2: ROCT = 8 weeks and SSC = 1.5 weeks				
SD Inventory Model	17361	6138	2.44802e+08	2.44490e+08
Run 3: ROCT = 5 weeks and SSC = 1 week				
SD Inventory Model	10778	5225	2.42311e+08	2.42006e+08

Table 5.15 Effect of ROCT and SSC on ODI, RIS, Total Cost and Profit

According to the analysis, increasing retailer order cycle time makes the model more unstable and unsteady. Like other behaviour measures, retailer order cycle time and safety stock coverage is concluded as the most significant parameters that improves the policy.

Furthermore, smaller value of the parameter of retailer order cycle time indicates that systems, which have smaller retailer order cycle time, are more robust to the incoming shocks. These results are also verified with smaller size sensitivity simulations in the table above.

5.23 Effect of Low Order on Oil Distributor Inventory, Retailer Inventory Storage, Total Cost, and Profit

As customer order is highly unpredictable, low customer order rate explores the effect of the opposite case of high customer order rate, i.e., order rate falls rapidly. The results are exactly the opposite of those obtained by testing with high order rate; lower order results in low inventory levels as depicted in **Figures 5.23 (a) and (b).** These results confirm the fact that there is an invert relationship between customer order and inventory levels. **Figure 5.23 (c) and (d)** presents the total cost and profit, the total cost is low as a result of low inventory level with low profit. There is always a risk when reducing the customer order in the system, the effects of these changes in the level of inventory is realised in later periods. The risk of ending up holding obsolete inventory is increased, therefore, it is essential that the inventory levels are set as low as possible to maintain maximum customer fulfilment.

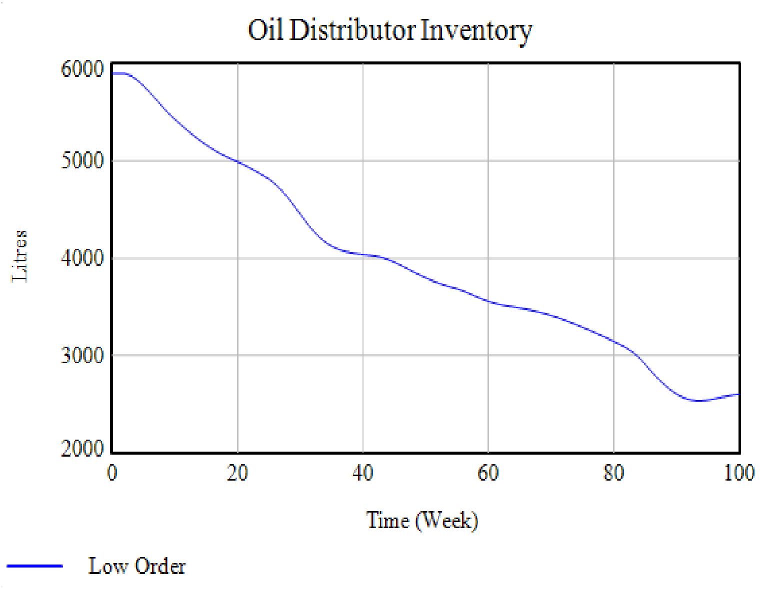


Figure 5.23 (a) Effect of Low Order on Oil Distributor Inventory

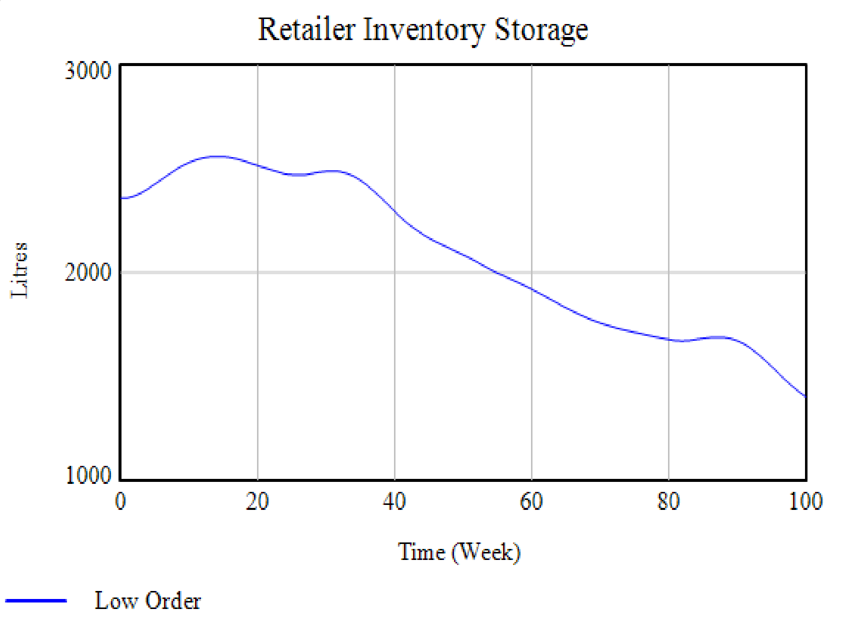


Figure 5.23 (b) Effect of Low Order on Retailer Inventory Storage

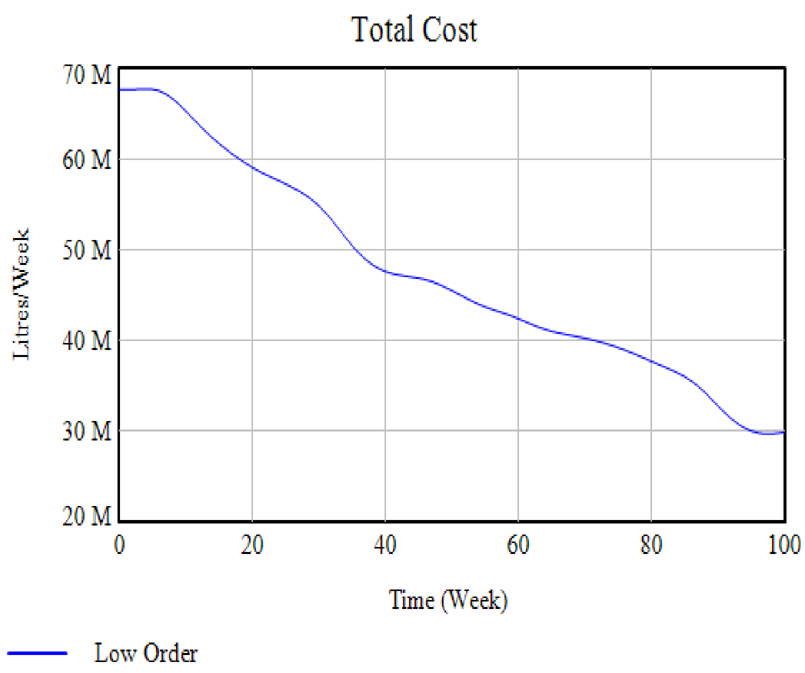


Figure 5.23 (c) Effect of Low Order on Total Cost

Figure 5.23 (d) Effect of Low Order on Profit

5.24 Effect of Retailer Order Cycle Time on Low Customer Order Pattern

This test explores the effect of retailer order cycle time on low customer order. As shown in **Figure 5.24 (a).** Reduction in retailer order cycle time reduces the instabilities in the oil distributor inventory but less sensitive in the retailer inventory storage as seen in **Figure 5.24**

(b), as the graph depicts, the instability in the oil distributor inventory dampens. In **Figures 5.24 (c) and (d),** total cost and profit are vaguely affected by reducing these parameters.

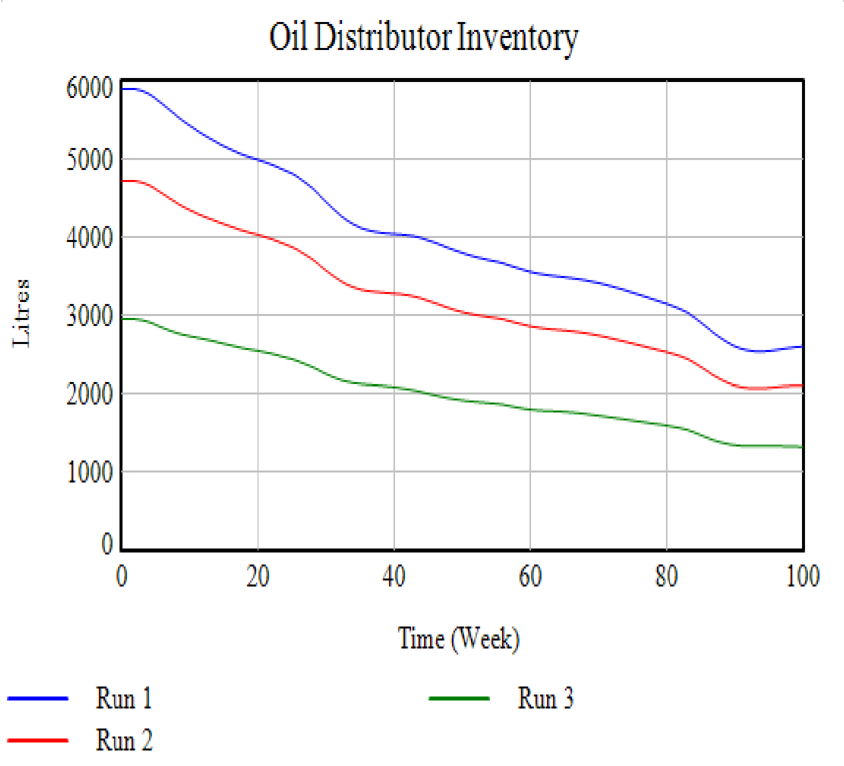


Figure 5.24 (a) Effect of ROCT on Oil Distributor Inventory

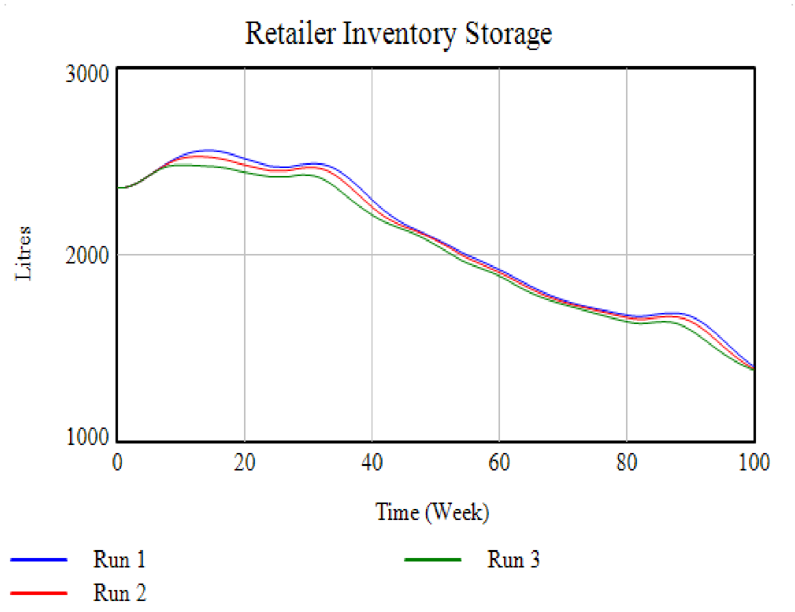


Figure 5.24 (b) Effect of ROCT on Retailer Inventory storage

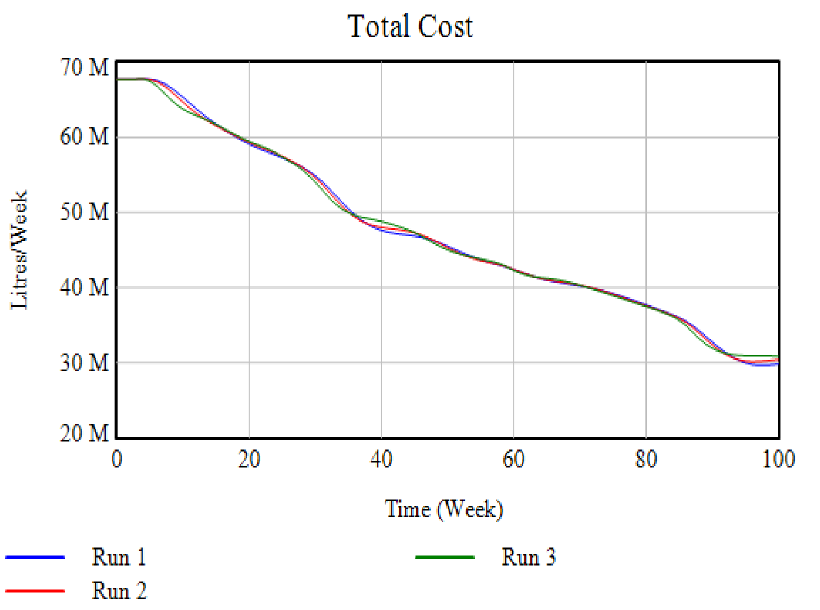


Figure 5.24 (c) Effect of ROCT on Total Cost

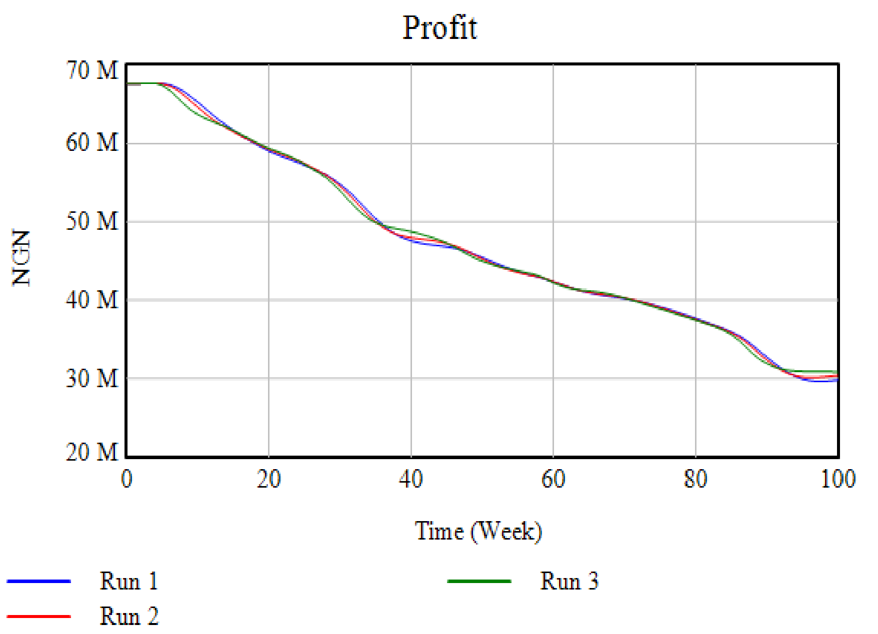


Figure 5.24 (d) Effect of ROCT on Profit

.

Run 1: ROCT = 10 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	2599	1400	2.98401e+08	2.97995e+08

Run 2: ROCT = 8 weeks				
SD Inventory Model	2099	1388	3.04197e+08	3.03791e+08
Run 3: ROCT = 5 weeks				
SD Inventory Model	1317	1381	3.08321e+08	3.07915e+08

Table 5.16 Effect of ROCT on ODI, RIS, TOTAL COST AND PROFIT

Table 5.16 summarises the result of these runs. Effect of retailer order cycle time has a significant impact on oil distributor inventory but with less or vague impact on retailer inventory storage when this parameter value is reduced. The total cost remains high and a minimal profit after the parameter changes.

5.25 Effect of Safety Stock Coverage on Low Order Pattern

The parameter safety stock coverage determines how many weeks the worth of inventory the manager would like to hold available in stock. **Figures 5.25 a, b, c** and **d** shows the effect of safety stock coverage on oil distributor inventory, retailer inventory storage, cost and profit. The decrease in this parameter reduces the retailer inventory storage but less effect on oil distributor inventory. This particular test is conducted to gain insight or understand the effects of carrying more or less inventory.

