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Downstream automotive supply chain simulation: A system dynamics approach to improve performance

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Downstream automotive supply chain simulation: A system dynamics approach to improve performance

by

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Declaration

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.

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Abstract

Supply chain instabilities and fluctuations commonly known as (Bullwhip Effect) have been existing and is known for many years as a problem for companies. The bullwhip effect is an occurrence indicating a situation where there is an amplification of demand fluctuations as orders move upstream from customers to suppliers and this can be costly and disadvantageous for supply chains as it causes problems in form of excessive inventory, excessive capacity, which causes high cost and low profit for companies.

This thesis presents the analysis of the dynamic behaviour arising from the bullwhip effect using two inventory models in the downstream automobile supply chains in Nigeria. Models of push and hybrid push/pull inventory models are developed using system dynamics modelling methodology by allowing comparisons between the two inventory models. Although, there are number of literatures that have discussed these supply chain inventory models using system dynamics by evaluating their performance, this research has a different approach by using actual case study in Nigeria. The inventory models allow the investigation of the bullwhip effect in the downstream automobile companies in Nigeria using different demand patterns (business as usual, optimistic and pessimistic demand patterns) as input in order to show the uncertainty in customer demand. This problem remains one of the most difficult issues to resolve by the managers.

The results from the investigation through simulation runs are analysed comparatively. Performance metrics used for measuring the performance of these models are distributor inventory, dealer inventory, total cost, profit and cash balance. The instabilities and fluctuations can be observed arising from the downstream by customers placing orders, through dealers before orders moves upstream to the distributor. This is the point where this study suggests policy interventions for managers. Findings from the analysis provides insight how these instabilities occur from uncertain demand and its effect on the two inventory models together with the costs involved. Finally, sensitivity analysis is conducted on the parameter values in the models to reduce the total cost and improve profit and cash balance. This investigation shows that system dynamics modelling methodology can be a useful methodology tool for managers in making decisions regarding inventory policies.

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List of Acronyms/Abbreviations

AB	Agent Based
BDG	Beer Distribution Game
CLD	Causal Loop Diagram
CB	Cash balance
CONWIP	Constant Work in Progress
DEAT	Dealer Adjustment Time
DEOFCT	Dealer Order Fulfilment Cycle Time
DES	Discreet Event Simulation
DEINV	Dealer Inventory
DIAT	Distributor Adjustment Time
DSS	Decision Support System
DIINV	Distributor Inventory
DS	Dynamic System
ERP	Enterprise Resource Planning
GIS	Geographic Information Systems
ICC	Inventory Carrying Cost
ISFF	Integrated-error State Feedback and Filtering
JIT	Just in Time
MRP	Material Requirement Planning
MSPT	Minimum Sales Processing Time
SC	Supply Chain
SCM	Supply Chain Management

SD	System Dynamics
SDM	System Dynamics Modelling
SDDES	System Dynamics Discreet Event Simulation
SMM	Stock Management Modelling
SOR	Soft Operational Research
SR	Sales Revenue
SSC	Safety Stock Coverage
ST	System Thinking
SFD	Stock Flow Diagram
TACD	Time to Average Customer Demand
TC	Total Cost
TOC	Theory of Constraints
UC	Unit Cost

Chapter 1. Introduction

1.1 Research overview

In the past years, there have been extreme competition in the business environment as a result of changes due to global competition, demand uncertainty, short product life cycle, and environmental factors (Christopher and Holweg, 2011). Moreover, competition between businesses have been on the rise thus, to be competitive in the unpredictable business environment companies are using and implementing customer focused approach in integrated-system approaches (Zemzam et al., 2017). Supply chain management (SCM) has been viewed by most researchers as a system that can allow companies to react or act swiftly to these unpredictable business environment and thus have been a leading priorities for both companies, practitioners and researchers (Cannella et al., 2018). One of the functions and objectives of supply chain is to provide the right qualities, provide the right product, and at the right time to their customers.

To achieve this, companies should strive to reduce the disruption and delay along their supply chain, they need to understand customer demand behaviour, manage production efficiently, reduce instability, collaborate and share accurate information with all partners in the supply chain in order to improve profitability in response to competitive environment. Moreover, as a result of fast changes in supply chains, current business environment motivates supply chain decision maker to continuously evaluate its policy and take all important actions to satisfy their customers at a minimum cost. Making best decision is thus important to improve the flow of goods from suppliers to end users. Chopra and Meindl, (2010) suggests that this reason prompts managers to make right decisions at different level like operational, strategic and tactical level. In tactical and operational level, the combination of planning and controlling of inventories and their activities as a single unit is important for effectively managing supply chain management (Jones and Riley, 1987). Effective inventory management involves considering fluctuation in the supply chain because once fluctuation affects the supply chain its income can significantly reduce and competitiveness compromised (Guojun and Caihong, 2008). Therefore, uncertainties must be taken into consideration in order to make suitable operational decisions. Carvalho and Machado, (2007) stipulate that for a supply chain to remain competitive, they must be robust and able to predict uncertainty in order to quickly return to the original state. Two main method can be used for solving inventory problem: simulation method and analytic method. The simulation method allows decision makers to test different scenarios and choose the best suitable one. However, most decision makers prefer using the analytic method because it is relatively simple (Soshko et al., 2010). Using model to represent inventory problem allows to realistically decide the amount of inventory to purchase and when to purchase (Vrat, 2014). Moreover, there are decision variables with situational parameters present in inventory models like cost, lead time and demand uncertainties subject to the implemented inventory policy. Researchers have suggested many methods used for modelling inventories (Vrat, 2014). According to Vrat, these models are usually classified as dynamic and static models. Other types of models are deterministic vs probabilistic inventory models. Forrester (1958) introduced Industrial dynamics which was later called system dynamics used for analysing and improving dynamics in production and inventory systems through feedback standpoint.

System dynamics is an approach for the modelling and simulation of nonlinear dynamic systems that aims to understand a system's structure and the deduction of the behaviours from it to develop policies for system improvement (Yan, 2009; Spiegler, 2013). One of system dynamics advantage is the ability to deduce the problem of a specific behaviour mode because the structure that leads to systems' behaviour is made apparent (Wang and Cheong, 2005; Bhatti et al, 2012).

In this research, system dynamics modelling will be used to investigate the effect of customer demand uncertainties on downstream automobile companies in Nigeria to measure the performance of inventory level and cost under different policies. The performance is measured by the inventory level, total costs, profit, and cash balance incurred as part of the oscillations and instabilities in the models. In this study, system dynamics inventory models of distributor and dealer inventory are developed as a basis for the analysis of push and hybrid push/pull inventory models. These models are tested using a series of future projection demand patterns which reflect the uncertainties in customer demand. These patterns comprise: business as usual demand, optimistic demand and pessimistic demand patterns. The models reflect the change of the different demand patterns versus policy choices within these structures, policies on inventory level like safety stock coverage and cycle time are included to reflect decision making in the inventory models.

The push and hybrid push/pull inventory system dynamics models presented in this study differ in terms of the approach to policies. The push model for instance, is based on a forecast of demand from downstream. Uncertainties in forecasting lead to a larger number of inventories being held to absorb any unexpected changes in the customer demand Figure 1.1 depicts a push system. A hybrid push/pull supply chain system on the other hand, holds a few number of inventories waiting to be ordered. Towards the end of the downstream, the value of the units increases. Moreover, the hybrid push/pull system, exhibits a combination of push and pull processes, dividing the stages into two sections (Lin, 2018). Towards the final process, the pull system is applied. Initial processes in the inventory line of a hybrid push/pull supply chain system adopt the features of a push system Figure 1.2 depicts a hybrid push/pull system.

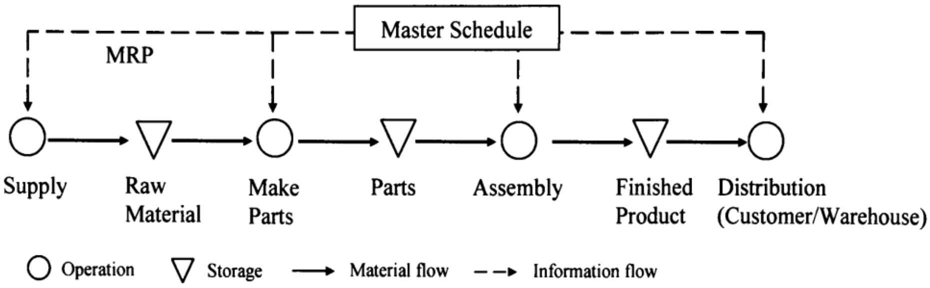


FIGURE 1. 1. INVENTORY AND INFORMATION FLOW FOR A TYPICAL PUSH MODEL (Bazin, 2010)

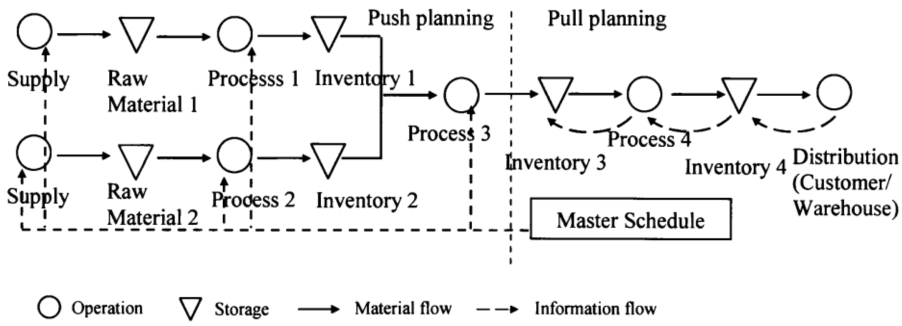


FIGURE 1. 2. INVENTORY AND INFORMATION FLOW FOR A TYPICAL HYBRID PUSH/PULL MODEL (Hodgson and Wang 1991a)

There are three types of test performed on the two models. The first test is carried out to smooth the expectation of managers of an unexpected change in customer demand. This is accomplished in the model by using a smoothing parameter, a component of a built-in structure in the simulation software, VENSIM™. In the second test, the discrepancy between the customer demand and smoothed demand is reduced. From these tests, the inventory level in the two models are analysed under the different demand patterns to understand the behaviour of the models. In the third test, the safety stock coverage and dealer order cycle time are decreased to analyse the inventory levels and financial measures in the push and hybrid push/pull inventory models under the different demand patterns.

The resulting financial metrics incurred by fluctuations and instabilities in the inventory level are calculated. The findings from these analyses of costs reveal that the action of managers to respond quicker to changes in demand only slightly minimises costs under particular demand patterns. For this reason, the models are tested further using sensitivity test to improve the performance and search for those parameters that have the most impact and effect on the inventory levels, within the policies implemented, which can reduce total costs and improve profit and cash balance in respect of each variant of demand. The finding from the analysis reveals that the action of managers to the reduction of dealer order fulfilment cycle time and safety stock coverage significantly reduce the instabilities and inventory levels, total cost with more profit and cash balance.

More discussion in this chapter focuses on the motivation behind this research by emphasizing some of the issues in the supply chains literatures. Thus, the connection between the supply chains and inventory models is established; this progresses to the main reason and the importance of this research. The final sections justify the purpose of this research: research objectives, research scope, research questions to be answered, and methodology of the research. Finally, the research expected contributions and structure of the thesis are described.

1.2 Supply chain and inventory management

The main reason and motivation behind this thesis are linked to the growing uncertainties on the aspects of downstream automobile supply chains in developing economy. Supply chain uncertainty can be characterized into process uncertainty, supply uncertainty, demand uncertainty and control uncertainty, which is based on the study of perceived uncertainties (Geary *et al.* 2002; Geary *et al.* 2006). They defined these uncertainties as: process uncertainty as a kind of uncertainty in a supply chain that has an effect of a firms internal capacity to fulfil delivery objective, supply uncertainty as a kind of uncertainty that occurs as a result from suppliers unable to perform or meeting their order as a result limiting their ability to fulfil their customers, demand uncertainty which is the discrepancy between the actual downstream demand and the orders coming from their customers, and control uncertainty which is a kind of uncertainty related with flow of information from downstream and the method the firm converts customer orders into final product to fulfil customer demands.

Some other researchers have similar views of Geary *et al.* (2002; 2006) on the main reason of supply chains uncertainty. For example, Wangphanich (2008), Petrovic (2001) and Calle (2016) argues that uncertainties in the supply chain result from the behaviour of a supplier in delivering stocks for their partners, customer demand; and variations in the processing time at the work stations. These uncertainties, perceived among the participants of a supply chain, can be as a result of random events, lack of available material, inaccuracy in judgment, or lack of certainty in orders. Mason-Jones and Towill (1998, 2000) and Mason-Jones et al 2000 have similar view as Wangphanich (2008), Petrovic (2001) and Calle (2016). In their study, they categorized supply chain uncertainties as marketplace and system-induced uncertainties. System-induced uncertainties arise due to the involvement of the relationships and strategies that can be controlled by a company directly. Market place uncertainty on the other hand, is more challenging to handle as it is related with customer ordering behaviour.

Companies can ease the marketplace uncertainties by the improvement of their performance as regards to satisfying customer demand. However, for innovative goods, uncertainties in the marketplace are unavoidable. Davis (1993) identified three causes of supply chain uncertainties, which are supplier uncertainties, manufacturing uncertainties, and demand uncertainties. Davis (1993), argued that supplier uncertainties are influenced by delays in delivery and material supply performance inconsistencies. Uncertainties in manufacturing can be caused by delays of processes in production and machine break downs. Lin (2018), Mason--Jones et al 2000, Jones and Towill (2000) and Davis (1993) stipulates that uncertainties in demand is as a result of inaccuracies in forecasting coming from uncertainties as to the level of orders from the customer.

From these discussions, it can be established that supply chain uncertainties are a consequence of actions and processes by every member involved. Supply chain is a universal system of suppliers, factories, manufacturers, warehouses, distribution centres and retailers whereby raw materials are acquired, converted or transformed into finished products, and finally delivered to end consumers (Fox et al, 2000; Cannella et al 2018). Inside this chain, there are forward flows of materials and/or inventory and backward flows of information that link the partners (Huang *et al,* 2002) as displayed in Figure 1.3.

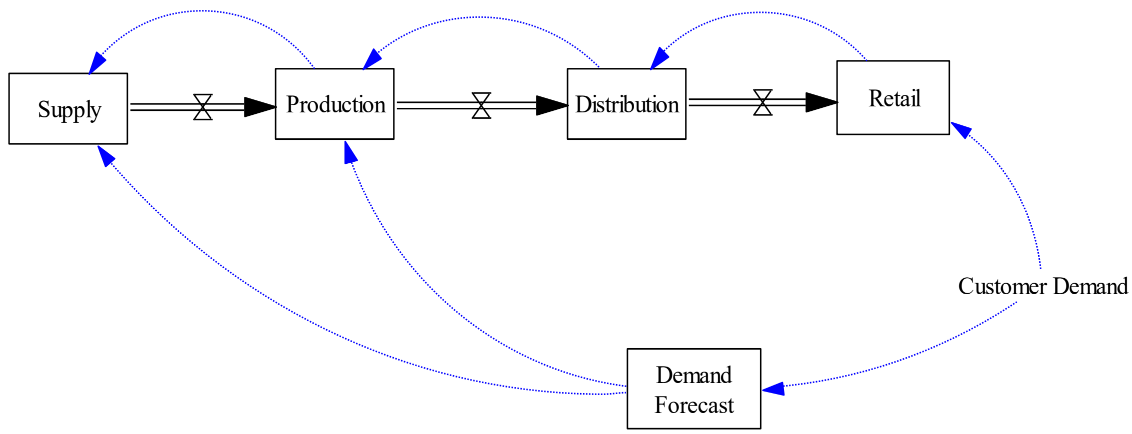


FIGURE 1. 3. GENERIC STRUCTURE OF A SUPPLY CHAIN

Based on explanation of Fox *et al* (2000) and Cannella et al. (2018) of a supply chain and their observations of observed uncertainties of supply chains (Geary *et al.,* 2002 and 2006; Petrovic, 2001; Mason-Jones and Towill, 2000; Davis, 1993; Poles, 2010; Calle, 2016; Cannella et al. 2018), Figure 1.4 is created to underline the role of every member of a supply chain in causing the uncertainties. The control and process uncertainties are perceived in the factory processes. Hence, these uncertainties flow to the partners in the supply chain through the flow of information and materials as illustrated in Figure 1.4.

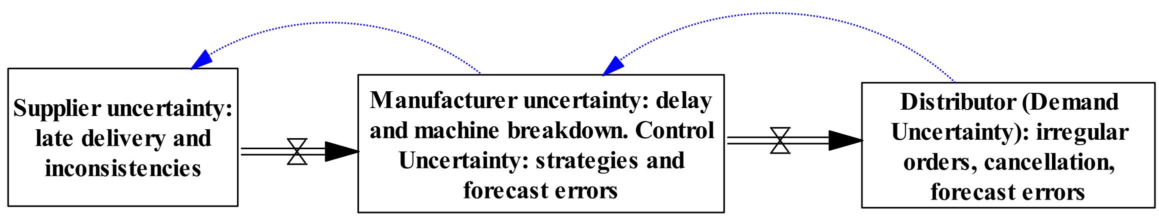


FIGURE 1. 4. SUPPLY CHAIN UNCERTAINTIES

In the study of Geary *et al.* (2002) and Geary *et al* (2006) present the results of supply chain audit based on numbers of uncertainty. These results argued that only 10% of companies in the audit are quickly reaching their supply chain objectives. A high percentage, 45% of companies, are still having major uncertainties, which proves that the supply chains performance is far from perfect. The unpredictability of supply chain environment drives managers to make all possible effort so as to cope with any likely disruption. There is suggestion from the real-world scenario that a reduction of this uncertainty is one of the key practices in exemplar supply chains. A smooth supply chain is proven to the reduction of uncertainty by the improvement of information flow and materials flow with visibility and two ways of communicating among partners of a supply chain (Geary *et al.*, 2002 and Geary *et al.*, 2006). They stipulated that the first process in the reduction of uncertainty in a supply chain is to address the process uncertainty. The major reason for this is that a company understands the way they operate better, and they have the control to make changes in any certain area that needs improvement. Control uncertainty reduces along the improvement plan introduced by the company.

Fisher (1997) points out the failure of planning an effective and efficient supply chain because of managers' inability to identify the best suitable operations to match the customer demand trend for their goods. Based on the previous discussion on the issue of uncertainties, it can be argued that system-induced uncertainties are much easier to control, as they are within the company's operations. On the other hand, marketplace uncertainties, influenced as a result of customers, are much more difficult to handle, despite the fact that new products demand uncertainties are inevitable. Due to the important functions and role of the downstream in a supply chain, this thesis focuses on investigating the performance of the downstream supply chains using different demand patterns. This provides understanding on the reaction of the company's supply chain to different demand pattern to assist downstream managers in reducing uncertainty.

1.3 Supply chain issues

The evidence that increasing unpredictability in the current market environment is a major concern in supply chain management. Christopher and Holweg (2011) define supply chain management as end-to-end management of the system, and of the connections between various links. Managers do not only have to handle uncertainties in their process within the company, but also must manage the uncertainties in demand driven by the end users or final consumers as well as uncertainties from their suppliers. Geary *et al.* (2006) in their review of past and present problem in supply chain management identified amplification of customer demand commonly known as (bullwhip effect) as the main problem in a company. In the past period of the emergence of bullwhip effect, the phenomenon was generally known to economists but attracted less attention in the literature. Since it was first recognized by Forrester (1958), demand amplification still remains one of the most difficult problems to solve.

One of the most often cited is Lee *et al.* (1997) who argued that price fluctuations, demand forecasting, shortage gaming, and rationing and order batching, as the main reason to the bullwhip effect. This therefore shows that the action by the participants of a supply chain to gain competitive advantage for their own company has increased the level of uncertainty in their supply chain. Some research seeks to decrease the bullwhip effect understanding the impact and benefit on the company supply chain. For example, Boute *et al.* (2007) tried to reduce the higher level of safety stock at the retailer by analysing the suitable degree of dampening of the demand amplification. This effort has the capability of reducing the costly variability in orders at the upstream, which results in a better trade-off between upstream variability and the level of safety stock at the downstream. Hua and Li (2008) have the same interest in the upstream – downstream relationship as Boute *et al.* (2007) but study the dominance of downstream over upstream based on the sensitivity of downstream to the upstream price in a non-cooperative model. Their analysis was extended to two cooperative scenarios by integrating a Nash bargaining model for profit sharing implementation.

In spite of the numerous improvements suggested by researchers, interest in supply chain problems remains unabated which proves that some problems in supply chain are still unanswered. In one of the publications on demand amplification, Dooley *et al.* (2010) provided proof of the bullwhip effect during the downturn of economy from 2007 to 2009. Subsequently, Sprague and Callarman (2010), in their article on the improvement of supply chain in China, quote a speech from a CEO of a chip company who identified that the effect of economic decline is amplified further moving down the supply chain. This again suggest that the bullwhip effect still remains a major unanswered problems and issues in supply chain management. As earlier mentioned, the uncertainty or volatility experienced by a partner in the supply chain is reflected in the information flow and materials flow, which affects the whole chain.

1.4 Challenges in managing inventory

The increasing customer demand uncertainty and the customer requirements for product customization have made the business environment unstable and highly competitive. Since Material Requirement Planning system (MRP) was introduced in the 1960s, a series of improved systems have emerged to handle and manage the changing unpredictable business environment from mass production to more of mass customization. Inventory policies implemented by companies in their supply chain network need to be studied from time to time so as to smoothly operate given the dynamics and complexity of the whole system. Christopher and Holweg (2011) mentioned the three most unfavourable situations to companies as increasing unpredictability of customer demand, increasing difficulty to forecast demand accurately and precisely, and product life cycle reduction. In a later publication by Dai et al (2017) they argued that companies have no choice but to deal with a significant reduction in product life cycles, unpredictable customer demand, high product variety, short customer lead times and delivery delay with a long lead time.

The challenges faced in managing inventory are apparently emanating from customer demand uncertainty, variety of products, reduction of product life cycle, and needs for shorter delivery time by the customer as well as long supplier lead times to fulfil customer demand.

While the problems existing in supply chain management remain, complexity in the marketplace is also increasing. The main aim of companies supply chain is to become global and customer focused (Venkateswaran, 2005; Ivanov et al, 2016; Botha, 2017). This significantly adds to the issues that companies need to address in their inventory policies. Moving to a customer orientation, supply chain managers must deal with an extremely diversified product customization. Thus, delivery time should be reduced ideally to an acceptable range. The reduction will result in a degree of unresponsiveness to changes in customer needs. Shorter delivery time enables companies to produce and ship their products quicker than their competitors to guarantee sales. This reflects an urgent need for a reduced delivery lead time. In a competitive market environment, companies can work hard to survive keeping their costs as low as possible to stretch their profit margin. All the challenges described above reflect the need for improvements in a company supply chain.

1.5 Research importance

Supply chains management are constantly becoming more complex and vulnerable to uncertainty as a result of globalisation (Christopher and Peck, 2004; Bhamra et al., 2011; Zemzam et al., 2017) which causes bullwhip effect and instabilities in inventory level (Lin 2018). Researchers and practitioners have continuously been suggesting ways to improve supply chains by proposing outsourcing non important activities, reducing the number of suppliers, reducing the number of inventories held and sourcing globally by assuming that global market is predictable and stable (Kearney, 2003). These complexity in supply chains has increased the importance of effectively managing supply chains uncertainty which can come from customers (Mason-Jones, 1998). In this study, the investigation of supply chain inventory management in regard to demand uncertainty on downstream automobile company will be explored. When investigating the supply chain, potential issues of demand uncertainty involve the discrepancy between supply and demand and inability to serve customers efficiently and this demand uncertainties affect all the members of the supply chain.

Number of studies have modelled this issue in the supply chain in a hypothetical basis to address the need to reduce the negative effect of demand uncertainty and improve supply chain performance. However, there are limited research that have used system dynamics to model the supply chain problem specifically at the downstream supply chain using an actual case study in developing countries. Therefore, this thesis focuses on the performance of inventory levels and cost on downstream automobile company in Nigeria. The additional knowledge proposed in this thesis will help managers in devising further actions or policies to address the bullwhip effect. The detailed framework for this research is presented in the next section.

1.6 Research purpose

The motivation of this research is the issue of bullwhip effect present in two automobile companies in Nigeria. The study demonstrated that even though the bullwhip effect problem is well documented, it is difficult for companies to identify it, identify its causes, and take corrective action. The companies under investigation specializes in sales of automobile in Nigeria, discussions with the managers of these companies confirmed the existence of the bullwhip effect. The bullwhip effect has put these companies under a lot of financial pressure like experiencing lost sales even as they hold high number of inventories. Moreover, these companies have to deal with competitors which have reduced their profit margins. The companies' inefficiencies in managing this problem have reduced their cash flow, which threatens the companies' ability to stay in business. An initial review of the companies' policies in managing the bullwhip effect showed the causes of demand amplification. Nonetheless, in practice the managers did not think that it is practical to start major changes to their operations, because in their present reduced financial position, any wrong decision by the management can cause them to be out of business. Therefore, it made more sense to reduce demand amplification on a cost and impact basis. Unfortunately, current knowledge is not sufficient to find the best policy by managers because of the complexity present in the operations of supply chain.

This study recognizes the difficulty and challenges faced by the managers in effectively managing this problem therefore motivating this study to use system dynamics modelling methodology in investigating the bullwhip effect and its impact on the company's performance as system dynamics offers a continuous, system thinking approach to develop a comprehensive simulation models of complex supply chain systems in a cost effective way. The study adapts a well-established system dynamic inventory model that are sophisticated but also inexpensive and simple that encompasses the operational decision-making levels in the companies to support managers in developing policies and comprehensively testing them.

1.7 Research objectives

The following research objectives listed below aim to achieve the research purpose stated:

1. Modelling the push and hybrid push/pull downstream automobile inventory in Nigeria using system dynamics methodology.

2. Testing the push and hybrid push/pull downstream automobile inventory policy interventions using different customer demand patterns to mimic the present increasing demand uncertainty.
3. To investigate the dynamic effects on the inventory level of the push and hybrid push/pull downstream automobile inventory in Nigeria given the different demand patterns.
4. To investigate the costs incurred as a result of fluctuations and instabilities in the inventory level of the downstream automobile companies based on different policy interventions.

1.8 Research questions

The above-mentioned research objectives motivates the following research questions:

1) What are the effects of customer demand uncertainties in the downstream automobile companies in Nigeria?

2) How does the customer demand uncertainties relate to the costs borne by the downstream automobile companies in Nigeria?

3) Which of the two system dynamics inventory models is the most affected?

4) What are the best policies to be implemented in order to reduce costs?

1.9 Research scope

The research is mainly concerned with the information flow and inventory flow in distributor and dealer inventory policies. The system dynamics model boundary include demand by the customers as presented in Figure 1.5. The discussion on supply chain issues given above suggests it is essential and necessary to take a wider insight of the research topic.

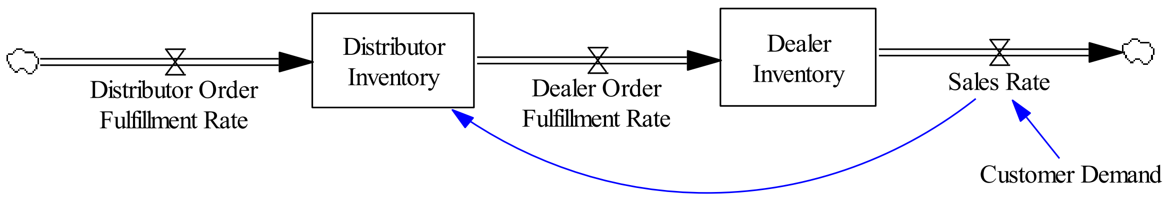


FIGURE 1. 5. RESEARCH BOUNDARY

1.10 Research methodology

The issues in the supply chains which includes the downstream automobile inventory is identified at the first stage through critical literature review. The performance metrics are identified to evaluate the downstream automobile supply chain which are derived through extensive literature review in the field of supply chain and inventory management. To identify the feedback effect, system dynamics modelling is used in the next stage prevalent in supply chains and inventory issues. The push and hybrid push/pull system dynamics inventory models are developed upon the mental model of both. Once the push and hybrid push/pull system dynamics models are developed, a series of simulation are conducted to validate that the two system dynamics supply chain models produce behaviour which matches knowledge of each of the models. Further policy analysis tests are then carried out to analyse the response of each model against the changes in customer demand. In each case, the performance is measured based on the distributor inventory level, dealer inventory level as well as the costs, profit and cash balance incurred, and profit gained.

In the final stage, the performance improvement of the push and hybrid push/pull models are applied through sensitivity test to the two models to search for the best possible combination of policies that reduces the costs and maximize profit and cash balance. The research structure adopted is illustrated in Figure 1.6.

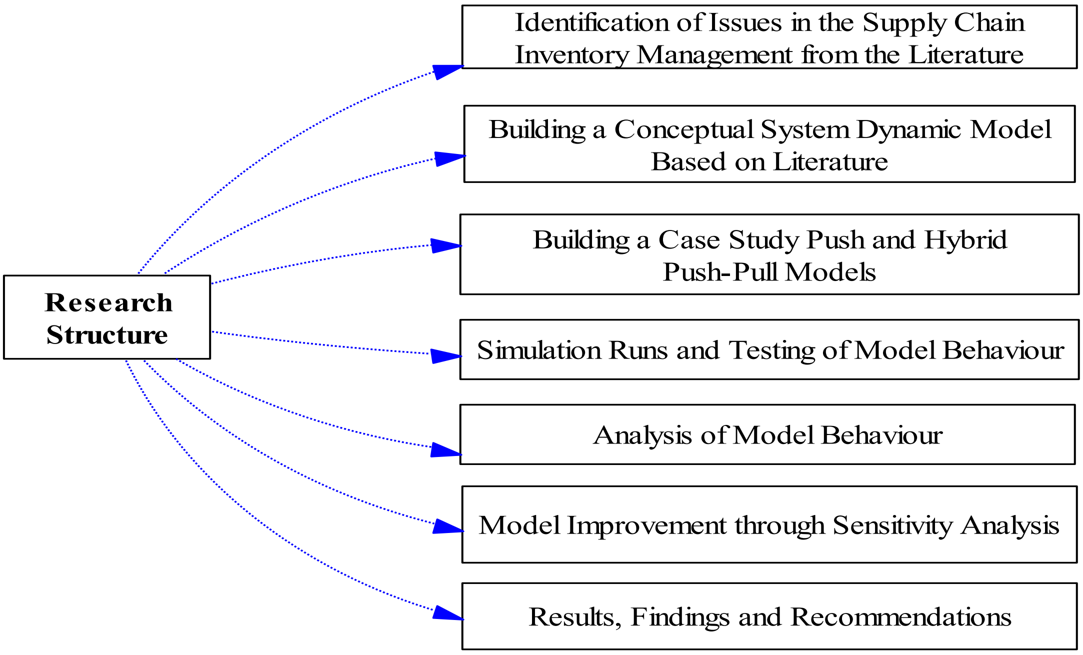


FIGURE 1.6. RESEARCH STRUCTURE

1.11 Expected research contribution

This research seeks to enhance the understanding of the performance of push and hybrid push/pull inventory models under three different customer demand pattern namely; business as usual demand pattern, optimistic demand pattern and pessimistic demand pattern in the downstream automobile supply chains in Nigeria. The expected research contributions are:

1. Encouraging and demonstrating that system dynamics methodology as a useful method for combining complexity in developing understanding of supply chain inventory models.

2. Testing the push and hybrid push/pull inventory system dynamic models under two different case studies of downstream automobile companies as a new perspective in evaluating the performance of a supply chain model.

3. Presenting more policy insights on the model response under demand patterns resulting on the tests conducted.

4. Improving the push and hybrid push/pull models to formulate policies to reduce total costs, improve profit and cash balance.

1.12 Thesis structure

This thesis contains seven chapters and can be categorized as: an introduction of the research in Chapter One, reviewing the literature in Chapter Two, the research philosophy in Chapter Three, conceptualization of the problem and system dynamics modelling in Chapter Four and performance analysis in Chapters Five for case study A and Chapter Six for case study B. The final Chapter discusses the findings and contributions coming from this research.

Chapter One has introduced the background to the research; its purpose, objectives, scope, questions to be answered, and research methodology. Finally, the expected contributions from and structure of the thesis were described.

Chapter Two reviews the current and previous research in supply chains in which system dynamics modelling and other simulation methods are used as tools.

Chapter Three provides a thorough explanation of the research philosophy used for this thesis

The Fourth chapter goes into a detailed description and explanation of the push and hybrid push/pull inventory models by building a conceptual model where the construction of stock and flow diagrams for the distributor inventory and dealer inventory is presented, validated, and the case study used for this research is introduced in this chapter. Important equations from the models are extracted and discussed in this chapter.

Chapter Five continues with the analysis of the models for the purpose of validation and performance measurement for case study A. At the end of this Chapter Five, the results of the tests are presented in terms of the inventory level (volume measures) that covers the analysis of costs (financial measures) incurred by the inventory level in the two models. Model improvement is carried out on the two models to uncover new policies to reduce costs to gain profit and cash balance. The findings from the analysis of costs and model improvement are reported. Chapter Six covers the analysis of case study B following the same process used in critically analysing Chapter Five. Finally, in Chapter Seven, the thesis concludes with a discussion of the findings, contributions to knowledge and suggestions for future research.

Chapter 2. Literature Review

2.1 Introduction

This chapter discusses the significance of this research. In the first section, the structure of the literature review is discussed, beginning with a review of supply chain management. In this review the importance of the push and hybrid push/pull system is highlighted to justify the relevance of conducting this specific study. The literature review also discusses past research work in the field of supply chain management. The reason for including this review is to demonstrate that it is important to manage company's supply chains and the efforts of managers to improve their business operations. The relationship between the issues in supply chain management and system dynamics modelling is discussed by extensively presenting the present and past work carried out by other researchers in the field of supply chain management and system dynamics.