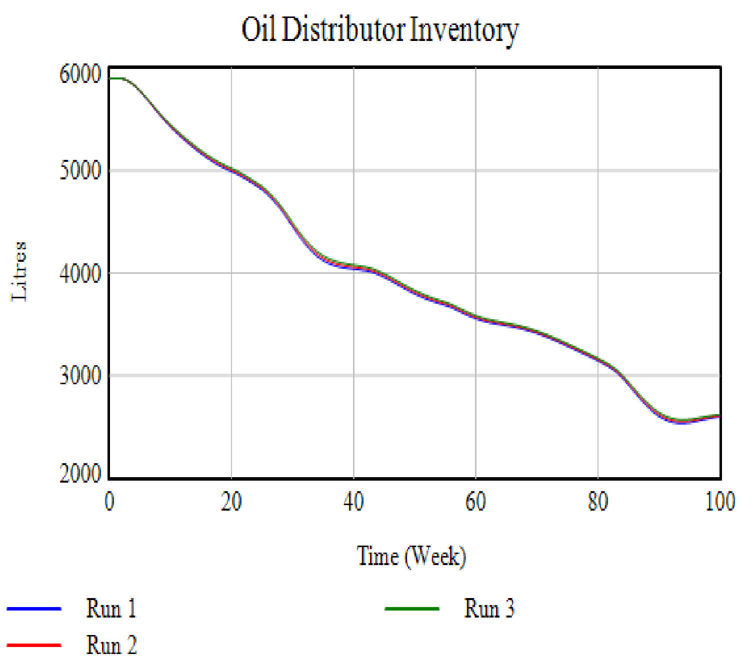


Figure 5.25(a) Effect of SSC on Oil distributor inventory

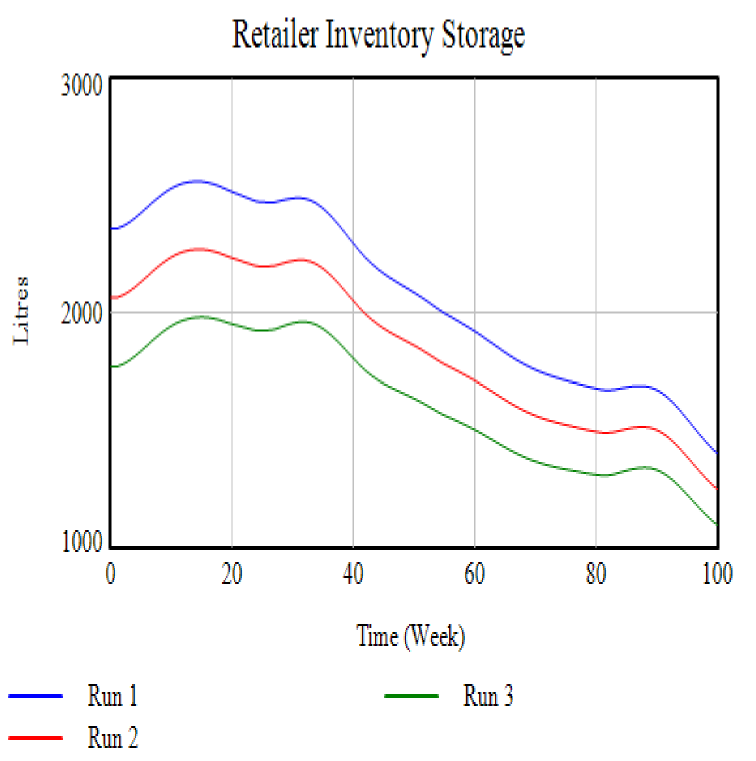


Figure 5.25 (b) Effect of SSC on Retailer inventory Storage

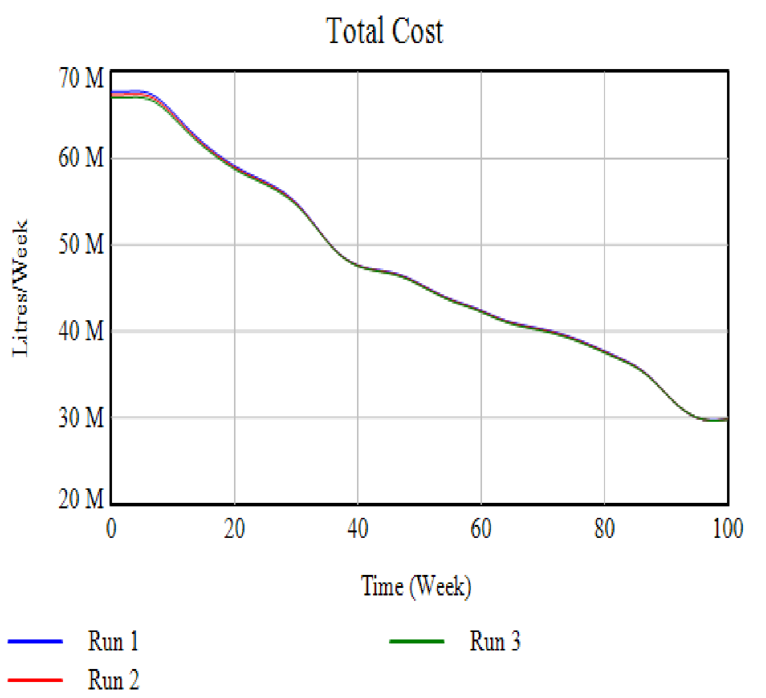


Figure 5.25 (c) Effect of SSC on Total cost

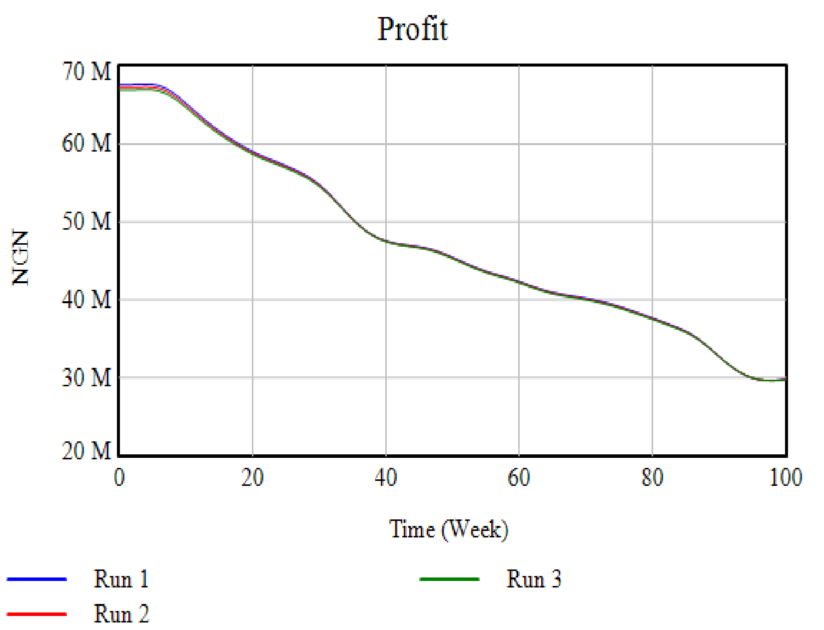


Figure 5.25 (d) Effect of SSC on Profit

Run 1: SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	2599	1400	2.98401e+08	2.97995e+08
Run 2: SSC = 1.5 weeks				
SD Inventory Model	2610	1247	2.98085e+08	2.97679e+08
Run 3: SSC = 1 week				
SD Inventory Model	2620	1094	2.97769e+08	2.97363e+08

Table 5.17 Effect of SSC on ODI, RIS, Total Cost, and Profit

Table 5.17 summarises the result of these runs. Safety stock coverage has less effect on the model output when conducted with a single parameter testing. As seen in the table, the effect of safety stock coverage has a significant impact on retailer inventory storage but with less or vague impact on oil distributor inventory when this parameter value is reduced. The total cost slightly reduces and little effect on profit after the parameter changes.

5.26 Effect of ROCT and SSC on Low Customer Order Pattern

After running different single parameters test to determine which parameters helps to reduce the unsteady pattern, it was observed during the simulation testing that single parameter testing have a slight influence in reducing the instability in the oil distributor inventory and retailer inventory storage hence, the need for multiple parameter testing. The first observation suggests that a reduction in retailer order cycle time and safety stock coverage leads to lower discrepancy in inventory level on both the oil distributor and retailer inventory storage as **Figures 5.26 (a) and (b)** depicts. The results shows that there is a significant decrease in inventory when ROCT is reduced from 10 weeks to 8 weeks and 5weeks and SSC is reduced from 2 weeks to 1.5week and 1 week, respectively.

Figure 5.26 (c) and (d) depicts that when the safety stock coverage (SSC) and retailers order cycle time (ROCT) are changed simultaneously the total cost is significantly reduced. These two parameter values have the capability of reducing total cost thereby increasing the profit for the company. **Table 5.18** summarises the oil distributor inventory, retailer inventory storage, total cost and profits.

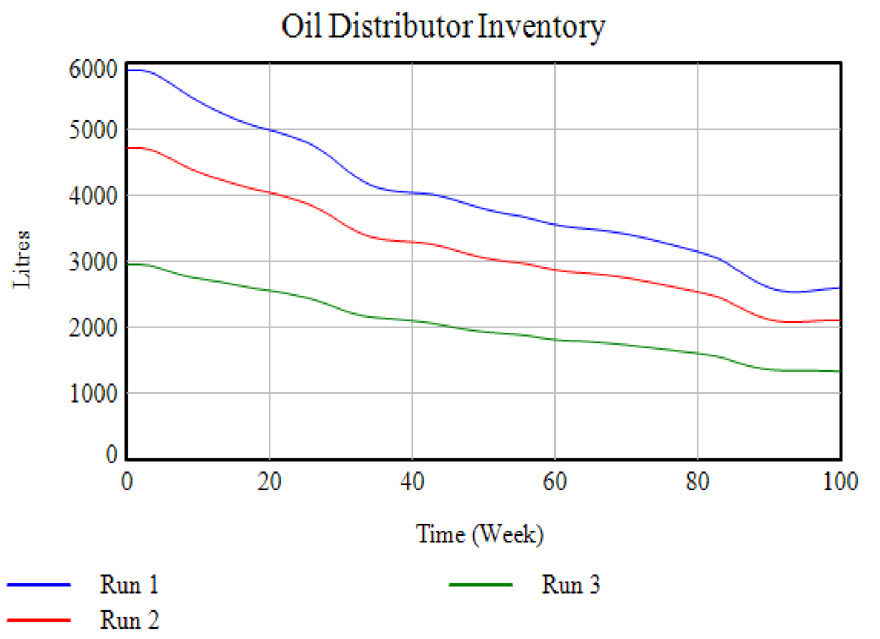


Figure 5.26 (a) Effect of ROCT and SSC on Oil distributor inventory

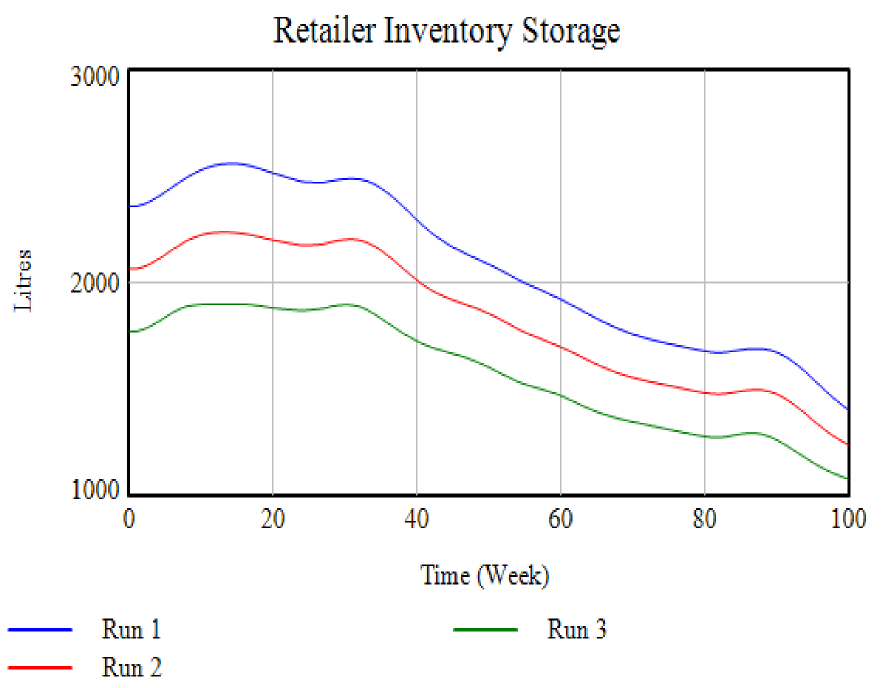


Figure 5.26 (b) Effect of ROCT and SSC on Retailer Inventory storage

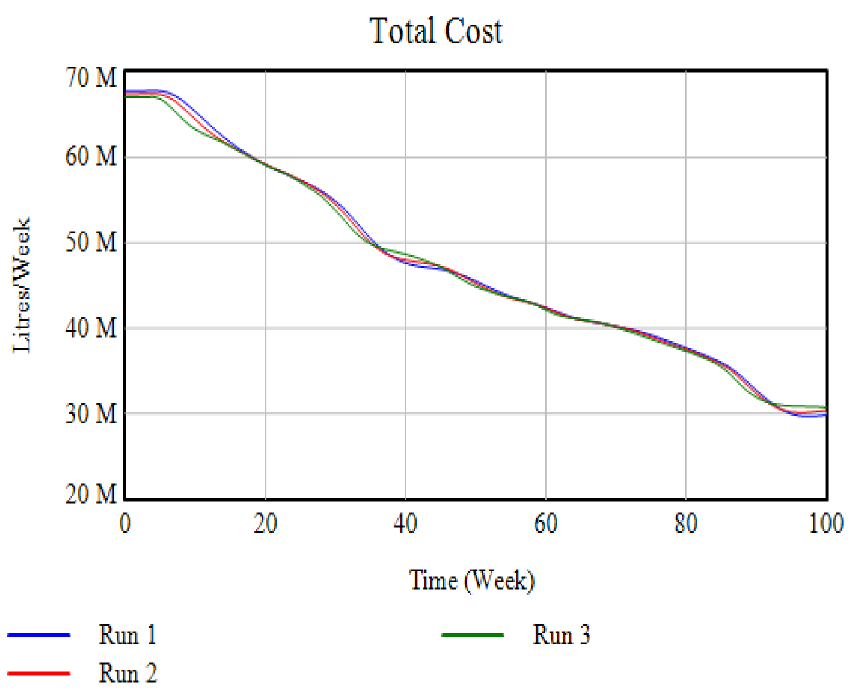


Figure 5.26 (c) Effect of ROCT and SSC on Total cost

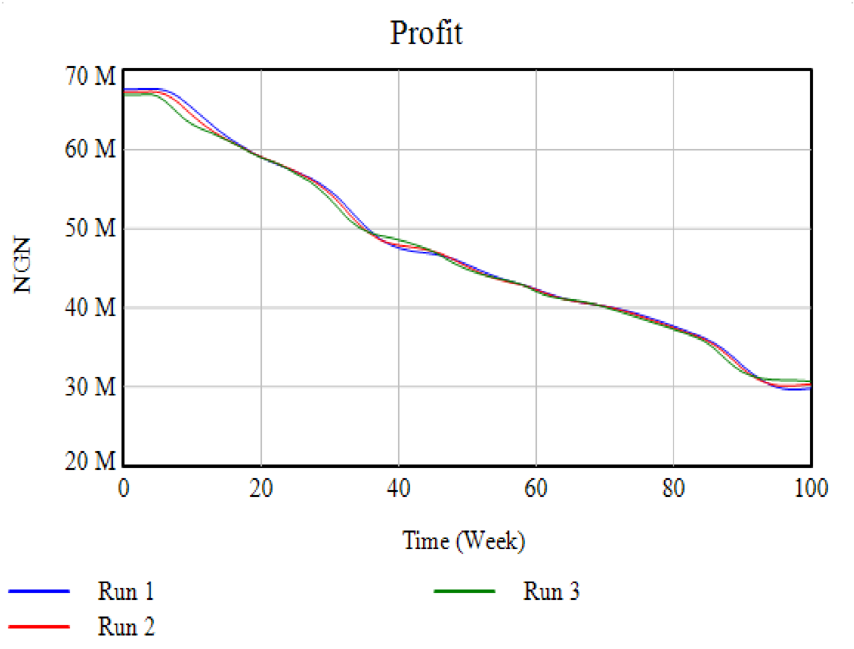


Figure 5.26 (d) Effect of ROCT and SSC on Profit

Run 1: ROCT = 10 weeks and SSC = 2 weeks				
	ODI	**RIS**	**Total Cost**	**Profit**
SD Inventory Model	2599	1400	2.98401e+08	2.97995e+08
Run 2: ROCT = 8 weeks and SSC = 1.5 weeks				
SD Inventory Model	2107	1235	3.03728e+08	3.03322e+08
Run 3: ROCT = 5 weeks and SSC = 1 week				
SD Inventory Model	1329	1074	3.07211e+08	3.06805e+08

Table 5.18 Effect of ROCT and SSC on ODI, RIS, TOTAL COST AND PROFIT

Smaller values of these parameters lead to reduced response to the demand input, so more stability emerge.