Different methods have been used to review, analyse, and compare supply chain models performance of push, pull and hybrid push/pull models. These reviews of these methods are important in justifying the system dynamics methodology to help model the inventory push and hybrid push/pull models. Finally, the research gap in the supply chain policies and system dynamics is emphasized in the final section of the literature review. This section shows the importance of this thesis in filling the knowledge gap in those fields.

2.2 Review scope

The research scope covered by the literature review involves supply chain, research work conducted in supply chain inventory management and the application of simulation in the decision-making process. Managing inventories in supply chains are widely discussed across publications related to supply chain management, inventory management, operations management, management science, logistics, production economics and decision science. The literature review focuses on the past development of various supply chain models discussed in the literature. This includes the most-discussed supply chain inventory management systems, which are discussed in detail in this chapter. The supply management discussion on the research work continues from the description of the issues in supply chains presented in chapter one. The publications used for this review are selected based on the previous research to address commonly discussed problems, for example the information sharing and 'bullwhip effect' among supply chain partners.

The link between the supply chain and inventory management model is highlighted again in this chapter to emphasize the importance of the simulation design for the models in this thesis. Following the review of supply chain inventory models, the methods applied in published articles are analysed. This is to understand and know the available methods for modelling inventory models. The focus is the simulation approach often used to help managers with decision making. The scope here includes system dynamics modelling methodology, discrete-event simulation (DES), and agent-based modelling (ABM). Finally, the research gaps are discussed. The literature review also provides further understanding about the effects of demand uncertainties in a supply chain.

2.3 Definitions of supply chains

Supply chain management can be described as a network of organisation that involves managing the flow of goods and raw materials between upstream and downstream in their different activities and processes that offers value in the form of services and products which is finally delivered to end users (Wikner et al, 1991; Janamanchi and Burns, 2007; Sarmiento 2010; Jaipuria and Mahapatra 2014; MacCarthy et al, 2016; Lambert and Enz 2017). Ouyang and Li, (2010) stipulated that supply chain might be described as a process in which retailers, distributors, producers, and suppliers come together to collaborate in an effort to acquire raw materials and then convert these basic raw materials into defined final products, and provide these end products to retailers. These processes of supply chain is generally identified by a forward flow of products and a backward flow of information (Azfar et al. 2014). Min and Zhou (2002) proposes two primary business process in managing a supply chain which are product flow and flow of information.

The processes of supply chain can be described as physical distribution and material management (Canella, 2013; Cannella, 2018; Fowler, 2019). Material management describes the incoming logistics such as shipping, warehousing, production control, and transportation of these end products. Physical distribution on the other hand refers to outgoing logistics that are pricing, promotional support, life cycle support, and returned product handling. Stevens (1989) suggested that there are many strategies in identifying supply chain problems. This strategy consists of three decision hierarchy levels. The first strategy described is the competitive strategy this includes tactical decisions, management of new product development, flow channel, planning location-allocation, network, supplier selection, outsourcing, restructuring, and information technology. The second is the strategic strategies which includes inventory control, order consolidation, production/distribution coordination, layout style, and product handling. The third is the functional strategies that consists of labour force scheduling, automobile scheduling packaging, and record keeping another.

These strategies are important in managing supply chain as they enable managers or decision makers to react as quickly as possible knowing what to produce, how to produce, and when to distribute their products at the lowest cost and at the highest suitable quality. Moreover, they also ensure that supply chain must be responsive to change even in the face of supply chain uncertainty. Another set of three strategies was proposed by Cooper et al. (1997b). The first strategy is the sort of supply chain collaboration i.e. primary collaboration and secondary collaboration, the second strategy is the structural dimensions of a supply chain network which can be vertical and horizontal and the third strategy is the features of process links between supply chain partners for example handled service process links (the firm incorporates a supply chain procedure with several customers/suppliers), keeping an eye on company process links (this process the involves the firm auditing or monitoring how the link is handled and integrated), not handled service process links (this process involves the firm completely trusting its partners' capacity in managing the process links and at the same time leaves the management duty for them to handled), and non-member company links (this process involves the ones in between non-members and members of the company's supply chain involved).

Pointing out the full scope of the supply chain model helps in building the structure of the model. However, to bring the model more close to a real world meaning or system the constraints, main variables, and best performance procedures and processes must be added to the model according to defined supply chain framework. There are many examples of structures and framework sighted in the supply chain literature that can be useful to most of the supply chain designs. Decision variables can be network structuring, location, variety of centres and equipment allocation, size of labour force, production/distribution scheduling, plant item, service sequence, volume, level of outsourcing, customer service relationships, variety of product types, and variety of tiers kept in stock. Constraints in the design of the supply chain can consist of capacity, service compliance (e.g. maximum holding time for backorders, delivery time, number of driving hours for truck drivers), and level of requirement.

Chopra and Meindl (2007) stipulate that supply chain performance processes can be categorized as either quantitative or qualitative. However, there is limited single direct numerical measurement for qualitative performance compared to quantitative performance processes which can be directly termed numerically. However, the qualitative performance processes is termed as customer flexibility and satisfaction, material flow and information flow, supplier performance and effective risk management. The quantitative performance are divided into 2 categories that is measures based on processes and expense based on customer responsiveness. Examples of the first classification are excessive stock minimization, cost minimization, revenue maximization, return on investment maximization, and sales maximization are provided. An example of the second classification are measures based on the performance steps which can be fill rate maximization, customer responsiveness, product long delivery minimization, lead time minimization and customer fulfilment time reduction.

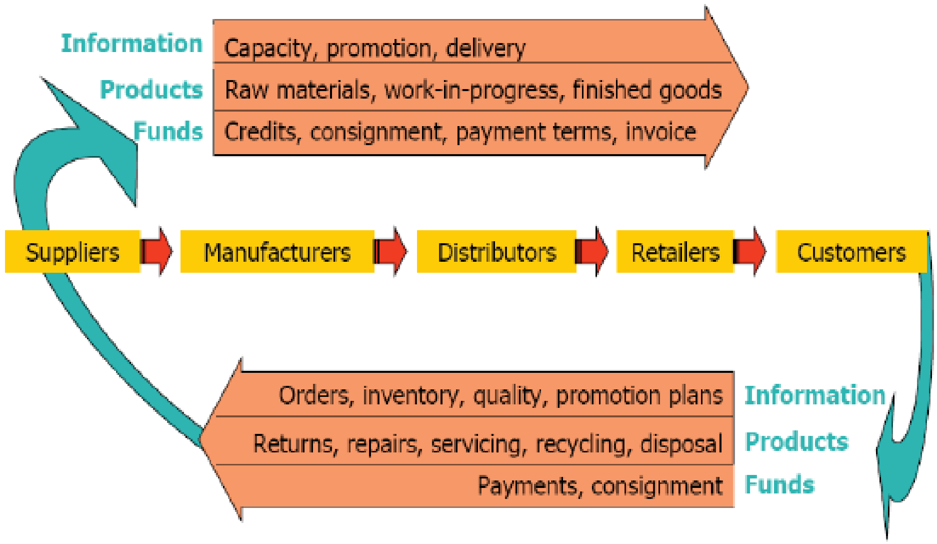


FIGURE 2. 1. BASIC FLOWS IN THE SUPPLY CHAIN NETWORK

(Anne, 2009)

2.4 Supply chain performance and cost management

Supply chain management has more than the last years emerged as among the bigger areas where business can develop a competitive advantage. But handling a supply chain in an effective way is a complex and difficult task, this is due to outsourcing, and globalization (Lee et al, 2004; Lee et al 2015). The continuous increase in competitiveness in the business environment in the last decade has led more interest in supply chain issues (Prasad and Shankar, 2011). If companies continuously have the problem of unnecessary high inventories, reduced customer service, increased costs and decreased profits, their supply chain is not well managed.

If companies are moving to new markets or start using new methods, it must have its supply chain ready for the new challenges and problems they might deal with along the line. To create an effective supply chain, it is of importance that companies comprehend that various products often have various demand for this reason, supply chain should therefore be managed regarding such variation. Goods that have a stable customer demand and a reliable supplier (partner) should be managed differently from a good that have an uncertain demand and an unreliable supplier. Companies that use one strategy for their products will typically be unable to achieve success with such approach (Lee, 1997).

By limiting unnecessary losses due to production, distribution and improper routing of transporting goods, the costs in the supply chain can be lowered ((Prasad and Shankar, 2011). Therefore, the purpose of supply chain management is to balance low inventory, customer service, and low total cost by matching customer demand with material flow from suppliers (Goncalves, 2003; Stevens, 1989). Synchronizing supply with customer demand in the most effective and efficient way. Furthermore, the use of total cost is to analyse the financial performance of the supply chain. A well-known method for reducing the cost of supply chain is to make sure there is smooth flow of materials and smooth flow of information (Lin, 2019; Wikner et al. 1991).

One of the major problems that a supply chain encounter is the decision-making process, as the whole supply chain system involves different working boundaries. For example, the impact of investment capacity on costs related to order processing and inventory. A framework used for measuring supply chain performance was developed namely, tactical, level, operational level and strategic level (Gunasekaran et al. 2001).

2.4.1 Types of supply chain cost

Gunasekaran et al. (2001) suggested the types of supply chain cost when dealing with inventory, delivery to customers, logistics operations, suppliers, and customer-service and types of supply chain cost suggested by the study used for measuring supply chain performance is explained in the following sub-sections.

Ordering costs

For all company, the first stage of their business process is the purchases of goods. The method the orders are carried out and planned manages the downstream performance and levels of inventory. The response of company supply chain can be reduced by reducing the order cycle time (Gunasekaran et al., 2001). Moreover, order placement can also create cost in the supply chain. Numerous transactions are required each time order is placed, thereby leading to costs of ordering for the company. The cost of ordering comprises transaction record maintenance, order prepayment, communication of supplier, delivery arrangement, payment of orders, (Chopra and Meindl, 2007).

Cost of production

The next process of a supply chain is the production, manufacturing and final assembling of the final products, as soon as orders are placed, and the products are received. There are several causes that have influence on the cost of production, an example of such costs is capacity utilization, throughput time, maintenance, raw material cost, labour cost, volume of products and service etc. (Gunasekaran et al., 2001). The cost of production can also be increased driven as a result of high discrepancy of production rate, like ramps up and down machines (Bavin, 2010).

Costs of assets

The cost of supply chain assets consists of plant, inventories, accounts receivable, property and equipment (Azfar, 2012). Therefore, the cost associated to all asset to the revenue must be measured to determine the company productivity (Gunasekaran et al., 2001). According to

Azfar (2012), the cost associated to assets can be measured as the average number of days necessary to convert the investment of cash in assets into the cash claimed from a customer as a result of sales of goods.

Costs of delivery

Supply chain delivery performance can be calculated and measured using important performance measures, example of such are transport scheduling, delivery channel, and the location of warehouse all play a significant role in delivery performance (Gunasekaran et al., 2001). Supply chain delivery performance also have a direct relation to loyalty cost and customer satisfaction, particularly in order driven supply chain systems, for example assemble to order (ATO) and make to order (MTO) systems in which all customers are required to wait before their customized products are received.

2.4.2 Main functions in a supply chain

Global interconnections or system of supply chains network involves many companies executing different complex tasks in order to provide products and services to their customers. Thus, the functions of all connected companies are the main supply chain network components. In order to understand better the supply chain network, it is vital to understand the basic meanings of these important components.

Supplier

Suppliers are those who offer products or raw materials for the manufacturer to produce/ put together a product (Poornikoo, 2019). The supplier role in a supply chain is important and essential in the success of the manufacturer of products. The reliability of the suppliers, quality of the raw materials, the capability of the supplier to react at short time play a key function in the success of the supply chain network (SCN) of the product (Akan, 2006; Ellram and Cooper, 1993).

Manufacturer

Manufacturers are companies that manufacture and/or assemble an item (Klug, 2013). These companies include raw materials manufacturers and manufacturers of final products. Examples of manufacturers of raw materials are miners for minerals, companies that drills for oil and gas, and companies that cut wood. It likewise includes companies that farm the land, raise animals, or capture seafood (Ellram and Cooper, 1993). Manufacturers of final products utilize the subassemblies and raw materials made by other manufacturers to manufacture their products. Manufacturers produce products that are intangible such as music, entertainment, software, or styles (Ellram and Cooper, 1993; Ayers, 2006). Manufacturers and/or producers are therefore moving to various areas of the world where cost of labour is lower compared to their former operating areas.

Distributor

Distributors are business or company that take inventory in large quantities from manufacturers and deliver to retailers and customers (Ellram and Cooper, 1993; Ayers, 2006). Distributors likewise offer products to other organisations in addition to selling bigger quantities of items that a specific customer would generally purchase (MacCarthy et al, 2016). Therefore, distributors are also known as wholesalers in the sense that they find and service customers by storing inventory. Additionally, distributor carries out storage facility operations, inventory management, and product transportation in addition to customer service and post-sales service which includes product promotion and sales (Kumar and Nigmatullin, 2011). Furthermore, a distributor brokers a product between the customer and the manufacturer, and they don't take ownership of that product (Ayers, 2006), hence just performing the works of promoting and sales of products.

Retailer

Retailer in their capacity store inventory and they sell in smaller amounts to the final consumers or general public (Ayers, 2006). The tastes, choices and needs of the consumers to whom the items or product are sold are usually monitored by the retailers. Retailer, likewise, advertises and uses packages to attract its clients. Product selection, combination of price, convenience, and service are used to bring or win over customers. An example of such type of combination is product selection and price utilized by discount rate.

Customer

Customers can be classified as any person, organization or group of individuals that buys and uses a product (Ahmadi et al, 2019). A customer can also purchase an item in order to add it to another item that they in turn would sell to other clients. Or a customer can be classified as the final user of an item or product who in order to consume it.

Therefore, to effectively manage supply chain, researchers' proposes the use of decision variables, specified constraints, and performance measure as a guide for their study to modify and implement the processes for designing their supply chain (Amaya, 2011; Anne, 2009). Therefore, supply chains are designed particularly to examine and solve possible issues or problems in a company supply chain. From the result conducted from experiments related to supply chain, researchers found a common problem for most supply chains. This typical issue is the increase of demand uncertainty as information and order move up the supply chain (Agrawal et al, 2009; Dai et al, 2017; Zhou et al 2010; Zhou et al, 2017). They assert that the uncertainty of demand have vital effects on performance of supply chain and this problem in is known as "Bullwhip Effect".

2.5 Bullwhip Effect

Bullwhip effect is a common occurrence in every supply chain, denoting a situation where there is an amplification of demand fluctuations as orders move upstream from customers to suppliers (Lee et al., 1997a, b). Bullwhip effect can be costly for supply chains as it causes problems in form of excessive inventory, excessive capacity, unused capacity, overtime and labour idling. Aeppel, 2010, Cannella et al., (2014) stipulate that bullwhip effect can also be amplified by the volatility presented by the economic environment. Dooley et al. (2010) discovered the bullwhip effect in the monthly sales data and inventory in the US manufacturers when they researched the effect of economic recession on retailers, wholesalers, and manufactures. Application of demand variance is a result of the structure of replenishment policies by decision makers as each supply chain players strives to quickly act to individual demand signals (Forrester, 1958). Five main operational causes of bullwhip effect were categorised by Lee et al. (1997a, b) namely: shortage gaming, order batching, demand signal processing, rationing and lead time. Behavioural aspects can also cause bullwhip effect (Croson and Donohue, 2006). Sterman (1989) introduced a method (management games) to study and understand the cause of supply chain problems and bullwhip effect known as the beer game. The beer game depicts a common four-tier supply chain distribution process where each player (retailer, wholesaler, distributor and factory) in the game has the responsibility of managing each tier of ordering beer in the supply chain. The beer game is a representation of most real-world supply chains and has been utilized by many researchers (Croson and Donohue, 2003, Disney et al., 2004). The beer game yields important anecdotal evidence as it studies how people react in the supply chain during the game. However, the limitation of the beer game is that nothing can be proved mathematically (Wang and Disney, 2016). This limitation has prompted researchers in this field to embark on this study to gain in-depth understanding by developing simulation models letting supply chain players to test inventory models and policies

(Van Ackere et al., 1993; Hong-Ming et al., 2000; Coppini et al., 2010). In the study conducted by Wang and Disney (2016), they stipulates that there is an ongoing attempt to study and improve the literature of the bullwhip effect utilizing simulation methods, statistical research methods, control theory, operational research methods, and system dynamics methods.

2.5.1 History of bullwhip effect

Forrester (1958) was the first researcher of oscillation in a supply chain and he named it Bullwhip Effect. At first, he did not use the term "Bullwhip Effect" however he specified this problem as "Demand Amplification" and demonstrated the differences between manufacturer orders and customer demand. This important study motivated other researchers to research this phenomenon connected to bullwhip effect in order to study the reason and improve the supply chain by figuring out the main causes of this problem. Studies such as Wanphanich (2008), Wu et al, (2017), Wang et al, (2015), Jaipuria and Mahapatra, (2014), Poornikoo, (2017) and Naim et al (2017) argued that there is a presence of bullwhip in every supply chain, and a few of them went further to ascertain the possible causes and solutions of bullwhip effect. Figure 2.2 depicts the bullwhip amplification as order moves up the supply chain from downstream to upstream.

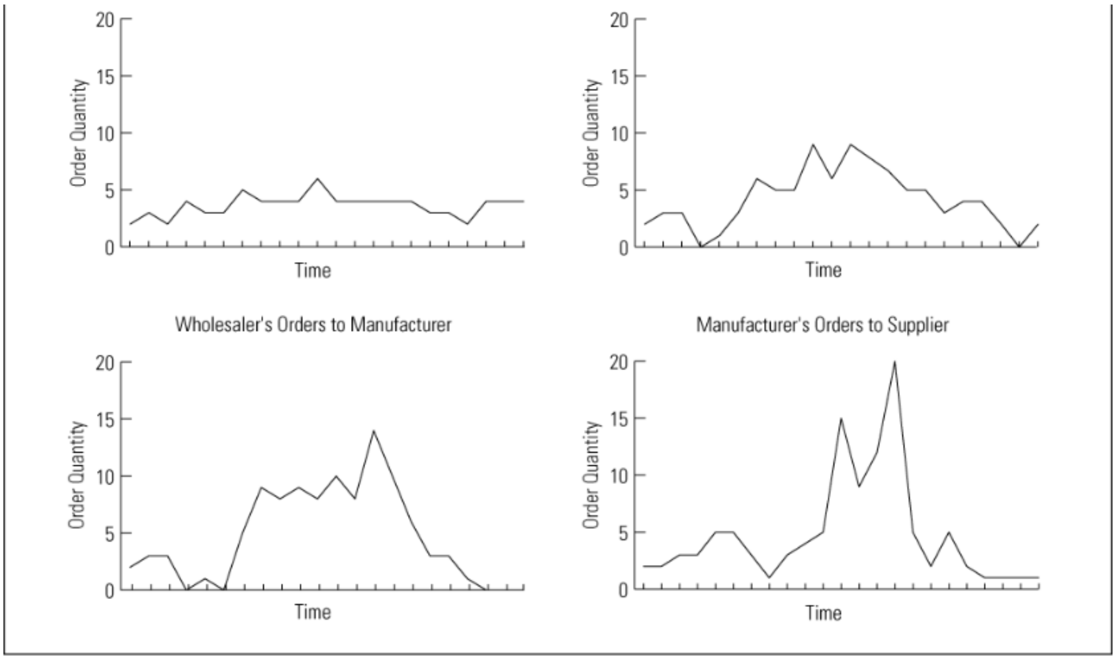


FIGURE 2. 2. BULLWHIP EFFECT
(Forrester, 1958)

Lee et al. (1997a, b) in their research argued that there are five main reasons why the bullwhip effect appears in a supply chain; they categorized them as lead times, demand forecasting, rational and gaming, price fluctuations, and batch ordering. There are different approaches to demonstrate the presence of bullwhip effect. The most common method of displaying the bullwhip effect is the Beer Distribution Game (BDG). A 4-stage supply chain is played in this game including a seller, a factory, a supplier and a wholesaler is modelled. Simchi-Levi et al. (2000) then went further in their study to enhance the beer game to an electronic version. At present, researchers use different version of playing the beer game such as computerized or manual web-based variations.

In a simple 2-stage supply chain, Chen et al. (1998) measured the bullwhip effect to understand the effect of forecasting in the supply chain and lead times. They argued that a moving average forecasting technique dampen the oscillation in the supply chain. Additionally, with a centralized customer demand information, all members involved in a supply chain can share the same access to customer demand information, with this method the bullwhip effect cannot be completely removed but can be decreased or dampened. Furthermore, Chen et al. (1998) suggested some factors that have the most impact on bullwhip effect and the success of utilizing supply chain simulation. Thus, findings are same, that is to centralize information sharing technique, which positively affect the bullwhip effect, furthermore, reducing the lead time can reduce or dampen these bullwhip effect. A beer game simulation was conducted by Cantor and MacDonald (2008).

In this study, laboratory students played the beer game to understand the effect of customer demand and lead time on bullwhip. Methods of sharing information and ordering policies are the typical causes of bullwhip effect (Amaya, 2011). However, cost structure, demand forecasting technique, and ordering decisions are another crucial element that affect bullwhip. However, there are limited research study which goes in-depth to show and discuss all causes of bullwhip effects and their impacts under different actual case study customer demand patterns with established simulation tool.

2.5.2 Measures of Bullwhip

The evaluation and quantification of the bullwhip effect is influenced by the way the bullwhip effect is measured. Bullwhip effect can be defined as order amplification as orders moves up the supply chain from downstream to upstream (Lee et al., 1997; Aeppel, 2010). The method of measurement of this instability is standard deviation, coefficient of variation, and variance. The variance normally begins through mathematical study. The measurement of bullwhip effect is more suitable by comparing the variance between order and demand and the comparison is made either by difference or ratio where order amplification is denoted by greater difference (less) than zero or larger ratio smaller than one (Cachon, et al., 2007). According to Blinder and Maccini, (1991) when data is available, some researchers use other options that are easy to observe and understand like shipments, sales and production quantity instead of demand and orders. West, (1986) argued that it is crucial to conduct different operations on time series under nonstationary demand, which means measuring the bullwhip effect by variance of order changes as an alternative rather than variance of orders itself. On the other hand, Gaalman and Disney, (2012) stipulated that one can compare the difference between demand variance and order variance which is finite as proven. Thus, as discussed for bullwhip measurement, bullwhip and production and inventory smoothing are different occurrences signifying order fluctuation amplification and attenuation. Nonetheless, if bullwhip effect measurement is changed from an increasing order variability to order uncertainty then both effects can coexist (Bray and Mendelson, 2015).

2.5.3 Empirical and experimental research in bullwhip

The methodologies adopted in bullwhip research can be categorized into empirical, experimental, analytical and simulation-based. Historical data on shipment, sales, demand and production is collected and analysed in empirical studies on bullwhip effect and it can come with company background information or information regarding the supply chain under study (Wang and Disney, 2016). This is efficient in detecting bullwhip effect and it also allows the ability to identify the main causes of the problem; inductive and corollaries hypothesis can be tested; and the performance of the implemented strategies can be measured (Duc et al 2008b). However, sometimes there can be contradiction on the observations and conclusions. For experimental research management games and laboratory experiments is used to study the causes of the bullwhip effect (Chen et al., 2000a). They normally focus on cognitive, psychology and behavioural aspects of the policy makers with respect to replenishment and forecasting behaviour. Theories in experimental method can be tested in isolation decreasing the effect of exogenous problem and if the experiments are adequately designed they can be used for the purpose of pedagogy (Wang and Disney, 2016). For mathematical modelling the causes of the bullwhip effect can be precisely quantified for prediction in regards to response of the system to various kinds of disturbances and to provide suggestions for total elimination or prevention and it is advantageous to simplify the model and conduct thorough analytical insights. However, simulation methods give the opportunity to handle more real bullwhip effect problem computationally and numerically when mathematical model is highly complex and above our analytical ability. Although, the main problem is to simplify and abstract the real problem under investigation into a mathematical one.

2.5.4 Components in bullwhip modelling

To analytically examine the bullwhip effect, the conventional approach is to model the supply chain players as a dynamic inventory system. The effect like ordering policy, delay, forecasting policy, demand and the mechanism for information sharing can be studied and some of these listed factors can be categorized as an exogenous effect to the policy makers and some endogenous and each of them can positively or negatively affect demand amplification.

Demand

Bullwhip effect has been identified as partly a result of demand uncertainty, the importance for future demand forecast and lead times as argued by Chen et al., (2000a) making the bullwhip problem receiving a great amount of research attention. Positive feedback strategy involves holding orders when large number of stock-outs have drastically increased (Delhoum & Scholz-Reiter, 2009). Another reason for demand amplification is the objective of the policy makers. The policy makers strive to minimize the cost of holding inventory and backorder costs. The introduction of production cost and order changes by Cantor and Katok (2012), they discovered that production can be smoothed when there is seasonal demand and that smoothing behaviour is well-known when cost of production is high. Demand has been assumed to be stochastic process in most research in this direction.

Forecasting

There are a significant number of literatures used for studying and exploring the bullwhip effect forecasting methods. The moving average (MA) forecasting method have been studied by Duc et al. (2008a), on the other hand, simple exponential smoothing (SES) method have been studied by Chen, et al., (2000b) and also simple exponential smoothing method has been studied by Dejonckheere et al, (2003). These forecasting methods are user friendly and they have been widely used in industry. Another forecasting method known as the minimum mean squared error (MMSE) reduces the squared forecast error expectation. This forecasting method is able to achieve the greatest possible accuracy for the process of specified demand and is usually used as a benchmark (Hosoda & Disney, 2006a; Zhang, 2004a). The effect of a more sophisticated forecasting methods like Holt's, Brown's and Damped Trend forecasting was studied by Wright and Yuan (2008) and Li et al (2014), these forecasting methods are designed trended demand and seasonal demand. Zhang (2004a) stipulates that MMSE forecasting techniques reduces inventory related cost and discussed about forecast accuracy and total cost.

Time delay

Lead time which can be classified as the delay of information flow and material flow has been discussed by Forrester (1961). He argued that it is one of the factors that causes demand amplification. Is support of this statement, Chen et al. (2000a), Steckel et al (2004) Agrawal et al (2009) also stipulates that lead time increases bullwhip. However, delayed demand information decreases bullwhip effect and can be classified as a positive effect for upstream suppliers (Hosoda & Disney, 2012). When lead time is modelled as a random variable it mimics the variability or instability of real supply chain. Kim et al (2006) and Duc et al (2008b) have argued that lead time variability increases order variability and this argument have been supported by the study carried out by Ancarani et al (2013). All the study anticipated that lead time distribution is exogenous and not affected by the capacity of the suppliers. Another study conducted by Boute et al (2007) were they examined state dependent lead times. The studies argued that bullwhip is taken too lightly if the indigeneity of lead time is ignored.

Ordering policies

Ordering policies can be described as policies that is based on whether orders are constrained or not for example if order are negative and if a minimum order quantity exists and the elimination of these constraints is good for mathematical investigations. Linear ordering policies: Sterman (1989) have suggested the use of weighted feedback as an active and adjustable control method to depict the misperception of Beer Game delays although, the weighted feedback has been used long before Sterman's suggestion. The weighted feedback is also known as proportional feedback control. Therefore, lead time misperception can be understood by designing a satisfactory feedback parameter to shed light how it affects the bullwhip effect. Batched policies: when orders are done in batches it allows economies of scale in transportation, set-up or ordering. There is minimum of ordering quantity in these policies that prompts impulsive order process. Burbidge, (1961), Wangphanich et al (2010) argued that to reduce operational cost and stabilise orders a smaller batch size can be of great assistance. Aggregation issues: when a supplier has to deal with multiple distribution centres or producing different goods on same line or by multiple retailers then there is a problem of product or location aggregation. The aggregation problem has been studied under (s,S) policy by Kelle & Milne, (1999), base stock policy by Suck, (2009) and (Q,T) policy by (Lee et al.,1997). Temporal aggregation problem emerges when time series data is summed on a periodic bases for decision maker process and example of temporal aggregation is weekly replenishment orders and quarterly financial reports. Chen & Lee, (2012); Noblesse et al (2014) suggested that aggregation of time and location both have an influence on bullwhip effect meaning that the bullwhip effect can be decreased with the aggregation period but impossible to completely remove.

<u>Information sharing</u>

Information sharing has been suggested as one of the strategies used to mitigate bullwhip effect in supply chains. The common structures for information sharing order status, sales data, production schedules, delivery schedules, inventory levels, and sales forecast (Lee and Whang, 2000). Whang explained that is information can be share by the downstream and upstream partners. Through advanced integration amongst supply chain partners, members can collaborate with their peers and entrust planning and replenishment decisions with them. Through advanced integration amongst supply chain partners, members can collaborate with their peers and entrust planning and replenishment decisions with them. There are two supply chain collaboration mechanism namely demand information sharing and vendor managed inventory (VMI). Demand information sharing can be described as a process whereby end customer demand is shared or communicated amongst all supply chain members allowing them to use this information to forecast in spite of being needed to provide their own customer order. Demand information sharing has been suggested by Lee et al. (1997) as a strategy to reduce the bullwhip effect produced by demand signal processing.

2.6 Inventory management and control

Even with the debates on the meaning of supply chain management (Simchi-Levi et al., 2000; Lambert and Cooper, 2000; Mentzer et al., 2001) as well as the discrepancy with logistics management (Cooper et al., 1997; Lummus et al., 2001; Mentzer et al., 2001), one essential issues regularly faced in this topic is how to decide the amount of inventory to order from suppliers to allow the supply chain satisfy their customers without holding excessive inventory and accumulate cost. Wei et al (2013) described inventory management and control as all products and materials a company owns or holds, to fulfil customer demand. One of the main issues with holding inventory is to know the actual amounts of inventories and the number of models that needs to be stored this causes a great deal of capital to be held in inventories. It is referred to as manufacturing as well as inventory control problems. Companies hold inventory for many reasons. One of the reasons for holding inventory is a buffer to fulfil customer orders with an improved service level. The players in supply chain must hold more level of inventory to guard against forecast errors because of manufacturing and distribution lead time to avoid losing customers to other companies as a result of not being able to fulfil their need. Another reason company hold inventory as a buffer is to absorb uncertainty in customer demand. This enables the manufacturing and distribution system to function as planned. This is important because the frequent changing of production and inventory levels which can be costly. Other benefit of holding inventory are circumventing inflation, quantity discount, increase in price and unreliable supplier. However, there are disadvantages of holding inventories as Bonney (1994) argues that the opportunity cost involved with money held in holding inventory that can be used for other important purpose, costs of maintenance, storage cost and costs in managing the inventory with less obvious inventory costs related like obsolete cost.

Grunwald and Fortuin (1992) argued that it can be difficult to accurately balance the level of required inventory, i.e. the aim to hold a reasonable level of inventory in order to reduce cost of holding inventory at the same time keeping customer service levels and guarding against uncertainty in customer demand. Companies use computer systems for the management of their business processes and inventory levels. However, these computer systems that help managers in managing their inventories are typically difficult given that they are not able to completely effectively synchronise business processes with the full inventory management policies (Wang et al, 2012; Wang et al, 2014; Wang et al, 2015; Relph, 2015).

For a successful inventory management and control, companies need to optimize inventory and decrease demand uncertainty by reducing forecast errors and flexible policies in capacity which reduces cost and improve profit (Wang et al., 2014; Relph, 2015). One method to examine this is to begin measuring the performance. Factors affecting inventory levels are shipment time, delivery accuracy, forecast accuracy, and inventory accuracy. If the inventory performance is not optimised, the costs of logistics, capital, and service level will be greater due to lack of inventory management and control policies. The inventory levels are changed from the different sorts of product for instance batch sizes, lead times, service level, demand variations and suppliers (Wang et al, 2016; Wang et al, 2015; Relph, 2015). In a study conducted by Wang et al (2012) they suggested that making use of inventory management control systems for scheduling and planning to know the quantities of order required are essential for business to keep the inventory levels as low as possible.

Supply chain inventory management can be achieved through different approaches by modelling the most important issues in the supply chain. Examples of supply chain inventory models for reducing and dampening bullwhip effect also utilized simulation technique. These supply chain modelling methods will be extensively discussed in the next sections. Beamon (1998) mentions that generally there are four supply chain modelling techniques namely deterministic analytical designs, stochastic analytical designs, financial designs and simulation models. She specifies that the initial three designs (stochastic economic models, deterministic analytical models, and analytical models) are utilized to provide best heuristics or algorithms generally for manufacturing and inventory. In simple terms, these model's emphasis on some variables of manufacturing and inventory for lead time reduction (i.e. the number of time when orders are placed and when the orders are received) and smoothing customer demand. Simulation models are utilized for both manufacturing and inventory companies. The objective is to design real problem in the model to determine and discover ways to solve these issues.

Min and Zhou (2002 improved these classifications and categorized supply chain models into four different classifications. The first classification is the deterministic model known as non-probabilistic, the second classification is the stochastic model known as probabilistic, the third classification is the hybrid model and the fought classification is the IT-driven model. The deterministic models presume that the parameters are fixed and known, while stochastic models presume the uncertain/unsure parameters.

Queuing models and optimal analysis derived from stochastic models are omitted as supply chain designs hardly ever utilized such methods. Hybrid models encompasses the components of both stochastic and deterministic models. These models comprise simulation and inventory-theoretic models that have the capability to deal with both uncertainty and certainty including model parameters. Thus, since the proliferation of information technology (IT) applications for supply chain modelling, this research chose to add and discuss the classification of IT-driven models to the classification. The aim of IT-driven models is to integrate numerous stages of planning a supply chain on real-time basis utilizing simulation software to improve the whole supply chain. Nevertheless, to go further in describing the modelling techniques in supply chains, the different modelling techniques is briefly described below.

Deterministic modelling method: Ishii, (1988) calculated the lead times and base stock levels a supply chain on a limited horizon. A constrained optimization design known as PILOT was established by Cohen and Moon, (1990) to examine the results of different specifications on cost involved in a supply chain. In a research conducted by Nozick and Turnquist (2001) they studied the functions of cost on inventory and then linked it to a fixed-charge centre in order to consider a compromise between costs associated and demand coverage.

Stochastic modelling method; Pyke and Cohen (1993), conducted a research on integrating supply chain with one production facility, one storage facility, and one merchant, and studied numerous types of product this modelling design produces financial reorder level, order-up-to levels for replenishment batch for a specific supply chain. A solution to the vanilla box problem was proposed by Swaminathan and Tayur, (1999) where the stocks of semi-finished goods are kept in vanilla boxes. When customer places order (random customer order) the semi-finished goods are then assembled to final products.

Hybrid modelling method: Karmarkar and Patel, (1977) utilized a decomposition method to solve supply chain problems with stochastic demands and transhipment between places. To understand the links and connections between transportation, manufacturing, and inventory. Cachon, (1999) used a game theory to address an unlimited time horizon and stochastic demand issue between a single supplier and a single retailer. Karabakal et al. (2000) combined mixed-integer programs and simulation models to identify the number and location of distribution and processing centres while measuring customer fulfilment such as the ability to deliver customer's order within a short time.

IT-driven modelling Method; Camm et al. (1997) combined an integer model that includes the warehouse location and locating different products using geographic information systems (GIS) to build a robust decision support system (DSS). A goal programming model was developed by Talluri (2000) to study an effective ordering decision in the same study suggested the reason why IT is important for managing supply chain. The proposed model can be used to choose the best enterprise resource planning (ERP).

Simulation modelling Method: Towill, (1992) selected simulation strategies to assess the impacts of demand variations on demand amplification. In this study, the just-in-time technique is suggested to be the most efficient in smoothing variations in customer demand. Figure 2.3 presents the classification of supply chain model.

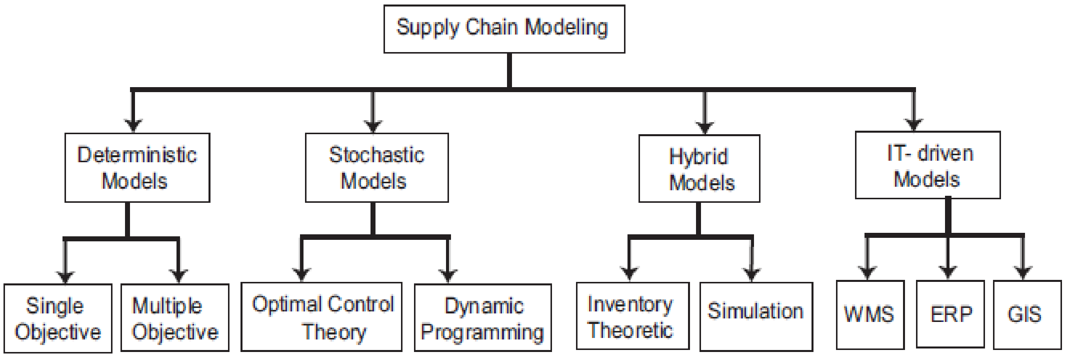


FIGURE 2. 3.CLASSIFICATION OF SUPPLY CHAIN MODEL

(Shapiro, 2000)

2.6.1 Inventory theory

Inventory theory is widely taught as part of purchasing management or operations research, with books such as (Winston, 1994; Hillier and Liberman, 2005; and Benton, 2007). This section discusses inventory position and forecasting. Inventory positioning in the supply chain is an important financial aspect, which impacts cost and profitability, however much more significantly, service shipment to the customer (Willems, 2011). The study also specifies, "Not all inventory is of equivalent consequence." In order word, not all inventories have the exact same importance in a company. Therefore, inventory levels cannot be decreased immediately it takes time to perceive and correct any discrepancy in the inventory level. Inventory optimization is, for that reason, a constant process. Graves and Willems (2000) developed a model they call the guaranteed service (GS) model. The model ensures that each chain in the supply chain system guarantee 100% customer delivery within the agreed time.

The safety stock in the supply chain system can then be calculated, utilizing a multi-echelon method. Bossert and Willems (2007) examine the GS model for a routine review of supply chains. They extend the methodology to resolve acyclic networks, stochastic method and time phased demand. They argued that the models are continuously being complex, affecting the solvability of these models. Neale and Willems (2009) investigate the ramifications of the GS model to supply chains with non-stationary demand. Non-stationary demand is defined as demand for an item that will change over the product life cycle. They identified several counter instinctive results. To start with, safety stock should be a function of backwards demand and secondly, demand forecast accuracy and demand uncertainty propagate differently through the supply chain. Humair and Willems (2006), Graves and Willems (2008) and Humair and Willems (2011) developed improvements in solving the GS model to optimize the position of safety stock in the supply chain system. Case studies of this work are provided by Farasyn et al. (2011), Billington et al. (2004), Wieland et al. (2012), and Manary and Willems (2008). In all cases improvements were derived.

2.6.2 Demand Forecasting to ascertain inventory levels

Forecasting forms a basic part of any operations research. It utilizes historical information to project the future. In supply chain management, the application is generally concentrated on the demand side. Demand is not always smooth and simple to forecast. According to Choy and Cheong (2012) three kinds of demand functions exist, namely: A generic cyclical model with standard demand following a pattern, which could include seasonal listed as stochastic demand with variability, and uncertain demand which is extremely irregular. If these demand patterns are connected to the purchasing behaviour recognized by Gattorna, (2010), base demand and semi-wave demand would be covered by the generic cyclical demand function. The surge demand pattern would be a stochastic demand function and cavitation would be comparable to the uncertain demand function.

2.6.3 Inventory measurement

There are many performance measures in inventory management literatures which can be grouped into non-financial measures and financial measures. A typical financial measure does not always support continuous improvement (Bazin, 2010). Which may not be sufficient to provide insight to a particular problem in a supply chain. Therefore, the consequence of this limitation led this research to financial measures, which can provide improvement in areas that will then be reflected in financial performance (Kaplan, 1990). A later study by Kleijnen and Smits (2003) suggested that some companies use multiple performance metrics such as fulfilment rate, sales rate and stock. Burbidge and Halsall (1994) argued that the improvements in the performance metrics is as a result of applying smooth material flow throughout the supply chain. Some of the metrics mentioned are annual sales, set up time, overdue sales, lead-time, return on investment.

Caterpillar a well-known company which is interested in providing flexibilities maximising profit and gaining market share on one of their products (Rao et al., 2000). On the other hand, some mobile communication firm’s emphasis on lead-time, quality, and cost aspects in the supply chain, despite the accelerating growth in the industry (Persson and Olhagor, 2002). Chow and Stede (2006) carried out a survey that involves 128 managers from different companies to capture the possible combinations of financial and non-financial measures. In their study, the financial measures listed are the cost measures related to the company’s operation such as total costs and unit costs while the non-financial measures can be categorized as employee-oriented measures, internal operating measures and customer-oriented measures as well as subjective measures, which comprise morale of employee and the perspective of firm's on business. Laugen et al. (2005) in their study also outlined performance measures from the top performing companies chosen from the International Manufacturing Survey Database, 2002. Performance measures of flexibility, speed, quality, and cost were highlighted.

In a study by Ozbayrak et al. (2007), a supply chain model is developed using the system dynamics model to represent a make-to-order manufacturing company's operation. The measures used to measure the supply chain performance are the inventory level, work in process, customer satisfaction and order backlogs. From this study, there are extensive range of non-financial and financial measures applied to a firm or supply chain; in most cases several metrics are used. However, competition in current unpredictable business environment is no longer between companies but between supply chains. The literature on inventory management and performance measurement influenced the choice of the performance measures used for this research. Both non-financial measures and financial are applied to the inventory system dynamics models, constrained within the boundaries of the models for comparison purpose.

The models can show inventory accumulation. From a non-financial perspective, the models can be measured by the inventory level, cycle time and safety stock coverage. The inventory models performance can be measured based on total costs, cash balance and profit for the financial measures. In order word, non-financial measures for inventory management models can lead to financial consequences in the performance measures (Bazin 2010). When the possible performance measures have been identified, the simulation design of the models and analysis is developed based on these measures. The early phases of the ordering process, such as stamping, casting or fabrication of parts, need a higher level of stocks to reduce the probability of shortages when there is need for inventory. The hybrid push/pull model is usually applied in the high-tech industry (Minnich and Maier, 2007), where larger number of stocks are held which is beyond this scope of the model. These differences discussed above between the push and hybrid push/pull model behaviour will show the effect of the different policies. Similar parameter values are initialised in the two models. Consequently, the two models have the same level of safety stock coverage, smoothing values and cycle times at the beginning of the analysis. By having consistent or same parameter values in the two models, it is possible to analyse the effect of the different models on the inventory level.

Moreover, the demand smoothing, in the models, smooths the noise in the uncertainty in customer demand which is connected to the customer demand rate and the desired distributor order. The different information arrows show that smoothing of customer demand always requires information feedback from the actual customer demand rate and always provides information to the desired distributor order. The demand smoothing structure in the models uses a first-order exponential smoothing principle when smoothing customer demand (Sterman, 2000). Compared to a moving average smoothing principle, by which all values of demand are given the same weight for approximating the demand, exponential smoothing gives lesser weight to older demand values, ensuring that these older values receive inferior significance when determining the demand (Sterman 2000).

Hence, the exponential smoothing attempts to portray a scenario in which recent demand is given higher information value than older demand (Hopp and Spearman, 2011). Therefore, it should be noted that the two models are developed based on allowing comparisons. This means that customer demand smoothing only serves the purpose of synchronising the two models. It is difficult to separate the effects of smoothing and the policy interventions if there are inconsistencies in the implementation of demand smoothing across the two models. The analysis would involve the dynamics in the demand pattern from week 0 to week 130. During this period, each of the two models has its own policies set for adjusting the delays and safety stock coverage to cope with different demand patterns. The analysis will show the differences in inventory levels of the distributor and dealer in the two models during the period of dynamic demand.

Yamashina (1987), Harrison (1992), and Higgins et al (1996) all argued that some of the most challenging situations for companies is dealing with the growing uncertainty in customer demand, as well as reducing product life cycles. Thus, reducing the uncertainty in customer demand is the preferred demand pattern for supply chains.

2.7 Definition of system dynamics

System Dynamics (SD) is referred to as a technique to analyse, model and simulate complex and dynamic systems. To distinguish between these applications, SD is separated in 2 main locations, depending on the objectives and the function of usage. Forrester (1987) pointed out the main achievement of SD in a clear initial identification of the model purpose and for that reason these designs should assemble, clarify and merge understanding. Wolstenholme (1997) gave a short design of the term system dynamics and the essential principle behind. His description, stated as; 'What' a rigorous method to assist sharing, visualizing, thinking, and in the communication of the future development of complicated companies and problems with time. 'Why' for the function of problem solving and creating a more robust designs, which decreases the probability of unexpected effects and undesirable results. 'How' this process involves creating simulation designs and operational maps which expresses mental models and records the connectivity of information feedback, behavioural and physical processes, structural boundaries, policies, and by using these structural design to experiment the holistic results of other strategies and concepts. 'Within' a structure which appreciates and cultivates the openness, needs, equality, values of awareness, responsibility of people and teams. (Wolstenholme, 1997).

A big advantage of system dynamics is the ability to accept the complexity, non-linearity and feedback loop structure of dynamic systems. These qualities, specifically in the field of social and physical systems, force the development and implementation of system dynamics (Forrester, 1994). As already noted, system dynamics is divided into two ways of its application, called quantitative and qualitative. While qualitative models are mainly used for recognition and understanding of closed-loop relations, the quantitative designs are used for simulations. Richmond (1993) specified the qualitative part as system thinking (ST) he argued that system thinkers use a diagramming language to depict feedback structures visually. The qualitative modelling does not include simulation and is likewise referred to as the soft operational research SOR (Coyle, 1998). Thus, the quantitative modelling is not always possible and even though it is essential. Different modelling techniques are used depending on the field of application.

Causal Loop Diagrams (CLD) are common in the qualitative modelling and gives an excellent understanding of feedback loops. These diagrams provide the base for more quantitative models if a simulation is required. Flows and stocks are applied as fundamental aspects of the quantitative designs running different conditions in a suitable simulation software application. Peterson and Eberlein (1994) argued, that a qualitative model alone, might typically not be adequate for analysing due to problem being modelled by the modeller. In some cases, mental ideas could lead to incorrect assumptions and a simulation would reveal unanticipated behaviour.

2.7.1 Applications of system dynamics modelling in businesses

Based on the early principles of Forrester, economic and social studies are widely spread. More suitable methods exist for the operational field of management and therefore SD research focuses on more intangible or ecological aspects. Hidaka et al. (1999) used SD to transfer the standard Total Quality Management (TQM) approach into a causal loop diagram. They also in their research stated, that this technique provides a much better understanding for managers. Kim and Burchill (1992) used SD-archetypes to create a better understanding in the field of total quality management implementations.

Ewaldt (2000) used SD to explain the effects of capacity constraints within multilevel production chains and revealed the dynamics due to different delays within the production processes. In the recent years, business is also interested in sustainable manufacturing and the impact on the environment. To understand these effects as a result of reduction of pollution, the consumption of raw material, and waste. Kibira et al. (2009) developed a modelling structure. More dynamic and complex behaviour occur in the link between production and process improvement. System dynamics is also suitable and appropriate to manage this complexity and provides a much better understanding of these dynamics. Morrison (2010) asserted, based on SD research that managers should focus on the development of confidence and experience.

Effectively managing supply chain inventory is generally complex as it involves different players. For this reason, many research studies are constantly trying to solve this problem because it causes bullwhip effect (Goncalves, 2010). A system dynamic modelling framework of Georgiadis et al. (2005) addresses the problem of bullwhip effect in a food supply chain industry. A more detailed supply chain research was also conducted by Bijulal and Venkateswaran, (2008) and this study deals with a closed-loop supply chains, concerning manufacturing and re-manufacturing, under different inventory policies. Therefore, the use of system dynamics in the strategic project management can be of great benefits for managers. Handling the complexity of tasks effectively and efficiently can help improve business performance. Lyneis et al. (2001) discussed, that the use of SD is most efficient when it is used as a learning process, because further works and decisions are based on the experience of previous studies. The decision-making process is primarily based on the understanding of the decision maker, hence Yim et al. (2004) used SD for improving the decision making performance in strategic level. Rodríguez-Ulloa and Paucar-Caceres (2005) pointed out, that

SD does not guarantee effective strategy therefore integrated the SD method with the field of soft operation research to support the strategic decision-making processes within companies.

The field of strategic planning belongs to the strategic management process and primarily based on forecasting system (Neubacher, 2012). Poles (2010) provided a strategic planning tool of a closed loop supply chain using system dynamics modelling for evaluating system improvement strategies within business that is based on a research study, about end of life vehicles. The philosophy of using SD to assist managers is as old as SD itself and numerous applications were made in almost every area. Forrester (2003) specified, that thus model design has been rather unsuccessful. He assessed the many reasons of failure and discussed, that specifically the structure of financially regenerative loops that shows the financial system are wrongly reflected.

2.7.2 Using system dynamics modelling in supply chain management

The system dynamics modelling application to supply chain management has its initial origin in industrial dynamics ID (Forrester 1958, 1961). Forrester presented a three-level supply chain model that involves the retailer, the distributor and the storage facility. In this study Forrester put forward that a manager's main task is to understand and manage the five different flows that take places in industrial companies: example of such flows are information, materials, cash, capital, and manpower. He examined how improper management of production and distribution in a supply chain can cause insufficient evaluation of perceived demand that can develop a demand amplification effect. Uncertainty in demand at the downstream supply chain are amplified as customer demand move up the supply chain that is from downstream to upstream, thereby increasing inventory level, causing irregular capacity utilization, and decreased service level (Barlas and Gunduz, 2011; Lin, 2019; Botha, 2017).

Sterman (1989) in his study utilized a system dynamics model to study the beer distribution game, which can be described as a realistic simplification of the supply chain for producers of beer, to carefully test and analyse the bullwhip effect presence in an experimental context. He suggested that there is existence of bullwhip effect and this might have been caused by other supply chain member's inability to forecast customer demand. In 2000, Sterman introduced a generic system dynamics model of the stock management structure that was used to discuss, analyse and experiment the origin and causes of oscillations and instabilities in supply chains. He stipulated that the distortions of supply chain are usually amplified due to company's safety stock policies. The main reason for oscillations and instabilities in supply chain is the combination of presence of time delays and inability of the managers or decision makers to point out the time delays and take it into consideration. Villegas and Smith (2006) extend the work of Sterman by studying the trade-off between inventory oscillations and production quantity oscillations as a performance measure of a supply chain. Thus, the study suggest that this problem can be managed in a way of changing the planning policy in order to give more relevance to the projection of customer demand instead of the safety stock policy.

Anderson Jr. et al. (2000) examined the effects of demand amplification in a machine tool market by using the system dynamics modelling methodology. System dynamics model allowed the integration of normal financial measures in the model, example of such normal financial measures are feedback delays, nonlinearities and loops. The research proves that the amplification that is observed and simulated is mainly caused due to the capacity and financial investment of the machine tool market. The study also recognized the order projection of the machine tool users as an important point for lowering instability, which can be improved in the machine tool industry by close collaboration between consumers and suppliers (Angerhofer and Angelides 2000).

In the study of Ashayeri et al. (1998) they developed a distribution chain model of Edisco which is the European distribution arm for United States of America Company Abbott Laboratories. In this study, they suggested a new conceptual structure for performing a structured organisation process reengineering by using the system dynamics simulation method. Moreover, the system dynamics model was simulated in order to know and understand which techniques have the ability for the best performance improvements and to assist companies to get to its vision. The experiments and analysis are to increase the capacity of production that is a structural change however does not assure a steady supply chain. Another study was carried out by Joshi (2000) where he built a structure for enhancing information visibility of the supply chain in which delays in the information flow is decreased. He also evaluated the supply chain dynamics under various situations of forecasting decisions and information visibility by using system dynamics simulation method.

A Japanese pet-toy supply chain known as Tamagotchi using system dynamics model was carried out by Higuchi and Troutt (2004). In this study, they utilize a multi-echelon model to synchronise influences of numerous occurrences, like the boom and bust, bullwhip effect, and multi-echelon perspective. The developed model adds to the knowledge of decision-making like the effect of advertisement and manufacturing capacity. Since system dynamics utilizes simulation to examine supply chain techniques, it also shows that system dynamics is more flexible in modelling nonlinear dynamic systems compared to mathematical analytical approaches. However, one of the advantages of system dynamics compared to other methods that study supply chains behaviours is its ability to capture complex relationships of a system by using feedback loops.

2.8 Literature summary

The objective of this thesis is to contribute to the research in supply chain using the system dynamics methodology. The simulation design aims to evaluate and compare inventory level performance by carrying out rigorous tests using different demand patterns from case study companies in Nigeria automobile downstream company. Bazin (2010) used SD to compare three different systems namely push system, pull system and hybrid push-pull manufacturing system using different demand patterns to compare. The different customer demand patterns introduced in the models are to show the effect of downstream automobile demand uncertainties on company supply chain. This integrates the modelling of the inventory with supply chain problems. This section will attempt to provide an obvious gap in the system dynamics modelling and supply chains fields.

In previous work of supply chain inventory planning and control as a technique of handling inventory, the literatures evaluated the performance and issues related with implementation of different approaches to managing manufacturing and inventory systems e.g. push, pull and hybrid push system (Huang et al, 2002, Fu et al, 2006, Garcia et al, 2013, Gonçalves et al, 2005, and Hua and Li, 2008). The discussions on performance of each system push, pull and hybrid push/pull systems has led to relative evaluations and analysis of the advantage of one system over another, as presented by (Lee, 1989; Dingwei, 1991; Lim et al. 2012; Hodgson and Wang 1991; Spearman and Zazanis, 1992; Li, and Scheller-Wolf, 2010; Kim et al, 2012; Cheng et al. 2012; Gonçalves et al 2005; Guo et al 2015; Fowler et al. 2019; Ma, 2015).

At the same time, these researchers have found it difficult to provide consistent definitions and classifications of the push, pull and hybrid systems. This was shown by the extensive variety of research discussing this problem (Bavin, 2010; Cheng et al. 2012; Albrecht et al. 2015; Ma, 2015; Fowler et al, 2019). Regardless of the extensive number of publications which contrasted and compared the push, pull and hybrid systems, there is still gap for more study in this field especially in the developing countries. The comparisons between push, pull and hybrid systems were conducted with the goal of evaluating the best system performance over another. In addition, the comparison involved two production and inventory systems; for example, the push and pull systems, push and hybrid system, or the pull and hybrid systems. Nevertheless, these three important systems are still applied in existing business environment because each system has its own advantages to fit various operational environments. Hence, the comparison of push and hybrid systems under uncertain demand in a Nigeria downstream automotive company as presented in this thesis, can shed some light on the behaviour of these systems under the existing operating environment. The reason for using these models for this research was made when conducting the literature review and while building the conceptual inventory models. Literatures on this problem shows that study of supply chain instability/bullwhip effect requires models which represent inventory and shipment processes precisely. The models used for this study also have a clear purpose, variables and the equations represent the supply chain system being investigated.

Research of supply chain management employing the system dynamics methodology is limited, as stated by Spiegler (2013). In this research, a manufacturing and inventory system was classified as a secondary market, consisting of assembly, production, project management and engineering. Other areas from the evaluation are resources, services and any level (general company application in any sector or industry). The study show that the modelling of manufacturing and inventory systems using system dynamics was not popular regardless of the ability of system dynamics modelling to expose the underlying reasons for fluctuations in industrial systems, as demonstrated by Forrester (1958) in his first paper on Industrial Dynamics.

In a similar study by Özbayrak, (2007) research in manufacturing and inventory operations the research is concerned with designing manufacturing system, inventory system, production planning, operations management and other operational concerns. Although, the number of system dynamics papers in manufacturing and inventory system is argued to exceed other methods, more research in this area has been done using other method like discreet event simulation (DES) (Özbayrak, 2007). A possible reason for the few number of SD studies is the common application of DES to modelling manufacturing and inventory systems, because of the level of information provided by this simulation method. Forrester (1983) stressed the need for improving system dynamics methodology due to criticism from the social sciences and the research environment around that time.

System dynamics has been previously applied in many fields, but this has shown inadequate to demonstrate the complete potential of the paradigm. Since then, publications in system dynamics worked to focus on improvements in the method and to show the potential of the methodology through extensive research in numerous issues. However, in the last fifteen years (2005 onwards), there have been prevalent financial recessions and increasing competitors in the business environment. There has been a considerable increase in the number of research papers concerned with manufacturing and inventory systems. However, the growing complexity of manufacturing and inventory systems increases the difficulty in representing detailed operations in a simulation model.

This view is extensively discussed by Cannella (2018) who outline the main problem in modelling and imitating a complex manufacturing system. Among the three difficulties is to minimize the amount of time needed to solve the problem in a manufacturing and inventory system using a simulation model. This is the point where system dynamics methodology can be advantageous for lowering such complexity. In the system dynamics modelling methodology feedback relationships in the system variables are modelled to enhance and improve learning in a complex system (Sterman, 2000). Moreover, system dynamics modelling methodology offers through continuous simulation an expansion of the constraints of human mental capabilities in understanding the effects of a decision.

Since the review conducted by Baines and Harrison (1999) there is continuous publications in manufacturing and inventory system in the System Dynamics Review and international conferences of the System Dynamics Society. Marquez et al. (1996) presented a paper which provides causal diagrams for the kanban and the CONWIP systems. Performance measures were reached include order backlog and total inventory, in addition to throughput applied in the previous paper (Usano et al., 1995). They attempted to compare the performance of the constant work-in-process (CONWIP), kanban and push systems to get a further understanding of lean manufacturing. Nevertheless, this research was carried out utilizing the discrete-event simulation (DES) technique.

The interest in modelling production and inventory systems using the system dynamics methodology is still ongoing. Publications have been found mainly in the SD conference proceedings rather than the system dynamics review. Haslett and Osbourne (1999) tackled the issue of adjusting production daily in the kanban system by presenting local rules in a system dynamics model. Mayberry et al. (1996) implemented a pull system through conceptualisation and modelling using the system dynamics methodology. The systems thinking approach helped the business re-engineering group to understand the root of the issue, which lay in the material requirements planning (MRP) technique applied in the system.

Listl and Notzon (2000) in their research applied system dynamics modelling to a real-life operation. A simple system dynamics model (SD) was built or developed in order to assist managers in a production planning department at BMW to understand the effect of their policies in reacting to any unforeseen excess in the inventory level of the work-in-process. System dynamics modelling was proven to be a strong tool in assisting managers in the decision-making process. Juerging and Milling (2006) built a system dynamics models of the automobile system to analyse the manufacturing start-up stage, which is specified as the time gap between the time-to-market and time-to-volume. Time-to-market is the time period between the point the product is developed and sales. On the other hand, 'time-to-volume' is the time required to achieve full-capacity of manufacturing.

Jeong and Maday (1996) in their research conducted a numerical study to manage the information flow in a manufacturing and inventory system, constraints in production, utilizing an Integrated error with State Feedback and Filtering (ISFF) dynamic control law. The generic model was numerically simulated to study and understand the dynamic behaviour of production-distribution system with a constrained production capacity and an uncertain multi-echelon system. The constrained production caused a falling level of inventory, which led to a higher level of back-orders. Georgiadis et al. (2005) in their study gave a holistic model to determine a lengthy food supply chain at a strategic level. They used the system dynamics modelling methodology as means of modelling the supply chain and analytical tool to analyse the strategic problems for food supply chains. Moreover, the system dynamics model is utilized to determine efficient optimal and best parameters to improve the policies for different strategic decision-making problems of multi-echelon and single supply chains.

In a previous study, Minegishi and Thiel (2000) developed a model to enhance complex logistics behaviour understanding of a food market by allowing the researchers to analyse the impact of various decision policies for poultry processing and production, in addition to demonstrate the causes of instabilities in supply chains as a result of uncertainty in customer demand. Spengler and Schröter (2003) used system dynamics methodology to model and examine different supply chain scenarios for spare parts recovery of an electronics industry. These different scenarios analyse the decisions of managers where production capacity and cost are used as performance measures.

Georgiadis and Vlachos (2004) researched on the behaviour of reverse supply chain with product recovery to understand the effect of various environmental impact on capacity planning policies. The behaviour of the system is analysed by using a dynamic simulation model on the basis and concepts of the system dynamics modelling methodology. Two main environmental problems were analysed, which are the effect of green image on customer demand behaviour, and the effect of state environmental management policies, like the state projects for appropriate disposal of used products and items. Thiel (1996) developed a system dynamics model to represent an elementary cell in an assembly line. The goal of the model was to study the instability of the production system, which applied kanban control, from the perspective of the inventory level. Zahn et al. (1998) evaluated the investment in a flexible automatic assembly system by thinking about the soft and hard aspects influencing the decision-making process.

In another study Panov and Shiryaev (2003) developed a simple generic manufacturing supply chain consisting of a demand curve forecast in the modelling of price influences on the distribution rate. The evaluation of the demand curve was also presented using a direct demand curve estimate model and anticipated by least squares and rapid smoothing. Model experimentation was under both invariant and changing demand. The result from the simulation highlighted that an optimal price and production rate for increasing profit was much easier to determine under the invariant demand, in contrast to the changing demand situation. Goncalves et al. (2005) constructed a model of three phases of a hybrid push/pull production and inventory system in a manufacturer of semiconductor products. In their model customer demand was treated as endogenous; this had effects on sales and production. Shortages in the manufacturer's stock caused loss of sales that led to a reduction in demand from consumers.

In turn, the manufacturer reacted to this scenario by reducing production further to avoid excess inventory. The delayed effect of this action is a reinforcement of the positive loop in the system, which meant a prolonged lack of stock causing customer demand to decline even more still. A various viewpoint on modelling the hybrid push-pull system existed by Minnich and Maier (2007). They modelled the supply chain in a modern business utilizing a push and pull control to attain responsiveness and performance in the system. Three demand patterns were used in showing the product life cycle in the experiment. The demand patterns are high, low and without variation. Although pull control, with initial stock displayed a greater level of effectiveness and responsiveness than push control, the trade-off was fluctuations in capacity utilisation upstream of the supply chain.

Another technique to modelling push and pull models in system dynamics is by using qualitative method (Zapata and Marquez, 2003). They presented the behaviour of both systems using a qualitative analysis to find and understand the stability and instability areas. The analysis consists of a qualitative analysis of the behaviour produced by the simulation, which begins with a sensitivity analysis of the preliminary conditions. Politou and Georgiadis (2008) modelled the Theory of Constraints (TOC) of the Drum-Buffer-Rope (DBR) production system utilizing the system dynamics methodology. The TOC was presented by Goldratt and Cox (1984) to run an organisation by handling the constraints in the system, described them as everything that restricts the system from attaining greater performance against its aim and objective. An influence diagram by Coyle was developed to represent a generic three phase make-to-order production and inventory system with a capacity constraint resource (CCR). The impact diagram was transformed into a stock and flow diagram, which was then explore using pulse and oscillatory demand signals.

The results showed that the production rate in the model with CCR fluctuated after a pulse change in customer demand. In the second experiment, the production rate changed in the exact same pattern as the oscillatory demand pattern. Baines and Harrison (1999) presented their study using a generic system dynamic manufacturing and inventory models. Additionally, modelling of generic manufacturing and inventory systems using system dynamics methodology have also been carried by other researchers see (Thiel, 1996; Panov and Shiryaev, 2003; Politou and Georgiadis, 2008; Bavin, 2010) or a 'case research study' basis see (Mayberry et al., 1996; Haslett and Osborne, 1999; Georgiadis and Vlachos, 2004; Juerging and Milling, 2006; Georgiadis et al., 2005; Listl and Notzon, 2000; Higuchi and Troutt, 2004).

The models were developed to provide and increase understanding of problems in supply chain. Nevertheless, just few studies presented a comparison between different models of manufacturing and inventory systems (Marquez et al., 1996; Usano et al, 1996 and Bazin

(2010) for example. This reveals that researchers in the field of system dynamics are more interested in seeking explanations of the problems in manufacturing and inventory systems other than comparing different systems. However, comparison of performance between different systems have recently start to emerge as a new approach and method of analysing is on the rise to deal with the limitations of previous approaches and methods. The analyses have been used to modernize manufacturing and inventory systems, which were typically generic.

The growing significance of supply chain management, due to the increasing customer demand uncertainties, has proposed a new direction of research in the field of system dynamics. The work of Bazin (2010) investigated the importance of comparing different hypothetical demand patterns under different manufacturing and inventory push, pull and hybrid push/pull manufacturing and inventory systems have on the effect of a company's supply chain. The push, pull, and hybrid push/pull manufacturing and inventory systems used in this study by Bazin have an important influence on the performance of a company supply chain. This is an area where this research fit in. Although, this study aims to use a downstream automobile case study in Nigeria for investigation on the company supply chain. The models of push and hybrid push/pull system dynamics inventory models are evaluated to show the effect of customer demand uncertainties on downstream supply chain using two case studies.

Review of the system dynamics modelling methodology and supply chain literature in the previous sections suggests that push, pull and hybrid systems are all important planning approaches and are frequently appropriate to a company's operations. From the above discussed literatures, this research attempts to fill the gap in modelling various policies in Nigeria downstream automotive company in system dynamics field. It also attempts to contribute to knowledge in the supply chain inventory management field by using different customer demand patterns (business as usual, optimistic, and pessimistic patterns) under the push and hybrid push/pull system dynamics model to compare and contrast with the use of actual case study companies in Nigria for testing and analysing the effects on the supply chain.

2.9 Conclusion

The literature review has discussed various introductory supply chain management concepts. Several supply chain inventory management frameworks, history of system dynamics, the dynamic behaviour of supply chains (supply chain instabilities) and the research gaps have been discussed. Despite several measures suggested and adopted by many researchers, supply chain instabilities still exist arising from uncertainties in customer demand. An important theme from the literature review was that reducing this instabilities and fluctuations in the supply chain remains a challenge for companies. Several authors have mentioned both indirectly and directly, that this problem can be traced back to customer demand uncertainty. However, empirical study addressing it as a 'supply chain problem' comparing two different models using actual case study companies in developing economy in this case Nigeria is limited.

In summary, two models push, and hybrid push/pull inventory system dynamic models are proposed for this study to provide useful management tools, addressing in detail the supply chain management problems. Opportunities exist in extending the body of knowledge in the development of improved supply chain inventory management approaches based on customer demand uncertainty. Chapter Four focuses on the development of the push and hybrid push/pull model for designing the supply chains using system dynamics modelling to provide a much better understanding of the structure of those models and their characteristics for addressing this problem.

Chapter 3. Methodology

3.1 Introduction

The methodological chapter will explain the process of the research undertaken like the ontological position for this research, epistemological, research design, methods as well as research tools applied. To begin with the discussion, the chapter attempts to first describe supply chain management research ontological underpinnings and epistemological underpinning and their philosophical position and its effect in this thesis. The other sections discuss, more information on the research methods and research tools employed will be discussed. Finally, the research design employed to answer the research question will be discussed.

3.2 Research paradigms and philosophies

Most research paradigms should have an ontological, epistemological and methodological position (Saunders et al., 2009; Blanche et al., 2007). Thus, ontology entails an assumption about the nature of reality or its knowledge which can be described as the science of being, ontology questions if reality naturally takes place, or if reality is an idea of social interactions amongst people. To simplify the above statement, it checks if reality is tested from the perspective of objectivity or perspective of subjectivity. On the other hand, Epistemology describes the presumptions as to how the knowledge of reality is acquired or gathered (Saunders et al., 2009). Therefore, an ontological as well as epistemological assumptions have a direct effect on the chosen methodology. The methodological position is the methods of how the knowledge of the world is gained. Therefore, methodology is the foundation and also justification about the choice of methods, concepts as well as theories (Bryman and, 2007).

When choosing a research method, compromises between control, realistic perspective and generalisation will be necessary. Quantitative research usually tries to enhance control and also generalisation that is external validity, on the other hand qualitative research try's to increase realistic perspective that is internal validity (Golicic et al., 2005). Thus, it is extremely important for a researcher to know the ramifications of the proposed epistemological positions for the research as well as the proposed chosen methods when embarking on social science research. As a consequence, to specify the ontological as well as epistemological positions for carrying out this thesis, the researcher has carefully researched of what is to be the nature of phenomena in this study by reviewing the literature to understand the ontological position and epistemological position of a supply chain system dynamics research.