This means, the unstable and unsteady state is a result of increasing the time in the system. Therefore, the manager designing the system including inherent delays should keep the delay times as small as possible in order to avoid instability behaviours. Interestingly the result of sensitivity analysis is retailer order cycle time parameter. Like other behaviour measures, retailer order cycle time and safety stock coverage is found as the most significant parameters. Furthermore, lesser value of the parameter of retailer order cycle time indicates that systems, which have smaller retailer order cycle time, are more robust to the incoming shocks. These results are also verified with smaller size sensitivity simulations in the table above.

Summary

The analysis of company B is very similar to company A, it explains the importance of changing the two effective parameters in the model which are retailer order cycle time and safety stock coverage in supply chain management by comparative analysis of the three ordering patterns (Base case, high order and low customer order) . It explains the effect before reducing the retailer order cycle time and safety stock coverage and after reducing the retailer order cycle time and safety stock coverage under customer order change pattern base case, high customer order and low customer order pattern.

Changes of these parameters play a significant part to several factors in the supply chain and can also aid the supply chain managers to make a variety of management decisions by reducing total cost and by improving profit when these crucial parameters are reduced.

Furthermore, from the analysis of the three scenarios, different policy changes to parameter produce different results as observed during the test. Base case order pattern was found to be effective in all conditions with normal total cost and profit. High order rate results to high level of inventory which means more total cost to hold the inventories as well as profit. The disadvantage of this policy is the excessive stock that is unable to be sold which would turn to obsolete stock at the end resulting to less profit. Low order rate results to lesser inventory which means low total cost and profit. This policy could be detrimental to the company as a result of out of stock situation and loss of sales. The effect of low order rate pattern was found to be the worst while base case is suggested to be the best in all the three scenario testing.

CHAPTER 6 CONTRIBUTION AND DISCUSSION

6.0 Introduction

Bullwhip effect is a continuous problem within companies supply chain systems, particularly, as result of customer order uncertainty in the downstream Nigeria petroleum supply chains. This study used three different demand inputs (base case order pattern, high order pattern, and low order pattern) to show customer order uncertainties for the simulation and analysis for the Nigeria petroleum case companies. These demand inputs are adequate representation of the common demand that was observed by the two case companies these demand inputs was to project the what if scenario when there is a unpredictable future demand which serves the purpose of this research as discussed in Chapter 5.

Examining the three ordering patterns with respect to different policy responses has enable the researcher to test an expansive number of scenarios, 9 real world calibrated scenario for each case study has been investigated. The policy tested were established policies and significant to generate some insight in other to contribute to knowledge and achieve the objective.

Therefore, the primary goal of this study was to simulate the key problems that lead to these bullwhip effects in order to analyse and assess practical solutions for enhancing the efficiency of Nigeria's downstream oil supply chain's supply networks. To address the research objectives, this study adopts and extends Sterman (2000) system dynamics inventory model within the context of downstream petroleum supply chain in Nigeria focusing on the effect of customer order uncertainty. This study also uses real data and information collected from the case companies' (Nigeria) understudy that are presently encountering this problem to validate the developed model and research findings. Therefore, the purpose of this chapter is to link the research findings back to the research objectives that emerged from reviewing the literature.

Furthermore, theoretical, methodological and practical contributions will be discussed. Finally, the research limitations and possible areas for further research will be discussed.

6.1 Discussion of findings

The main research question that this thesis addresses is: What are the consequences of uncertainties of customer demand within downstream petroleum companies in Nigerian? To answer this research question, this research addressed the research objectives stated in Chapter one. How each of the research objectives was carried out individually and when collectively put together they answer the research question is presented in the following sections.

Adapting System dynamic model

To achieve this objective, relevant system dynamics modelling and supply chain management literatures, including definitions and applications of system dynamics modelling on supply chain management issues were reviewed in Chapter two. Further, oil and gas (petroleum) supply chain management related publications were reviewed and analysed to identify the important variables and characteristics of petroleum supply chain. The issues were reviewed in connection to downstream petroleum companies in Nigeria case studies. Analysis showed that similar extant supply chain management literature findings, Nigeria petroleum companies systems comprise of two important partners (distributor and retailer) that work together to fulfil customer orders. The network begins with the downstream customer that purchases petroleum directly from the retailers. The retailers then place their orders from their distributors who subsequently places orders from upstream partners which is out of the boundary of this study as this study investigates the downstream petroleum systems in Nigeria. This variable and information feedback and parameters that depicts this scenario has been extensively discussed in Chapter four in the system dynamics modelling sections. From the analysis, it was discovered that any discrepancy or unpredictability from consumers destabilizes the ability to effectively manage their inventory by both partners which causes out of stock thereby losing customers to competitors as the economy of Nigeria is mainly dependent on petroleum consumption. A limited number of studies have identified these important feedback in the Nigeria downstream petroleum companies in Nigeria.

Ordering pattern and policy intervention.

In Chapter four, the system dynamics inventory model was first validated with different validation technique as Barlas (1994) suggested these validation tests includes structure assessment, boundary adequacy, dimensional consistency, sensitivity analysis and extreme condition tests was carried out to ensure the model is robust. After validating the model, calibration of the model was then performed by identifying the known variables with their estimated values, setting the calibration reference variable and identifying the variable (customer order rate) to be calibrated with the case data using Thiel inequality statistics to produce a decent historical fit to the actual pattern of the case companies.

Reducing bullwhip through sensitivity analysis

In Chapter two, petroleum supply chain related literature and industry publications are critically reviewed to analyse the objectives of reducing the instabilities in the downstream petroleum systems in Nigeria caused by uncertain customer order. These analyses were carried out through extensive sensitivity testing to find the best policy of reducing this problem. A continuous simulation with 8 model parameters was run in order to investigate which parameter explains most variation in behaviour measures. The results of the analysis show that six of the eight parameters are not relevant and have little impact on the behaviour and functionality of the model. In other words, some model parameters only have a small impact on the instability impacting both organisations' inventories. Little time to average order rate additionally shows that the amount of demand perturbation smoothing has no impact on the oscillation period of the behaviour. The smoothness of external input has little bearing on this behaviour measure since the oscillation duration is most closely connected to the internal time delays in negative feedback loops. According to the results from the simulations the retailer order cycle time and safety stock coverage parameter is significant and plays a significant role in the model behaviour while distributor adjustment time, and retailer adjustment time, minimum sales processing time are insignificant as they have less or no effect on the model behaviour.

The models were constructed using case studies of downstream petroleum corporations in Nigeria, and the main assertions are summarised. To comprehend variations in the retailer order cycle time and safety stock coverage, simulation experiments were run. Here is a summary of the simulation results: The low order under retailer inventory storage experiences a large increase in inventory level above the base case and low order pattern.

- With the exception of high order, the model reacts well to the base case and low order pattern, resulting in a decreased oil distributor inventory and retailer inventory storage level.
- A low order volume has the unfavourable consequence of increasing retailer inventory storage.

These findings are important because they show that the test can adequately reflect the impact of demand uncertainty under various policies. The findings of the sensitivity analysis inventory storage, total expenses, and current profit raise issues on how managers can make the appropriate policy choice in response to various ordering patterns. An extensive sensitivity analysis is performed in order to identify the optimum course of action. The models' performance indicators was constructed on both financial metrics and non-financial metrics. In order to prevent storing too much inventory, decreasing the degree of safety stock coverage

(SSC) and retailer order cycle time (ROCT) was the optimum approach. The results for sensitivity are summarised as follows:

- For all demand patterns, the retailer order cycle time should be lowered from 10 weeks to 5 weeks. The managers can complete orders more quickly by lowering this value.
- It is ideal to reduce the safety stock coverage from two weeks to one week.. The managers might hold the proper quantity of inventory, cutting overall expenses and raising profit, by lowering the SSC. To enhance the model's performance and offer the example firm management insights into the best policies to apply to save costs and boost profits, a sensitivity analysis was carried out. This study reveals that even though demand amplification has a large body of information and a matured theory, the connection between theory and practise is shaky in emerging nations. However, there is little research on Nigeria's supply chain management using the system dynamics model that can capture the nuances of the bullwhip effect that arises from each unique scenario, prohibiting practitioners from performing consistently.

6.2 Research contribution

This thesis has made the following scientific contributions:

6.2.1 Subject Contribution

Given the multidisciplinary nature of this work, this study makes different subject contributions to different fields. According to Sung-il Park et al. (2014), in the field of system dynamics, little study has been done on supply chain inventory models. They recommend encouraging research into inventory models since managers may find system dynamics to be a useful and important tool for designing policies. In response to these claims, managers can benefit from the models and sensitivity analyses in this research as they develop policies.

System dynamics approach of supply chain management: the downstream oil supply chain in Nigeria has been properly modelled considering the conceptual and representational issues. The model development was extended from the work of Sterman (2000). The work of Sterman has been previously used by Morecroft (1983) and Minnich and Maier (2007). Therefore, this study identified structural, behavioural and all the relevant parameters to conceptualise the case companies in a way that is tailored to the field. The resulting model is comprehensive and can sufficiently describe real supply chain issues. A causal model of the problematic supply chain understudied has also been defined, capturing causal relationships and their important variables. In addition, this study provided a simulation analysis for analysing and experimenting with different order uncertainties scenarios. The model demonstrates how applying the system dynamics methodology can reduce the complexity of supply chain modelling, as mentioned by Fowler and Rose (2004). Therefore, there are limited subject contribution that explicitly and thoroughly analyse downstream oil companies in Nigeria using system dynamics modelling approach for supply chain dynamics. This study contributes to this area of supply chain management by formal definition of supply chain downstream System dynamics model.

Another contribution from this study is to reconstruct a well-established model (base model) through a simplified supply chain structure that will allow analysing the behaviour of bullwhip effect i.e., the instability in the supply chain and the impact on the case company performance. in this specific case, by analysing the variables that affect the downstream oil supply chain in Nigeria. Therefore, the model will be a simulation of different scenarios to study what could are the consequences with the behaviour of the system dynamics structure arising from the decision of managers, creating new questions like: What would happen if some specific parameters that has significant effect on the model is changed? What would be the consequences on the inventory level and times based on some certain decisions from the managers? What would happen if customer order were forecasted? The model also includes other variable like total cost, profit, and carrying costs and to analyse the impact on the company performance.

6.2.2 Theoretical Contribution

This study has contributed to theory. Theoretically seen, first a review of literature is conducted in the theories of system dynamics and supply chain management. It became clear, especially the literature of supply chain management was widely dispersed. To develop a combined approach, it was necessary to develop a clear overview of both theories of supply chain management and system dynamics modelling. This study combines both theories by providing an overview of definitions, features/ characteristics and literature schools of thought. Furthermore, the developed approach provides a basis of the combination of supply chain management and system dynamics. This could be used to deal with dynamic complexity in supply chain issues. The study provides a structured method to handle both dynamic complexity and uncertainty in complex systems.

In addition, the research contributes to theory by further validating a well-known Sterman (2000) inventory model by testing and using the model to provide insight on how to provide lessons, insights and how to organise supply chain policies for downstream actors in oil supply chain, the study adds to the knowledge of supply chain dynamics by demonstrating throughout the study the consideration of the inventory model using different ordering patterns as discussed in Chapters 4 and 5. In this study, the amplification of demand is seen as results of ordering actions of partners in the supply chain (Amaya, 2011). The study reveal that different policies also influence the level of performance under different ordering patterns.

Geary *et al.* (2002) argument who suggested that information visibility along the supply chain is important for reducing uncertainty. The system dynamic model was based on system thinking, using the methodology of system dynamics that includes most important supply chain management variables and processes, demonstrating all the variables that consist of the downstream players namely distributor and retailer and the delivery of products to their final customers, demonstrating how orders are managed and the interactions of the supply chain players. The system dynamics model offers the chance to understand the behaviour of complex system in the supply chain that gives managers a level of confidence to conduct scenario simulation without making significant error in the real world (Lin, 2018)

6.2.3 Practical Contribution

System dynamics model can be a beneficial method in developing policy. One of the advantages of system dynamics model is the ability to deal with a particular issue of a system. Therefore, the time required to analyse and develop the model is reduced, which is perfect for assisting decision-making for managers who operate in a dynamic setting. Sensitivity analysis demonstrates how system dynamics helps in searching for appropriate policy depending on a variety of management inputs through simulation. Therefore, the simulation study can show the impact of various techniques on the models, reducing the likelihood that poor judgments would be made in the actual world.

Managers are able to understand the best policy to respond to different demand patterns, particularly when there is a bullwhip, they can combine both retailer order cycle time and safety stock to dampen down the oscillation (bullwhip).

In practice, the suggested method can help to understand complex systems while developing scenarios. Therefore, SD approach could be used as great learning experience in complex and uncertain systems. Understanding dynamic complex principles as feedback loops, stock and flows, and time delays helps individuals to better understand behaviour in complex systems and increases effective decisions making (Lee et al, 2015). In combination with supply chain management issues, managers will be able to identify uncertainty in dynamic systems.

Furthermore, this research developed an approach which companies can use as management approach to address both dynamic complexity and uncertainty. So, besides learning about complex systems in supply chain, the approach could help companies to develop dynamic complex scenarios which could help to develop robust strategies based on future uncertainty and complexity (Aslam, 2013). Finding the right balance between lowering uncertainty and determining a suitable policy is a key component of these strategies, and doing so may be a very difficult task. The study's suggestion of a method for evaluating inventory-level rules that reduce supply chain costs makes it a good fit for this field of study. It can assist in offering guidance for how system dynamics research in this field should be carried out in the future.

System dynamics model allows the possibility to compare the different policy through the simulation of prediction versus reality in the different scenarios analysis. When the variables are modified, system dynamics provide the possibility to simulate different scenarios of the supply chain with better behaviours, like understanding how the bullwhip effect in the supply chain affect the inventory level and the total cost. one of the advantages of system dynamics modelling approach is that it signifies cycles that can be created as a nonlinear differential equation meaning that there is no permanent solution to a problem but there is endless amount of likely solution to the problem in the supply chain enabling the simulation of these problems and how it is easy to understand the complex system (Lin, 2018).

6.3 Summary of the thesis

The System dynamics (SD) inventory model of the downstream petroleum companies in Nigeria was developed in this research, to investigate uncertain customer order and the ability for the companies to manage their inventory to fulfil customer requirement at the same time reduce their overall total cost. The system dynamic inventory model shows a thorough analysis and description of the system operations, considering crucial factors and elements such as cycle time, customer behaviour, safety stock coverage, and lead times. The system dynamic inventory model was then used to gain a proper insight and as well understand the dynamic relationship of the factors causing the instability in the system of the downstream petroleum companies in Nigeria and to evaluate and examine the strategies and policies relating to the problems in the supply chain.

The inventory model has been adapted from a well-known SD inventory model based on the influencing factors, and their close correlations representing the real system of the downstream petroleum companies in Nigeria that was established based upon theoretical details acquired from the literature evaluation and originated from conversations with the managers of the case companies under study. This research helps to gain insight in the real world of downstream petroleum company supply chain in Nigeria not readily available in the literature. Once the inventory system has been identified and modelled, the effect of the three ordering patterns (base case, high order and low order) is used to investigate how instability develops in downstream petroleum companies and how it affects their performance, ultimately lowering costs and increase profits for the companies.

In particular, the problem of uncertainty in customer order which causes instabilities in the downstream Nigerian oil supply chain was the major reason and motivation to adapt a well-known system dynamic model as the model captures the relevant and important factors being investigated. The stock and flow diagram were established to represent the quantitative and qualitative elements of the model through a comprehensive description of the feedback structures that represent the case companies' supply chain and mathematical equations that represent the relationships between the variables in the real system and the policies to be considered. The model validation was conducted through some number of test which are face validity by the researcher and the managers, parameter test, extreme condition test, dimensional consistency test, behavioural reproduction test, and sensitivity test to identify the parameters that have the most effect on the model to reduce inventory level for the companies, reduce cost and increase profit.

Subsequently, simulation of the model through sensitivity analysis as suggested by Barlas 1989 was carried out to investigate and understand the effect of the three customer ordering patterns that represent an actual ordering pattern and its impact on the two case companies in the downstream petroleum companies in Nigeria. Results of the simulation and interpretations were measured and evaluated employing existing data provided by companies from the findings of two case studies on downstream oil companies in Nigeria. McCullen & Towill (2002) argued in their study that bullwhip effect (instability) has been the centre of attentions in the supply chain studies for more than fifty years. This is the reason and motivation to undertake this study as this problem has an undesirable effect. The bullwhip effect idea has also been extensively researched in the literature, and the body of information is pretty strong for both the cause of the problem and its effects on other supply chain levels; yet there is still a significant gap between theory and practise. Additionally, the majority of the literature currently in circulation focuses on oscillations, instabilities, and the "bullwhip effect," and the analysis techniques are based on conventional ideas that owe their success more to the expertise of the analyst than to a methodical and organised approach to problem-solving (Rene, 2011).