3.2.1 Supply chain management research

Considering that supply chain management can be categorized as an important research to undergo considering the importance and effect on present business environment, there has been constant discussion on what the philosophical nature of this field should be. Nonetheless, the academic argument on the paradigmatic, disciplinary, and theoretical nature of supply chain management (SCM) different work may be conducted from various viewpoint (Spiegler, 2013; Wolf, 2008). Moreover, large number research field that includes different paradigms such as leadership, intra-organizational, inter-organizational relationships, logistics, process improvement alignment, information systems, and business results (Burgess et al., 2006), systems engineering, strategic management, law, and marketing (Giannakis and Croom, 2004), as a supply chain researcher it is important to understand the philosophical positions of specific theories that encompass supply chain management. As explained by Arlbjørn and Halld´orsson (2002), since researchers in supply chain might have different academic histories, this will cause different epistemological perceptions of supply chain problems.

3.2.1.1 Supply chain management research designs and methodologies

Many scholars of logistics have extensively argued that logistics and supply chain management research can be linked or associated with a positivist paradigm they also argued that supply chain management research is largely normative and quantitative (N¨aslund, 2002; Mangan et al., 2004; Mentzer and Kahn, 1995). However, the issue with this claim is the inadequate and comprehensive evidence in the supply chain field. (Aastrup and Halld ´orsson, 2008). Subsequently, many studies have argued about the combination of two paradigm positions namely, positivism paradigm as well as interpretivist or non-positivism paradigm.

Before finalizing on these thoughts, researchers have proposed that before supply chain management research is conducted there is need to consider whether a study should be quantitative, qualitative, or mixed research methods. Therefore, the relationship and connection between epistemology and method should not just be a mere quantitative versus qualitative debate (Duberley and Johnson, 2005) but a rigorous consideration and justification of chosen paradigm. Hence, in order to select the most appropriate methodology for this research, a comprehensive review of existing supply chain management, supply chain dynamics and system thinking will be discussed in the next section.

3.2.2 Ontological position

System dynamics characterises a collection of information about what the world is. All constants and variables in a system dynamics model can be categorized as an equivalents idea in the real system (Forrester 1961). The system dynamics ontological assumption is that the dynamic behaviour of any type of complex social system is as a results of its internal causal structure derived from the pattern of physical constraints, benefits, as well as things that makes individuals to act the way they do (Meadows and Robinson (1985).

To simplify the above statement, things are connected in complex patterns, therefore the world is comprised of rates, levels, non-linearity, feedback loops, information flows which are fundamentally different from physical flows, and delays which are important components in systems (Sterman, 2000). Dynamic behaviour of complex systems can be discussed and analysed in terms of positive feedback loops and negative feedback loops connected with stock and flow component in the model as well as delays (Mingers and Rosenhead 2001). According to the discussion system dynamics ontology position best fit post-positivism (critical-realism).

3.2.3 Epistemological position

There are three school of thoughts from questions of objectivity in social science: empiricism, critical-realism, and positivism. Empirical school of thought suggests that realities help themselves and call for no explanation through theoretical suggestion (Mingers, 2004a; Mingers, 2004b). As a reason, few purely empirical researches have been applied in supply chain management, the study disposed of the idea of publishing this perspective. Another school of thoughts in social science were introduced positivism and also post-positivism (critical-realism). The positivism is suggested to be the major philosophy in supply chain management research and as a result of its key use quantitative methods lots of system studies have been classified as simply positivist by early researchers.

The post positivism is an intermediate method that tends to include a holistic strategy essential to supply chain dynamics understanding. Therefore, if system dynamics has a certain epistemology, we can understand what kind of knowledge might be found and the relationship between the knower and the known (Lane 2001a) which can be described as moderately subjective epistemology, not objective epistemology as might be expected which is similar to post-positivism (critical-realist).

3.2.3.1 Positivism

Positivism can be described as a philosophical theory describing it as a certain knowledge that is based on natural phenomena. Therefore, information gathered from physical experience, interpreted by means of reason and logic, builds the specific origin of most knowledge (Lane 2001a). A positivist researcher believes that the methods should be extended to examine social life and mental ability of human to develop these subjects as social sciences (Pruyt, 2006). Only when reputable social scientific knowledge has been established, will regulating and controlling private or group behaviour finally be possible (Durkheim, 1964; Duberley and Johnson, 2005; Patton, 2002; Benton and Craib, 2001). To summarize the statement, positivism implies the adhering to features: objectivity or self-reliance, cross-sectional analysis, value-freedom, reductionism, causality, and generalisation (EasterbySmith et al., 1991).

3.2.3.2 Post-positivism (Critical Realism)

Post positivism (critical realism) emerged as another option to the two simple and extremely epistemological choices in social science which are interpretivism and positivism (Benton and Craib, 2001; Mingers, 2004a) therefore, using a methodological pluralism. Post positivism is described as an anti-positivist but is nonetheless still objective. In order word, just like positivism perspective, post positivism (critical realism) believes that an outside world exists free of our knowledge of it. On the other hand, unlike positivism, post positivism (critical realism) presumes that there is a meaning in the world by how we interpret it (Pruyt, 2006; Thomas, 2004). Many researchers have influenced the development of post positivism (critical realism) Benton, 1977; Harr´e, 1970; Hesse, 1966; Keat and Urry, 1975 however, Benton and Craib, (2001) argued that Bhaskar's Realist Theory of Science has given the best systematically developed and influential version of the approach, particularly in its explanations of social science.

Benton and Craib, (2001) argued in this study that critical realist theory follows three processes which are the accumulation of data about patterns, recognizing and explaining the fundamental structure, and carrying out more experiments through observation of the reality. After that, the reality is then later arranged in three stages which are the real world that science seeks to find, the real issue produced under speculative problems, and the empirical. Critical realism is against reductionism, an understanding of philosophy that argues that a complex system is nothing other than the accumulation of components. A major issue of this method is identifying the point to stop as the world is an open system. Therefore, using intensive research strategies is a possibility meaning that they are mainly interested in the things that occurs in specific cases rather than showing how broad certain patterns and occurrences are in the population (Sayer, 2000).

3.2.3.2.1 Post-positivist in system dynamics

A small number of modern system dynamics practice is post-positivist. Characteristics of initial system dynamics practice, the subgroup of wide system dynamics focussed on validity, calibration of data as an example in Homer (1997) as well as pure stock and flow modelling, element of policy engineering, moreover, the focus of quantitative system dynamics is on validity while the focus of qualitative system dynamics is on trajectories therefore, the insight can be categorized as post-positivist system dynamics. The ontological position and epistemological position are classified as realist or objective with a minimal of nominalist and subjective elements. The approach and rigorous scientific modelling are presumed to aid post-positivists obtain as close as possible to probably objectively real world meaning (Pruyt 2006; Homer 1996).

The best system dynamics model is the one closest to the real-world. Hence, models are minor content theories or dynamic hypothesis to be tested, confirmed or refuted (Sterman, 2000). Axiologically, it is known that knowledge is subjective by the theories of the scientist's and values, that indicates that models and interpretation are value-laden (Easton, 2010, Vennix 1996; Lane, 2000a; Lane, 2000b).

System dynamics modelling methodology is mostly quantitative and the percentage of qualitative data is referred as soft variables, qualitative models diagrams are used with the objective of creating full quantitative models also simulation are termed by post-positivist in system dynamics to be the main function of system dynamics (Wolstenholme 1990; Homer and Oliva 2001; Oliva 2003; Pruyt, 2006). The results from the simulation of the quantitative models are then analysed qualitatively. Generalisations might nevertheless be made in terms of framework, e.g. system archetypes (structurally nomothetic). Post-positivist (critical realism) in system dynamics presumes that there are causal relationships amongst social phenomena that are probabilistically understood that changes overtime (Lane, 2001a). This causality is unidirectional from aspect to aspect around a loophole and is not uncertain or relatively easy to fix' (Forrester 1980, p15). This perspective is mainly deductive. The best model is the one closest to the real world.

<u>Post-positivism for this research</u>

Having extensively discussed past literature and various paradigm of inquiry it is now time to show more specifically why post-positivism (critical realism) is ideal as an approach for this research. Thus, post positivism (critical realism) enables this research to take an essentially rationalist stance which has been supported by majority of system dynamics modellers. Post positivism (critical realism) addresses both natural and social science and this includes both complex and soft techniques, and post positivism (critical realism) fits well with the reality of system dynamics as an applied subject. According to Richardson and Pugh, 1981, there are seven steps to build system dynamics models; understanding of the problem, problem identification, model conceptualization, model formulation and simulation, model testing, policy formulation and policy Implementation Figure 3.1 presents the steps in building a system dynamics model.

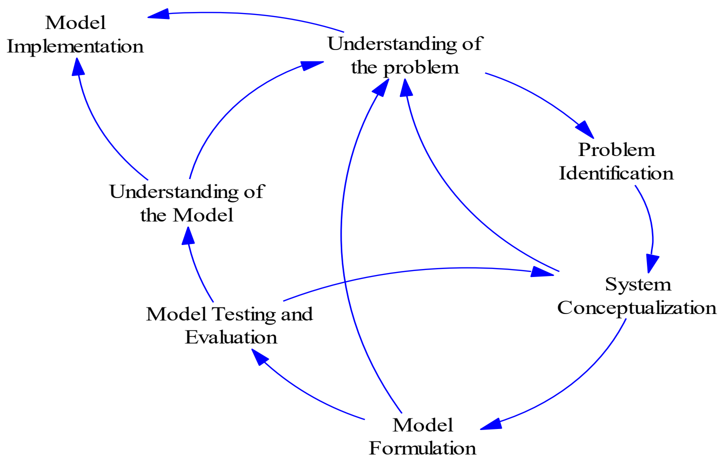


FIGURE 3. 1. SYSTEM DYNAMICS MODELLING PROCESS (RICHARDSON AND PUGH, 1981)

3.2.3.2.2 Adopting a combined approach of supply chain dynamics and system thinking

According to the study of Dunn et al. (1994), they suggested that both the artificial paradigm and a direct observation of reality motivated research supply chain dynamics. They stated that the artificial paradigm is mainly controlled by an axiomatic as well as positivist approach while the direct monitoring is attained by studying, performing field experiments, which can be considered as a purely interpretivist approach for some researchers. On the other hand, Gammelgaard's (2004) describes the field of supply chain management based on its connections of components to that of the systems thinking method considering that its main point is the interdependency between the different supply chain components. In the systems technique, theory can be considered contextual rather than universal. Moreover, collection of data for the research as well as structure of the theory usually takes place almost simultaneously. Nevertheless, the reality is still taken into consideration objective and consequently it exists individually of human ideas or beliefs.

More so, dynamics system is concerned with solving problems in complex systems which can be qualified by dynamism. The systems approach allows the examination of dynamic feedback and complexity, by examining the dynamic behaviour of the components in the system and their interactions in all areas of the chain the system (Wolf, 2008). Additionally, system feedback suggests that one component have the ability to affect another. These feedback loops have been termed systems modelling (Forrester, 1961; Towill, 1991). Mingers (2000) suggests that system dynamics appears to show several of the major principles of critical realistic perspective given that system dynamics is embedded in a holistic view as well as abductive or retroductive method. Previous scholars have used this approach when modelling observed real life supply chains during model building process. In addition, it is not the objective of this field to generalise theory, but to determine, by using analytical experiments, mostly with simulation modelling or mathematical modelling, by empirical monitoring the different elements in the systems.

Conversely, more time is devoted in developing the feedback loops for analysis rather than observing actual systems and conducting empirical analysis. Therefore, the systems approach might require less intensive research than a critical realist but not as extensive as in positivism. The researchers also suggest that there is more research work on experimental analysis than research on empirical analysis. Golicic et al (2005) argued that there is inequality in research conducted on qualitative research like phenomenology, grounded theory, semiotics, ethnography, and historical analysis. Regardless of analysing contextual systems, research in supply chain dynamics usually tests theories then data is provided for generating scientific laws. Bailey (1994) argued that this a basic principle of positivism. The researcher also suggests that the main perspective among scientists in management is linked to some form of positivism. Williams (2008) also supports this notion that positivism provides the source for research work in management science. Hence, this research work can be described as complex as it gives emphasis to the elements and procedures for analysing the performances of supply chains and its design (Aastrup and Halld´orsson, 2008).

In this research, a value free, an objective and holistic perspective will be used. Both deductive and abductive approach seem effective for contributing to the theory of supply chain by answering the research questions and research objective. However, this study adapts existing system dynamic models instead of building new SD models through observations. Moreover, a well-established model is more suitable for answering methodological questions. Therefore, conceptual approach and a deductive reasoning were selected for this research.

3.3 Research methods and tools

The methods and tools used for achieving this thesis is presented in this section. Wolf (2008) classified research strategy as either conceptual and/or empirical, depending whether collected data is gathered for generating theory or not. Conceptual research strategy does not normally depend on empirical field data; however, concepts and structure tools can be utilized for increasing the reliability and validity of the study (Bowen and Sparks 1998). For example, Wolf (2008), stipulates that for analysing a study, simulation, mathematical modelling, and experiments is utilized to create artificial data and are usually refined for making theoretical models more accurate. Conversely, Adams and Schavaneveldt, (1991) stipulate that unstructured or exploratory research technique is used for reviewing literature for example, the word exploratory represents a research type whose key purpose is to find new understandings, measure occurrences and ask questions. The goal of conceptual literature review is to define knowledge in an area of research to build conceptual models and these models can be tested empirically (Denyer and Tranfield, 2006). Cameron and Price, (2009) described mathematical modelling as an analytical method that employs the concepts of mathematics.

On the other hand, Wolf (2008) described simulation as experimenting to see the behaviour of the model by manipulating variables in an artificial environment. In support of this statement, Saunders et al., (2009) asserts that the researcher controls some variables to observe changes. Therefore, this study uses exploratory and structured conceptual research strategies. The exploratory approach refers to when the researcher conducts literature searches for meanings of inventory management and bullwhip effect (instabilities and fluctuations) supply chain literatures and therefore proposes quantitative model to assess bullwhip effect from supply chain system dynamics perspective.

3.3.1 History of system dynamics

System dynamics was developed by Jay Wright Forrester throughout the mid-1950s. Forrester was a professor in the MIT Sloan School of Management that was formed a few years ago. The first use of SD was at a workshop with managers of General Electric (GE) (Forrester, 1995). They had a big issue with human resources and Forrester asked to make a note of employing selections to a changing demand. This game had the capability to offer a better understanding of the issue. The principle at that time was based on stocks and flows and is nowadays still used for the quantitative designs. In the following years, Forrester developed the field of system dynamics from the hand composed stage to the computational phase. In 1958 Richard Bennett a co-worker of Forrester developed the first computer modelling language. It was known as SIMPLE (Simulation of industrial management problems with lots of equations) and Jack Pugh extended this early system dynamics modelling and established DYNAMO. This modelling language was used as a business standard for over thirty years.

After Forrester has released Industrial Dynamics in 1961, which is known as the origin of SD, this approach became popular in management science (Dangerfield and Roberts, 1996;

Dangerfield, 2009; Botha, 2017). In collaboration with John Collins, a past mayor of Boston, the Urban Dynamics book was written and published in the year 1969 (Forrester, 1969).

3.3.2 System thinking

Cavana and Maani (2000) explained four various levels of thinking on system dynamics and built an analogy of an iceberg. In this idea, the level of events is pointed out and represents the state where most people are pleased and stop thinking. System thinking (ST) have regularly been improving over the years based on hidden levels - patterns, mental models and systemic structures. Sterman (1994) showed the popular event-oriented view that causes an event-oriented decision making. Figure 3.2 shows the basic technique of the majority of problem-solving scenarios.

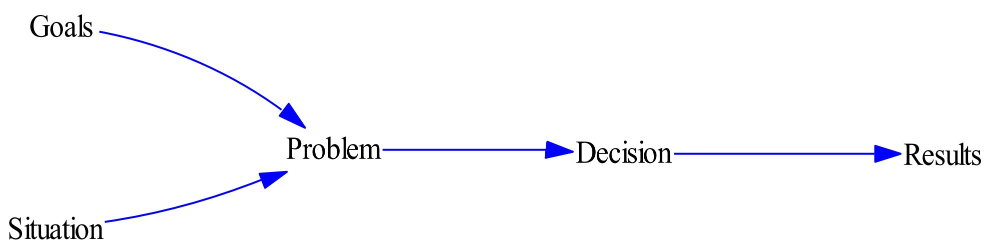


FIGURE 3. 2. EVENT-ORIENTED VIEW OF THE WORLD
(Sterman 2000)

Often the current situation changes as preferred. This discrepancy develops an issue, which should be fixed by doing something about it. After implementation, we anticipate the desired state as a result/outcome. This one-way thinking does not include any other systems and is based on the presumption that the environment or the present situation is not altered during the entire process. Sterman (1994) gave a brief- example, considering price decrease as a decision to increase sales volume. As a result, the quantity of given products would reach the required level and the issue appears to be resolved. After the sales volume have been increased, competitors begin to cut rates too and the sales volume decreases once again. This feedback is not discussed by the event-oriented view. Not considering such side effects or the actions of others could result in big problems. System thinkers understand these realities, because they tend to think in a feedback way. Figure 3.3 shows the basic structure of this approach.

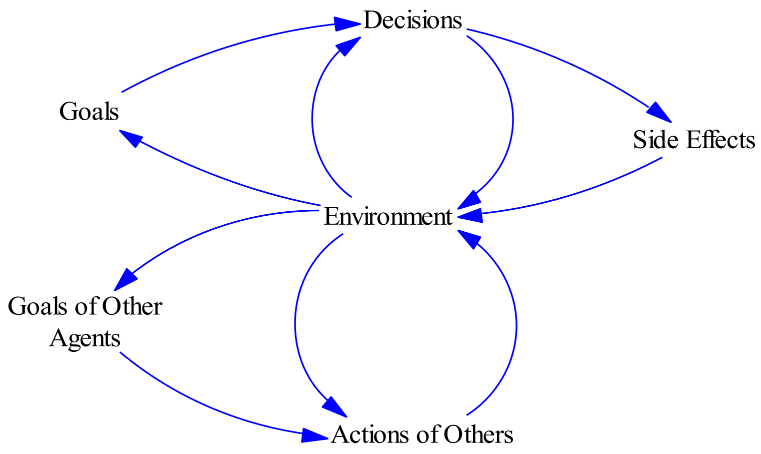


FIGURE 3. 3. FEEDBACK VIEW
(Sterman, 2000)

When a goal is set and a decision is made the result will change the existing situation discussed as environment and this decisions might cause new choices or perhaps different goals. To be familiar with unforeseen reactions of the environment, the effects of the behaviour should be extensively discussed as well. The term effect is not always correct, since an effect on surrounding systems can change their state of the situation in a large way. A feedback to the observed system could be delayed and would change the situation in the future.

As pointed out in the brief example above, other representatives are acting in this environment too and they also set actions to reach their objectives. Another example of the feedback thinking process is the fundamental learning process. Sterman (1994) asserted, that all learning depends on feedback and each decision we make changes the real world. In consequence of information we gather from the present state, we modify our understanding and we bring the system better to the desired level by implementing new decisions.

Causal loop diagrams

As pointed out in earlier section, the qualitative models in the field of system dynamics provides a much better understanding of intricate and dynamic systems. While system dynamics has its first roots in control engineering, its ability to model feedback loops differently makes it unique. System dynamics utilizes causal loop diagrams (CLD), this ability makes it simple to determine and comprehend the causal-effect relationships that affects the behaviour of a system, extending the understanding of the system not only from the engineering but to management levels. The complexity of systems does not develop from single variables, however rather it is connected by the relationships between variables. These connections and the dynamics within the system are based on two kinds of feedback (Sterman, 2000).

Basic loops are either positive (re-enforcing) or negative (self-correcting) and develops the basis of all causal loop diagrams (CLD). These diagrams are regularly used in SD research, however they are likewise typical for various applications, because they are easy to provide lots of information and built within a short time.

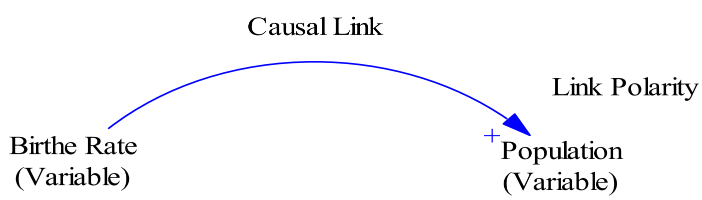


FIGURE 3. 4.CAUSAL LOOP DIAGRAM NOTATION
(Sterman 2000)

Figure 3.4 highlights the basic notation of causal loop diagrams. As a fundamental rule, each variable represents a noun and the linkage between verbs. The arrows provide the effect of the information and are signed with a minus or a plus to signal the polarity. A plus represents a positive (+) feedback that means if variable A is increasing, variable B is increasing too. The minus polarity is called a negative (-) feedback and symbolizes, that variable B decreases, when variable A increases. For this reason, the figured example highlights: If the birth rate is positive the population is going to increase.

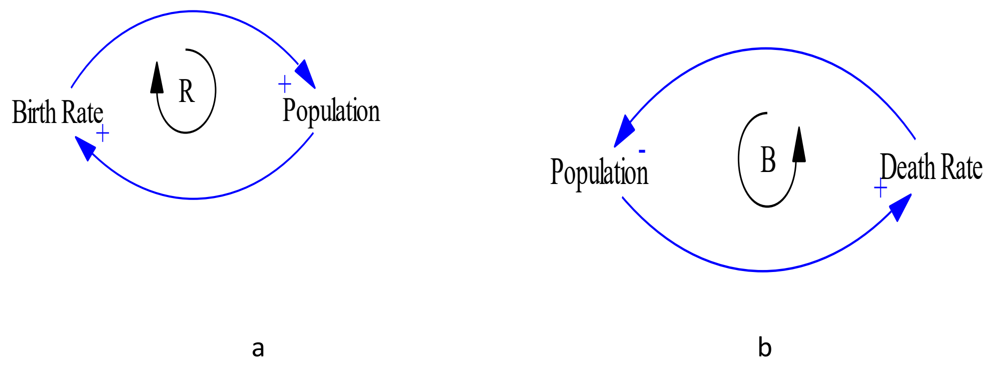


FIGURE 3. 5.FUNDAMENTAL STRUCTURE AND BEHAVIOUR OF FEEDBACK LOOPS (Sterman, 2000)

Figure 3.5 shows an easy example of a causal loop diagram. The primary feedback loops are marked with an identifier and provide an information about the behaviour. A positive feedback loop is self-reinforcing and marked with an R, sometimes a plus (+) or an avalanche sign is used as well. These loops continuously grow, however in reality nothing can grow forever. The regulation is caused by negative feedback loops that are self-correcting. These loops are related to a B, minus (-) or scale symbol.

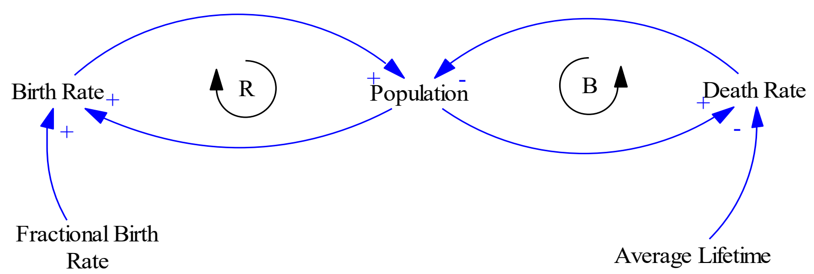


FIGURE 3. 6.EXAMPLE OF A CAUSAL LOOP DIAGRAM (Sterman, 2000)

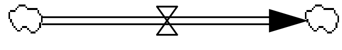
All systems consist of just these feedback loops, no matter how complex they are. As Figure 3.6 in the example above shows, a positive loop will constantly increase the population. Assuming a provided amount of human beings, the birth rate (individuals per year) will increase, if the birth rate fraction increases. The population will be affected by a second feedback since individuals are going to die after a specific period of time.

Causal loop diagrams are not assuming stocks and flows, although they act similar sometimes. To describe the difference a brief example is given. The population is discussed as a stock, representing the amount of people in the world, and it is increased by births and reduced by deaths. As a result of a large population, the birth rate is high and if it increases, the birth rate will do so too. Births will constantly elevate population, while deaths will always decrease it. If fewer people die, more of them will survive.

As mentioned above, these qualitative models must provide a very good understanding of interactions and are extensively utilized to represent feedback processes and interdependencies. Causal loop diagrams (CLD) are commonly utilized in the early stage of system dynamic projects to map mental models. They do not provide any information about the stock and flow structure of the system and therefore they are not direct basis for simulation.

Stock and flow diagrams

Stock and flow diagrams (SFD), compared to the CLD, illustrate a more comprehensive structure of the real system. The feedback processes form the main principle of the system dynamics theory (Spiegler, 2014). Stocks are accumulations and represent the current state of the system at any time. They are increased by inflows and drained by outflows. Flows represent rates, which are adjustable by valves. The basic diagramming notation is shown in Figure 3.7.



Flow

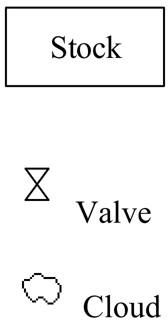


FIGURE 3. 7.STOCK AND FLOW DIAGRAM NOTATION
(Sterman 2000)

Stocks are characterized by boxes and flows by arrows. Depending on the direction, a flow can be an outflow - pointing far from the stock (or an inflow) pointing in the stock. Connected valves change the amount of time-dependent in or outflows. Clouds shows stocks that are outside the system boundary they are also called sources or sinks.

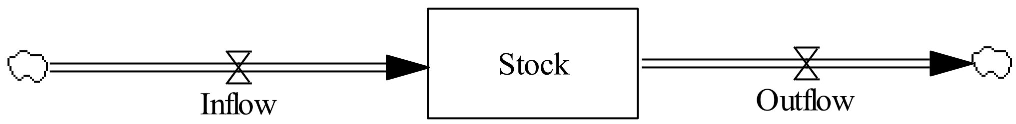


FIGURE 3. 8.FUNDAMENTAL STRUCTURE OF STOCK AND FLOW DIAGRAMS
(Sterman, 2000)

Figure 3.8 shows a simple structure of a stock and flow system dynamics model. Stocks represent the state of the system throughout simulation runs. After simulations, graphs are developed and provided to understand the system behaviour. Many stocks that are representing real systems are known as tanks. Like a bathtub, they can be filled and drained by the valves, but if there is no water within, absolutely nothing can drain out of it.

3.4 Basic behaviour modes

According to the previously mentioned characteristics, all dynamics of systems emerge from the feedback loops, flows and stocks, and non-linearity due to decision making processes of acting agents within (Coyle, 1977). He listed some basic modes of dynamic behaviour. The most essential modes of system behaviour are explained in this section. Determining such basic archetypes works in early stages of the modelling process, especially when producing qualitative models (Cavana and Maani, 2000). Senge (2006) extended these essential modes and published system archetypes which are very powerful in suggesting existing systems. These archetypes could be utilized as a diagnostic tool to establish a better understanding of business structures (Kim and Burchill, 1992).

Exponential growth

Exponential growth is a result of positive (self-reinforcing) feedback. That is, the more the quantity, the more the net increase, thereby enlarging the quantity even more leading to continuous growth in the system Figure 3.9 presents the behaviour of exponential growth (Wolf, 2008). An example of cases are the growth of populations and compound interest. For example, the more cash invested, the more interest received, so the more your balance and more still the next interest payment will be received. When there is more population there would be more birth rate which adds to the number of populations which however leads to more births rate in an ever-accelerating trend. A pure exponential growth has the significant feature that the *doubling time* is continuous: the state of the system multiplies in a fixed period, no matter how large.

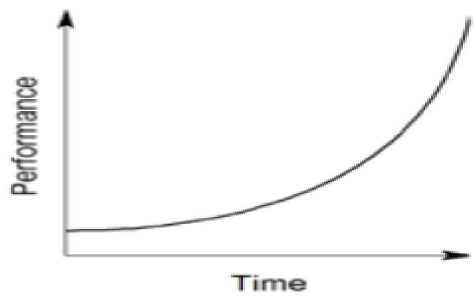


FIGURE 3. 9.EXPONENTIAL GROWTH

Goal-seeking

In the goal seeking mode, the system attempts to reach a required value. A desired state of the system is set and compared to the present state (Wolf, 2008). Figure 3.10 presents the behaviour of a goal seeking behaviour. Assuming the preferred state is higher than present state. The negative polarity within the feedback loop produces a self-correcting behaviour to bring the system to equilibrium. At the beginning, the discrepancy between the desired and actual state of the system is big and the corrective action is great. This leads to a difficult situation in the system to correct. As a result of the rapidly increasing state of the system the inconsistency becomes smaller and hence the corrective action too.

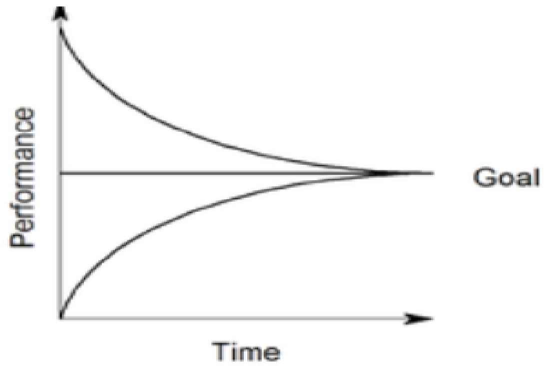


FIGURE 3. 10.GOAL SEEKING

Oscillation

The third essential mode emerges from the time delays between variables. The actual is compared to the desired state of the system and a discrepancy leads to corrective actions. Because of understanding, measurement, and reporting the discrepancy is calculated with obsolete information (Sterman, 2000; Wolf, 2008). The corrective action is based on decisions, made by factors within the system. Moreover, each administrative process takes a specific time, the decision for a corrective action, in addition to the realization, and the impact on the system are delayed and information feedback delay. Figure 3.11 presents the behaviour of an oscillatory behaviour.

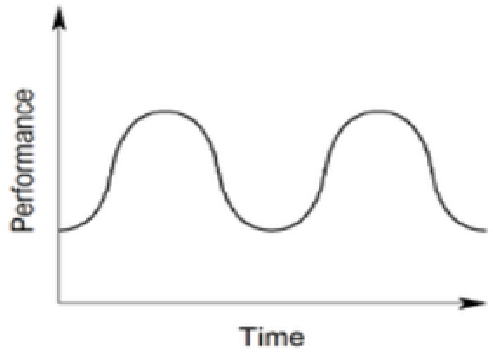


FIGURE 3. 11.OSCILLATION

In the beginning the inconsistency is substantial and strong corrective actions are set, like the goal seeking scenario. As a result of the delayed perception of the present state, the corrective action tends to be high and the preferred state of the system will be exceeded. Corrective actions change and the current state requires to be narrowed to reach the goal. Due to the delays the required level will be undershot, and the adjustments need to be changed once again. Depending on the delays, this action can stabilize over a period, oscillate in a constant frequency or blow up, which is known as the chaos-scenario. Delays prevail in real systems and for that reason oscillations are amongst most common modes of behaviour.

S-shaped growth

The previous three modes are called the vital modes and based on a single feedback loop with or without delays. The next behaviour modes which is the S-shaped are more complex in the real world. This system contains a positive loop and a negative loop that support it. The positive loop is an increase as previously mentioned. A maximum capacity is included and if the existing state of the system approaches the limitation, the fractional net increase rate is shrinking. Thus, the net increase rate will stop, if the capacity is reached. Figure 3.12 presents the behaviour of S-shaped growth behaviour.

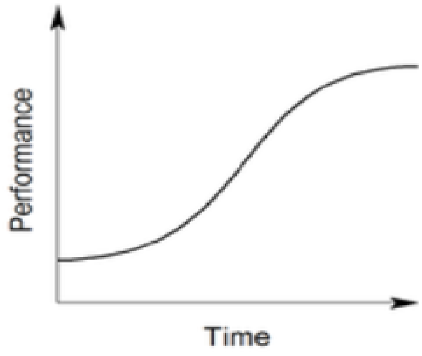


FIGURE 3. 12.S-SHAPED GROWTH

S-shaped growth with overshoot

This behaviour mode is like the S-shaped growth. As discussed above, delays occur as a result of late recognition of an occurrence in the system due to the fact that the balancing loop is not active at the beginning (Coyle 1997). After the overshoot due to the information feedback, the system will oscillate around the capacity and depending on the delays, it could support, oscillate in a constant frequency. Figure 3.13 presents the behaviour of S-shaped growth with overshoot.

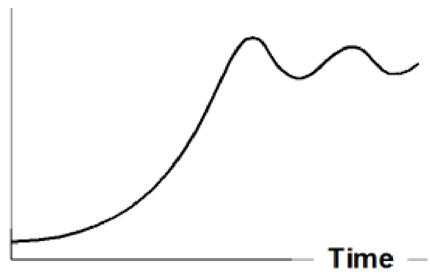


FIGURE 3. 13.S-SHAPED GROWTH WITH OVERSHOOT

Overshoot and collapse

A basic assumption in the S-shaped growth behaviour mode is, that the carrying capacity is constant and does not change gradually (Coyle 1997). A second balancing loop is included, that deteriorates the capacity. In the starting the behaviour is comparable to the S-shape growth, since both stabilizing loops are not active, and an exponential growth is possible. Instead of just one guideline, that would guide the model in equilibrium, the second loop begins to reduce the capacity. After a period, the current state of the system is equal to the capacity. When the system reaches the maximum, the erosion is at its maximum and the capacity shrinks quickly. Because of the undesirable resource adequacy the state of the system continues declining as a result of information feedback delay. Figure 3.14 presents the behaviour of overshoot and collapse.

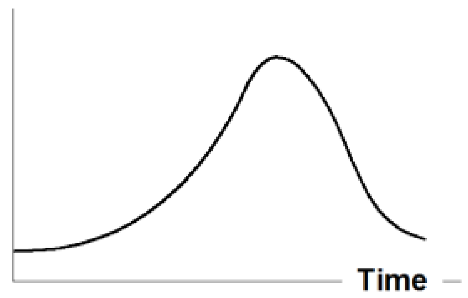


FIGURE 3. 14.OVERSHOOT AND COLLAPSE

3.4.1 Model evaluation

All models are an abstraction of the real life and due to the various perceptions and understanding of relationships, the behaviour of a model might vary from the real situation (Wolf, 2008; Towil et al, 1992, Vennix, 1996). Forrester pointed out, that the reliability of a model should be evaluated by its suitability for a particular purpose it is built for. Models can be very useful for a particular purpose, however, may not be adequate for another purpose or insignificant for another (Forrester, 1961). Forrester pointed out, that model suitability must be analysed relative to: (1) system boundaries: Are the important variables and their connections effectively discussed within the model? (2) Interacting variables: Are all important variables and their connections effectively discussed within the model? (3) Values of parameters: Constant coefficients provide the state of the current circumstance and require to be declared within a possible range. Sensitive parameters must be recognized by model testing and values based upon decision functions could be based upon an analytical research.

The study provides three main steps in the modelling process. According to Forrester and Senge (1980) they stated the fundamental notation as follows: Testing phase: this imply the comparing a model to empirical reality for the purpose of refuting or supporting the model. Validation phase: a method of building confidence in the strength, weakness and usefulness of a model and Structure verification phase: structure verification phase means directly comparing the model structure with the real system structure that the model represents. Sargent, (2005) pointed out, that it is extremely costly and time consuming to completely validate a model. Sargent likewise highlighted, that validation and verification is not a single action in a model development process, however rather it is a concept that is generally part of the whole process. At the beginning in the real world, all readily available data needs to be structured and unnecessary information needs to be figured out.

In the early phase a conceptual model is built and due to different understandings of the problem, some elements in the model could be presumed incorrect. Further confirmations are required, until the simulation provides useful results. Finally, validation needs to be done by comparing the simulation results with the current real system. Basically, all validation strategies can be divided into subjective or objective approaches (Sargent, 2005). There are lots of techniques readily available, depending on the information and time in many cases a combination of different approaches is used.

3.5 System dynamics model and simulation

System dynamics (SD) is a methodology as constant simulation process. It is a useful tool for understanding the dynamics of highly complex world where there are presence of feedback loops and delays. The basic idea is to understand and point out the nonlinear feedback present in the system (Forrester, 1958). For example, industrial activities and economics are normally represented by information feedback and closed loop therefore the models should retain the closed loop structure. Additionally, system dynamics uses the idea of feedback for social systems for building robust policies. System dynamics modelling can also be described as a system thinking method that integrates different perspective while modelling a system or problem. Forester suggested that system dynamics can be an approach to solve essential problems on for companies (Sterman, 2000; Lyneis, 1980; Forrester, 1958; 1961).

Wolf (2008) stipulated that system dynamics applies the use of structures of causal feedback loop and drawing tools connecting all components to describe the relationships and link that affect the dynamic system performance. The main tools for drawing or building the diagram in a system dynamics model are the stocks also known as levels this diagram symbolise variables in the model, the flows on the other hand also known as rates denote the components action in the model in other word, these are the policies of the management by which the stocks are being affected (Botha, 2017). All stocks and flows have a mathematical representation as they are linked together while being designed by the modeller. Computer simulation is then utilized to implement or input these equations into the model to allow continuous simulation experiments for policies analysis.

Feedback loops can be described as either positive or negative based on the model parameters and components and its impact on one another. A negative feedback loop known as self-correcting can be described as a causal relationship that can change, adjust or alter the behaviour of a system. On the other hand, a positive feedback loop known as self-reinforcing amplifies the behaviour to produce greater discrepancies in the system behaviour. Figure 3.15 presents an example of positive feedback loop and negative feedback loop.

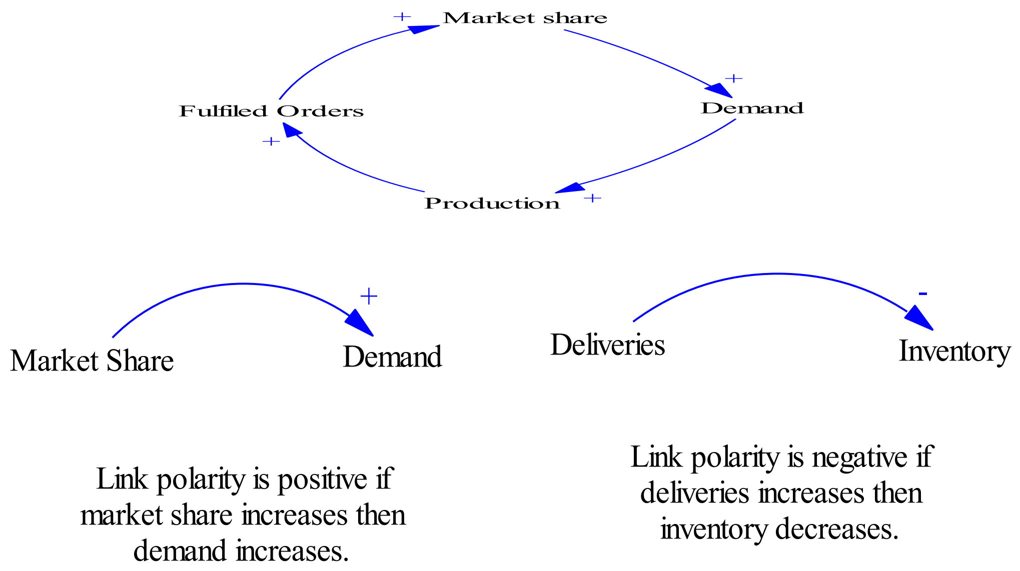


FIGURE 3. 15.POSITIVE AND NEGATIVE FEEDBACK LOOP IN SYSTEM DYNAMICS (Helal, 2008)

Flows and stocks are symbolised by rectangular shapes and taps respectively as earlier discussed in chapter two. In Figure 3.16, Inventory and products are two stocks. Stocks can have several flows connected to it or out of it to reduce or increase its value in the system. The arrows in the model signify causal relationships in the system. For example, an order rate is the movement or a flow which is affected by the adjustment time, desired order rate, Inventory, and desired inventory. The parameters or constants present in the system besides the stock and flow are known as the auxiliary variables and the equations present in the flows are usually long and complex to understand. In order to simplify the equations of the flows, they are usually disaggregated or broken into several parts for better understanding. The negative indication under products on order suggests indicates a balancing/negative feedback loop signifying that the model begins with order rate, then flows through product on order, delivery rate, and inventory, sales rate and finally finishes at order rate.

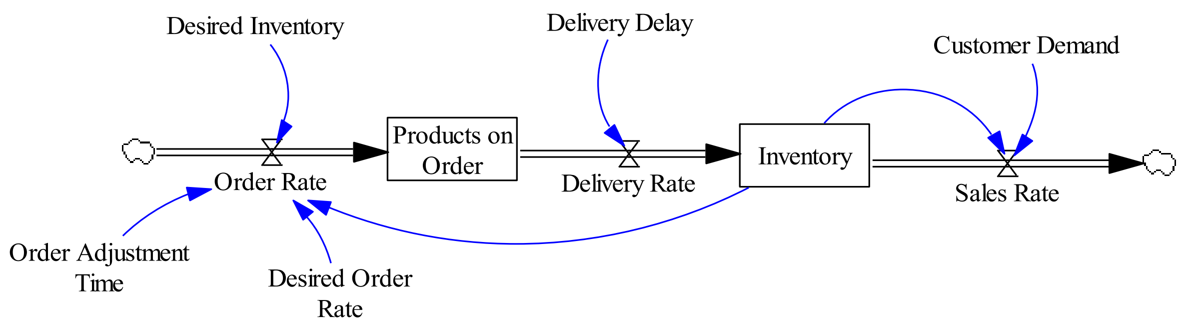


FIGURE 3. 16.BASIC STOCK AND FLOW SYMBOLS IN SYSTEM DYNAMIC MODELS

The system dynamics model in its last stage are the set of stocks connected with the set of flow rates, in a rotational way presented in Figure 3.17. The Figure suggests that stocks are represented as rectangles (the red box) and flows are represented as taps (the blue structure) the arrows represent the connections between them (the purple line). And the green dotted arrows represent sharing of information.

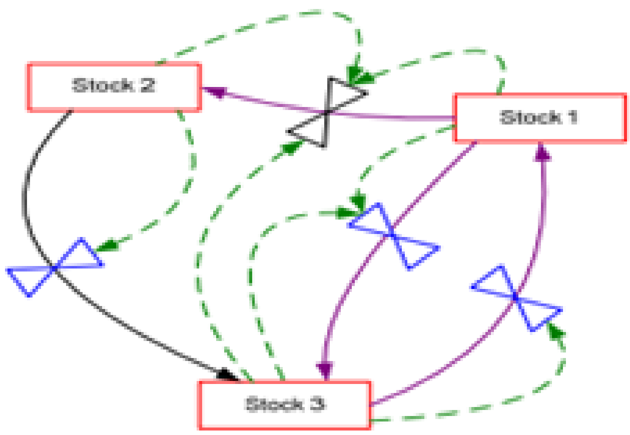


FIGURE 3. 17.A GENERIC STRUCTURE USED IN SYSTEM DYNAMICS MODEL (Forrester, 1965)

The presented structure (Figure 3.17) is a generic structure used in system dynamics model by Forrester, 1965 clearly explains that the stocks can only be affect by the flows while on the other hand the flows are only reliant on the stock that depends on the state of the model or system. For example, in a production or inventory model, the stock can be represented as the level of inventories while the flows in the system dynamic model are the policies/decision rules of the management of managing inventory. Only by the policies in the system can the stock level be adjusted. Thus, the management is required to monitor the level of the stock in the system to implement the best and suitable policies. To put in a simple term, the managers should carefully monitor the feedback loops present in the system since stocks is determined by flows and flows influence stocks. To build a system dynamic model the modeller begins with identifying the important parameters from the purpose of the model before identifying the causal relationships between the components in a feedback structure. The important parameters are then defined from the stock and flows before mapping out the mathematical equation.

Forrester (1965, 1975) described that once the mathematical equation has been mapped out the model should have the ability to show the causal relationship present in the model in the simplest form of mathematics. Also, the mathematical equations in the model should have the ability to generate alternate modifications in decisions when required. Before experimenting a system dynamics model, Sterman suggested that the stock and model should be initialized this means that the initial state of the system need to be well understood. With the state of the system being understood, decision makers in the system identifies its policy to test and what to improve in the system through continuous testing and experimentation by adjusting the parameters. Flow rates (management actions) attempts to adjust the values of the stocks whether to increase or decrease the stock level.

The constant improvement of the system (time step) is suggested by Forrester to be minimized in a small time periods of magnitude Δt. Figure 3.18 presents the calculations series in system dynamics (Forrester, 1965). The Figure suggest that if existing time is t^2 then the state (stocks) need to be understood at t^1. Meaning that the system progresses from t^1 to t^2 to reach the new state of the system at t^2. The state at t^2 is the effect of the state at t^1 added with the effect of the flow rates during Δt from t^1 to t^2. At t^2, the stocks in the system are calculated using the flow rates for *Δt* from t^2 to t^3 and when they are calculated then the state of the system at t^3 can be known or identified. Therefore, this computations order lowers the reliance at the initial state. However, just the state before *Δt* is used.

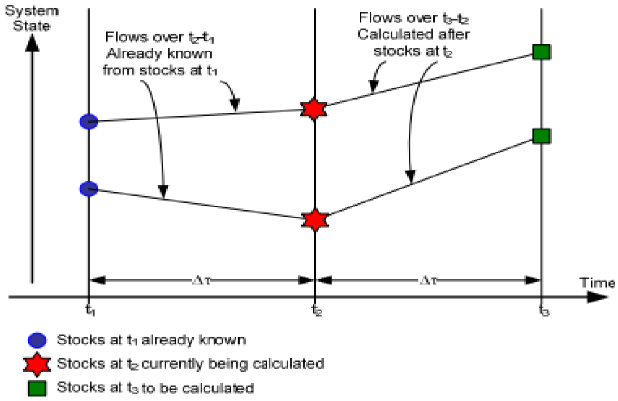


FIGURE 3. 18.COMPUTING SERIES OF SYSTEM DYNAMICS
(Forrester, 1965)

3.5.1 General mathematical equations for system dynamics model

As Figure 3.20 and Figure 3.21 below suggest by using stock to characterize the state of the system and supposing there are two flow rates in the system i.e. the flow into the system that increases the stock and the flow outward that reduces the value of the stock in the system, the value of the stock at time *ti* is presented in equation *1*:

$$Stock_{t_i} = Stock_{t_i - 1} + \Delta t(Inflow - Outflow)_{(t_i - t_{i-1})} \quad (1)$$

Furthermore, in a mathematical calculation, equation *1* generally attempts to derive the number of the stock in time *t* started beginning at time *0* during the simulation time. The equations become the integration of time of clear change in the flow rates, as presented in equation *2* where the previous value of stock is *0*. This equation provided symbolizes the mathematical notation in the model structure presented in Figure 3.19 without the absence of the delay time variable).

$$Stock_t = Stock_0 + \int_0^t (Inflow - OutFlow)dt \qquad (2)$$

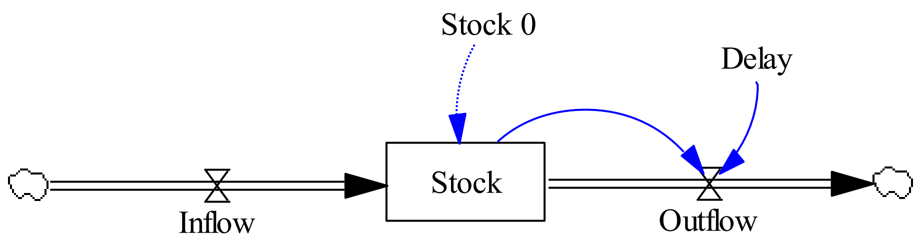


FIGURE 3. 19.STOCK AND FLOW REPRESENTED IN SD MODELS
(Helal, 2008)

Conversely, flows use a different mathematical representation and are still functions in the stocks. That is, flow rates are usually calculated for each time interval *Δt* meaning the flow rate value is the slope of the curve that denotes the behaviour of the stock over *Δt (*Forrester, 1965*)*. Flows are functions in the stock values in the system at the start of the simulation or period. Additionally, when a unit of measurement is added in the stock for example (units of people, water, variables, money etc.) the flow rate can then be determined in respects to units per unit time. Therefore, from Figure 3.19, the outflow is represented in equation *3*.

$$Outflow_{(t_i - t_{i-1})} = \frac{Stock_{t_{i-1}}}{Delay} \qquad (3)$$

The parameter delay in equation *2* can be described as the average time required for the stock to move from one point to the next point at the outflow rate. The movement out from the stock (outflow rate) is described as the rate accumulation of stock departs, therefore the outflow rate is level of accumulation divided by the time required for the accumulation of stock to depart. The equations for flows in a system dynamics model are normally disaggregated into smaller components if there are too complex. The auxiliary variables are algebraically summed together to give meaning to the flow maintaining still acknowledging that flows are functions in the stocks utilizing auxiliaries. Auxiliary variables simplify system dynamics model development and enables the modellers to understand the in-depth problems in the system structure. Equation 4 present a general description for auxiliaries for flows, where *g* and *f* are random functions.

$$Flows = f(Stocks, Auxiliaries)$$
$$Auxiliaries = g(Stocks, Auxiliaries) \quad (4)$$

Delays are an important factor in system dynamics models. Wang et al (2012) stipulated that the failure or inability for managers to fully understand the effect of delays in a feedback system causes significant problems. For instance, it is impossible to consume stock immediately or filled instantly because it requires time to build up stock and consume. This delay between the manager's actions to identify any discrepancy in their stock level and their effects is the cause of dynamics in the system should be identified in the model that holds true in system dynamics. Equation three represent a first order delay that leads to a simple exponential behaviour of stock over time, second order delay can be described, if the flow is cascaded into two stocks. A system dynamics model structure with a third order delays is presented in Figure 3.20. Commonly used for modelling manufacturing process scenario.

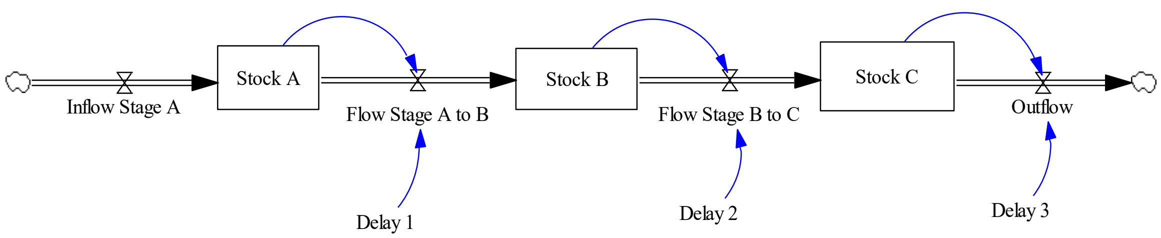


FIGURE 3. 20.GENERIC STRUCTURE OF THIRD ORDER DELAY IN SD

The behaviours of first, second, and third order delays are presented in Figure 3.21 presuming an increase in the step input to the system. The three graphs present the behaviour of the delays.

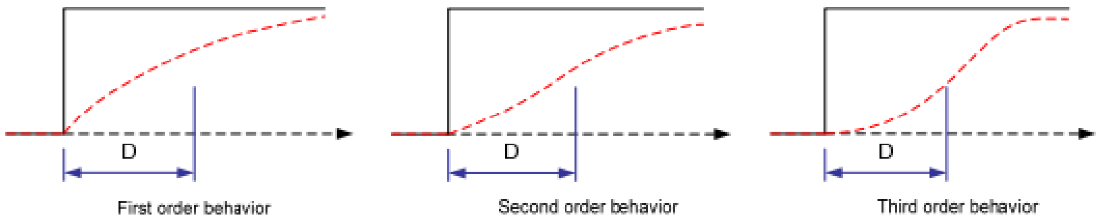


FIGURE 3. 21.BEHAVIOURS OF SYSTEM DYNAMICS STOCKS AS A RESULT OF DIFFERENT DELAYS (Sterman, 2008)

The above description of the system dynamics model shows a relatively basic technique that SD is advantageous to managers in modelling larger systems. Model needs to represent the continually interacting forces in the system that requires continuous adjustment to achieve and implement best policies (Forrester, 2003; Forrester and Senge, 1980). Example of a manufacturing and inventory system that system dynamics can support are: System dynamics concentrates on the policy decisions in feedback loops, system dynamics concentrates on system structures with less data required, system dynamics can evaluate and analyse strategic issues over long period of time horizons with less difficulties with the statistical presumptions, system dynamics can analyse and evaluate stability of a system for long period of time horizon and it requires less information, system dynamics can be easily generalized and generic principles currently exist for different type of system, a system dynamic model is an instinctive representation of an observed cause and effect relationship among the real system components that top management can understand easily and the complexity of system dynamic model increases linearly (Sterman, 2000) for a more complex system can be added with basic models.

3.6 Alternative modelling techniques

In general all model is used to map real problems in an abstracted world. This process is called abstraction. Afterward the analytical model is optimized, evaluated, and the solution is moved back to the real life, which is called implementation (Borshchev and Filippov, 2004; Helal, 2008). Models are carried out in order to solve problems (Bradl, 2003). Analytical models are commonly dependent on functions and analytically fixed with simple solutions e.g. spreadsheets. Sometimes an analytical solution is not possible, and problems need to be resolved by simulations. The term simulation is utilized to explain the model's implementation. Borshchev and Filippov (2004) highlighted the common problems that are subject of typical simulation modelling strategies. In addition to the system dynamics method two other simulation modelling techniques are also very popular namely, Discrete Event (DE or DES) and Agent Based (AB). Also, Dynamic Systems (DS), which are known for modelling physical systems. However, DS was not extensively discussed since this approach is not related to managerial issues.

Depending on the abstraction, the discreet event simulation (DES) method is utilized in the functional and operational level. In the field of management, DES is effectively used in a macro or micro level, which can also be known as operational level. Like the agent based (AB) technique, DES calculates with discrete time, which means that after an event is processed the computation advances to the next event. While SD and DES are more of a standard techniques Kortelainen and Lattila, 2009, the field of AB modelling is comparatively new, because the computational power was low until recently.

AB modelling is hard to categorize within the abstraction scale since this classification depends on the kind of modelled representation. A categorical meaning of entities, that are required to produce an agent, does not exist (Schieritz and Milling, 2003). In the same study of Schieritz and Milling, (2003) they compared the SD approach to the AB technique (in their certainly called research): "designing the Forrest or modelling the trees" Each technique has weak points and strengths. Gary et al. (2008) stipulated in their study about the existing state of SD applications in an extensive range of field of management. They argued that the thinking of strategic field is about understanding the dynamics that lead to big differences in company's performance and the linkage to supervisory decision making. Thus, they forecasted huge opportunities for system dynamic researchers in the future. Therefore, this thesis is carried out on the idea of using SD to model the supply chain of the downstream automobile industry for simulation and analysis.

3.6.1 System dynamics software

The first introduced software solution was based on the 1958 established SIMPLE compiler and named DYNAMO (Forrester, 1995). Although DYNAMO was established and used for simulation, it was also an impulse for the development of discrete event simulations (Nance, 1993). EAGER BEAVER was a state of art software for about 30 years, however because of the technological development and especially the creation of Windows, new software was established (Clark Jr. and Kurono, 1995). STELLA was introduced in the year 1985 and it provided a visual demonstration of model behavioural output STELLA is still used by modellers as of present.

There are numerous system dynamics software packages providing comparable and similar usage, however, differ in the handling techniques, some examples of such system dynamics software packages are STELLA, ModelMaker, Powersim Studio, and Vensim.

3.7 Other research methods

The researcher have previously explained in earlier sections that system dynamics methodology best fits post positivism (critical realism) school of thought therefore, this research will follow an objective, holistic and value-free view. To answer the research questions, the researcher believes that an empirical research through conducting case studies in combination with system dynamics modelling in an abductive approach would be an alternative research method to contribute to the supply chain theory in evaluating the performance of the system dynamic models. However, the methodological research objectives imply the use of system dynamics modelling in a conceptual stage before testing the models with case studies. Hence, the choice of methodology by the researcher appeared the most appropriate one for answering both the theoretical and methodological questions.

3.7.1 Case study research approach

The method for data collection for this research is case study based. Fellows (1997) and Yin (1984) stipulated that a case study approach can give analytical generalization rather than only statistical generalizations which can allow more informed basis for developing theory. Moreover, according to Khothari (1997, p140-141), suggested that a case study method can be classified as a form of qualitative analysis by means of carefully and completely observing an institution, a situation, and an individual. The study also suggested that efforts are made by the researcher to study and understand through observations, inferences and case data generalizations are drawn. A case study approach is usually employed to study rather than breadth and more emphasis is normally placed on analysing large number of events and their relationships (Saunders et al., 2009). Therefore, a case study approach is basically a rigorous study of a certain unit under investigation. One of the objectives of a case study approach is to identify elements or factors that causes the patterns of the behaviour of a unit as a combined totality. Eisenhardt (1989, p537) supports the use of cases that are unique in nature for study.

For this study, the cases have been chosen actual supply chain problem and the manager(s) availability and their willingness to share their experience and information with the researcher. Yin (1984) argued that there is no best accepted number of cases that can be undertaken in a research study. Romano (1989) also gave a similar suggestion arguing that the number of case study used for a research should be decided by the researcher. However, Eisenhardt (1989) recommend that case study should be employed up to theoretical saturation or at a level of redundancy which therefore, neglects time and money constraints (Perry and Coote, 1994). Even with the realistic case study selection, there is limitations in gathering the level of necessary information needed in the study. Therefore, limitations in a case study research should be considered in all research. The benefit of the case studies for this research have been limited to the downstream automobile companies in Nigeria which will be discussed in section 3.7.2 to 3.7.5 and availability of the senior members of the case study companies. Two case studies were chosen to investigate and understand the characteristics of the downstream automotive supply chain companies in Nigeria and the cost involved, and to validate the finding of the system dynamics inventory models.

3.7.2 Research location

An important aspect for the successful completion of an empirical research of collecting primary data is mainly based on access to the case studied company (Saunders et al., 2009). Thus, the researcher has chosen to conduct the study with two downstream automotive companies based in Nigeria, of which he has some established contacts. During the study, the researcher expected that these contacts will ease the researcher access to the companies. However, the access to the case companies was not granted quickly as was expected by the researcher.

3.7.3 Interview

It was important in this study to use interviews as one of the data collection methods as it offers the researcher the manager's mental data and opinions. The managers' mental data includes all the information they have, their understanding of the system, who and how the company decisions are made, the stories and descriptions they tell, and their impressions. Bryman and

Bell, 2007, Bryman 2012, Yin, 2009, and Saunders et al. 2009 have suggested in their studies that the process of collecting mental data cannot be directly collected but through interview. Saunders et al. (2009) characterised interviews into structured, semi-structured and unstructured interviews. Structured interviews can be described as a predetermined and the same set of questions is directed to all participants in a predefined way (Saunders et al., 2009). However, the interviewees that partook in this study have different job roles in the company and functions therefore, all information needed to achieve the research objectives cannot be collected from a single participant. On the other hand, unstructured interview which is also termed as informal interview is not conducted based on a predetermined lists of questions and the interviewing process like the structured interview but is normally guided by the interviewee (Khothari 1997, p140-141). The purpose of this research is to study an occurrence (instabilities and fluctuations) in a perspective framed by the research objectives. Thus, the intentions of the researcher is for various interviewees to give answers to the questions to offer understanding on ‘why’ certain phenomenon or social event occur and ‘how’ social actors interacts with events to bring about social reality: instability and fluctuations.

For conducting a semi-structured interview, the researcher did require to have a list of questions (known as an interview guide) for the interviewees to answer during the process (Bryman and Bell, 2007). Ellram, (1996) argued that an important benefit of applying semi structured interview lies in its flexibility because the researcher can decide to purposefully omit or add questions to a particular interview depending on the interviewed individual or specific organizational opinion that the researcher came across related to the issue being studied. Walker (1994), Yin (1984), and Sidwell (1982) argued that the type of interview to be employed should be consistent with the nature of the research questions, objectives and the overall purpose of the research. Therefore, as this study seeks to study the supply chain processes of downstream automotive companies in Nigeria, semi structured interview was employed as it allows the researcher flexibility to omit questions and/or add questions depending on the participant as they all have different roles in the organization. Moreover, the semi structured interviews gave the researcher an opportunity to conduct more qualitative observations that would have an effect of the later research deployment. The collected interview data were insightful and important to confirm and validate the results of this research. The background information of the two case studies and the results will be discussed further in the relevant Chapter.

3.7.4 Interview protocol

The preparation of the interview protocol started with formulating the main research objectives and research questions, sub-questions were then designed to enhance the understanding of the main research questions. The researcher ensured that the questions were not too specific so that he can uncover other areas of inquiry that may arise during the process (Bryman and Bell, 2007). Collis and Hussey, (2009) argued that this is an important concern in order to garner understanding and also to provide flexibility of the hypothesis used as root for opinions and responses. The lengths of the questions were short and understandable, starting with mostly 'how', 'what' and 'why'. A total of nine interviews were conducted and the rationale for the interviewee selection is described in the following order presented in Table 3.1.

Interviewees (9)	Rationale for Selection
Supply Chain Manager (2)	To give a detailed account of the company's supply chain and the people involved in the company's operation.
	To provide information regarding the company's experience with instability and fluctuations in their supply chain and the effect on their financial performance.
Sales Representatives (5)	To provide insight into what happens at the downstream supply chain, demand and supply dynamics, and to triangulate data from other sources.
First Line Sales Supervisor (2)	They are involved in monitoring of sales and distribution of products.

TABLE 3. 1. RATIONALE FOR INTERVIEWEE SELECTION

3.7.5 Interview conduct

After the case study companies granted access to conduct the research, the researcher first contacted the participants through emails that explained and described the purpose of the study as well as each participant role during the interview process. In responding to the researcher emails, some participants asked the researcher to provide an interview guide then which the researcher ensured that the interview guide was available to all the participants. However, the researcher made some changes. The interviews were carried out on a one-on-one basis by the researcher. The researcher desired to carry out a face to face interview with all participants in the premise of the companies however, this was not possible as a result of time constraint and other factors. For example, some participants were unavailable at the research location as at the time of data collection and/or some of the participants were too busy for the interview during working hours. Hence, telephone interview was chosen by the researcher to reach some distant participants. Moreover, some interviewees like the company's sales representative do not have a personal office in the company. Thus, carrying out some of the interviews with the participants at an agreed location.

While preparing for the interview see Appendix B and C, the researcher ensured that he acquainted himself with the topic of the research and the situational context by thoroughly studying the drafted literature and interview guide. The researcher ensured that the information of the case study companies and related publication to the research issues were thoroughly studied. Saunders et al., (2009) and Luis et al., (2003) suggested that this process is important in order to validate the response given by the participants. The researcher also ensured to adopt the acceptable dress code of the companies to gain their trust and confidence. Before commencing with interview, the purpose of the research was explained once more, and the researcher suggested to the interviewees to freely express their view. The interviewees introduced themselves and their role in the companies during the introductory stage. This process took few minutes and was important to make the interviewer and interviewee feel at ease.

The researcher used probing questions during the interviews in order to collect more information and summary questions to avoid uncertainty from the interviewees (Collis and Hussey, 2009). Example of some questions used by the researcher began with 'from your experience' in order to encourage interviewee to provide their personal experience and/or account that are critical in answering some questions needed for the study or evaluating statements from other sources. Saunders et al., (2009) stipulated that this method known as "critical incident technique" is normally used to explore occurrence were the participant has a clear and definite idea regarding the effects and the consequences. The interview gave the researcher an elaborate and broad understanding of the role of how customer demand, inventory and sales in the downstream automobile companies in Nigeria is managed, and to have a full picture of the stock and flow diagrams with their causal links to formulate the relationship between the most important factors with the most effect and their relationship for the decision makers. In addition, the interviews were used to define the variables that influence the occurrence of instability and fluctuations in the company's supply chain. Coyle (1977) proposed such method for formulating a causal relationship.

3.7.6 Other source for data collections

Furthermore, to the above discussed approach, observing the companies directly, documents available on the website of the companies and the two company's records provided by the managers were used for data development. Sterman (2000) stipulated that a modeller should use his/her own observation and experience in order to propose the connections when some of the important feedback links are missing. Different sources, such as sales lists, cost of unit and cost of carrying their inventory, number of inventories, time parameters of order and time of receiving orders will also be used to identify the cause of the instability and their implications on the case study company's financial performance. Todd, (1979) stated that an approach of data collection such as this is usually known as "triangulation".

3.7.7 Reliability and validity

Reliability can be described as the level of consistency of the research findings from the collected data and the analysis processes (Saunders et al., 2009). Bryman and Bell, (2007) in their study described reliability as level of the research result repeatability. Case study protocol containing the interview guide was used to address the threats to reliability (Yin, 2009). Validity means whether a research finding really represents the reality or whether it does not. Three tests of validity were identified by Yin (2009) namely, (construct validity, internal validity and external validity) which are normally used to determine the quality of social research. Inconsistencies in construct validity were reduced by applying many sources of data mainly by several interviews. For this study research findings, secondary sources and literature were used to support and establish the internal validity (Ellram, 1996; Yin, 2009), however external validity stipulates the generalization of research findings outside the case study. This was not the research aim. Hence, for a two case studies like this one, the use of theory can be used to achieve analytical generalization (Yin, 2009).

3.7.8 Triangulation

Triangulation can be describe as using multiple data sources, multiple data collection methods or multiple researchers in a study to explore an occurrence and to reduce level of bias (Collis and Hussey, 2009). This study employed the use of multiple data collection using company's records and interviews for practical triangulation. Company records, audio-recording of some interviews with the case study note have been used for data triangulation (Easterby-Smith et al. 2002; Yin, 2009; Perry, 1998). On the other hand, investigator triangulation involves multiple researchers collecting data, analysing data and comparing data individually (Collis and Hussey, 2009). Investigator triangulation was not practicable as this study involves one researcher.

3.7.9 Ethical issues

This study gave ethical concerns as an utmost importance during the research process see Appendix D. The researcher requested for consent from the chosen case study companies through regular telephone calls and email. The researcher clearly stated in his email and telephone calls the research study purpose and explained the roles of the participants. After the case study companies granted the researcher access to undertake the study, the researcher then contacted all participants involved in the study reassuring them of confidentiality and any information they provide. Some interviews were recorded with the interviewees consent. Summary report was forwarded by the researcher in order to assure that the participant thoughts were accurately reflected (Saunders et al., 2009). The researcher avoided asking threatening and personal questions and avoided all form of dishonesty in gathering information.

3.8 Research design

The research design that encompasses the procedure employed to conduct this research is illustrated in in this section. As for every research process, this study began by thoroughly reviewing the literature. In this thesis, both supply chain management, bullwhip effect, inventory management, and system dynamics modelling was critically reviewed in Chapter Two and the research philosophy that underpins this study has been critically reviewed and discussed in the methodology chapter (Chapter Three). Literatures have been explored in order to establish the research questions. Two quantitative system dynamics models for measuring the downstream automobile supply chain in Nigeria has been used in (Chapter Four). These system dynamics models was explored through analytical and simulations models in (Chapter Five) for case study A and (Chapter Six) for case study B and these processes have been frequently linked back to the research aim and objectives to check the suitability of the proposed measures. Finally, the results from the investigation of the models made contributions to knowledge (an understanding of supply chain instability) and methodology (how to better investigate and understand the downstream automobile company in Nigeria using system dynamic modelling methodology). More discussion on the processes and strategies about how the literature and the model building process is undertaken will be provided.