Therefore, adapting Sterman (2000) inventory model is necessary whenever the source of the bullwhip effect is vague and blurry. Besides, when modelling supply chain systems in most cases, information gathering and decision making are required to deal with ‘soft’ variables and finally, human judgment in the process of decision making cannot be exactly captured by simulation models; primarily because human behaviour follows uncertain rules when tackling an issue.

6.4 Research limitations

In generalising the findings of this research, certain limitations needs to be taken into consideration. While the system dynamics inventory system for downstream petroleum supply chain is investigated using different scenarios and customer ordering patterns, the findings within this research is supported by the two companies that specialise in the sales of petrol to varying consumers. Subsequently, the findings from this research could be restricted to the petroleum case companies. Based on the theoretical information, the system dynamics inventory was developed without taking into some important management operation activities relating to real assumptions. For instance, capacity constraints were not involved in the model. Adding capacity constraints can affect the findings of the research, resulting to additional operation cost. In addition to this research limitation, critical realism was adopted as a philosophical paradigm which views ontological reality as probabilistic and imperfect. Although internal validity of this study has been demonstrated and proved, the limitation of external validity i.e., generalising the research findings is limited as a result to the nature of social science research which is concerned with practice.

6.5 Suggestions for future research

This study investigated the issue of the "bullwhip effect" in Nigeria's downstream petroleum industries. However, further research on this study can consider expanding this area of research as there are more areas to be modelled. In other to gain more insight and understanding in this field, a number of challenging problems for additional research are recognised and outlined below:

- The research findings were achieved through the modelling, analysing and simulation of a well-known inventory system dynamic model. In order to streamline the analysis and understanding of the system, a variety of tests was carried out, a few of which were made to model the dynamic behaviour of the inventory level and performance. Nevertheless, a prospect for more research study depends on the assessment of system efficiency by reducing the assumptions remaining. It might be accomplished by modelling the feedback structure of the system again and including the elements and their impact relationships that influence the system processes and activities.
- The development of the model and the research study contributes to the knowledge of supply chain system dynamics by considering the different ordering patterns in the supply chain. However, this study also proposes future research the introduction of additional variables like capacity constraints, residence time, and service agreement by considering a more sophisticated system dynamics inventory model for enabling to understand and change the system' structure causing bullwhip. Another suggestion for future research can be improving the structure of the model and its real-world application of existing issues. Precisely, several exogenous variables like customer behaviour, cycle time, lead time, and safety stock coverage were investigated in this study without considering their economic, social, and management backgrounds. Exploring the roles and origins of these variables could broaden the model to cover more and new areas of research investigating different fields of research.

REFERENCES

1. Aastrup, J. and Halld´orsson, A. (2008) Epistemological role of case studies in logistics: A critical realist perspective. *International Journal of Physical Distribution & Logistics Management*, 38 (10), pp.746–763.

2. Ackoff, R. L., and Sasieni, M. W. (1968) Fundamentals of Operations Research. John Wiley & Sons. New York.

3. Aggelogiannaki, E., Doganis, P. and Sarimveis, H. (2008) An adaptive model predictive control configuration for production-inventory systems. *International Journal of Production Economics*, 114 (1), pp. 165–178.

4. Ajit, K. S., Mishra, P.C., Routra, B.C., Amitabha, B. (2012) An Extensive Literature Review on Lead Time Reduction in Inventory Control . *International Journal of Engineering and Advanced Technology*. 1 (6), pp.2249 – 8958.

5. Akanle,O., Adebayo, K, and Adebayo, O. (2014) Fuel subsidy in Nigeria: contexts of governance and social protest. *International journal of sociology and social policy*, 34,88-106

6. Akkermans, H. and Dellaert, N., (2005) The rediscovery of industrial dynamics: the contribution of system dynamics to supply chain management in a dynamic and fragmented world. *System Dynamics Review*, 21, pp. 173–186.

7. Akkermans, H. (2001) Emergent supply networks: system dynamics simulation of adaptive supply agents. P*roceedings of the 34th Annual Hawaii International Conference on System Sciences*, Hawaii, USA, 6 January. pp. 3006-3007.

8. Aliyu, S. U. (2011) Oil price shocks and the macro economy of Nigeria: a non-linear approach. Journal for International Business and Entrepreneurship Development, 5(3), pp. 179-198.

9. Allen, T.T. (2011) *Introduction to Discrete Event Simulation and Agent-based Modeling*. New York, USA: Springer.

10. Alsop, R. and Armstrong, D. (2010) Resilient supply chain in time of uncertainty.

11. Amaya, R.A. (2011). A Diagnostic Framework for Demand Amplification Problems in Supply Chains, PhD Thesis, *Florida International University*.

12. Aminu, S. and Olawore, O (2014) Emperical investigation of challenges of distribution of premium motor spirit (PMS) in federal capital territory (FCT) Abuja and environs. *Nigeria International journal of management sciences and humanities* 2/; 11-38

13. Anderson, E. (2003) *Supply Chain Strategy in the Oil and Gas Sector*. Business Briefing: Exploration and Production.

14. Angerhofer, B.J. and Angelides, M.C. (2000) System dynamics modelling in supply chain management: research review. *Proceedings of* the *2000 Winter Simulation Conference*, Orlando, USA, 10-13 December. pp. 342-351.

15. Arbnor, I. and Bjerke, B. (1997) *Methodology for Creating Business Knowledge*. Newbury Park, CA.: Sage.

16. Arlbjørn, J. and Halld´orsson, A. (2002) Logistics Knowledge Creation: Reflections on Content, Processes and Context. *International Journal of Physical Distribution & Logistics Management*, 31 (1), pp.22–40.

17. Asbjørnslett, B.E. (2008) Assessing the Vulnerability of Supply Chains. *In*: G.A. Zsidisin and B. Ritchie, eds. *Supply Chain Risk: A Handbook of Assessment, Management and Performance*. New York, NY: Springer.

18. Ashton, D. (1998) Systematic risk and empirical research. *Journal of Business Finance and Accounting*, 25 (9/10), pp. 1325–1356.

19. Aslam, T. (2013). Analysis of manufacturing supply chains using system dynamics and multi-objective optimization, *PhD Thesis, University of Skövde.*

20. Atherton, D.P. (1975) *Nonlinear Control Engineering*. 1st New York: International Offices.

21. Ayadi, O. F. (2005) Oil price fluctuations and the Nigerian economy. OPEC review, 29(3), pp. 199-217.

22. Bailey, K.D. (1994) *Methods of social research*. 4th New York: The Free Press.

23. Barlas, Y. and Gunduz, B. (2011) Demand forecasting and sharing strategies to reduce fluctuations and the bullwhip effect in supply chains. *Journal of the Operational Research Society*, 62(3), pp. 458-473.

24. Barlas, Y. (1994) Model validation in system dynamics. I*nternational Conference of System Dynamics Society*, 12th, Stirling, UK. System Dynamics: Methodological and Technical Issue. Proceedings, ed. by Monaghan, C. and Wolstenholme, E. pp. 1-10.

25. Barlas, Y. (1996) Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, 12(3), pp. 183-210.

26. Barry, J. (2004) Supply chain risk in an uncertain global supply chain environment. *International Journal of Physical Distribution & Logistics Management*, 34(9), pp. 695 – 697.

27. Bechtel, C. and Jayaram, J. (1997) Supply chain management: a strategic perspective. *International Journal of Logistics Management*, 8 (1), pp. 15–34.

28. Berry, D. and Naim, M.M. (1996) Quantifying the Relative Improvements of Redesign Strategies in a Personal Computer Supply Chain. *International Journal of Production Economics*, 46-47(1), pp. 181-196: 131–153.

29. Berry, D. and Towill, D.R. (1992) Material Flow in Electronic Product Based Supply Chains. *International journal of Logistics Management*, 3 (2), pp. 77–94.

30. Bhamra, R., Dani, S. and Burnard, K. (2011) Resilience: the concept, a literature review and future directions. *International Journal of Production Research*, 49 (18), pp. 5375–5393.

31. Bhaskar, R., 1975. *A Realist Theory of Science*. 1st London: Verso.

32. Bhatti, R.S., Kumar, P. and Kumar, D. (2012) Evolution of system dynamics in supply chain management. *International Journal Indian Culture and Business Management*, 5 (1), pp. 1–14.

33. Bicheno, J., Holweg, M. and Niessmann, J. (2001) Constraint batch sizing in a lean environment. *International Journal of Production Economics*, 73 (1), pp. 41–49.

34. Blanche, M.T., Durrheim, K. and Painter, D. (2007). *Research in Practice: Applied Methods for the Social Sciences*. 2nd Cape Town, South Africa: University of Cape Town Press.

35. Blumenfeld, D.E., Burns, L.D. and Diltz, J.D. (1985). Analyzing trade-offs between transportation, inventory and production costs on freight networks. *Transportation Research-B*, 5 (5), pp. 361–380.

36. Boin, A., Kelle, P. and Clay Whybark, D. (2010) Resilient supply chains for extreme situations: Outlining a new field of study. *International Journal of Production Economics*, 126 (1), pp.1–6.

37. Bryman, A. and Bell, E. (2007) *Business Research Methods*. 2nd New York: Oxford University Press.

38. Burbidge, J.L. (1961) The new approach to production. *Production Engineer*, 40 (12), pp. 769–84.

39. Burgess, K., Singh, P.J. and Koroglu, R. (2006) Supply chain management: a structured literature review and implications for future research. *International Journal of Operations & Production Management*, 26 (7), pp. 703–729.

40. Burgess, T., Hwarng, B., Shaw, N. and De Mattos, C. (2002) Enhancing value stream agility: The UK speciality chemical industry. *European Management Journal*, 20(2), pp. 199-212.

41. Burns, J.F. and Sivazlian, B.D. (1978) Dynamic analysis of multi-echelon Supply systems. *Computer & Industrial Engineering*, 2, pp.181–193.

42. Burrell, G. and Morgan, G. (1979) *Sociological Paradigms and Organisational Analysis*. London: Heinemann Books.

43. Bryman, A. and Burgess, R. (2004). *Analyzing Qualitative Data*, New York: routledge.

44. Budina, N., Pang, G. and van Wijnbergen, S. (2007) "Nigeria's growth record: Dutch disease or debt overhang?".

45. Callioni, G., de Montgros, X., Slagmulder, R., Wassenhove, L.N.V. and Wright, L. (2005) Inventory-Driven Costs. *Harvard Business Review*, March, pp. 1–8.

46. Cameron, S. and Price, D. (2009) *Business Research Methods*. London: Chartered Institute of Personnel and Development.

47. Cannella, S., Ciancimino, E. and M´arquez, A.C., (2008) Capacity constrained supply chains: a simulation study. *International Journal of Simulation and Process Modelling*, 4 (2), pp. 139–147.

48. Carvalho, H. and Cruz-Machado, V., 2011. Integrating Lean, Agile, Resilience and Green Paradigms in Supply Chain Management. May, http://www.intechopen.com/books/supply-chainmanagement/ integrating-

lean-agile-resilience-and-green-paradigms-in-supply-chain-manageme [Accessed 22 APRIL 2017].

49. Carvalho, H. (2011) Resilience Index: Proposal and Application in the Automotive Supply Chain. *Proceedings of the 18th EUROMA Conference, Cambridge, UK, 3-6 July*.

50. Cavinato, J.L. (1992) Total cost value model for supply chain competitiveness. *Journal of Business Logistics*, 13 (2), pp. 258–291.

51. Cakravastia, A., and L. Diawati. (1999) Development of System Dynamic Model To Diagnose The Logistic Chain Performance Of Shipbuilding Industry In Indonesia. Paper read at International System Dynamics Conference, Wellington, New Zealand.

52. Celly, K.S. and Frazier, G.L. (1996) Outcome-based and behavior-based coordination efforts in channel relationships. *Journal of Marketing Research*, 33 (2), pp. 200–210.

53. Chae, B. (2009) Developing key performance indicators for supply chain: an industry perspective. *Supply Chain Management: An International Journal*, 14(6), pp. 422-428.

54. Chen, F., Drezner, Z., Ryan, J.K. and Simchi-Levi, D. (2000). Quantifying the Bullwhip Effect in a Simple Supply Chain: The Impact of Forecasting, Lead Times, and Information. *Management Science*, 46 (3), pp. 436–443.

55. Chick, S. (2006) "Six ways to improve a simulation analysis." Journal of Simulation, 1(1), pp. 21-28.

56. Childerhouse and Towill (2016) Engineering supply chains to match customer requirements.

57. Choucri, N., Electris, C., Goldsmith, D., Mistree, D., Madnick, S. E., Morrison, J. B. and Sweitzer-Hamilton, M. (2006) Understanding & Modeling State Stability: Exploiting System Dynamics. In Aerospace Conference, 2006 IEEE pp. 1-11.

58. Chow, K.V. and Denning, K.C. (1994) On variance and lower partial movement betas: the equivalence of systematic risk measures. *Journal of Business Finance and Accounting*, 21 (2), pp. 231–241.

59. Christopher, F.H., Patil, S.R. (2002) Identification and review of sensitivity analysis methods. *Risk Analysis*, 22(3), pp. 553-578.

60. Christopher, M.L., (1992) *Logistics and Supply Chain Management*. London: Pitman.

61. Christopher, M., Lee, H. (2004) Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management*, 34(5), pp. 388-396.

62. Christopher, M., Peck, H. (2004) Building the Resilient Supply Chain. *International Journal of Logistics Management*, 15 (2), pp. 1–14.

63. Christopher, M. and Rutherford, C., (2004) Creating Supply Chain Resilience through Agile Six Sigma. *CriticalEYE Publications*, June-August, http:// martin-christopher.info/wp-content/uploads/2009/12/critical_eye.pdf [Accessed 1 AUG 2017].

64. Christopher, M. (2007) Supply chain Management Issues in the oil and gas Industry. *Journal of Business and Economic research.* 5 (6).

65. Christopher, M. (2011) *Logistics and Supply chain Management*. 4th ed. Edinburgh: Pearson Education limited.

66. CIA. (2010) Available:https://www.cia.gov/library/publications/the-world factbook/rankorder/2174rank.html. Last accessed 16th feb 2016.

67. Colicchia, C., Creazza, A. and Dallari, F. (2010) Supply chain risk management: insights from an explorative study in the Italian industry. *Logistics Research Network Annual Conference proceedings, Leeds, UK, 8-10 September*.

68. Colicchia, C., Dallari, F. and Melacini, M., (2010) Increasing supply chain resilience in a global sourcing context. *Production Planning & Control: The Management of Operations*, 21 (7), pp. 680–694.

69. Colicchia, C. and Strozzi, F. (2012) Supply chain risk management: a new methodology for a systematic literature review. *Supply Chain Management: An International Journal*, 17(4), pp. 403-418.

70. Collier, P. (1988) "Oil shocks and food security in Nigeria". Int'l Lab. Rev., 127, 761.

71. Collins English Dictionaries. (1995) *Dictionary and Thesaurus*. 2nd Glasgow: Harper Collins.

72. Comte, A. (1865) *A general view of positivism*. London, UK: Trubner and Co.

73. Cook, P.A. (1986) *Nonlinear Dynamical Systems*. Exeter, UK: Prentice.

74. Cooper, D. R. and Pamela S. S. (2014) Business research methods, 12th ed. New York: McGraw-Hill/Irwin.

75. Cooper, M.C., Lambert, D.M. and Pagh, J.D. (1997) Supply Chain Management: More Than a New Name for Logistics. *The International Journal of Logistics Management*, 8 (1), pp. 1–14.

76. Coyle, R.G. (1977) *Management System Dynamics*. Chichester: Wiley.

77. Coyle, R.G. (2001) *System dynamics modelling: A practical approach*. Boca Raton: CRC Press LLC.

78. Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J., Handfield, R.B., (2007) The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities. *Decision Sciences*, 38 (1), pp. 131–156.

79. Croom, S. and P. Romano, (2000). Supply chain management: an analytical framework for critical literature review. *European Journal of Purchasing and Supply Management* . 6 (1), pp. 67-83.

80. Cuypers, J.G.M. (1973) World Dynamics: Two Simplified versions of Forrester's Model. *Automatica*, 9, pp. 399–401.

81. Cuypers, J.G.M. and Rademaker, O. (1974) An analysis of Forrester's World Dynamics Model. *Automatica*, 195-201, pp.195–201.

82. Dai, J., Peng, S. and Li, S. (2017). Mitigation of Bullwhip Effect in Supply Chain Inventory Management Model. *Procedia Engineering*, 174, pp.1229-1234.