3.8.1 Literature review process

The literature review process was conducted by using keyword searches in several databases, for example Science Direct, Scopus, EBSCOHost, and Emerald. Google Scholar was also used to find conference papers and reports. The researcher began with keyword supply chain management and system dynamics modelling methodology to map out the study outlines. Keywords like bullwhip effect and oscillations were searched alone for the identification of the fields that use these concepts. As the researcher went further the search was narrowed down using keywords such as supply chain, supply chain uncertainty, supply chain delays, thus at the last stage of the search the researcher collected all quantitative studies and qualitative studies that would be relevant to develop and build the supply chain system dynamics inventory models. For the aspects of the methodology, the researcher employed same search methods of same source with the combination of nonlinear and supply chain management using system dynamics. It was revealed from the results of the searches that supply chain literature is mainly dominated with numerical and simulation methods. Furthermore, the analytical studies found during the search do not clearly discuss the research methods and applied theories. Finally, the researcher made use of textbooks as academic papers in these fields are limited by page numbers making the full description of methods not added.

3.8.2 Assessment model

To develop the system dynamics inventory models for measuring the effect of the bullwhip effect and instability on the company’s performance, further exploration of the literature has been undertaken. A customer's perspective and the supply chain's main objective have also been considered. Hence, based on the existing literature a performance index to measure the supply chain instability has been proposed and tested in Chapter Four.

3.8.3 Analytical and simulation models

The models used for investigating both the methodological and theoretical questions will be introduced in this subsection however, more discussion is found in Chapter Four. The researcher chose to adapt a very well-established model, Sterman manufacturing and inventory model (Sterman, 2000). The selection for these models was made during the literature search and conceptual stage as shown in Chapter Four. It will be shown that the study of supply chain instability/bullwhip effect require models which represent inventory and shipment processes precisely. When building a dynamic model Forrester, (1961) suggested that it is important to have a clear purpose of the model. He also argued that their variables should be chosen to represent the system being studied. Thus, the main reason and motivation in using Sterman's manufacturing and inventory model is that it contains many variables and equations that represent a typical supply chain system required for decision making.

3.9 Conclusion

This methodological chapter has thoroughly explained how this research is carried out the research ontological position, epistemological positions, methodological position, research design and justification have been discussed. The discussion on the research tools and methods used has been provided. Based on the definition of the research problem and the scope of this research, this methodological chapter has also extensively discussed the best suitable method to carry out the research and the data collection method. The data will be mainly collected from the case studies companies through interviews, company records and other sources. The capturing of the company's key variables is important to understand the best policies that are robust enough to changes and the limitations of the decision maker in the companies. Hence, the selected research and the justification of using system dynamics model as the most appropriate means of explaining the relationship and link between the different elements causes the instability in the companies through validating the stock and flow model to simulate and analyse the effect of the parameters involved for decision making. Moreover, the main reason of a robust design is relevant to the design of processes and has been an important aim of system dynamics since its inception. The model boundary is the understanding of the case company's internal function (endogenous clarification). System dynamics modelling can provide the means to create suitable models for an organisation to understand the cause and effect that lead to the occurrence being studied. Thus, this chapter has given the foundation for the later analysis and functions of the model by using the collected data thoroughly discussed in this chapter.

Chapter 4. Modelling the Push and Hybrid Push/Pull System Dynamics Inventory Model

4.1 Introduction

This chapter describes the background of the model structure and characteristics of the supply chain inventory push and hybrid push/pull system dynamics model. The discussion starts with an overview of building a system dynamics simulation model. The discussion then proceeds with the detailed description of the two generic models in the following section. The description will start with an explanation of the push and hybrid push/pull inventory model. As the understanding of the models are further developed, a formal calibration will be introduced for each of the models. Steps involved in developing the stock and flow diagrams for the push and hybrid push/pull system dynamics model will be explained in separate sections in this chapter. This research applies empirical results from the two cases to compare the performance of the push and hybrid push-pull inventory system dynamic models.

4.2 The stock management model

Forrester (1991) predicted that 20 generic system dynamics models would represent some of the scenarios that supply chain managers would come across. Therefore, this research uses few of Forrester's ideas. Forrester developed models for a basic supply chain in (1965; 1968) and for the world's economical dynamics (Forrester, 1973) using system dynamics tools. In (1989), Sterman developed and presented a general stock management model (SMM) structure for organization. He combined Forrester's principles and the principles of Lyneis (1980) and Morecroft (1985). The stock management model has been applied by many researchers such as Shin et al, (2010), Aslam, (2013), Elkhady et al (2014), Bezemer and Akkerman (2003), Neubacher (2012), Janamanchi and Burns (2013), Yasarcan (2003), Poornikoo (2017), Lertpattarapong (2000), Sarmiento (2010), and Amaya (2011).

The stock management model can be divided in two parts: the stock and flow structure, the first is the physical structure of the real system, while the second is the decision making rules by which management or managers act to reduce the discrepancy between the actual and the desired. Figure 4.1 present Sterman's (2000) generic stock and flow model. The physical flow is comprised of three flows and two stocks which in this case represent the ordering of materials in a production system and receiving them. Order Rate is the rate at which materials is being purchased. Supply on order are the products ordered but not yet delivered.

Acquisition rate is the ordered products received by the company, stock is the total accumulation of received products and the loss rate signifies used or sold products from the inventory. The acquisition rate is dependent on the level of stock in the supply on order. Order rate on the other hand, is dependent on the significant parameters in the system. The acquisition delay and loss rate are impacted by external exogenous parameters. The amount of loss rate can be influenced by the rate at which customers order. Finally, acquisition delay is influenced by the delays in the management policies for instance by planning with suppliers.

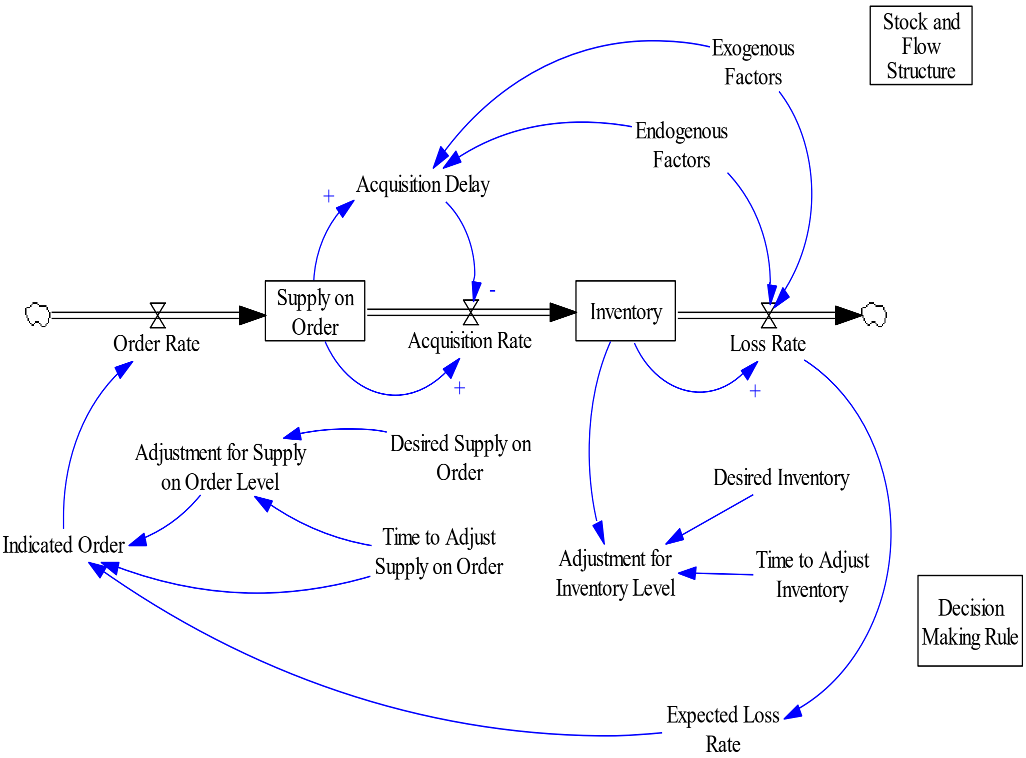


FIGURE 4. 1.THE GENERIC STOCK MANAGEMENT MODEL STRUCTURE

(Sterman, 2000)

Thus, the management must set the policies to manage the information flow and the material flow. The indicated order is the result of the policy. However, input from other external parameters not included in this generic stock management model structure are required for a complete policy analysis. In this example model, it is the loss rate, i.e. the customer order rate or use rate. Management is required to estimate the expected loss rate to avoid excessive inventory due to the management adjustment policy. This management decision policy however technically closes the feedback loop in which the adjustment policy is embodied. Thus, the feedback loop begins at the loss rate and ends at the loss rate in a clockwise direction. The next sections discuss the initialization and settings, and the model building process of the push and hybrid push/pull models for this thesis.

4.3 Initialization and settings

The two built and presented models in this chapter are carried out using the simulation software Vensim. To begin building and initializing the model some settings needs to carry out to run the simulation. Depending on the application range the adjustments differ (Vensim 2007). Therefore, the following sections comprises information about the simulation settings, model building process and the initial values for the simulation scenarios.

<u>Simulation settings</u>

One of the most important things to do, before starting a simulation, is to define the duration and the time step (Neubacher, 2012). Vensim has multiple integration methods that are appropriate for different approaches. Changing the settings of the simulation could lead to different solutions therefore it is important to know these effects. As mentioned in chapter three system dynamics (SD) deals with nonlinear normal differential equations and are not solved analytically. Future stocks are computed numerically and hence all numbers calculated are estimated values. By reducing the simulation time step, it is possible to find a better solution (Neubacher, 2012). Figures 4.2 presents the simulation settings used for the two case studies in this research.

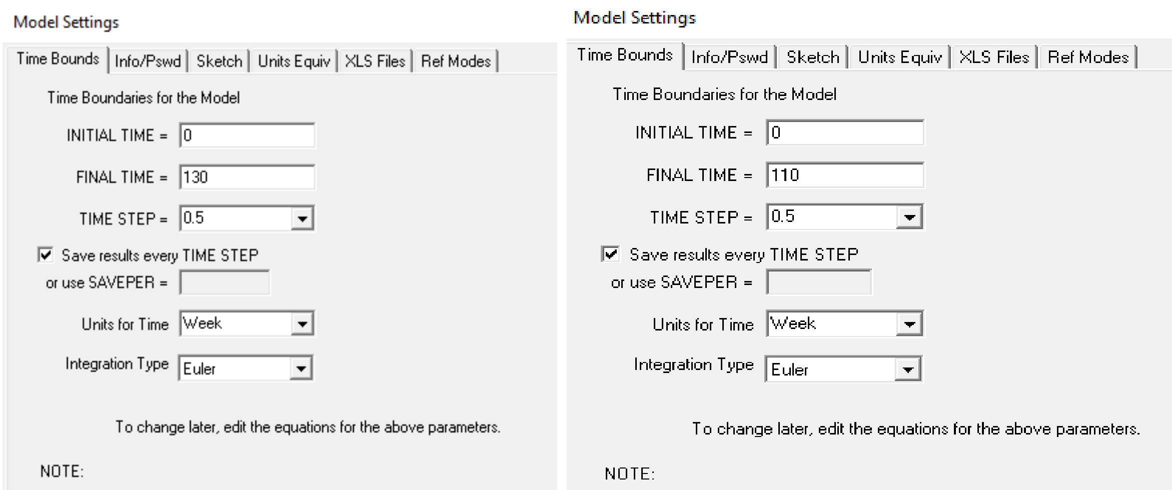


FIGURE 4. 2.SIMULATION SETTINGS USED FOR THIS RESEARCH

Time horizon

Particularly in the field of management, the time horizon of simulations is very important (Neubacher, 2012). Strategic decisions will not always trigger effects within a short period of time. Generally, the time horizon is divided into different stages, called short, long or middle term. Up to five-year time horizon is pointed out as a short-term, any more period can be described as long-range horizon. Other techniques regard strategic management are dealing with long term goals, starting at a minimum time horizon of five years (Lander, 2005). Forrester (1961) pointed out, that long-range time horizon is a big obstacle for management, specifically beyond five years. In addition, long-range responses should be seen with apprehension and short-term behaviours may set the base of additional responses (Forrester, 2003).

Short-term models concentrate on a time horizon ranging from one month up to five years. Barringer and Bluedorn (1999) stated, that a five years' time horizon at maximum might be optimal for business companies since they typically compete in turbulent and uncertain environments with short-lived product or services life cycles. Market situations can change in an extended period and present assumptions, analysis and results are not valid anymore. Therefore, simulation results after five years would not be plausible anymore. As a combination of these various approaches, this research has used less than five years (one hundred and thirty weeks for case A and one hundred and ten weeks for case B) of time horizon for simulation and analysis.

Time step

There are three influences, which need to be considered, when picking an appropriate computation time step (Neubacher, 2012). At the start of setting the simulation time step the first step is to set the accuracy of the numerical integration, secondly the round-off error and third the consideration of the shortest delay. According to the method of combination, the deviation of the approximated value is strong dependent on this interval. The larger the time step is selected, the more inaccurate the result ends up being.

Assuming a one-week time step for a simulation period, the system is calculated 260 times. By decreasing the time step to one day, the system needs to be calculated 1820 times. Depending on the scale of the computer system and the model, this aggrandizement could cause very long computing time. New computers are able and very powerful to calculate with small-time steps. For that reason, the time step is kept extremely low, however lowering the time step would activate another problem. Each calculated value includes a small round-off error. Figure 4.3 presents the time step used for this research. Sterman (2000) recommended to set the time step in between one-fourth and one-tenth of the smallest time constant within the model. For that reason, the chosen time step is 0.5 week for both case studies with limited rounding error.

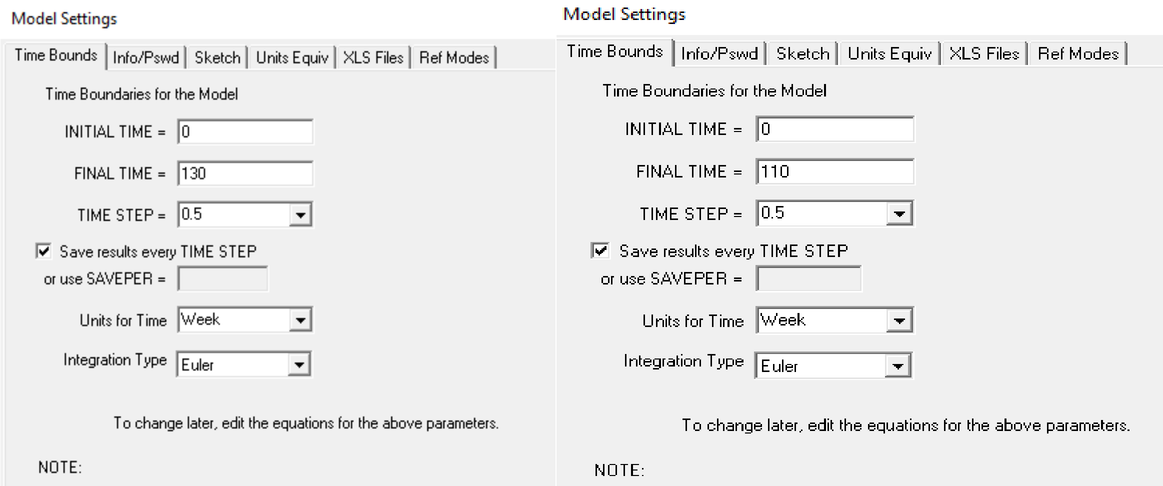


FIGURE 4. 3.TIME STEP USED FOR SIMULATION

Integration method

Vensim provides different integration methods when building a system dynamics model. Neubacher (2012) suggests that it is best to start with the Euler Integration, which is adequate for many applications. Normally, the impreciseness within numerous assumptions creates a bigger impact in the error due to the combination approach. Therefore, the Euler Integration is adequate for almost every model that deals with human behaviour or social systems. Vensim offers other integration techniques, such as the Runge-Kutta. The integration errors are smaller, for this reason this technique permits larger time steps, but more computation power per time step is needed. Runge-Kutta integration techniques might have problems in computing alternate components, such as pulses. As a result of the social and human involvement, that are included in this model the Euler combination technique is chosen. Figure 4.4 provides the integration method used for this research for the two case studies.

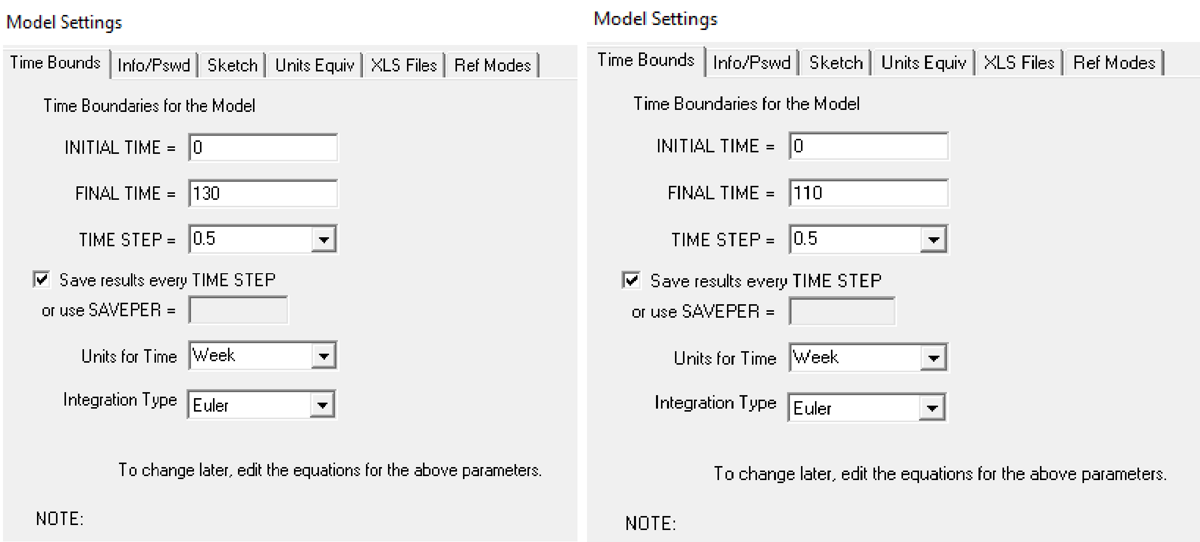


FIGURE 4. 4.INTEGRATION METHOD USED FOR THIS RESEARCH

Mental model

Models are commonly used in management and should be a substitute, representing the real system. Forrester (1961) classified models basically as physical and abstract models. Depending on the linkage to time, they are static or dynamic. He also mentioned that managers are dealing continuously with mental models, that are not necessarily correct, but rather they are substitutes of the reality in our thinking. There is no real framework for creating a mental model. Doyle and Ford (1998) named some definitions and demonstrated the big difference in perception. Mental models are also very common in the field of system dynamics. Sometimes the causal loop diagram is used to map a mental model as well, but in this chapter the first approach of building system dynamics models is based on the statement of Vosniadou and Brewer (1992). They see the main purpose of creating mental models by answering questions, solving problems and dealing with other situations. Especially for the understanding of interconnections between different areas and the flows within, a mental model of the industry is Figure 4.5 presents the mental model of the companies.

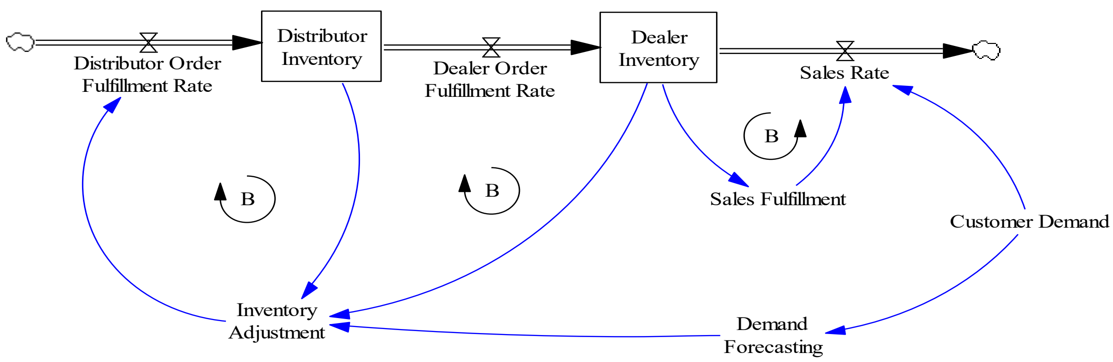


FIGURE 4. 5.CANDIDATE FIRST MODEL SUPPLY CHAIN

In the next step, the boundary of the model is defined. As earlier mentioned, the functions of the case companies is selling of automobiles to downstream customers. This model should only mention the scope of the downstream supply chain i.e. distributor and dealer. All flows within the model are specified for this this boundary. The model layer is divided into three segments. The distributor segment deals with their immediate downstream partners in this case the dealer however, supplier, manufacturer, etc. are not considered in this model as they represent the upstream sectors.

The second part of the structure of the physical model is the dealer inventory i.e. the case company which receives products from the distributor to fulfil all incoming orders to final consumers and send back the information of their sales to the distributor to adjust by increasing or reducing future their orders. The third is the financial structure which is focusing on the profit, cash balance, and total cost for the companies. Administration and operational expenditures are included and mentioned within the unit costs for each product. Revenues are dependent on the sales quantity and the product price. Because the product price is set by the government policy, the only way to increase the revenues is to raise the sales volume.

Boundary adequacy tests

Boundary adequacy tests examine the significance of the model boundary for the purpose of research, indicating that the vital variables of the model for the modelling problem are endogenous to the companies. Sterman (2000) recommends the stock and flow diagrams, interviews, workshops to demand, expert viewpoint, literature review and direct inspection of the model equations as beneficial tools for model boundary determination. In this study, the boundary adequacy test is accomplished through careful examination of model equations, direct interviews with supply chain managers to get their views and approval and more significantly, by thoroughly reviewing the literature in supply chain dynamics for model building. The result of boundary adequacy tests resulted in having one exogenous variable in the model, specifically customer demand. The next section describes the push and hybrid push/pull system dynamics inventory models for the purpose of this research.

4.4 Push model

The push model is presented in Figure 4.6 depicts the stock management problem which can be found in several different application domains as previously explained. The push model has been adapted based on Sterman 2000 stock management model. However, the model has been modified to fit the purpose of a push process and additional structure of the financial performance has been included for performance measurement. Thus, the inventory management model, presented is based on the concept of the generic stock management structure presented below but where it depicts the push inventory process of automobile company in Nigeria with the aim to investigate how the company manages its inventories when inventories are pushed down to meet customer demand.

The Fig 4.6 shows the information and material flows. These flows are important in showing the movement of information and physical units throughout the models. There are two types of stock existing in this diagram: distributor inventory and dealer inventory.

In the diagram, the distributor inventory and dealer inventory are differentiated from other variables by using a boxed outline, which is used to label an inventory in the stock and flow diagram. By referring to the causal links represented by the arrows, it can be observed that sales rate and dealer order fulfilment rate influences the stock of dealer inventory. Each arrow is labelled with its polarity to show the type of influence between the variables. Higher sales rates will, over time, reduce the amount of dealer inventory. On the other hand, the arrow that links the dealer order fulfilment rate and dealer inventory has a positive polarity. An increase in the dealer order fulfilment rate will increase the inventory level of dealer inventory. Each stock type has inflows and outflows of materials which directly influence the stock values. The dark arrows emphasise the information flow links from the expected customer demand (exponential smoothing).

Here the expected customer demand is derived based on the forecasted customer demand. Distributor inventory and dealer inventory will be triggered by the expected customer demand. The arrow from the dealer order fulfilment rate to dealer inventory is influenced by the availability of distributor inventory. Suppose the amount of distributor inventory is less than the amount required by the dealer. Then, only the available distributor inventory will be used to fulfil the dealers' inventory. This flow of inventory can be described as feed forward, which is represented by the direction of flow from the stocks. The expected customer demand will quote the amount of distributor inventory needed based on the demand for dealer inventory whilst any changes in the dealer order fulfilment rate will also influence the amount of distributor order fulfilment rate.

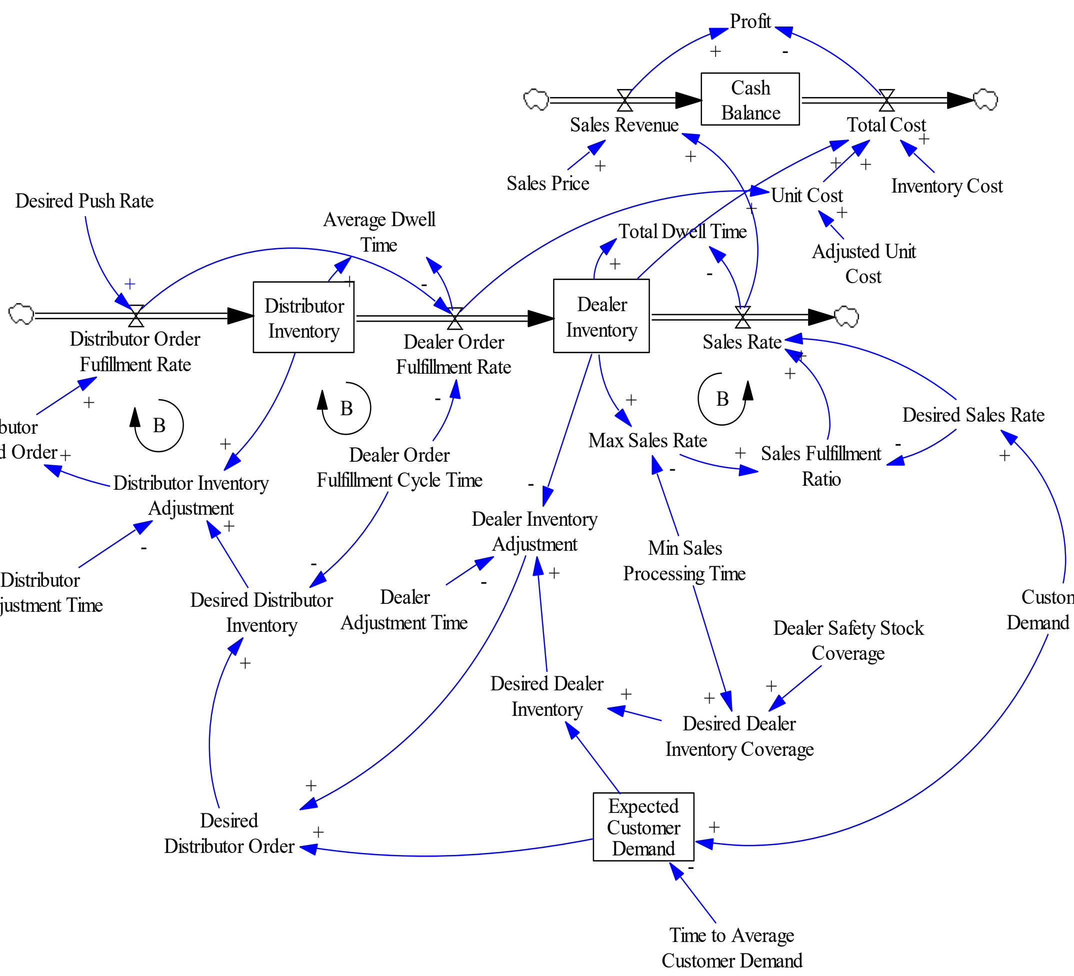


FIGURE 4. 6.PUSH MODEL (MODIFIED FROM STERMAN 2000 PG 768)

4.5 Hybrid push/pull model

The hybrid push/pull system performs both the push and the pull policies (Corry and Kozan, 2004; Geraghty and Heavey, 2004; Geraghty and Heavey, 2005; Teeravaraprug and Stapholdecha, 2004; Wee et al. 2014). A hybrid push/pull system combines a push system at the upstream stage and a pull system at the downstream stages. Figure 4.7 presents the hybrid push/pull model which also depicts the stock management problem found in several different application domains. The hybrid push/pull model has also been adapted based on Sterman 2000 stock management model and has also been modified with additional structure of the financial performance for performance measurement. The main inspiration for using Sterman's model is that it includes several complex behaviours seen in real supply chains. Besides, this model also has a many equations and variables that can well represent a typical supply chain. Thus, the inventory management model presented is based on the concept of the generic stock management structure presented below but where it depicts the push/pull inventory process of the two automobile companies in Nigeria with the aim to investigate how the case study companies manage their inventories as they try to balance orders and inventory to meet customer demand.

The distributor inventory increases by ordering more units from manufacturer/importer (their upstream partners) which is beyond the boundary and out of scope, the distributor inventory reduces after fulfilling dealer's orders. The dealer's inventory increases by receiving fulfilled orders from the distributor, and it decreases by sales rate. Smoothing of customer demand is mainly dependent on sales rate to customers. The different variables and parameters signify the dynamic and complex interrelations between customer demands, dealer desired inventory level, dealer order fulfilment rates, distributor order fulfilment rate, distributor own desired inventory levels, and the time to fill this desired inventory levels. Thus, the model has been built to have a similar decision rules to the push model. This is important in providing a platform for a valid comparison for the two models.

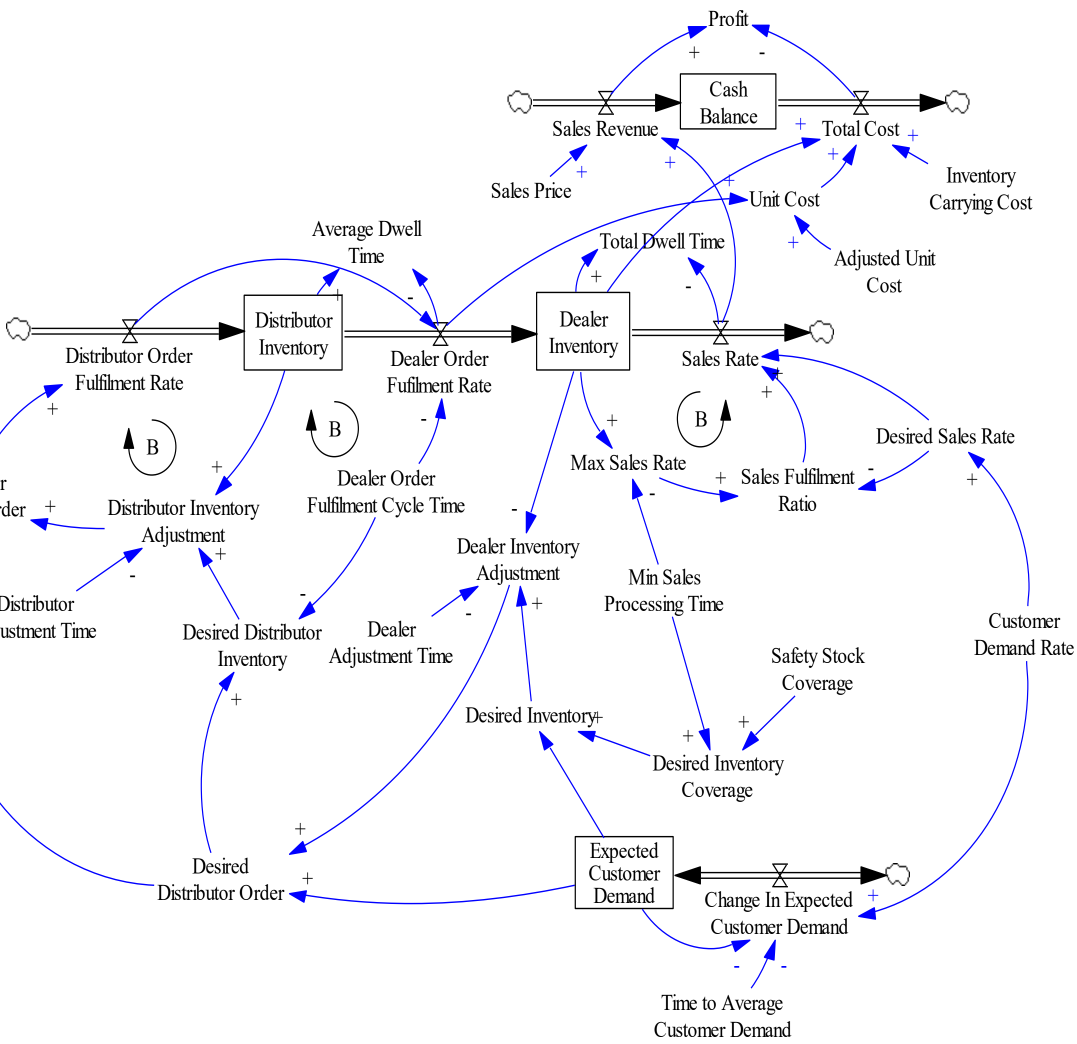


FIGURE 4. 7.HYBRID PUSH/PULL MODEL (MODIFIED FROM STERMAN 2000 PG 768)

4.5.1 Case study A

Case study A is a solely owned Nigerian company with businesses and interests all over Nigerian economy that includes engineering, foods, automobile, beverages, medical, information technology, and agriculture. The company partners with globally respected companies with an iconic brand portfolio, the company is still at present considered by the people of Nigeria as a major dealer of automobile products and a positive contributor to the Nigeria's economy. The company was first founded in late 1990 with a humble beginning of importing and distributing different kind of automobile products. This served as the beginning from which the company consolidated its automobile business with other sectors of the Nigeria economy.

4.5.2 Case study B

Case study B on the other hand is a smaller dealer of automobile products in Nigeria. The company is one of the dealers of Toyota cars and supply spare parts to other automobile dealers although in smaller quantity. The company marketing states that it strives to provide inexpensive and guaranteed vehicles to customers that exceed their expectations in a way that surpass the expectations of their customers' and to provide their vehicles/products at fair and affordable prices. Moreover, the company have strived constantly for many years to make sure that they fulfil their customers' needs as well as their satisfaction at every stage.

4.6 Problem statement of both companies

In the recent years, both companies have experienced market disturbance due to disruptions and delays in their supply chain and competition. In response to this situation, and especially for the sake of their market, the companies have taken a defensive policy to maintain its market share and regain customer loyalty by holding excessive inventory to guard against uncertainties or out of stock situation. However, these managers' decisions have made it difficult for the companies to meet promised delivery times to their customers. Competing in this market environment has made the management of the companies a complicated task. Observations of the case study companies showed that both companies exhibit symptoms of the bullwhip effect and instability in their inventories. The company often struggled to forecast customer demand and subsequently had difficulties with reducing the delivery times of their vehicles.

Structure assessment tests

The main reason for conducting structural assessment tests on system dynamics models is to investigate if the constructed model is consistent with relevant understanding of the system (Barlas, 1996). Figures 4.8 and 4.9 presents the structure assessment test of the push and hybrid push/pull models. It highlights on the suitability of the model to the physical realities such as the behaviour of actors. The procedures for conducting structure assessment tests includes causal diagrams, stock and flow diagrams. Further to the structure assessment test, the model has been modified based on existing literature with the validation of the managers.

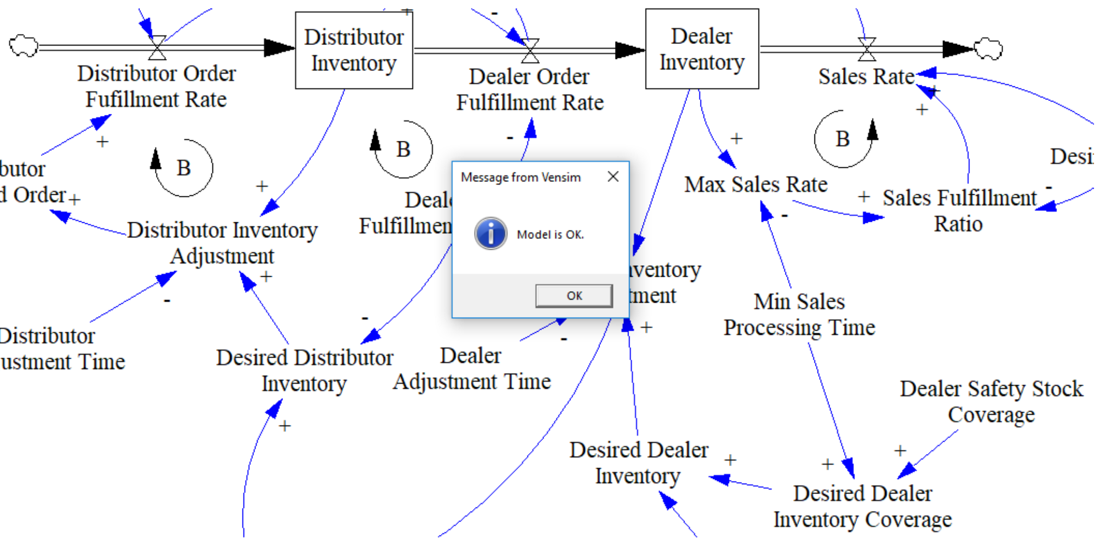


FIGURE 4. 8.STRUCTURE ASSESSMENT TEST OF PUSH MODEL

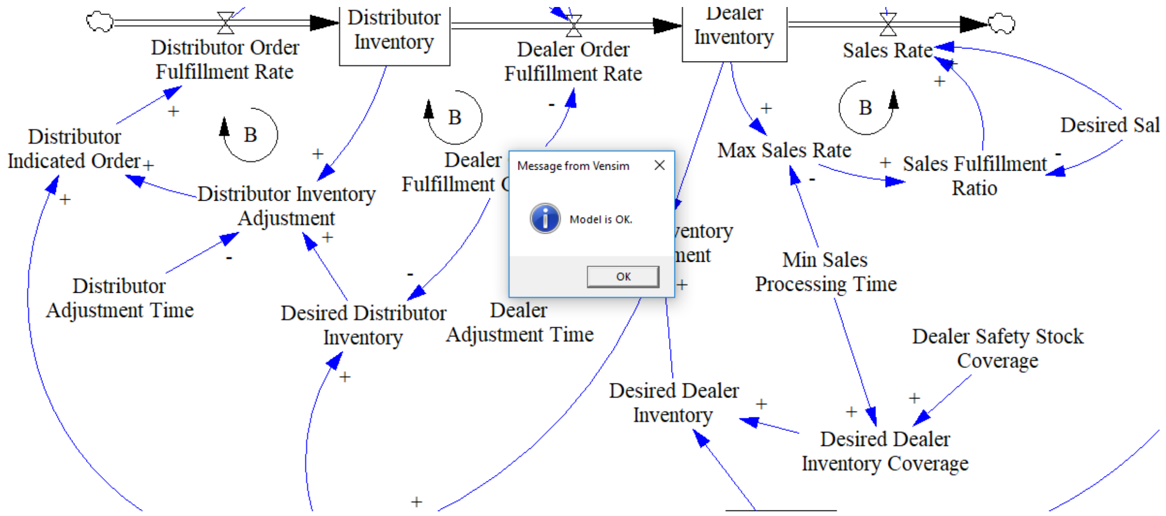


FIGURE 4. 9.STRUCTURE ASSESSMENT TEST OF HYBRID PUSH/PULL MODEL

Parameter assessment

To start testing the model, it is essential to sure that all constant (parameters) in the model have a clear, real-life significance (Ng et al 2012). Simply put, all the parameters need to have real world counterparts. Secondly, decisions on the numerical values of each parameter must be made in a logical manner. According to Barlas (1996) and Ng et al (2012), judgmental methods based on interviews, professional opinion and statistical methods to approximate parameters can be utilized for parameter assessment. In this thesis, the parameters utilized have been selected based on the case studies and the value of each parameter has been estimated in accordance with the managers views and company records. Table 4.1 presents the parameter values used for this thesis for both push and hybrid push/pull models.

Parameter	DIAT	DEAT	DEOFCT	MSPT	SSC	TACD
Values	2	6	8	2	3	6

TABLE 4. 1. PARAMETER VALUES USED FOR THE ANALYSIS

Dimensional consistency

Dimensional consistency is known as one of the rudimentary tests which ensures that all equations in the model are dimensionally consistent with their meaning in the reality (Barlas, 1996). In other word, the dimensional consistency test checks whether the dimensions of the variables in all the equations are balanced on each side of the equation. Figures 4.10 and 4.11 presents the dimensional consistency tests of the push and hybrid push/pull models. Dimensional analysis for the push and hybrid push/pull models has been done using units check in Vensim.

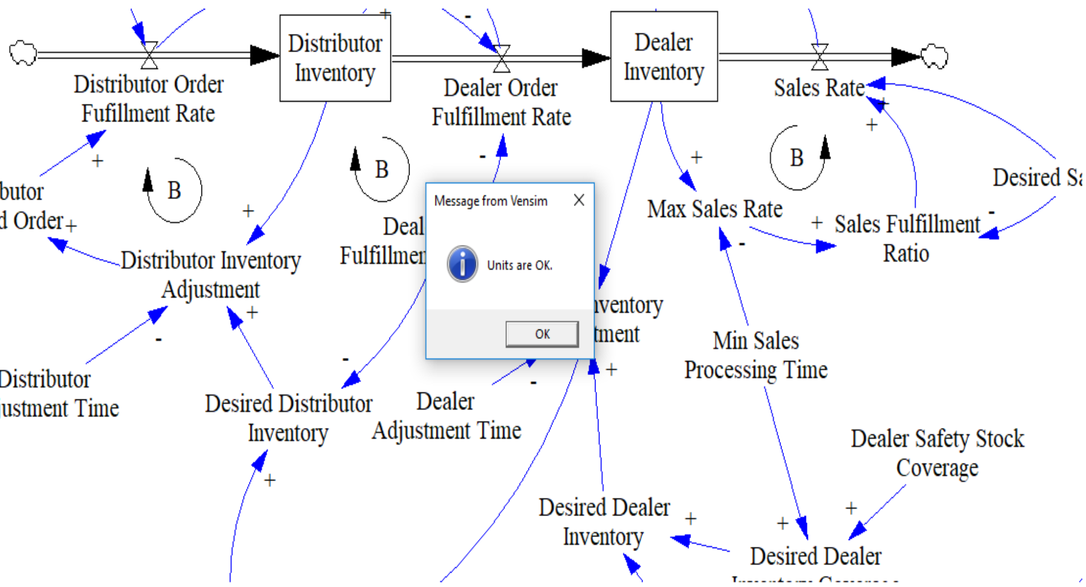


FIGURE 4. 10.STOCK AND FLOW DIAGRAM OF PUSH MODEL

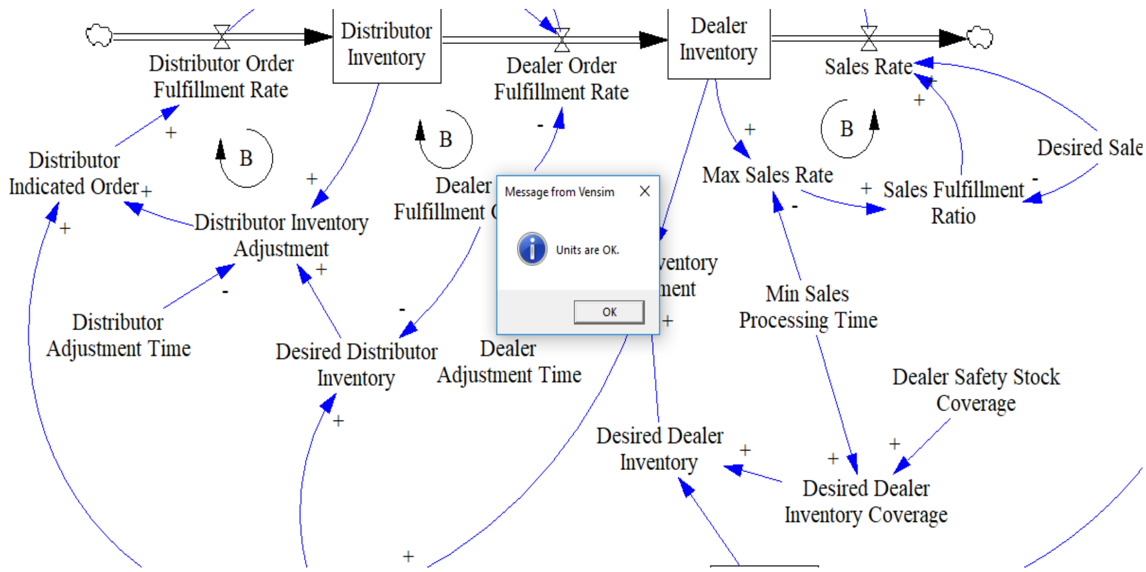


FIGURE 4. 11.DIMENSIONAL TEST FOR HYBRID PUSH/PULL MODEL

Extreme condition test

System dynamics models must be robust in extreme conditions. That is, robustness under extreme conditions indicates the model behaviour should realistically correct no matter how extreme the inputs or policies it may encounter (Barlas, 1996; Poornikoo, 2017). Inventories should never drop below zero no matter how big the demand may be. When the inputs take on extreme values such as zero or infinity, extreme condition tests ask whether models act appropriately.

Extreme condition tests can be performed in two main ways: by direct evaluation of the model equations and by simulation i.e. taking a closer look at each decision rule (rate equation) in the model and can also be carried out as policies in simulations of the model. In this research, extreme condition test is carried out for the sake of increasing confidence in the simulation models. Figures 4.12 and 4.13 portrays the behavioural output of the push and hybrid push/pull system dynamics inventory models Customer Demand = 0 Units/Week.

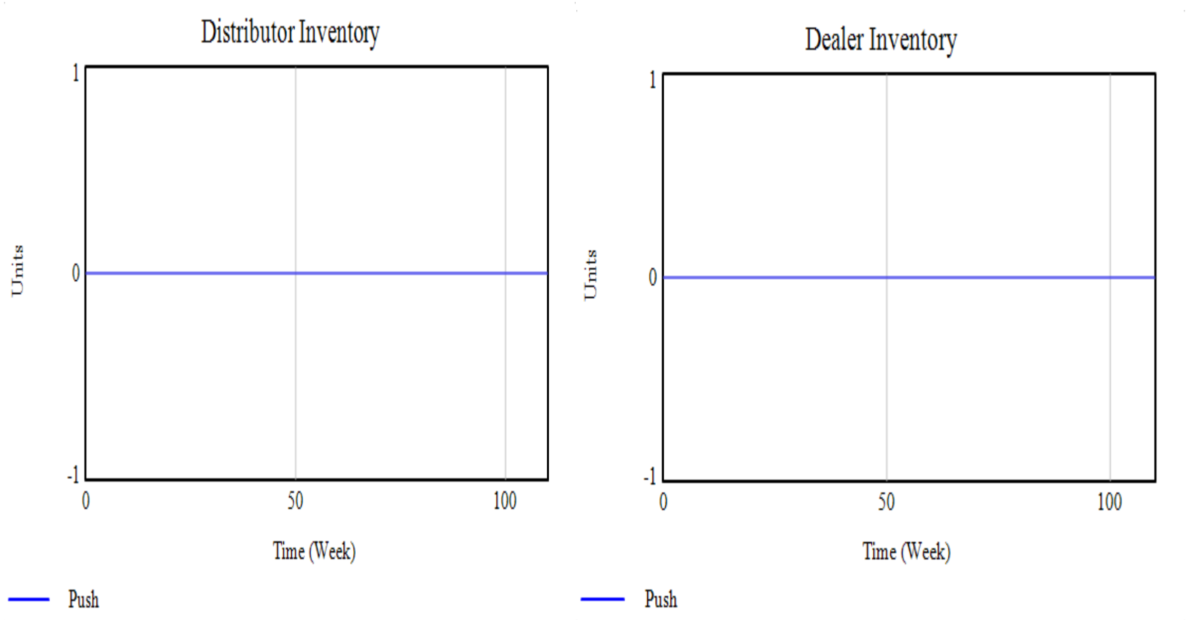


FIGURE 4. 12.EFFECT OF EXTREME CONDITION ON PUSH SD INVENTORY MODEL

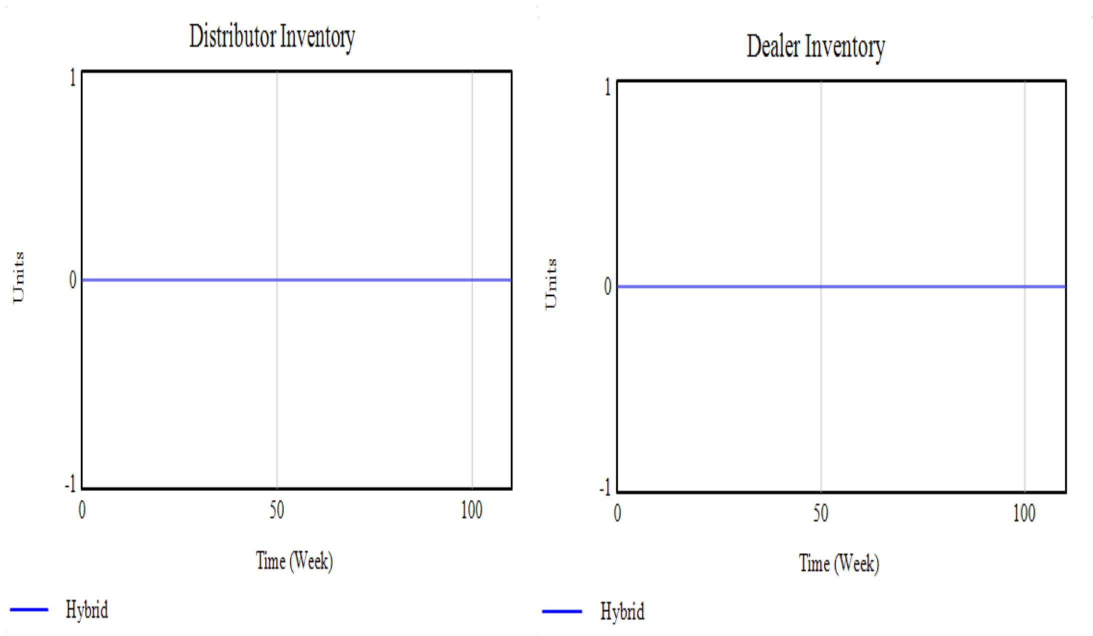


FIGURE 4. 13.EFFECT OF EXTREME CONDITION ON HYBRID PUSH/PULL SD INVENTORY MODEL

4.7 Initializing the models in balanced equilibrium

A balanced equilibrium implies that all stocks are equal to their desired values. In these models, equilibrium requires distributor order fulfilment rate is equal to dealer order fulfilment rate and is equals sales rate (the conditions for distributor inventory and dealer inventory to be constant); the change in expected customer demand is equals zero. In addition, a balanced equilibrium requires that inventory equals desired dealer inventory, distributor inventory equals distributor desired inventory and all flows equal their target rates as well: sales rate, desired sales rate, expected customer demand, desired distributor order, distributor indicated order, distributor order rate, and dealer order fulfilment rate all equal to customer demand rate.

Initializing the model in a balanced equilibrium facilitates the process of the model testing and experimentation because the system remains in equilibrium until perturbed by customer demand input. In these models, the balanced equilibrium has been achieved with the following initial conditions:

Distributor inventory = Distributor Desired Inventory

Dealer Inventory = Dealer Desired Inventory

Expected Customer Demand = Customer Demand Rate

The purpose is to determine how and where instability and bullwhip effect emerges, in order to trace where the distortion occurs due to the input of customer demand (exogenous variable). The two models showed steady behaviour throughout the simulation horizon in this experiment reflecting a balanced equilibrium. Figures 4.14 to 4.17 presents the graphs of the inventory level portraying the results in this fashion simplifies the discussion. As the input to the model is in steady state, the observation of the system's behaviour is straightforward. The steady state pattern of customer demand transfers along in the distributor and dealer inventory level, the distributor order fulfilment rate, dealer order fulfilment rate and sales rate all portrays a steady pattern in the push and hybrid push/pull SD inventory models.

Figures 4.14 and 4.15 show the same values of results (level of inventories) for the push and hybrid push/pull systems. In the two models, the distributor inventory is at steady state at 968 units and the dealer inventory is at steady state of 605 units at throughout the simulation time at 130 weeks. As shown by the graphs, the inflow and outflow rates that controls the inventory are at steady state of 121 units/week. The steady pattern of the inventories results from equality of the sales rate.

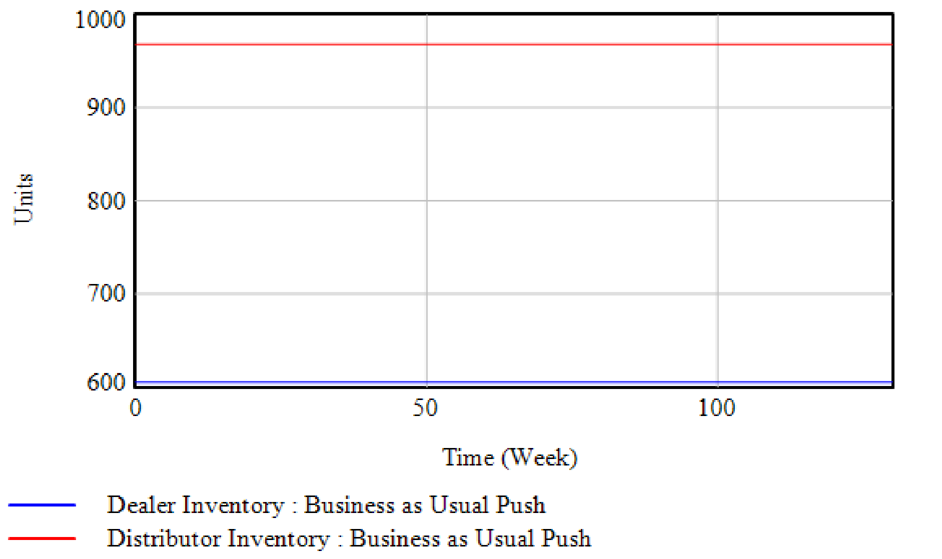


FIGURE 4. 14.EFFECT OF STEADY DEMAND PATTERN UNDER PUSH MODEL ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

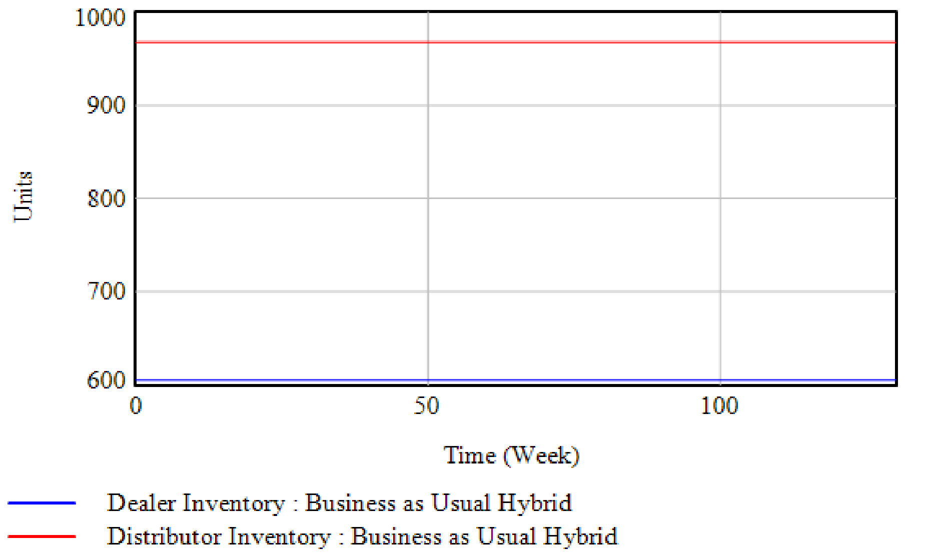


FIGURE 4. 15.EFFECT OF STEADY DEMAND PATTERN UNDER HYBRID PUSH/PULL MODEL ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

Figures 4.16 and 4.17 display the level of inflow and outflow rate across the two models. Given the equal inflow and outflow represented by the distributor order fulfilment rate, dealer order fulfilment rate, and sales rate, the level of inventory is stabilised at distributor and dealer echelon.

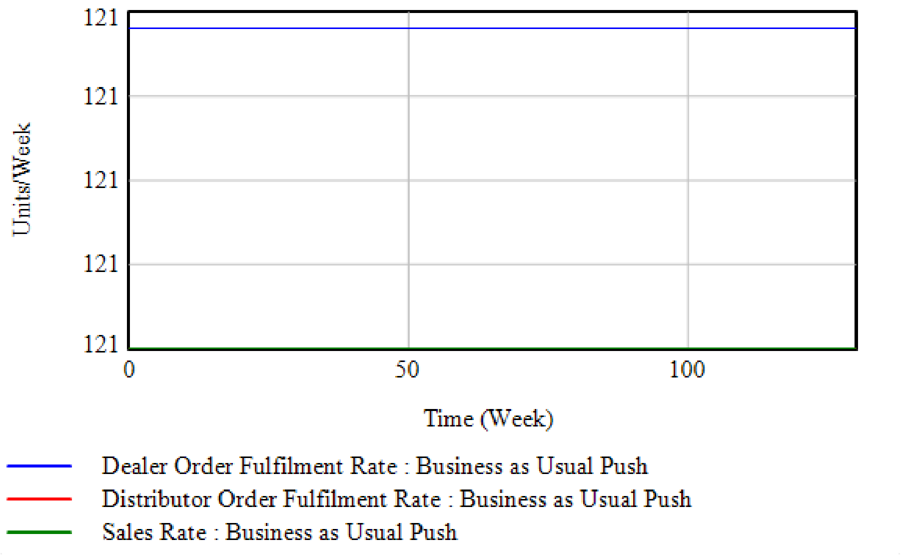


FIGURE 4. 16.EFFECT OF STEADY DEMAND PATTERN UNDER HYBRID PUSH/PULL MODEL ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

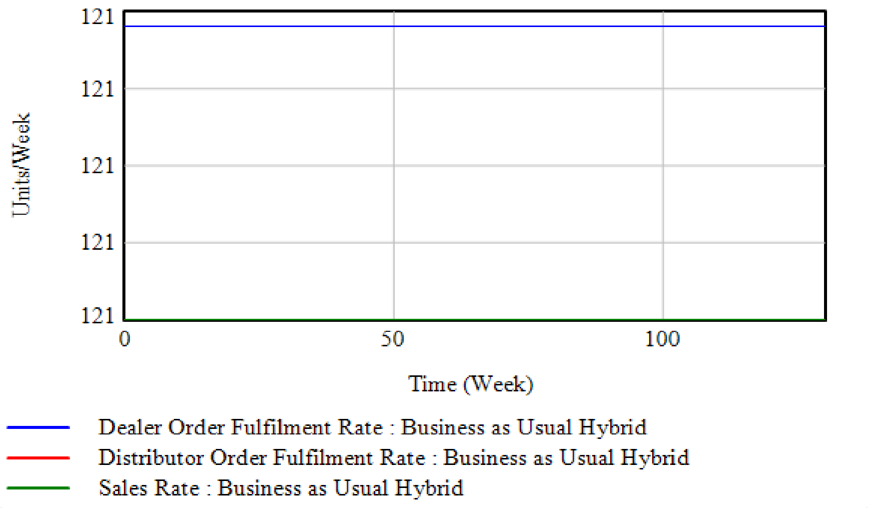


FIGURE 4. 17.. EFFECT OF STEADY DEMAND PATTERN UNDER HYBRID PUSH/PULL MODEL ON INFLOW AND OUTFLOW RATE

Although the results from this analysis do not provide a substantial understanding of the differences between the models, this is an important exercise for surfacing any errors in the structure of the models. From the Figures provided, it can be argued that when the models are initialized in a steady state, the demand is translated throughout the system in each one. Steady demand pattern induces steady pattern behaviour, which justifies that both the push and hybrid push/pull system dynamics inventory models structure as being adequate.

4.7.1 Model calibration

Calibration in system dynamics models is a procedure in which the model parameters are approximated for a statistical measurement between simulated and observed behaviour (Barlas, 1996). This implies, generating required model behaviour by controlling parameters in the model structure under specific boundaries. When handling undetermined parameters in system dynamics, modellers rely on the model to change its behaviour to a known system response by changing the unset variables and not gathering more data from reality. The model structure gets higher confidence as a legitimate representation of reality when such model can reproduce the observed behaviour without assigning excessive values for the calibrated inputs (Barlas, 1996; Olivia, 2003). However, there are limitations in carrying out calibration.

Carrying out model calibration means a partial test of the model where a model is made from a series of equations and parameters. For that reason, it is possible that a set of parameters with unrealistic solutions produce realistic behaviour. Thus, for good validation of the model structure, an extensive structure test is required (Olivia, 2003). The model calibration can be performed manually or automatically. The manual model calibration is usually done by analysing the inconsistencies between the simulated and observed case studies, spotting the possible reasons for the differences and lastly adjusting the parameters of the model by hand to fix these discrepancies.

The process of parameter adjustments and evaluations in manual calibration is carried out on the basis of the modeller's experience and expert's opinions (Lyneis & Pugh, 1996). On the other hand, statistical analysis can be utilized to make parameter assessment procedure more robust. Model calibration for this research have been carried out manually with the following steps: Defining the calibration recommendation variable;

- Identifying the known variables with their approximated values from real information.
- Selecting variables to be calibrated with an appropriate variety of values.
- Running the model with the calibrated parameters.
- Examining the referral variable fit to the real value.

The calibration of the model is done by hand by examining the differences between simulated output and actual output, by identifying those possible factors for those distinctions, adjust model parameters to remedy the discrepancy, and re-simulates the model.

Model error decomposition

The mean square error determines the deviation of the simulated variable from the actual value over a specified period of time. The benefit is that large errors are given more attention than small errors (Sterman 1984). Hence, by taking the square root of the mean square error, the forecast error can be placed in the same systems as the variable in question. Thus, the measure is known as the root mean square (RMSE) simulation error (Pindyck and Rubenfield 1991).

Mean Square Error (MSE) Test: the mean-square-error (MSE)**,** is the process of measuring forecast error, and can be given as:

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

Where

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

St = Simulated value at time t

At = Actual value at time t

Root mean square percent error (RMSPE): the RMSPE can be categorized as an easier measurement of forecast error i.e. is an error, which gives a stabilized variation of the error and is stated as:

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

In the root mean square percentage error, the deviation of the simulated variable from the real value over a given period also measures however, is represented in terms of percentage. (Pindyck and Rubenfield 1991).

Theil statistics test

The mean square error (MSE) and the root mean square percentage error (RMSPE) measures the total size of the error between the actual and simulated. Moreover, the mean square error is normally decomposed using Theil inequality statistics (Sterman 1984, Pindyck and Rubenfield 1991) to show the origin of the error. The sources of error in Thiel inequality statistics can be given as bias, variance, and covariance. The mean square error decomposition to Theil statistics in this research is as follows:

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

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

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

Ss and *SA* equal the standard deviations of S and A, respectively.

And finally r equals the correlation coefficient between simulated and actual data

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

By dividing each of the components of error by the total mean square error (MSE) the inequality proportions are derived:

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

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

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

The sizes i.e. bias (U^M), variance (U^S), and the covariance (U^C) shows the number mean square error in the form of bias, variance, and covariance, respectively. It is important to note that the addition of the error in the, $U^M + U^S + U^C = 1$ as it represents the cumulative mean square error (MSE). The bias error (U^M*)* shows the level of which the average values of the simulated and actual vary (Bush and Mosteller 1955). Thus, is best that the estimate of the model is unbiased. A large bias (i.e. large U^M and a large MSE) is defined as systematic error and this sort of error can be problematic for the model. A systematic error signifies that some variables or parameter in the real system may not have been presented in a proper manner. However, a model accurately depicting a real-world system is unlikely to have such results.

Bias errors may signify some parameter errors present in the model. In contrast, not all bias errors may not be detrimental to the model. An example of such a case is if U^M is large and the error size in the model is small (small MSE/RMSPE). As earlier mentioned, a systematic error can be allowed even when large so long the function of the model is not affected. A model should have a predictive behaviour when the reliability of the model is tested (Bloomfield 1986).

The variance proportion (U^S) determines the level of matches within the model estimate, and the level of variability in the actual value. For example, in this research a large U^S shows that there is significant fluctuation in the simulated values but low fluctuation in the actual values and vice versa. Additionally, a large variance also means systematic error (Sterman, 2000). On the other hand, the unsystematic error i.e. the co-variance proportion (U^C) is measured (this error can be described as the error present after the discrepancies between the actual and simulated have been represented) (Sterman, 2000).

The co-variant proportion (unsystematic error) is the least problematic error between the three errors. Unsystematic error suggests that the behaviour of the system has been influenced by an exogenous variable in the model. Moreover, when there is a presence of unsystematic error in the system, the model's ability is not compromised to fits it function since it is not in the models' scope to predict based on uncertain external influence. Doing so could counter the function and purpose of the model. As a rule, however, calibration builds confidence in a model (Barlas 1989, Rowland and Holmes 1978, Sterman 1984) if:

- The root mean square percentage error (RMSPE) are small and unsystematic U^C. Veit (1976), (Sterman 1984) suggested that a RMSPE of 10% is appropriate for an appropriate level of tolerance in an SD model.
- Large errors are due to noise in historical data, but does not necessarily affect the model as long as the nature of the error does not significantly affect the purpose of the model (Sterman 1984).

Case study A sales rate calibration

Figure 4.18 shows the fit between actual and simulated sales rate. Theil's inequality statistics indicates unsystematic error between the mean and variance of the structural model (U^M =0.006, U^S =0.006 and U^C =0.98) for the sales rate. The RMSPE is below 10% meaning that the difference between the actual and the simulated is small. The mean square error decomposition into the inequality statistics showed a small source of error as unequal covariance (unsystematic error).

In particular, the large U^C may be a as a result of noise or cyclical modes in the historical data not captured by the model. Therefore, a large U^C indicates most of the error is unsystematic with respect to the model's purpose.

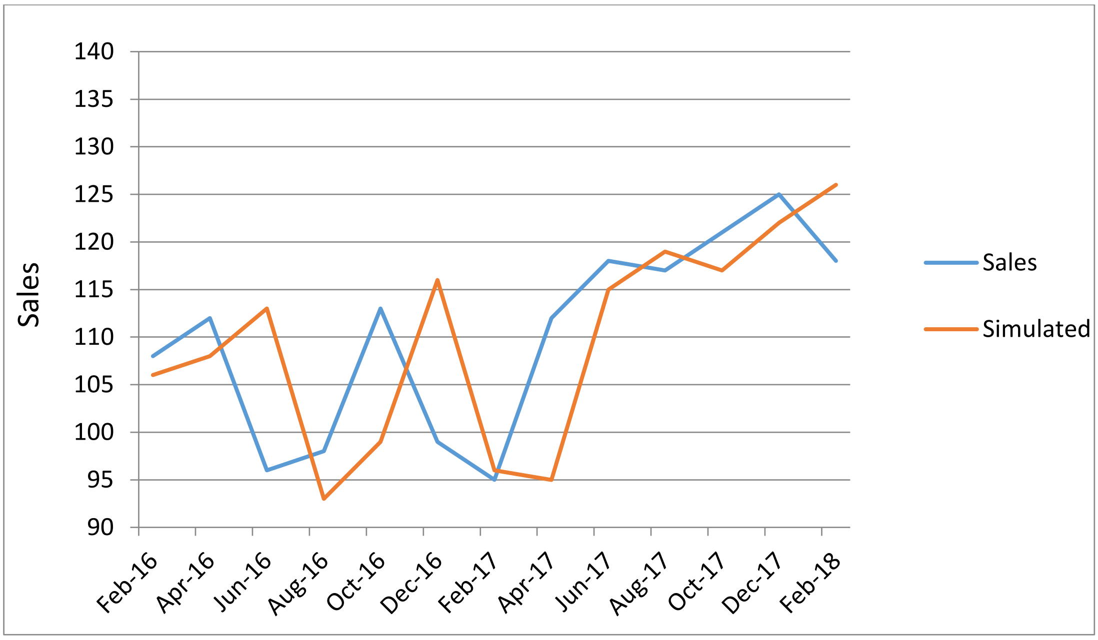


FIGURE 4. 18.ANALYSIS OF FIT FOR CASE STUDY A SALES RATE

Measure				Thiel		
R^2	*RMSE*	*RMSPE*	*MSE*	U^M	U^S	U^C
0.53	9.54	8.83%	91	0.006	0.006	0.98

TABLE 4. 2. SUMMARY STATISTICS FOR CASE STUDY A SALES RATE

Case study B sales rate calibration

Table 4.3 shows the fit between the actual and simulated sales rate. Theil's inequality statistics indicates unsystematic error between the mean and variance of the structural model (U^M =0.006, U^S =0.004 and U^C =0.98) for the sales rate. The RMSPE is below 15.81% meaning that the difference between the actual and the simulated are small. The mean square error decomposition into the inequality statistics showed a small source of error as unequal covariance (unsystematic error).