83. Das, D., and Dutta, P. (2013) A system dynamics framework for integrated reverse supply chain with three way recovery and product exchange policy. *Computers & Industrial Engineering*, 66(4), pp. 720-733.

84. Datta, P.P., Christopher, M. and Allen, P. (2007) Agent-based modelling of complex production/distribution systems to improve resilience. *International Journal of Logistics: Research and Applications*, 10 (3), pp. 187–203.

85. Davis, D. (2000) *Business research for decision making*. Duxbury: Thomson Learning.

86. De Souza, R., Zice, S. and Chaoyang, L. (2000) Supply chain dynamics and optimization. *Integrated Manufacturing Systems*, 11 (5), pp.348–364.

87. Dejonckheere, J., Disney, S.M., Lambrecht, M.R. and Towill, D.R. (2003) Measuring and avoiding the bullwhip effect: A control theoretic approach. *European Journal of Operational Research*, 147 (3), pp. 567–590.

88. Dejonckheere, J., Disney, S.M., Lambrecht, M.R. and Towill, D.R. (2004) The impact of information enrichment on the Bullwhip effect in supply chains: A control engineering perspective. *European Journal of Operational Research*, 153 (3), pp. 727– 750.

89. Denyer, D. and Tranfield, D., (2006) Using qualitative research synthesis to build an actionable knowledge base. *Management Decision*, 44 (2), pp. 213–227.

90. Disney, S.M. and Grubbstrom, R.W. (2004) Economic consequences of a production¨ and inventory control policy. *International Journal of Production Research*, 42 (17), pp. 3419–3431.

91. Disney, S.M., Naim, M.M. and Towill, D.R., (2000) Genetic algorithm optimisation of a class of inventory control systems. *International Journal of Production Economics*, 68 (3), pp. 259–278.

92. Disney, S.M., Potter, A. and Gardner, B., (2003) The impact of vendor managed inventory on transport operations. *Transportation Research Part E*, 39 (5), pp. 363– 380.

93. Disney, S.M. and Towill, D.R. (2002) A discrete transfer function model to determine the dynamic stability of a vendor managed inventory supply chain. *International Journal of Production Research*, 40 (1), pp. 179–204.

94. Disney, S.M. and Towill, D.R. (2003a) On the bullwhip and inventory variance produced by an ordering policy. *Omega*, 31 (3), pp, 157–167.

95. Disney, S.M. and Towill, D.R. (2003b). Vendor-managed inventory and bullwhip reduction in a two-level supply chain. *International Journal of Operations & Production Management*, 23 (6), 625–651.

96. Disney, S.M. and Towill, D.R., (2005) Eliminating drift in inventory and order based production control systems. *International Journal of Production Economics*, 93-94 (1), pp. 331–344.

97. Disney, S.M., Towill, D.R. and Warburton, R.D.H. (2006) On the equivalence of control theoretic, differential, and difference equation approaches to modeling supply chains. *International Journal of Production Economics*, 101 (1), pp. 194–208.

98. Dorf, R.C. and Bishop, R.H., (1998) *Modern Control Systems*. Addison Wesley Longmann, Inc.

99. Duberley, J. and Johnson, P., (2005) *Understanding Management Research: an introduction to epistemology*. London: Sage.

100. Dunn, S.C., Seaker, R. and Waller, M.A., (1994) Latent variables in Business Logistics Research: scale development and validation. *Journal of business logistics*, 15 (2), pp. 145–172.

101. Easterby-Smith, M., Thorpe, R. and Lowe, A., (1991) *Management research*. London:Sage.

102. Edghill, I., Olsmats, C. and Towill, D.R. (1988) Industrial Case Study on the Dynamics and Sensitivity of a Closecoupled Production-distribution System. *International Journal of Production Research*, 26 (10), pp. 1681–1693.

103. Edghill, J. and Towill, D.R. (1990) Assessing manufacturing system performance: frequency response revisited. *Engineering Costs and Production Economics*, 19, pp. 319–326.

104. Elliott, S. (2001) *Signal Processing for Active Control*. London: Academic Press.

105. Enarsson, L. (2006). *Future Logistics Challenges*. Abingdon: Marston Book Services

106. Eshlaghy, A.T. and Razavi, M. (2011) Modeling and Simulating Supply Chain Management. *Applied Mathematical Sciences*, 5 (17), pp. 817–828.

107. Evans, G.N. and Naim, M.M., (1994) The dynamics of capacity constrained supply chain. *Proceedings of International System Dynamics Conference, Stirling, Scotland*, pp. 28–39.

108. Fang, Y,& Shou, B. (2015) Managing supply Uncertainty Cournot competition, *European journal of operational research*

109. Fernie, J., Pfab, F. and Marchant, C. (2000) Retail Grocery Logistics in the UK. *The International Journal of Logistics Management*, 11 (2), pp. 83–90.

110. Fiksel, J. (2003) Designing Resilient, Sustainable Systems. *Environmental Science and Technology*, 37 (23), pp. 5330–5339.

111. Fiksel, J. (2006a). A Framework for Sustainable Materials Management. *Journal of Materials*, August.

112. Fiksel, J. (2006b). Sustainability and Resilience: Toward a Systems Approach. *Sustainability: Science, Practice and Policy*, 2 (2), pp. 14–21.

113. Fiksel, J., Low, J. and Thomas, J. (2004) Linking Sustainability to Shareholder Value. *Environmental Management*, June.

114. Fishman, G.S. (2001) *Discrete-Event Simulation: Modeling, Programming, and Analysis*. New York USA: Springer.

115. Forrester, J.W. (1958) Industrial dynamics: a major breakthrough for decision makers. *Harvard Business Review*, 36 (4), pp. 37–66.

116. Forrester, J.W. (1961) *Industrial Dynamic*. Boston, MA: MIT Press.

117. Forrester, J.W. (1968) Industrial Dynamics - after the first decade. *Management Science*, 14 (7), pp. 398–415.

118. Forrester, J.W. (1971) *World Dynamics*. Cambridge: Wright-Allen.

119. Forrester, J. W. (1975). Collected Papers of Jay W. Forrester, Waltham, MA: Pegasus Communications. Forrester, J. W. (1997). "Industrial dynamics." Journal of the Operational Research Society 48(10), pp. 1037-1041.

120. Forrester, J. W., Low, G. W., and Mass, N. J. (1974). "The debate on world dynamics: a response to Nordhaus." Policy sciences 5(2), pp. 169-190.

121. Forrester J. W. and Senge, P. M. (1980). “Tests for Building Confidence in System Dynamics Models”, in Forrester, Jay. W. et al. eds., System Dynamics. North-Holland, New.

122. Forrester, J.W. and Senge, P. (1980) Tests for building confidence in system dynamic models. *TIMS Studies in the Management Science*, 14, pp. 209-228.

123. Frankel, R., Naslund, D. and Bolumole, Y., (2005). The “white space” of logistics research: a look at the role of methods usage. *Journal of Business Logistics*, 26 (2), pp. 185–209.

124. Fransoo, J.C. and Wouters, M.J.F. (2000). Measuring the bullwhip effect in the supply chain. *Supply Chain Management: An International Journal*, 5 (2), pp. 78–89.

125. Gaalman, G. and Disney, S.M. (2009) On bullwhip in a family of order-up-to policies with ARMA(2,2) demand and arbitrary lead-times. *International Journal of Production Economics*, 121 (2), pp. 454–463.

126. Gao, D, Wang, N., He, Z, Jia, T., (2017) The bullwhip effect in an online retail supply chain: *A perspective of price sensitivity demand based on the price discount*

127. Georgiadis, P. (2013) An integrated system dynamics model for strategic capacity planning in closedloop recycling networks: A dynamic analysis for the paper industry. *Simulation Modelling Practice and Theory*, 32(2), pp. 116-137.

128. Gainsborough, M. . (2006). Building World-class supply Chain Capability in the Downstream Oil Business. *Business Briefing: Oil and Gas Processing Review*. pp. 29-32.

129. Gammelgaard, B. (2004) Schools in logistics research? A methodological framework for analysis of the discipline. *International Journal of Physical Distribution & Logistics Management*, 34 (6), 479–491.

130. Georgiadis, P., Vlachos, D. and Iakovou, E. (2005) A system dynamics modeling framework for the strategic supply chain management of food chains. *Journal of Food Engineering*, 70 (3), pp. 351–364.

131. Giannakis, M. and Croom, S.R., (2004) Towards the development of a Supply Chain Management Paradigm: a conceptual framework. *Journal of supply chain management*, 40 (2), pp. 27–37.

132. Gocke, M. (2002) Various Concepts of Hysteresis Applied in Economics.¨ *Journal of Economic Surveys*, 16 (2), pp. 167–188.

133. Golicic, S.L., Davis, D.F. and McCarthy, T.M. (2005) A Balanced Approach to Research in Supply Chain Management.

134. Goranson, T. (1999) *The Agile Virtual Enterprise.*. Westport, CT: Quorum Books.

135. Gosling, J., Naim, M.M. and Towill, D.R. (2012) A supply chain flexibility framework for engineer-to-order systems. *Production Planning & Control*, 24 (7), pp. 552–556.

136. Graham, D. and McRuer, D. (1961) *Analysis of nonlinear control theory*. 1st New York: John Wiley & Sons, Inc.

137. Graham (1980) *Parameter estimation in system dynamics modelling*

138. Gro¨*β*ler, A. and Schieritz, N. (2005) Of Stocks, Flows, Agents and Rules - “Strategic”Simulations in Supply Chain Research. *In*: H. Kotzab, S. Seuring, M. Muller and¨ G. Reiner, eds. *Research Methodologies in Supply Chain Management*. Germany: Physica-Verlag Heiedlberg.

139. Grubbstrom, R. and Wang, Z. (2000) Introducing capacity limitations into¨ multi-level, multi-stage production-inventory systems applying the input-output: Laplace transform approach. *International Journal of Production Research*, 38 (17), pp. 4227–4234.

140. Grubbstrom, R.W. and Huynh, T.T. (2006) Analysis of standard ordering policies¨ within the framework of MRP theory. *International Journal of Production Research*, 44 (18-19), pp. 3759–3773.

141. Grunwald, H.J. and Fortuin, L. (1992) Many steps towards zero inventory.¨ *European Journal of Operational Research*, 59 (3), pp. 359–369.

142. Gunasekaran, A., Patel, C. and McGaughey, R.E. (2004) A framework for supply chain performance measurement. *International journal of production economics*, 87(3), pp. 333-347.

143. Gunasekaran, A. and Kobu, B. (2007) Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications. *International Journal of Production Research*, *45*(12), pp. 2819-2840.

144. Hall, B. (2002) *A Structure for Supply Chain Information Flows and Its Application to the Alaskan Crude Oil Supply Chain*. *Logistics Innovation Management. 15* (1), pp. 8-23.

145. Hamdouch, Y. (2011) Multi-period supply chain network equilibrium with capacity constraints and purchasing strategies. *Transportation Research Part C: Emerging Technologies*, 19 (5), pp. 803 – 820.

146. Harr´e, R. (1970) *The Principles of scientific thinking*. London: MacMillan.

147. Hennet, J.C. (2009) Supply chain dynamics. *In*: Y. Merkuryev, G. Merkuryeva, M.A. Piera and A. Guasch, eds. *Simulation-Based Case Studies in Logistics: Education and Applied Research*. London: Springer.

148. Hesse, M. (1966) *Models and Analogies in sciences*. South Bend: University of Notre Dame Press.

149. Hicks, M.J., (2004) *Problem Solving and Decision Making: Hard, Soft and Creative Approaches*. 2nd London, UK: Thomson Learning.

150. Higuchi, T. and Troutt, M.D., (2004) Dynamic simulation of the supply chain for a short life cycle product. *Computers & Operations Research*, 31 (7), pp. 1097–1114.

151. Hilmola, O. (2011). *Logistics Sector Development Potential of World's Oil Exporters*. *International Journal of Energy Sector Management. 5* (2), pp. 256-270.

152. Holliday, C. and Pepper, J. (2001) Walking the Talk: The Business Case for Sustainable Development. *World Business Council for Sustainable Development*.

153. Holling, C.S. (1973) Resilience and stability of ecological systems. *Annual review of Ecology and Systematics*, 4, pp. 1–23.

154. Holling, C. (1959) The components of predation as revealed by a study of small mammal predation of the European Pine Sawfly. *The Canadian Entomologist*, 91 (5), pp. 293–320.

155. Holweg, M. and Bicheno, J. (2000) The reverse amplification effect in supply chains. *Global Logistics for the New Millennium - 5th International Symposium on Logistics*, 12-15 July, Tokyo, Japan, pp. 549–554.

156. Homer and Homer (1997) *Structure, Data and compelling conclusions*. Sd review

157. Hong-Minh, S.M., Disney, S.M. and Naim, M.M. (2000) The dynamics of emergency transhipment supply chains. *International Journal of Physical Distribution and Logistics Management*, 30 (9), pp. 788–815.

158. Hopp W.J., and Spearman, M.L. (2000), Factory Physics, 2nd Ed., McGraw Hill, Singapore.

159. Hsia, T.C. (1972) On the simplification of linear systems. *IEEE Transactions on Automatic Control*, June, 372,374.

160. Hwarng, H.B. and Xie, N. (2008) Understanding Supply Chain Dynamics: A Chaos Perspective. *European Journal of Operational Research*, 184 (3), pp. 1163–1178.

161. Hussain, R., Assavapokee, T. and Khumawala, B. (2006). *Supply Chain Management in the Petroleum Industry: Challenges and Opportunities. International Journal of Global Logistics & Supply Chain Management. 1*(2), pp. 90-97.

162. Hölshler, J., Bachan, R. and Stimpson, A. (2008). *Oil Demand in China*: an Econometric Approach. *International Journal of Emerging Markets. 3*(1), pp.54-70.

163. Inokoba, P. K. and Imbua, D. L. (2010). "Vexation and militancy in the Niger Delta: The way forward." Journal of Human ecology 29(2): 101.

164. Kirkwood (1998) *System dynamics methods: A Quick Introduction,* College of Business Arizona State University.

165. Janamanchi, B. and Burns, J.R. (2007) Reducing bullwhip oscillation in a supply chain: a system dynamics model-based study. *International Journal of Information Systems and Change Management*, 2(4), pp. 350-371.

166. Janamanchi, B. (2011) Optimizing Two-player Supply Chain Performance: A System Dynamics Simulation Study. American Society for Competitiveness's annual publication Competition Forum, Volume 9(2), pp. 413-428.

167. Jenkins, P.,G. and Wright, S., D. (1998) *Managing Inflexible Supply Chains*. *The International Journal of Logistics Management. 9*(2), pp. 83-90.

168. Jeong, S., Oh, Y. and Kim, S., (2000) Robust Control of multi-echelon production distribution systems with limited decision policy (II). *KSME International Journal*, 14 (4), pp. 380–392.

169. Johansson, M. (2003) *Piecewise Linear Control Systems*. Berlin, Germany: Springer.

170. John, S., Naim, M.M. and Towill, D., (1994) Dynamic analysis of a WIP compensated decision support system. *International Journal of Manufacturing System Design*, 1 (4), pp. 283–297.

171. Johnson, G., Scholes, K. and Whittington, R. (2009). *Fundamentals of Strategy* 1st ed. Edinburgh: Pearson Education Limited.

172. Juntunen, J. and Juga, J. (2009) Controlling the bullwhip with transport capacity constraints. *International Journal of Services and Standards*, 5 (2), pp. 160–171.

173. Juttner, U., Peck, H. and Christopher, M., (2003) Supply chain risk management:¨ outlining an agenda for future research. *International Journal of Logistics: Research and Applications Vol. 6, No. 4, 2003*, 6 (4), pp. 197–210.

174. Juttner, U. (2011) Supply chain resilience in the global financial crisis: an empirical¨ study. *Supply Chain Management: An International Journal*, 16 (4), pp. 246–259.

175. Jüttner, U., Peck, H. and Christopher, M. (2003) Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Applications*, 6(4), pp. 197-210.

176. Jüttner, U. (2005) Supply chain risk management: Understanding the business requirements from a practitioner perspective. *International Journal of Logistics Management*, 16(1), pp. 120-141.

177. Kaplan, H.B., (1990) Toward an understanding of resilience: a critical review of definitions and models. *In*: M.D. Glantz and J.L. Johnson, eds. *Resilience and devepment: positive life adaptation*. Kluwer Academic.

178. Kaplan, S. and Garrick, B.J. (1981) On the quantitative definition of risk. *Risk Analysis, Vol. I , No. I , 1981*, 1 (1), pp.11–27.

179. Kasi, V. (2005). *Systemic assessment of SCOR for modeling supply chains.*

180. Keat, R. and Urry, J. (1975) *Social theory as sciences*. London: Routledge.

181. Kennedy (1992*) A guide to econometrics.* Third edition (MIT) press

182. Kothari, C.R. (2004) *Research methodology: methods and techniques*. Delhi: New Age International.

183. Kotzab, S. Seuring, M. Muller and¨ G. Reiner, eds. *Research Methodologies in Supply Chain Management*. Heidelberg, Germany: Physica-Verlag. pp.91-106.

184. Kov´acs, G. and Spens, K.M. (2007) Humanitarian logistics in disaster relief operations. *International Journal of Physical Distribution & Logistics Management*, 37 (2), pp. 99–114.

185. Kov´acs, G. and Tatham, P. (2009) Responding to disruptions in the supply network - from dormant to action. *Journal of Business Logistics*, 30 (2), pp.215–229.

186. Kov´acs, G. and Spens, K.M. (2005) Abductive reasoning in logistics research. *International Journal of Physical Distribution and Logistics Management*, 35 (2), pp. 132–144.

187. Kumar, S. and Nigmatullin, A. (2011) A system dynamics analysis of food supply chains - Case study with non-perishable products. *Simulation Modelling Practice and Theory*, 19 (10), pp. 2151–2168.

188. Kumar, S. and Yamaoka, T. (2007) System dynamics study of the Japanese automotive industry closed loop supply chain. *Journal of Manufacturing Technology Management*, 18 (2), pp. 115–138.

189. Kumar, S., Himes, K.J. and Kritzer, C.P. (2014) Risk assessment and operational approaches to managing risk in global supply chains. *Journal of Manufacturing Technology Management*, *25*(6), pp. 873-890.

190. Lagoudis, I.N., Lalwani, C.S., Naim, M.M. and King, J. (2002) Defining a conceptual model for high-speed vessels. *International Journal of Transport Management*, 1 (2), pp. 69–78.

191. Lalwani, C.S., Disney, S.M. and Towill, D.R., (2006) Controllable, observable and stable state space representations of a generalized order-up-to policy. *International Journal of Production Economics*, 101 (1), pp. 172–184.

192. Lam, J. (2003) *Enterprise risk management: From incentives to controls*. New Jersey: Wiley.

193. Lane, D.C. and Sterman, J.D. (2011) Jay Wright Forrester. *In*: S. Gass and A. Assad, eds. *Profiles in Operations Research: Pioneers and Innovators*. New York: Springer.

194. Lane, D.C., Monefeldt, C., and Rosenhead, J.V. (2000) Looking in the wrong place for healthcare improvements: a system dynamics study of an accident and emergency department. *The Journal of the Operational Research Society*, 51(5), pp. 518–531.

195. Lang, D. and de Peretti, C., (2009) A strong hysteretic model of Okun's Law: theory and a preliminary investigation. *International Review of Applied Economics*, 23 (4), pp. 445–462.

196. Laníez, J.M., Puigjaner, L. and Reklaitis, G.V. (2009) Financial and financial engineering considerations in supply chain and product development pipeline management. *Computers & Chemical Engineering*, 33(12), pp. 1999-2011.

197. Laníez, J.M. and Puigjaner, L. (2012) Prospective and perspective review in integrated supply chain modelling for the chemical process industry. *Current Opinion in Chemical Engineering*, 1(4), pp. 430-445.

198. Larsen, E.R., Morecroft, J.D.W. and Thomsen, J.S. (1999) Complex behaviour in a production-distribution model. *European Journal of Operational Research*, 119, pp, 61–74.

199. Larson, P.D. and Halldo´rsson, A. (2004) Logistics versus supply chain management: An international survey. *International Journal of Logistics Research and Applications*, 7 (1), pp. 17–31.

200. Lassar, W.M. and Kerr, J.L. (1996) Strategy and control in supplier-distributor relationships: an agency perspective. *Strategic Management Journal*, 17 (8), pp. 613– 632.

201. Laugesen, J. and Mosekilde, E. (2006) Border-collision bifurcation in a dynamic management game. *Computers & Operations Research*, 33, pp. 464–478.

202. Lee, C.F., and Chung, C.P. (2012) An inventory model for deteriorating items in a supply chain with system dynamics analysis. *Procedia-Social and Behavioral Sciences*, 40, pp. 41-51.

203. Lee, J.H. (2003) Energy supply planning and supply chain optimization under uncertainity.

204. Lee, H.L., Padmanabhan, V. and Whang, S. (1997a). The bullwhip effect in supply chains. *Sloan Management Review*, 38 (3), pp.93–102.

205. Lee, H.L., Padmanabhan, V. and Whang, S. (1997b) Information Distortion in a Supply Chain: The Bullwhip Effect. *Management Science*, 43 (4), pp. 546–558.

206. Lee, H.T. and Wu, J.C (2006) A study on inventory replenishment policies in a two-echelon supply chain system. *Computers & Industrial Engineering*, 51, pp. 257–263.

207. Lee, H., Padmanabhan, V. and Whang, S. (2015). The bullwhip effect in supply chains. *IEEE Engineering Management Review*, 43(2), pp.108-117.

208. Lee & Whang (2006) Information sharing in a supply chain. *Journal of technology management*

209. Leigh, J.R., (2004) *Control Theory*. 2nd London: The Institution of Electrical Engineers.

210. Lertpattarapong, C. (2002) *Applying System Dynamics Approach to the Supply Chain Management Problems*. Msc. Thesis, Massachusetts Institute of Technology.

211. Li, Q., Disney, S.M and Galaman (2014) Avoiding the bullwhip using damped trend forecasting and order up to replenishment policy. *International Journal of production economics.149, 3-16.*

212. Lin, J and Yueliang S. (2016) Research in order financing system dynamics in chain finance model, cross cultural communication. 12(8), pp 25-30

213. Lin, L. (2018). System Dynamics Analysis and Design of Assemble-to-Order Supply Chains, *PhD Thesis, Cardiff University*.

214. Lummus, R.R., Duclos, L.K. and Vokurka, R.J., (2003) Supply Chain Flexibility: Building a New Model. *Global Journal of Flexible Systems Management*, 4 (4), pp. 1–13.

215. Lummus, R.R., Krumwiede, D.W. and Vokurka, R.J. (2001) The relationship of logistics to supply chain management: developing a common industry definition. *Industrial Management and Data Systems*, 101 (8), pp. 426–432.

216. Lynies and Pugh (1996) *Automated vs hand calibration of system dynamics model;* an experiment with a simple project model.

217. Mangan, J., Lalwani, C. and Gardner, B. (2004) Combining quantitative and qualitative methodologies in logistics research. *International Journal of Physical Distribuition & Logistics*, 34 (7), pp. 565–78.

218. .Mangan, J., Lalwani, C. and Butcher, T. (2008) *Global Logistics and Supply Chain Management*. Chichester: John Wiley & Sons.

219. Manuj, I. and Mentzer, J.T. (2008a) Global supply chain risk management. *Journal of Business Logistics*, 29(1), pp. 133-155.

220. Manuj, I. and Mentzer, J.T. (2008b) Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management*, 38(3), pp. 192-223.

221. March, J.G. and Shapira, Z. (1987) Managerial perspectives on risk and risk taking. *Management Science*, 33 (11), pp. 1404–1418.

222. Marques, V.L., Naim, M.M. and Disney, S.M. (2010) The impact of capacitated logistics operations on supply chain dynamics. *Proceedings of the 16th International Working Seminar on Production Economics, Innsbruck, 1-5 March, Austria,* PrePrints, Vol. 3., pp. 365-376.

223. Mashayekhi, A.N. and Ghili, S. (2012) System dynamics problem definition as an evolutionary process using the concept of ambiguity. *System Dynamics Review*, 28(2), pp. 182-198.

224. Mason-Jones, R., (1998) 'The holistic strategy of information enrichment through the supply chain dynamics'. Thesis (PhD). University of Wales, Cardiff.

225. Mason, R. and Lalwani, C. (2006) Transport integration tools for supply chain management. *International Journal of Logistics: Research and Applications*, 9 (1), pp. 57–74.

226. Mason-Jones, R., Naylor, B. and Towill, D.R. (2000) Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research*, 38(17), pp. 4061-4070.

227. Mason-Jones, R., Naim, M.M. and Towill, D.R. (1997) The impact of pipeline control on Supply Chain Dynamics. *The International Journal of Logistics Management*, 8 (2), pp. 47–62.

228. Mason-Jones, R. and Towill, D. (1998) Shrinking the supply chain uncertainty circle. *Control*, 24 (7), pp. 17–23.

229. Mast, T. (2005). *Oil and Its Alternatives: Why They Are So Important.* U-T Sandiego. Available at: http://legacy.signonsandiego.com/uniontrib/20050309/news_lz1e9mast.html

230. McManus, S., Seville, E., Brunsdon, D. and Vargo, J. (2007) Resilience Management: A Framework for Assessing and Improving the Resilience of Organisations. *Christchurch, New Zealand: Resilient Organisations (*www.resorgs.org.nz*)*.

231. Mentzer, J. and Kahn, K. (1995) A framework of logistics research. *Journal of Business Logistics*, 16 (1), pp. 231–50.

232. Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. and Zacharia, Z.G. (2001) Defining supply chain management. *Journal of Business Logistics*, 22 (2), pp. 1–25.

233. Meredith, J., Raturi, A., Gyampah, K. and Kaplan, B., (1989) Alternative research paradigms in operations. *Journal of Operations Management*, 8 (4), pp. 297–326.

234. Metz, P.J., (1998) Demystifying Supply Chain Management. *Supply Chain Management Review*, Winter, pp. 46–55.

235. Mingers, J. (2000) The contribution of critical realism as an underpinning philosophy for OR/MS and systems. *Journal of Operational Research Society*, 51 (11), pp.1256– 1270.

236. Mingers, J. and White, L. (2010) A review of the recent contribution of systems thinking to operational research and management science. *European Journal of Operational Research,* 207(3), pp. 1147-1161.

237. Mitra, K., Gudi, R.D., Patwardhan, S.C. and Sardar, G., (2009) Towards resilient supply chains: Uncertainty analysis using fuzzy mathematical programming. *Computer Aided Chemical Engineering*, 87 (7), pp. 967–981.

238. Moffatt, I. (1991) *Causal and simulation modelling using system dynamics*, Norwich: CATMOGS.

239. Mohapatra, P.K.J. (1980) Nonlinearity in system dynamics models. *Dynamica*, 6 (1), pp. 36–52.

240. Moizer, J.D. (1999) *System Dynamics Modelling of Occupational Safety: A Case Study Approach*, 1997-1999. Ph.D. thesis, University of Stirling.

241. Mokhtari, K., Ren, J., Roberts, C. and Wang, J. (2012) Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach. *Expert Systems with Applications*, 39(5), pp. 5087-5103.

242. Mosekilde, E. and Laugesen, J.L. (2007) Nonlinear dynamic phenomena in the beer model. *Systems Dynamics Review*, 23 (2/3), pp. 229–252.

243. Mullai, A. (2009) Risk management system-A conceptual model. In: Zsidisin, G.A. and Ritchie, B. (eds.) *Supply chain risk: A handbook of assessment, management, and performance*. New York: Springer. pp. 83-101.

244. Musawa, I. (2016) *Challenges facing government revenue from the Nigerian oil industry.*

245. Naim, M.M. and Towill, D.R. (1995) What's in the pipeline?. *Second International Symposium on Logistics, Nottingham, UK, 11-12th July*, pp.135–142.

246. Naim, M.M. and Towill, D.R., (1994) Establishing a Framework for Effective Materials Logistics Management. *International journal of Logistics Management*, 5 (1), pp. 81–88.

247. Naim, M.M., Disney, S.M. and Towill, D.R., 2004. Supply chain dynamics. *In*: S. New and R. Westbrook, eds. *Understanding Supply Chains: Concepts, Critiques, and Futures*. Oxford University Press.

248. Naim, M.M., Wikner, J., Towill, D.R. and Marques, V.L. (2012) Mitigating the bullwhip effect by exploiting archetypes of complex production and inventory control systems. *Proceedings of the 17th International Working Seminar on Production Economics, Igls/Innsbruck, 20-25 February, Austria*, 1, pp. 373–382.

249. Naslund, D. (2002) Logistics needs qualitative research: especially action research.¨ *International Journal of Physical Distribution & Logistics*, 32 (5), pp. 321–38.

250. Newman, W.R., Hanna, M. and Maffei, M.J. (1993) Dealing with the uncertainties of manufacturing: flexibility, buffers and integration. *International Journal of Operations and Production Management*, 13 (1), pp. 19–34.

251. Nigerian National Petroleum Corporation. (2016). Profile / products. Retrieved from www.nnpcgroup.com

252. Nsikan, E. Ekeins-wilson., Tarela., O., Maria M (2019) Supply chain distruptions in Nigeria oil and gas sector. *International journal of scientific research publications.*

253. Odofin, C. D. (1979). The impacts of the multinational oil corporations on Nigeria's economic growth: theoretical and empirical explorations. American University.

254. Oehmen, J., Ziegenbein, A., Alard, R., and Schönsleben, P. (2010) System-oriented supply chain risk management. *Production Planning Control*, 20(4), pp. 343-361.

255. Ogunleye, E. K. (2008) "Natural resource abundance in Nigeria: From dependence to development." Resources Policy 33(3), pp. 168-174.

256. Olivia (2003*) Model calibration as a testing strategy for system dynamics model*

257. Oliver, R.K. and Webber, M.D.(1982) Supply Chain Management: Logistics Catches Up with Strategy. *In*: M. Christopher, ed. *Logistics: The Strategic Issues*. Chapman & Hall, pp. 63–75.

258. Oshwofasa, B. O., and Anuta, D. E. (2012) "Environmental Degradation and Oil Industry Activities in the Niger-Delta Region." African Journal of Scientific Research Vol, 9(1).

259. Osuala. U.S (2013) The sublimeness of sleaze in the NNPC in the fourth republic, 1999-2007: A historical conspectus. *Journal of culture, society and development*. 2, 52-59

260. Ouyang, L.-H., Wu, K.-S., and Ho, C.-H. (2007). *An integrated vendor-buyer inventory model with quality improvement and lead time reduction.* International Journal of Production Economics , 108, pp. 349-358.

261. Özbayrak, M., Papadopoulou, T.C. and Akgun, M. (2007) System dynamics modelling of a manufacturing supply chain system. *Simulation Modelling Practice and Theory*, 15(10), pp. 1338-1355.

262. Paki, F., and Ebienfa, K. (2011). "Oil and Development Deficit in Africa: The failure of intervention agencies in Nigeria's Niger Delta". International Journal of Business and Social Science, 2(8).

263. Park, Y.W., Hong, P. and Roh, J.J. (2013) Supply chain lessons from the catastrophic natural disaster in Japan. *Business Horizons*, 56(1), pp. 75-85.

264. Pagell, M. and Krause, D.R. (1999) A Multiple-Method Study of Environmental Uncertainty and Manufacturing Flexibility. *Journal of Operations Management*, 17 (3), pp. 307–326.

265. Peck, H. (2005) Drivers of supply chain vulnerability: an integrated framework. *International Journal of Physical Distribution and Logistics Management*, 35 (4), pp. 210–232.

266. Peng, M., Peng, Y. and Chen, H. (2014) Post-seismic supply chain risk management: A system dynamics disruption analysis approach for inventory and logistics planning. *Computer Operations Research*, 42(1), pp. 14-24.

267. Peterson, D.W. and Eberlein, R.L. (1994) Reality check: A bridge between systems thinking and system dynamics. *System Dynamics Review*, 10 (2-3), pp. 159-174.

268. Pettit, T.J., Fiksel, J. and Croxton, K.L. (2010) Ensuring supply chain resilience: development of a conceptual framework. *Journal of Business Logistics*, 31 (1), pp. 1–21.

269. Poles, R. (2013) System Dynamics modelling of a production and inventory system for remanufacturing to evaluate system improvement strategies. *International Journal of Production Economics*, 144 (1), pp. 189–199.

270. Ponomarov, S.Y. and Holcomb, M.C. (2009) Understanding the concept of supply chain resilience. *International Journal of Logistics Management*, 20(1), pp. 124-143.

271. Potter, A. and Lalwani, C. (2008) Investigating the impact of demand amplification on freight transport. *Transportation Research Part E*, 44 (5), pp. 835–846.

272. Qudrat-Ullah, H. and Seong, B.S. (2010) How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. *Energy Policy*, 38(5), pp. 2216-2224.

273. Ratnatunga, A.K. and Sharp, J.A. (1976) Linearization and order reduction in system dynamics models. *Dynamica*, 2 (3), pp. 87–94.

274. Ray, S., and Jewkes, E. (2004). *Customer lead time management when both demand and price are lead time sensitive.* European Journal of Operational Research , 153, pp. 769-781.

275. Ribas, G., Leiras, A. and Hamacher, S. (2011). Tactical Planning of the Supply Chain: Optimization under Uncertainty. *XLIII Simpasio Brasileiro de Pesquisa Operacional. 15*(18).

276. Rice, J.B. and Caniato, F. (2003) Building a secure and resilient supply network. *Supply Chain Management Review*, 7 (5), pp. 22–30.

277. Richardson, G. P. and Pugh III A. I. (1981). Introduction to system dynamics modeling with DYNAMO, Productivity Press Inc.

278. Richardson, G.P. (2008) The Core of System Dynamics. *In*: R. Meyers, ed. *Encyclopedia of Complexity and Systems Science*. Springer, pp. 8967–8974.

279. Richardson, G.P., (2011) Reflections on the foundations of system dynamics. *System Dynamics Review*, 27 (3), pp. 219–243.

280. Ritchie, B. and Brindley, C. (2007) Supply chain risk management and performance. *International Journal of Operations & Production Management*, 27(3), pp. 303-322.

281. Robert, C.P. and Casella, G. (2013) *Monte Carlo statistical methods*. New York: Springer-Verlag.

282. Rose, A. (2004) Economic resilience to disasters: toward a consistent and comprehensive formulation. *In*: D. Paton and D. Johnston, eds. *Disaster resilience: an integrated approach*. Springfield, pp. 226–248.

283. Rozman, Č., Pažek, K., Prišenk, J., Škraba, A., & Kljajić, M. (2012) System dynamics model for policy scenarios of organic farming development. *Organizacija*, 45(5), pp. 212-218.

284. Rugh, W.J. (2002) *Nonlinear System Theory: The Volterra/Wiener Approach*. The Johns Hopkins University Press.

285. Sacha, A. and Datta, S. (2005) Review of supply chain management and logistics research. *International Journal of Physical Distribution and Logistics Management*, 35 (9), pp. 664–705.

286. Sala-i-Martin, X. and Subramanian, A. (2013) Addressing the natural resource curse: an illustration from Nigeria. Journal of African Economies, 22(4), pp. 570-615.

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

288. Saunders, M.N.K., Lewis, P. and Thornhill, A. (2009) *Research Methods for Business Students*. 5th Harlow, England: Pearson Education Limited.

289. Saunders, M., Lewis, P. and Thornhill, A. (2012) Research methods for business students, 6th Edition. Harlow: Pearson

290. Sayer, A. (2000) *Realism and Social Science*. 1st London: Sage.

291. Schildhouse, J. (2006) One on one: an interview with Willis D. Pugh. *Journal of Supply Chain Management*, 42(1), pp. 2-4.

292. Schmidt, A.J. and Singh, M. (2012) A quantitative analysis of disruption risk in a multi-echelon supply chain. *International Journal of Production Economics*, 139 (1), pp. 22–32.

293. Schmidt, G. and Wilbert, E.W. (2000) Strategic, tactical and operational decisions in multi-national logistics networks: A review and discussion of modelling issues. *International Journal of Production Research*, 38(7), pp. 1501-1523.

294. Sch eatzl, L. H. (1969) Petroleum in Nigeria, Oxford UP for the Nigerian Institute of Social and Economics Research.

295. Sheffi, Y. (2001) Supply Chain Management under the Threat of International Terrorism. *International Journal of Logistics Management*, 12 (2), pp. 1–11.

296. Sheffi, Y. and Rice, J.B. (2005) A supply chain view of the resilient enterprise. *MIT Sloan Management Review*, 47 (1), pp. 41–48.

297. Sheffi, Y. (2005a) Preparing for the big one. *IEE Manufacturing Engineer*, Oct./Nov., pp. 12–15.

298. Sheffi, Y. (2005b) Building a Resilient Supply Chain. *Harvard Business Review*, 1 (8), pp.1–5.

299. Shukla, V., Naim, M.M. and Yaseen, E.A. (2009) 'Bullwhip' and 'backlash' in supply pipelines. *International Journal of Production Research*, 47 (23), pp. 6477–6497.

300. Slack, N., Chambers, S. and Johnst, R. (2010) *Operations and Process Management*. 6th Essex: Pearson Prentice Hall.

301. Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2000) Designing and Managing the Supply Chain. The McGraw-Hill Companies, New York.

302. Spekman, R.E. and Davis, E.W., (2004) Risky business: expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution & Logistics Management*, 34 (5), pp. 414–433.

303. Spens, K.M. and Kova´cs, G. (2006) A content analysis of research approaches in logistics research. *International Journal of Physical Distribution and Logistics Management*, 36 (5), pp. 374–390.

304. Stalk, G. and Hout, T. (1990) *Competing against Time*. New York, NY: The Free Press.

305. Sterman, J.D. (1989) Modelling managerial behaviour: misperceptions of feedback in a dynamic decision making experiment. *Management Science*, 35 (3), pp. 321–339.

306. Sterman, J. D. (2000) Business Dynamics: System Thinking and modeling for a complex World. Irwin/McGraw-Hill, Boston

307. Sterman, J. D. (2002) "All models are wrong: reflections on becoming a systems scientist." System dynamics review 18(4), pp. 501-531.

308. Stevens, G.C. (1989) Integrating the Supply Chain. *International Journal of Physical Distribution and Logistics Management*, 19 (8), pp. 3–8.

309. Stewart, G. (1995) Supply chain performance benchmarking study reveals keys to supply chain excellence. *Logistics Information Management*, 8 (2), pp. 38–44.

310. Stewart, M., Reid, G. and Mangham, C. (1997) Fostering Children's Resilience. *Journal of Pediatric Nursing*, 12 (1), pp. 21–31.

311. Sung-il park, Ying Wang and Adolf K.Y. NG (2014) System dynamics modelling for determining optimal ship sizes in coaster liner services. *The Asian journal of shipping and logistics,* volume 30, pp 031-050

312. Suri, R. (1998) *Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times*. Productivity Press.

313. Svensson, G. (2000) A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution & Logistics Management*, 30 (9), pp. 731–749.

314. Tang, C.S. (2006) Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics: Research and Applications*, 9 (1), pp. 33-45.

315. Tang, C. and Tomlin, B. (2008) The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics*, 116 (1), pp. 12–27.

316. Thomas, A.B. (2004) *Research Skills for management studies*. 1st London: Routledge.

317. Thomas, A. and Fritz, L. (2006) Disaster Relief, Inc.. *Harvard*, 84 (11), pp. 114–122.

318. Tianyuan, Zhu, Jaydeep Balakrishan, Giovani (2018) Bullwhip effect in the oil and gas supply chain: A multiple case study. *International Journal of production economics*

319. Tierney,S. (2004) The Crude Reality of the Oil Supply Chain in Today's World. *Supply Chain Europe. 13*(9), pp. 20-22.

320. Tomlin, B. (2006) On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks. *Management Science*, 52 (5), pp. 639–657.

321. Torres, O.C. and Maltz, A.B. (2010) Understanding the financial consequences of the bullwhip effect in a multi-echelon supply chain. *Journal of Business Logistics*, 31 (1), pp. 23–41.

322. Towill, D.R. (1970) *Transfer Function Techniques for control engineers*. London: Iliffe Books Ltd.

323. Towill, D.R. (1981) *Coefficient Plane Models for Control System Analysis and Design*. Herts, England: John Wiley & Sons.

324. Towill, D.R. (1982) Dynamic analysis of an inventory and order based production control system. *International Journal of Production Research*, 20 (6), pp. 671–687.

325. Towill, D.R. (1991) Supply chain dynamics. *International Journal of Computer Integrated Manufacturing*, 4 (4), pp. 197–208.

326. Towill, D.R. (1992a). Supply chain dynamics: the change engineering challenge of the 1990s. *Proceedings Institute of Mechanical Engineering Conference on Engineering Manufacture*, 206 (4), pp. 233–245.

327. Towill, D.R. (1992b) The practical use of control theory in manufacturing design and manufacturing management. *Journal of Systems Engineering*, 1 (2), pp. 2–14.

328. Towill, D.R., Naim, M.M. and Wikner, J. (1992) Industrial dynamics simulation models in the design of supply chains. *International Journal of Physical Distribution & Logistics Management*, 22 (5), pp. 3–13.

329. Towill, D.R. (1996a) Time compression and supply chain management- a guided tour. *Supply Chain Management: An International Journal*, 1 (1), pp 15–27.

330. Towill, D.R. (1997a) Forridge - principles of good material flow. *Production Planning and Control*, 8 (7), pp. 622–632.

331. Towill, D.R. (1997b). The seamless supply chain - the predator's strategic advantage. *International Journal of Technology Management*, 13 pp. 37-56.

332. Tsiakis, P. and Papageorgiou, L.G. (2008) Optimal production allocation and distribution supply chain networks. *International Journal of Production Economics*, 111(2), pp. 468-483.

333. Tsiakkouri, M. (2010) *Risk Management Processes for Managing Disruptions in Supply Chains*, 2007-2012. Ph.D. thesis, University of Southampton.

334. Vanderminden, P. (2006) System dynamics–A field of study, a methodology or both. 24th International Conference of The System Dynamics Society. Radboud University Nijmegen, System Dynamics Society, Albany.

335. Van den Heijden, K. (1997) *Scenarios: The art of strategic conversation*. Chichester: John Wiley & Sons.

336. Van der Vorst, J.G.A.J. and Beulens, A.J.M. (2002) Identifying sources of uncertainty to generate supply chain redesign strategies. *International Journal of Physical Distribution & Logistics Management*, 32(6), pp. 409-430.

337. Van der Zee, D. J. and Van der Vorst, J. (2005) "*A Modeling Framework for Supply Chain Simulation: Opportunities for Improved Decision Making**." Decision Sciences 36(1) pp. 65-95.

338. Van Hoek, R., Harrison, A. and Christopher, M. (2001) Measuring agile capabilities in the supply chain. *International Journal of Operations and Production Management*, 21 (1/2), pp. 126–147.

339. Venetoulis, J., Chazan, D. and Gaudet, C. (2004) *Ecological footprint of nations*. Oakland: Redefining Progress.

340. Vennix, J. A. (1996) Group model building: Facilitating team learning using system dynamics, Wiley Chichester.

341. Vensim *Allocation by Priority Ventana Systems*

342. Vonderembse M.A., Uppal M., Huang S.H., Dis-mukes J.P. (2006) *Designing supply chains: towards theory development*, Int. J. Prod. Econs., 100(2) pp. 223-238.

343. Warburton, R. and Disney, S. (2007) Order and inventory variance amplification: The equivalence of discrete and continuous time analyses. *International Journal of Production Economics*, 110 (1-2), pp. 128–137.

344. Weick, K.E., Sutcliffe, K.M. and Obstfeld, D. (1999) Organizing for high reliability: processes of collective mindfulness. *Research in Organizational Behavior*, 21, pp. 13– 81.

345. Wikner, J., Towill, D.R. and Naim, M.M., (1991) Smoothing supply chain dynamics. *International Journal of Production Economics*, 22 (3),pp. 231–248.

346. Wikner, J., Naim, M.M. and Towill, D.R. (1992) The system simplification approach in understanding the dynamic behaviour of a manufacturing supply chain. *Journal of Systems Engineering*, 2, pp. 164–178.

347. Wikner, J., Naim, M.M. and Rudberg, M. (2007) Exploiting the Order Book for Mass Customized Manufacturing Control Systems With Capacity Limitations. *IEEE Transactions on Engineering Management*, 54 (1), pp.145–155.

348. Wildavsky, A. (1988) *Searching for Safety*. New Brunswick, NJ: Transaction Books. Williams, T., 2008. *Management Science in Practice*. West Sussex: John Wiley.

349. William, W (1991) *Simulation system employing Causal Tracing*

350. Wilson, B. (2001) *Soft Systems Methodology: Conceptual Model Building and Its Contribution*. Chichester, UK: Wiley.

351. Wilson, M. (2007) The Impact of Transportation Disruptions on Supply Chain Performance. *Transportation Research Part E: Logistics and Transportation Review*, 439(4) pp. 295-320.

352. Witt, D. B. and Meyer, R. (2005). *Strategy Synthesis* 2nd ed.. London: Thomson Learning.

353. Wolf, J. (2008) *The nature of supply chain management research*. Frankfurt: GablerVerlag.

354. Wolstenholme, E. F. (1990). System enquiry: a system dynamics approach, John Wiley and Sons, Inc.

355. Wu, D.D. and Olson, D.L. (2013) Computational simulation and risk analysis: An introduction of state of the art research. *Mathematical and Computer Modelling*, *58*(9), pp. 1581-1587.

356. Yates, J.F. and Stone, E.R. (1992) The risk construct. *In*: J. Yates, ed. *Risk Taking Behavior*. New York: Wiley, pp. 1–25.

357. Zhou, L., Disney, S. and Towill, D. (2010) A pragmatic approach to the design of bullwhip controllers. *International Journal of Production Economics*, 128 (2), pp. 556–568.

358. Zhu, Q., Cordeiro, J. and Sarkis, J. (2013) Institutional pressures, dynamic capabilities and environmental management systems: Investigation the ISO 9000-Environmental management system implementation linkage. *Journal of Environmental Management*, 114(15), pp. 232242.

359. Zsidisin, G.A. (2003) A grounded definition of supply risk. *Journal of Purchasing and Supply Management*, 9 (5-6), pp. 217–224.

360. Zsidisin, G.A. and Ritchie, B. (2008) *Supply chain risk: A handbook of assessment, management, and performance*. New York: Springer.

361. Zsidisin, G.A., Ellram, L.M., Carter, J.R. and Cavinato, J.L. (2004) An analysis of supply risk assessment techniques. *International Journal of Physical Distribution & Logistics Management*, *34*(5), pp. 397-413.

APPENDIX A
Interview Guide for Data Collection

The main aim is to understand how the downstream oil supply chain in Nigeria is managed, to gather relevant information from various participants and to answer the questions on how and why social events occur, understanding the causes of uncertainty and instabilities in the supply chain of the Nigerian downstream oil industry.

The interview would enable the researcher to gain a proper insight into the company's supply chain and its relationship with partners. The data gathered from the interview were important in validating the results of the research.

Section one: Overview of the company's supply chain

- From your knowledge please give an indebt description of the company's supply chain?
- Which system is currently implemented by your company to ensure oil (petroleum) flows as previously described?
- Describe the flow of inventory for Petroleum?
- List the sources of distribution employed by your company?

Section two: Identify channel partners and role rationalisation

- Kindly list names of key partners?
- What are the roles of key partners?
- What are the significance to the company?

Section Three: Understanding ordering, managing and forecasting inventory with the supply chain:

- Describe inventory flow from order to customer demand fulfilment?

- Which adopted method is used to transport inventory?
- In your opinion explain reasons for inventory delay and information delay?
- When making orders and forecasting, what method is utilised?
- Explain how information pertaining to orders is shared with partners?
- What mitigating methods are employed to manage delays?

Section four: Understanding the impact of delays on supply chain performance

- In your opinion, what do you understand by delays in a supply chain?
- Within the supply chain, when do you notice a delay of orders?
- Why are most delays detected at the points outlined above?
- What counter measures are utilised to reduce delays?
- From your perspective, what measures can be employed to respond to uncertainties caused by customer demand within a supply chain?
- How much collaboration takes place between you and your partners to better manage delays?
- What impacts do uncertainties have on the overall operation of the company?
- How do partners respond to these uncertainties?

APPENDIX B

RESEARCH WITH PLYMOUTH UNIVERSITY

Date: 29 January 2018

Dear Mac-Daniel,

Ethical Approval Application No: FREC1718.07
Title: An Evaluation of Supply Lead Time in the Nigerian Oil Sector.

Thank you for your application to the Faculty Research Ethics & Integrity Committee (FREIC) seeking ethical approval for your proposed research.

The committee has considered your revised application and is fully satisfied that the project complies with Plymouth University's ethical standards for research involving human participants.

Approval is for the duration of the project. However, please resubmit your application to the committee if the information provided in the form alters or is likely to alter significantly.

The FREC members wish you every success with your research.

Yours sincerely
(Sent as email attachment)

Dr James Benhin
Chair
Faculty Research Ethics & Integrity Committee
Faculty of Business

Faculty of Business
University of Plymouth
Drake Circus
Plymouth
Devon PL4 8AA United Kingdom

T +44 (0) 1752 585587
E FoBResearch@plymouth.ac.uk
W www.plymouth.ac.uk

APPENDIX C

Elements of Data

Measure Title	Data Type	Operational Definition	Data Source
Distributor Order Fulfilment Rate	Numerical	Distributor order to replace expected outflow from the stock and reduce any discrepancy between the desired and actual stock.	Company database
Oil Distributor Inventory	Numerical/Interview	This is the current amount of inventory the distributor has in stock.	Company database (Inventory data)
Retailer Order Fulfilment Rate	Numerical	Retailer order to replace expected outflow from the stock and reduce any discrepancy between the desired and actual stock.	Company database (inventory data)
Retailer Inventory Storage	Numerical	This is the current amount of inventory the retailer has in stock.	Company database (order data)
Sales Rate	Numerical/Interview	This is the rate at which oil are sold to customers	Company sales data/company report
Average Dwell Time	Numerical	Calculates the time it takes for the distributor to fulfil dealer order	Company database
Inventory Coverage	Numerical/Interview	Determines the time it takes for the dealer to finally fulfil customer demand	Company database (inventory data)
Distributor Order	Oral/Numerical/Interview	The distributor order is concerned with anchoring and adjustment process	Company database (order data)

Adjustment for Inventory	Numerical/Interview	The distributor maintains an enough inventory of unfilled orders by adjusting it.	Company database (inventory data)
Retailer Order Cycle Time	Numerical	This represents the average transit time for all items aggregated together	Company database (order data)
Inventory Adjustment	Numerical	The retailer maintains an enough inventory of unfilled orders by adjusting it.	Company database (inventory data)
Max Sales Rate	Numerical	This is assumed on the firm current inventory level and the minimum order fulfilment time	Company database (Sales Data)
Sales Fulfilment Ratio	Numerical		Company database (Sales Data)
Desired Sales Rate	Numerical/Interview	stipulates that the firm can sell what it wants	Company database (Sales Data)
Distributor Adjustment Time	Numerical	This is the time it takes to correct the records of the distributor	Company database
Distributor Desired Inventory	Numerical/Interview/Oral	This provides a level of inventory to yield the desired rate of order	Company database (inventory data)
Retailer Adjustment Time	Numerical/Interview	This is the time it takes to correct the records of the retailer	Company database
Min Sales Processing Time	Numerical/Interview	The minimum sales processing time is determined by the firms order fulfilment process	Company database
Desired Inventory Coverage	Numerical/Interview	Denote the preferred amount of time for which inventory is able to fulfil customer demand	Company database (inventory data
Desired Inventory	Numerical/Oral/Interview	This is the preferred amount of inventory	Company database (inventory data

Safety Stock Coverage	Numerical/Oral	is a level of extra stock in this model that is maintained to mitigate risks of stock out due to uncertainties in demand and sales	Company database (inventory data
Expected Order	Numerical/Oral	It is the value of the order rate in this model	Company database (order data)
Change in Expected Order Rate	Numerical/Interview	This variable represent changes in incoming orders	Company database (order data)
Time to Average Expected Order Rate	Numerical	This is the time required, on average, for expectations to respond to change in actual conditions.	Company database (order data)
Total Cost	Numerical	This is the aggregate of all expenses	Company database
Unit Cost	Numerical	This is the total expenditure incurred by the company to produce, store and sell one unit of vehicle.	Company database
Inventory Cost	Numerical	The cost of holding inventory	Company database
Profit	Numerical	The amount of money made after costs have been incorporated	Company database
Sales revenue	Numerical	Income from sales of goods and services, minus the cost associated.	Company database
Sales price	Numerical	The price of a good or service that is being sold.	Company database

APPENDIX D

Company A Sales rate

Week	Actual	Simulated	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE	St.Dev^{A}	St.Dev^{S}	Alpha
2	569	590										0.6
4	596	577	19	19	0.0318792	361	0.7241379	65.965517	0.1282966	77.47466	51.203235	
6	568	588	-20	20	0.0352113	400	0.0714286	67.642857	0.1317401	78.82146	51.762578	
8	551	576	-25	25	0.0453721	625	0.8148148	69.407407	0.1353152	79.92957	52.576576	
10	578	561	17	17	0.0294118	289	1.8076923	71.115385	0.1387745	81.42292	53.219216	
12	574	571	3	3	0.0052265	9	1.2	73.28	0.1431491	83.02738	54.117593	
14	543	573	-30	30	0.0552486	900	1.125	76.208333	0.1488958	84.62539	55.219773	
16	592	555	37	37	0.0625	1369	2.4782609	78.217391	0.1529674	86.36096	56.302496	
18	597	577	20	20	0.0335008	400	0.9090909	80.090909	0.1570796	88.26131	57.421574	
20	576	589	-13	13	0.0225694	169	0	82.952381	0.1629643	89.97705	58.771699	
22	440	581	-141	141	0.3204545	19881	0.65	86.45	0.169984	91.67676	59.977734	
24	538	496	42	42	0.0780669	1764	8.1052632	83.578947	0.1620645	93.89102	60.922816	
26	657	521	136	136	0.2070015	18496	6.2222222	85.888889	0.1667311	92.65742	62.150402	
28	613	603	10	10	0.0163132	100	-1.411765	82.941176	0.1643622	95.22867	62.590301	
30	519	609	-90	90	0.1734104	8100	-2.125	87.5	0.1736153	94.7866	64.034228	
32	447	555	-108	108	0.2416107	11664	3.7333333	87.333333	0.173629	96.53961	64.804032	
34	516	490	26	26	0.0503876	676	11.714286	85.857143	0.1687731	99.60269	65.09312	
36	447	506	-59	59	0.1319911	3481	10.615385	90.461538	0.1778797	99.03127	67.505189	
38	516	471	45	45	0.0872093	2025	16.416667	93.083333	0.1817037	102.3225	68.245221	
40	464	498	-34	34	0.0732759	1156	13.818182	97.454545	0.1902942	100.7407	69.924797	
42	567	478	89	89	0.1569665	7921	18.6	103.8	0.201996	104.1321	68.054524	

44	656	531	125	125	0.1905488	15625	10.777778	105.44444	0.2069993	102.6643	68.240099	
46	712	606	106	106	0.1488764	11236	-3.5	103	0.2090556	108.6566	64.216647	
48	654	670	-16	16	0.0244648	256	-19.14286	102.57143	0.2176526	112.9468	66.064768	
50	372	660	-288	288	0.7741935	82944	-19.66667	117	0.2498506	107.5081	70.671608	
52	623	487	136	136	0.2182986	18496	34	82.8	0.144982	108.8646	64.104342	
54	453	569	-116	116	0.2560706	13456	8.5	69.5	0.1266528	76.05064	49.383196	
56	651	499	152	152	0.2334869	23104	50	54	0.0835135	83.35666	42.324146	
58	584	590	-6	6	0.010274	36	-1	5	0.0085268	37.072	51.423082	
60	590	586	4	4	0.0067797	16	4	4	0.0067797	4.242641	2.8284271	

Company A Retailer inventory storage

Week	Actual	Simulated	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE	$St.Dev^A$	$St.Dev^S$	Alpha
2	2320	2664										0.6
4	1871	2458	-587	587	31.37%	344569	-1.758621	312.17241	13.03%	417.58779	327.62099	
6	1575	2106	-531	531	33.71%	281961	19.142857	302.35714	12.38%	424.85826	329.10824	
8	2011	1787	224	224	11.14%	50176	39.518519	293.88889	11.59%	421.26225	334.76564	
10	1852	1921	-69	69	3.73%	4761	32.423077	296.57692	11.60%	397.02216	336.93585	
12	2153	1880	273	273	12.68%	74529	36.48	305.68	11.92%	396.08815	321.39565	
14	2134	2044	90	90	4.22%	8100	26.625	307.04167	11.89%	385.36613	312.08128	
16	2121	2098	23	23	1.08%	529	23.869565	316.47826	12.22%	388.11736	296.88966	
18	2100	2112	-12	12	0.57%	144	23.909091	329.81818	12.73%	389.8275	290.50395	

20	2130	2105	25	25	1.17%	625	25.619048	344.95238	13.30%	390.42047	285.7785	
22	2117	2120	-3	3	0.14%	9	25.65	360.95	13.91%	389.08637	280.27424	
24	2540	2118	422	422	16.61%	178084	27.157895	379.78947	14.64%	388.18791	272.11942	
26	2242	2371	-129	129	5.75%	16641	5.2222222	377.44444	14.53%	385.10896	262.29576	
28	3630	2294	1336	1336	36.80%	1784896	13.117647	392.05882	15.04%	396.2108	248.44524	
30	3111	3096	15	15	0.48%	225	-69.5625	333.0625	13.68%	399.59644	251.19586	
32	2664	3105	-441	441	16.55%	194481	-75.2	354.26667	14.56%	305.93533	248.3311	
34	2148	2840	-692	692	32.22%	478864	-49.07143	348.07143	14.42%	272.11354	216.45734	
36	2684	2425	259	259	9.65%	67081	0.3846154	321.61538	13.05%	277.67397	161.25069	
38	2117	2580	-463	463	21.87%	214369	-21.16667	326.83333	13.33%	272.19575	138.04579	
40	2465	2302	163	163	6.61%	26569	19	314.45455	12.56%	278.19167	142.41031	
42	2753	2400	353	353	12.82%	124609	4.6	329.6	13.15%	265.74906	147.17053	
44	2199	2612	-413	413	18.78%	170569	-34.11111	327	13.19%	279.58215	139.55071	
46	2827	2364	463	463	16.38%	214369	13.25	316.25	12.49%	283.52048	141.65274	
48	2204	2642	-438	438	19.87%	191844	-51	295.28571	11.93%	279.09074	147.64146	
50	2435	2379	56	56	2.30%	3136	13.5	271.5	10.61%	272.31713	144.7168	
52	2400	2413	-13	13	0.54%	169	5	314.6	12.27%	264.78551	150.58774	
54	2903	2405	498	498	17.15%	248004	9.5	390	15.21%	290.84188	148.93791	
56	2407	2704	-297	297	12.34%	88209	-153.3333	354	14.56%	320.3831	147.11107	
58	2827	2526	301	301	10.65%	90601	-81.5	382.5	15.67%	301.20646	103.64523	
60	2243	2707	-464	464	20.69%	215296	-464	464	20.69%	412.95036	127.98633	

Company A Oil distributor inventory

Week	Actual	Simulated	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE	$St.Dev^A$	$St.Dev^S$	Alpha
2	2315	2357										0.9
4	2250	2319	-69	69	3.07%	4761	8.586207	120.7931	4.80%	168.4211	163.7038	
6	2200	2257	-57	57	2.59%	3249	11.35714	122.6429	4.86%	167.9996	164.7776	
8	2160	2206	-46	46	2.13%	2116	13.88889	125.0741	4.95%	164.0485	164.4525	
10	2251	2165	86	86	3.82%	7396	16.19231	128.1154	5.06%	155.5438	160.6799	
12	2355	2242	113	113	4.80%	12769	13.4	129.8	5.11%	140.8353	152.1725	
14	2425	2344	81	81	3.34%	6561	9.25	130.5	5.12%	131.3095	137.0838	
16	2421	2417	4	4	0.17%	16	6.130435	132.6522	5.20%	128.0199	125.9356	
18	2351	2421	-70	70	2.98%	4900	6.227273	138.5	5.42%	127.9903	121.3535	
20	2433	2358	75	75	3.08%	5625	9.857143	141.7619	5.54%	127.4694	120.5956	
22	2269	2426	-157	157	6.92%	24649	6.6	145.1	5.66%	121.3084	119.6272	
24	2522	2285	237	237	9.40%	56169	15.21053	144.4737	5.60%	120.051	112.897	
26	2544	2498	46	46	1.81%	2116	2.888889	139.3333	5.39%	97.82354	110.4051	
28	2597	2539	58	58	2.23%	3364	0.352941	144.8235	5.60%	98.95625	86.45132	
30	2651	2591	60	60	2.26%	3600	-3.25	150.25	5.81%	100.9753	85.37818	
32	2634	2645	-11	11	0.42%	121	-7.46667	156.2667	6.04%	104.2729	86.51433	
34	2588	2635	-47	47	1.82%	2209	-7.21429	166.6429	6.44%	107.1439	89.44102	

36	2608	2593	15	15	0.58%	225	-4.15385	175.8462	6.80%	110.7759	92.21192	
38	2743	2607	136	136	4.96%	18496	-5.75	189.25	7.32%	115.258	95.56948	
40	2428	2729	-301	301	12.40%	90601	-18.6364	194.0909	7.53%	120.3505	99.76742	
42	2703	2458	245	245	9.06%	60025	9.6	183.4	7.05%	116.8313	104.6325	
44	2528	2679	-151	151	5.97%	22801	-16.5556	176.5556	6.82%	110.2114	101.2379	
46	2755	2543	212	212	7.70%	44944	0.25	179.75	6.93%	110.5307	95.19643	
48	2520	2734	-214	214	8.49%	45796	-30	175.1429	6.82%	115.5567	97.48406	
50	2652	2541	111	111	4.19%	12321	0.666667	168.6667	6.54%	104.1101	102.6234	
52	2428	2641	-213	213	8.77%	45369	-21.4	180.2	7.01%	110.9422	93.47602	
54	2648	2449	199	199	7.52%	39601	26.5	172	6.58%	118.2844	101.9255	
56	2520	2628	-108	108	4.29%	11664	-31	163	6.26%	101.1414	113.2913	
58	2729	2531	198	198	7.26%	39204	7.5	190.5	7.25%	118.972	89.11977	
60	2526	2709	-183	183	7.24%	33489	-183	183	7.24%	143.5427	125.865	

Company B Sales rate

Week	Actual	Simulated	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE	$St.Dev^D$	$St.Dev^F$	Alpha
4	3100	3200										0.9
8	3250	3110	140	140	0.0430769	19600	45	117	3.52%	115.52898	74.709809	
12	3150	3236	-86	86	0.0273016	7396	33.125	114.125	3.43%	105.88253	78.160803	
16	3250	3159	91	91	0.028	8281	50.142857	118.14286	3.52%	112.37493	65.665821	
20	3400	3241	159	159	0.0467647	25281	43.333333	122.66667	3.65%	105.35089	70.440789	
24	3255	3384	-129	129	0.0396313	16641	20.2	115.4	3.44%	111.97098	60.667674	
28	3200	3268	-68	68	0.02125	4624	57.5	112	3.31%	116.74759	65.350593	
32	3300	3207	93	93	0.0281818	8649	99.333333	126.66667	3.70%	131.49778	35.449495	
36	3250	3291	-41	41	0.0126154	1681	102.5	143.5	4.15%	132.28757	42.099089	
40	3500	3254	246	246	0.0702857	60516	246	246	7.03%	176.7767	26.162951	

Company B Retailer inventory storage

Week	Actual	Simulated	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE	St.Dev^{D}	St.Dev^{F}	Alpha
4	18,120	18150										0.7
8	18,495	18129	366	366	1.98%	133,956	-2	133.6667	0.73%	149.5877	114.5915	
12	18,386	18385	1	1	0.01%	1	-48	104.625	0.58%	156.9482	120.7537	
16	18,160	18386	-226	226	1.24%	51,076	-55	119.4286	0.66%	114.6117	126.6581	
20	18,055	18228	-173	173	0.96%	29,929	-26	101.6667	0.56%	69.40667	110.1194	
24	18,202	18107	95	95	0.52%	9,025	3	87.4	0.48%	73.2168	62.51853	
28	18,106	18174	-68	68	0.38%	4,624	-20	85.5	0.47%	76.00526	48.91114	
32	18,150	18126	24	24	0.13%	576	-4	91.33333	0.51%	70.77429	55.97916	
36	18,000	18143	-143	143	0.79%	20,449	-18	125	0.69%	86.60254	53.50701	
40	18,150	18043	107	107	0.59%	11,449	107	107	0.59%	106.066	70.71068	

Company B Oil distributor inventory

Week	Actual	Simulated	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE	St.Dev^D	St.Dev^F	Alpha
4	48750	48823										0.9
8	48721	48757	-36	36	0.07%	1296	-3.88889	210.5556	0.43%	323.3265	297.1536	
12	48923	48725	198	198	0.40%	39204	0.125	232.375	0.47%	319.4797	298.3949	
16	48987	48903	84	84	0.17%	7056	-28.1429	237.2857	0.48%	301.4104	282.7174	
20	49131	48979	152	152	0.31%	23104	-46.8333	262.8333	0.54%	306.926	235.0651	
24	49553	49116	437	437	0.88%	190969	-86.6	285	0.58%	318.9382	201.2992	
28	49356	49509	-153	153	0.31%	23409	-217.5	247	0.51%	351.1713	146.5595	
32	49430	49371	59	59	0.12%	3481	-239	278.3333	0.57%	360.9035	72.0856	
36	49337	49424	-87	87	0.18%	7569	-388	388	0.80%	422.0146	39.8288	
40	48657	49346	-689	689	1.42%	474721	-689	689	1.42%	480.8326	55.15433	