In particular, the large U^C may be a as a result of noise or cyclical modes in the historical data not captured by the model. Therefore, a large U^C indicates most of the error is unsystematic with respect to the model's purpose.

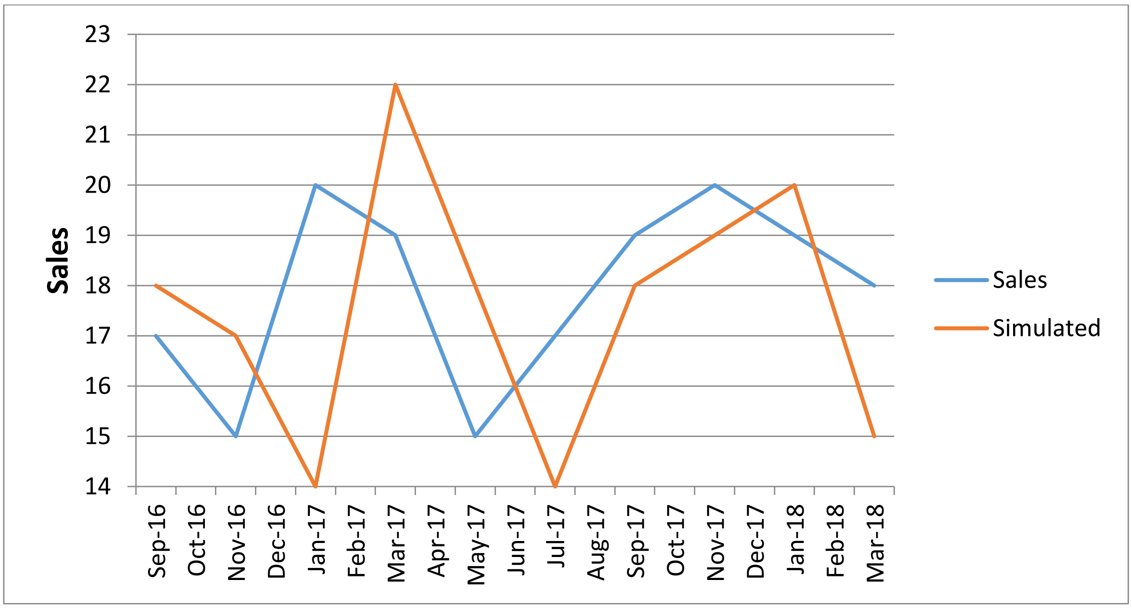


FIGURE 4. 19.ANALYSIS OF FIT FOR CASE STUDY B SALES RATE

Measure				Thiel		
R^2	*RMSE*	*RMSPE*	*MSE*	U^M	U^S	U^C
0.04	2.68	15.81%	7.22	0.006	0.004	0.98

TABLE 4. 3. SUMMARY STATISTICS FOR CASE STUDY B SALES RATE

4.8 Conclusion

This Chapter developed and described in detail the push, and hybrid push/pull inventory system dynamic models and captured the important variables in the supply chain issues being investigated. The elements of inventory, information, total cost, customer demand, the parameters, and cost involved are identified and included to support the modelling and simulation of the dynamic downstream automotive supply chain in Nigeria based on quantitative and qualitative information. In the models developed, the expected connections are formalised to show the system boundaries causal links and the conceptual stock and flow models developed to show the models and the impact on the model behaviour through simulation. Validation of the models have also been undertaken and discussed in this Chapter to increase confidence in the models. Analysis are carried out in Chapter Five and Chapter Six for case study A and B and further understanding and analysis of the models will follow in those chapters derived from the simulations.

Chapter 5. Simulation Design and Analysis of Case Study A

5.1 Introduction

The focus of this chapter is to analyse the push and hybrid push/pull system dynamics inventory models developed in chapter four for the first case study. The discussion of the results is in the perspective of validating the models and comparing the behaviour across the stock and flow models. The next sections describe the simulation results and analysis for the models. Later sections will discuss the results of the simulation runs in a comparison of the two stock and flow push and hybrid push/pull models and the cost analysis of the models.

5.2 Analysis of inventory level of case study A

In the earlier chapters, particularly in Chapter one and Chapter two, the uncertainties of customer demand over the years have been pointed out. Chapter five for case study A will investigate the effect of uncertain customer demand on the Nigeria downstream automobile push and hybrid push/pull system dynamics inventory models and the cost involved. This investigation is undertaken to achieve research objective three and four and answer the research questions by investigating the dynamics effects on the inventory level of the push and hybrid push/pull inventory models in the Nigeria downstream automobile supply chain inventory using different demand patterns and the costs incurred as a result of the fluctuations and instabilities. Three demand patterns are selected to adequately represent the different future demand projections. These demand patterns are shown in Figures 5.1 to 5.3. The future projection of demand shown in these figures were used with the agreement of the managers of the companies. The business as usual demand pattern has been suggested by the managers of the case study companies they suggested that the sales trend should be between an increase and decrease of 10% and 25%, the optimistic and pessimistic demand patterns was also suggested by the managers. There are many possible customer demand patterns that can be generated to be chosen as an input in the model. However, it is exceptionally difficult to provide insights to model behaviour under many differences in demand pattern. Therefore, the actual demands patterns in the simulation carried out in this research are rather to break down the patterns across them based on policy choices vs demand changes, and to offer some understanding of the model's responses to each trend.

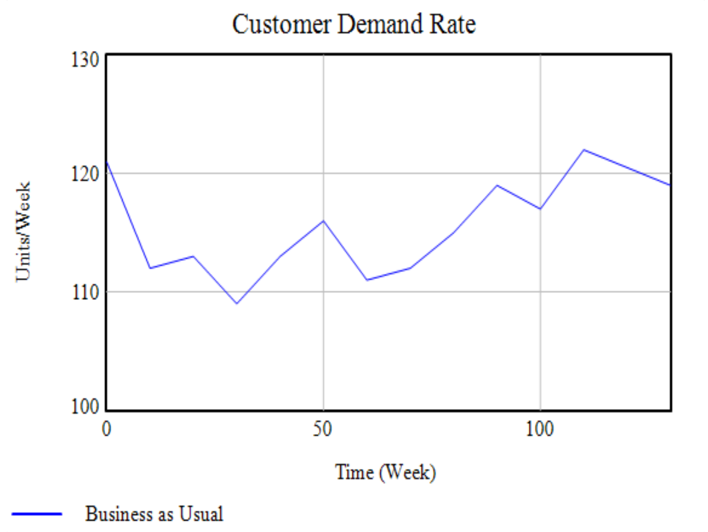


FIGURE 5. 1. BUSINESS AS USUAL DEMAND

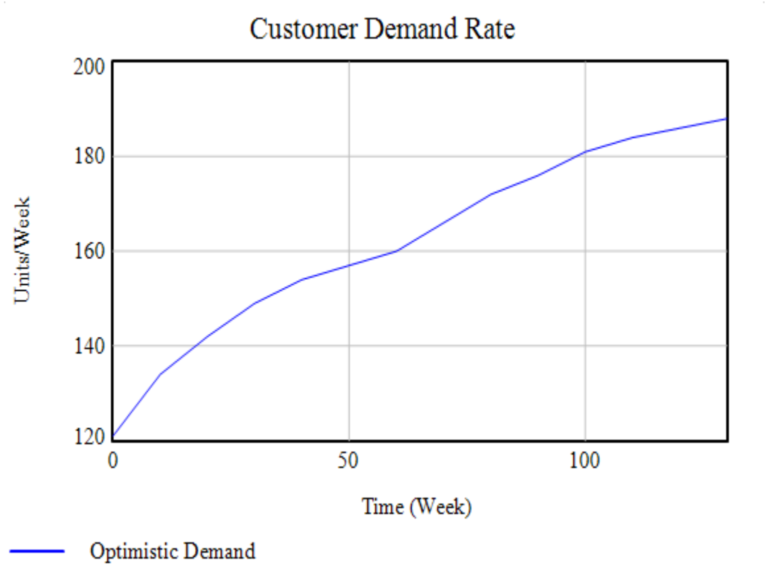


FIGURE 5. 2. OPTIMISTIC DEMAND

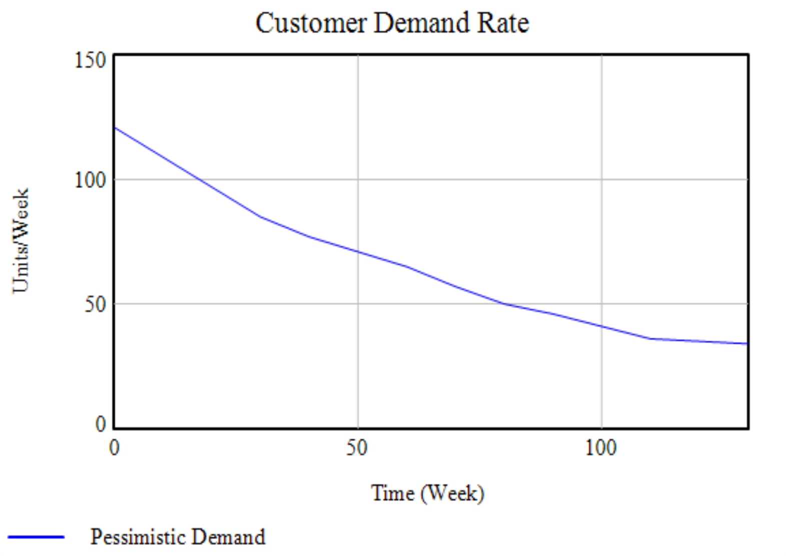


FIGURE 5. 3. PESSIMISTIC DEMAND

In each of the customer demand patterns the simulation start from week 0 and last until the end of the simulation time (130 weeks). Figure 5.1 displays the business as usual demand pattern. Figure 5.2 displays the second demand pattern which is optimistic demand and Figure 5.3 displays pessimistic demand pattern. In Figure 5.2, the demand increases from 121 to 187 units over 130 weeks. In Figure 5.3, the demand decreases from 121 units per week to 33 units per week over 130 weeks.

5.3 Analysis of inventory level

This section discusses the simulations results, in order to validate the push and hybrid push/pull models. Before commencing, it is necessary to point out the uniqueness in system dynamics model validation in comparison to other mathematical models. System dynamics model validation has been well argued since Forrester in 1956 introduced the method. The initial argument follows a different perspective of the validation between system dynamics (SD) and other models. Forrester and Senge (1980) suggested several tests and experiments that can be used for system dynamics models for building confidence in the models. This process has been extensively discussed. Their study explains processes of rigorous model testing of a system dynamics model which can be categorized as tests of model structure, tests of model behaviour and tests of policy implications.

Barlas and Carpenter (1990a) in their research clarifies the two types of mathematical models which are statistical/correlation and theory-like models. The research explains how and why a system dynamics models is unique philosophically from a non-causal mathematical model in the attempt to support the validity of system dynamics model. Regardless of criticisms of the system dynamics models validation, more attempt has been made by many researchers of system dynamics to formalise system dynamics modelling validation. Barlas (1996) shows the likelihood of applying statistical measures in system dynamics validation process, under the condition that the tests should be pattern-oriented rather than point-oriented.

The possible benefit from a statistical test is by testing the behaviour results and validity from simulation games. In a study conducted by Coyle and Exelby (2000) they went further on the discussion on formal validation in models for a paying customer by differentiating between truth and validity in a model. They placed emphasis that the developed model for their client has been simplified from the real system to propose valuable insights for solving specific problems which cannot be categorized as true or false. Therefore, the best way to satisfy the client is by proving that the model satisfactorily addresses the planned purpose. Furthermore on validation of model, Schwaninger and Groesser (2009) in their study many model validation processes are summarised and one of the tests in this summary are known as direct structure tests that is useful to validate the models in the research. They explained the indirect structure tests as a test that evaluate the validity and usefulness of the model structure directly by exploring the model behaviours and to perform these tests the modeller requires computer for simulating the model behaviour.

However, there are many tests being classified as direct structure tests, one of the important tests that is suitable to be applied is the extreme condition test which have been carried out in Chapter four. This test is done by giving extreme values to the model parameters then the model is simulated to see the model behaviour result. Finally, the patterns of the model behaviour produced are compared with the reality of the behaviour observed in. However, the direct structure tests carried out in Chapter Five and Chapter Six use the parameter values chosen by the researcher with the knowledge of the managers and it is based on company records.

The managers expected the researcher to first conduct a test using the actual parameter by the company (time to average customer demand) to understand the company's normal business as usual scenario and its effect on the companies' performance. The results from the simulation runs are compared to logical insights of the modeller which is based on knowledge gathered from the literature. The idea is to validate the models with the purpose of why the model is built Table 5.1 presents the validation of the models:

	Distributor Inventory	**Dealer Inventory**
Validation Purpose 1	Dealer Order Fulfilment rate must not exceed distributor inventory	Sales rate must not exceed dealer inventory
Validation Purpose 2	Inventory must reflect the inflow and the outflow. For instance, a higher sales rate of dealer inventory than distributor order fulfilment rate increases the inventory at the start of distributor inventory.	

TABLE 5. 1. VALIDATION PURPOSE

It is important to validate the models under the different demand patterns to justify that the model structure is suitable despite the different demand patterns. In addition to the validation purpose of a model, the argument by macroeconomists that customer demand is mostly unstable, therefore it is important to smooth customer demand (Kahn, 1987; Blinder, 1986).

Thus, this test is included for the analysis of the model behaviour. The analysis presented in the next section are continuation of the validation processes applied to the models.

5.4 Direct structure tests in business as usual

At this point the model output is compared in separate graphs, which is a more practical way to portray the validation outputs. The input (business as usual) is shown in Figure 5.2 and this generates a diverse dynamic response across the models. It is worth emphasising the differences in model behaviour in terms of distributor inventory, dealer inventory, distributor order fulfilment rate, dealer order fulfilment rate and sales rate in the output graphs. Having stated this, the subsequent validation purpose will verify that the models are adequate for addressing the research problem through confirmation of output graphs. Some of the discussion provides insight into the model's behaviour under each analysis. Eventually, the cost analysis section combines all the outputs from the simulation runs in the two models into one graph to provide a more obvious comparison.

The demand pattern used in this test presented in Figure 5.1 is unpredictable. Customer demand drops to 112 at week 10 this trend continues fluctuating until the end of the simulation time of 126 units/week at week 130. A smoothing function is used to represent the expectation of managers concerning the customer demand. The objective of this test is to further validate the model, as well as analysing the model response towards changes in demand. The results from this test with the push and hybrid push/pull models are discussed in the following sections.

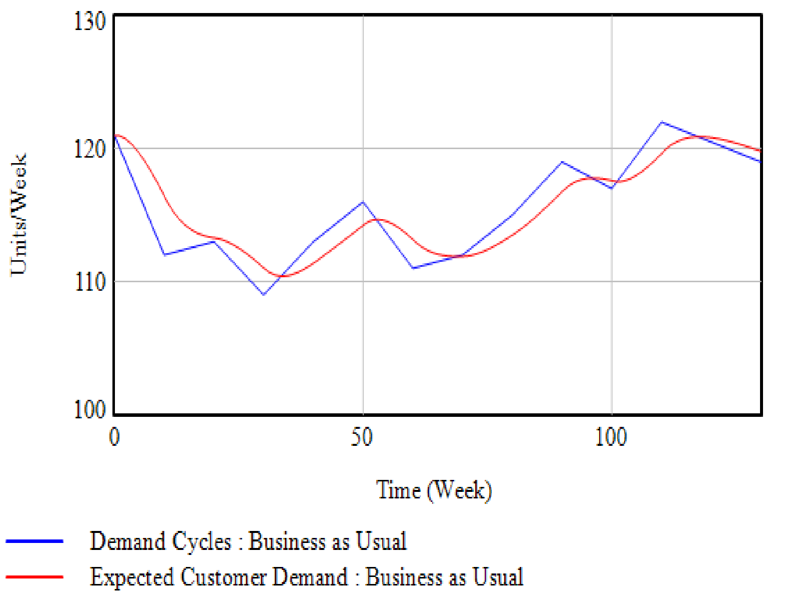
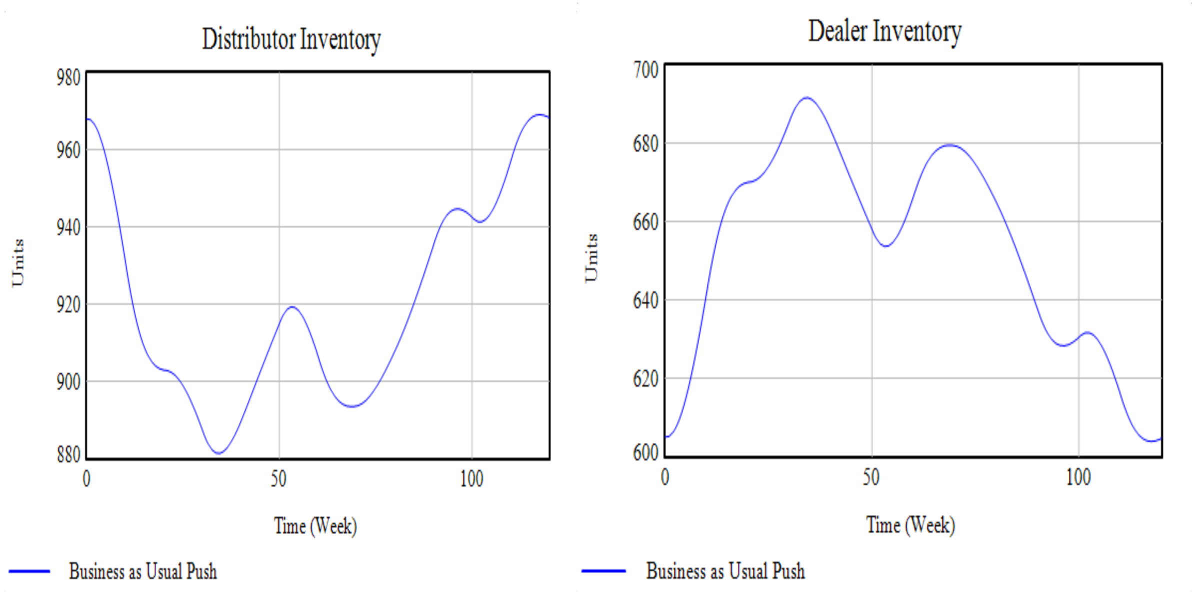


FIGURE 5. 4. CUSTOMER DEMAND AND SMOOTHED CUSTOMER DEMAND

5.5 Model validation under push model for business as usual

Under this test, the push model is simulated with a demand pattern given that the smoothing parameter for customer demand is equal to six weeks. Figures 5.4 displays the results from the first simulation run under this pattern. Customer demand starts at 121 units per week before gradually decreasing to the lowest of 70 units/week and then fluctuates to 130 units/week this pattern repeats for the rest of simulation. In Figure 5.5 (a) the distributor inventory drops and 5.5 (b) the dealer inventory increases after 121 weeks and fluctuates till the end of the simulation in converse dealer inventory increases and fluctuates till the end of the simulation time at week 130 as sales rate is unstable and unpredictable. In Figure 5.6 the dealer order fulfilment rate and distributor order fulfilment rate show evidence of amplification and instabilities. The underlying reason for this situation is the negative feedback and delay in the ability to fulfil demand as the shortest possible time.

The demand continues fluctuating, therefore in the graph the fluctuations in the distributor inventory, dealer inventory, distributor order fulfilment rate, dealer order fulfilment rate and sales rate continue till the end of the simulation at week 130 but the inflow and outflow as seen in the graphs does not exceed the levels of inventory.



a **b**

FIGURE 5. 5. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER PUSH MODEL

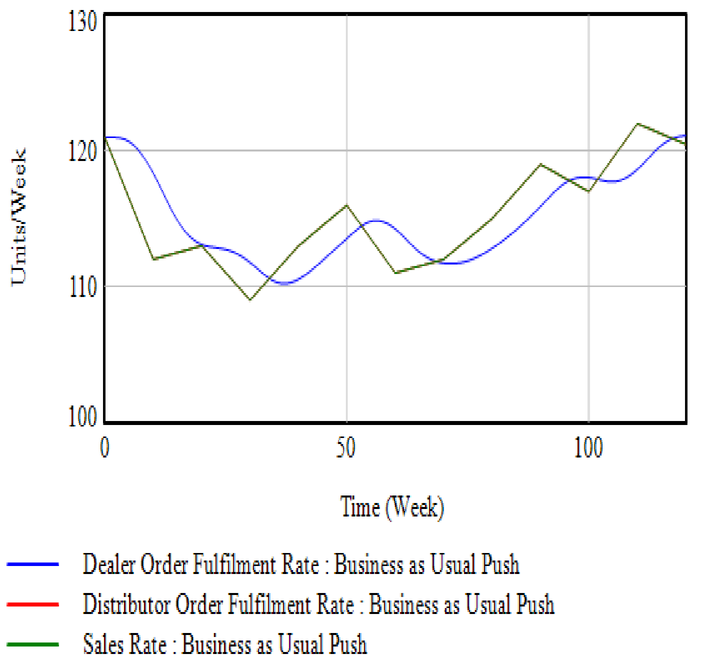
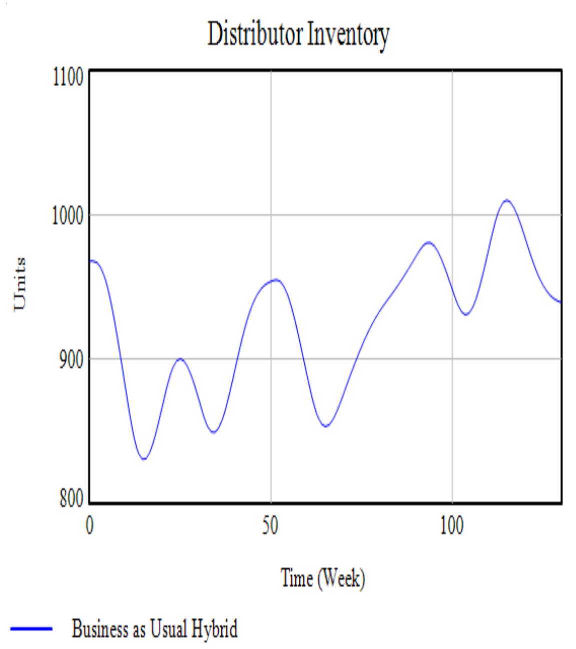


FIGURE 5. 6. EFFECT OF BAU DEMAND ON INFLOWS AND OUTFLOWS RATE UNDER PUSH MODEL

5.6 Model validation under hybrid push/pull model for BAU demand pattern

The results from the simulation runs for the hybrid push/pull model in this demand pattern is depicted in Figures 5.7 (a) and 5.7 (b). The fluctuations at the distributor inventory and dealer inventory continues throughout the period with this demand pattern as a result of delays in fulfilling orders. The fluctuations and instabilities in the inventory level are severe throughout the simulation in both graphs.



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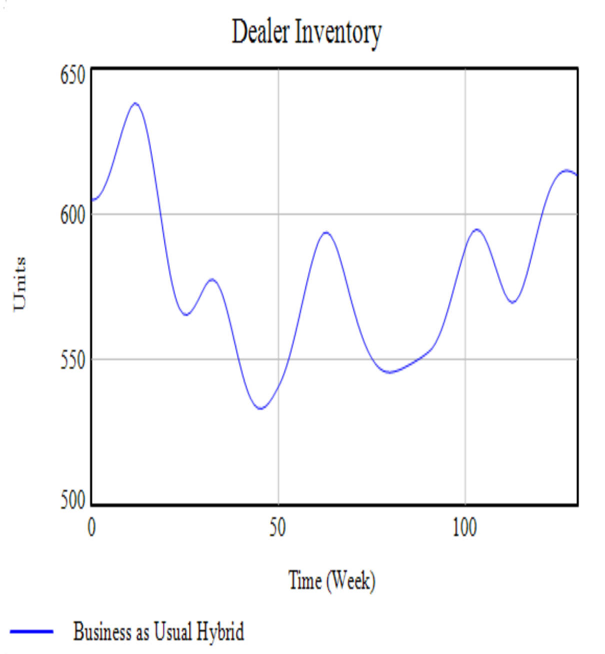

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FIGURE 5. 7. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER HYBRID PUSH/PULL MODEL

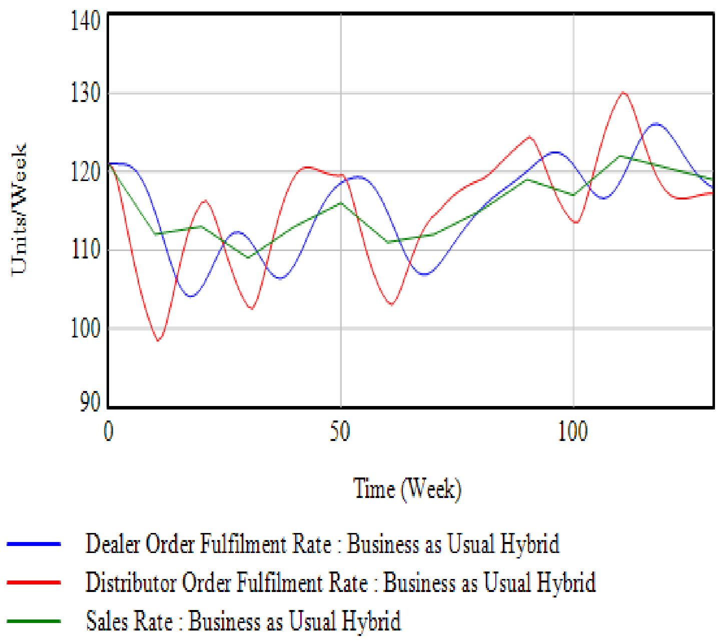


FIGURE 5. 8. EFFECT OF BAU DEMAND ON THE INFLOWS AND OUTFLOWS UNDER HYBRID PUSH/PULL MODEL

The inventory level oscillates more in the hybrid push/pull model in comparison to the push model under same demand pattern. The transition between the push and pull in this model have caused delays in adjusting the inventory level. Figure 5.8 shows that the inflow and the outflow is still below the inventory levels. Despite this, the behaviour observed complies with the validation purpose.

5.7 Direct structure tests for optimistic demand pattern

The second dynamic demand pattern is the optimistic demand pattern. The models are tested against the same purpose as in the test with business as usual demand pattern. Figure 5.9 depicts the optimistic demand and the smoothed optimistic demand employed in the test and analysis. The expected observation is that the model output will reproduce an increase pattern from the initial period at 0 weeks of 121 units/week and continues increasing upward till the end of the simulation. During the period of increasing demand there will be some instabilities and increase that carries through to the end of the simulation. These insights on the effect of delays and the instabilities of the system during a sudden rise in demand, may offer some help to managers for better policy implementation.

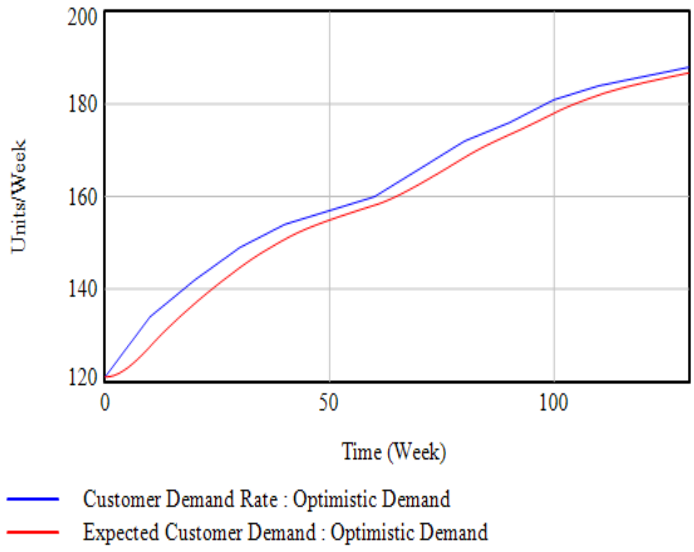
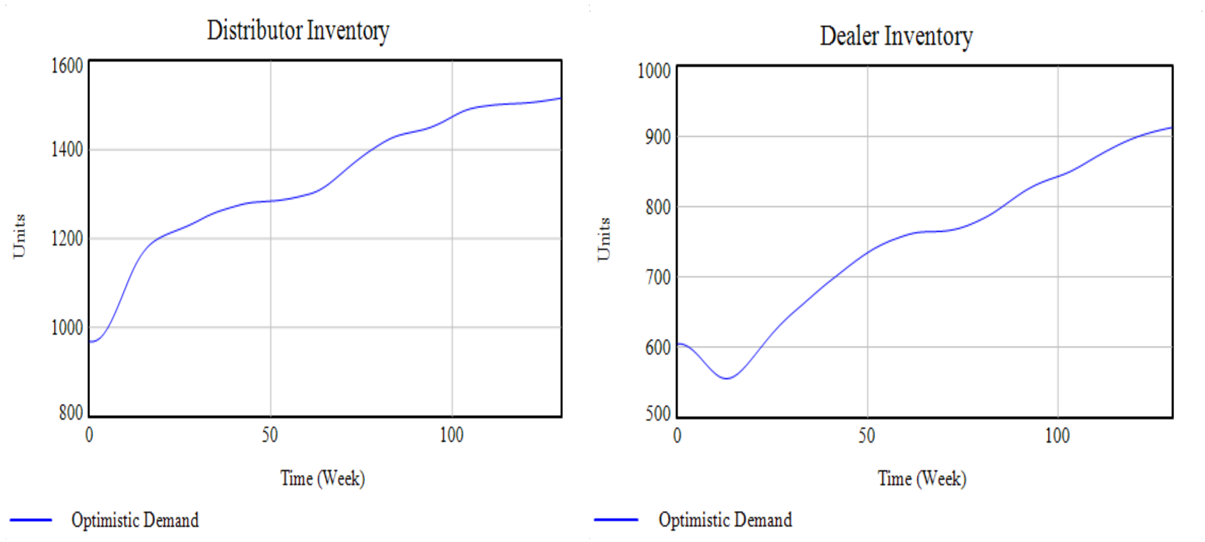


FIGURE 5. 9. OPTIMISTIC DEMAND AND SMOOTHED OPTIMISTIC DEMAND

5.8 Model validation under push model for optimistic demand

The optimistic demand is shown in Figure 5.9. As smoothing is applied, the demand pattern is smoother given the smoothing parameter is equal to six weeks. The distributor inventory builds up as the demand increases as shown in figure 5.10 (a). The dealer inventory gradually drops in about week 15 and gradually increases in a slight unstable pattern till the end of the simulation seen in Figure 5.10 (b). With safety stock coverage set to three weeks, the inventory level shows an excess of three-week inventories; many times, the level of customer demand. Nonetheless, the distributor order fulfilment rate, dealer order fulfilment rate and sales rate are persistently below the inventory. As such, it complies with the validation purpose.

In Figure 5.11, distributor order fulfilment rate, dealer order fulfilment rate, sales rate produces behaviour at almost the same level. However, the discrepancy between the inflow and the outflow rate has resulted in an increment in the distributor inventory and dealer inventory, respectively.



a **b**

FIGURE 5. 10. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER PUSH MODEL

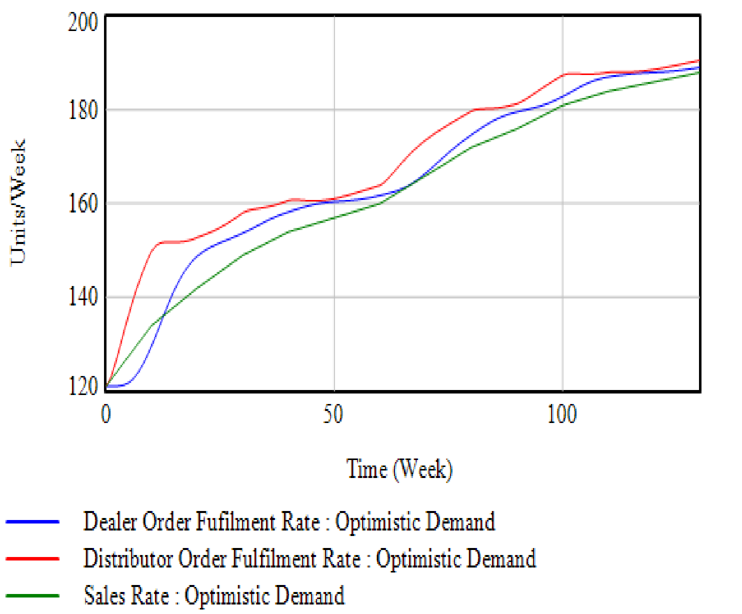


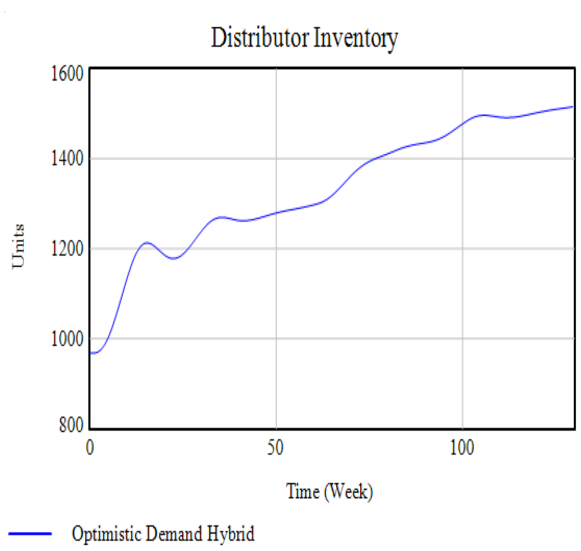
FIGURE 5. 11. EFFECT OF OPTIMISTIC DEMAND ON INFLOWS AND OUTFLOW RATES UNDER PUSH MODEL

The behaviour displayed in the model is a result of negative feedback value in the system. These values should be decided by the management to decide upon for their operations. As mentioned by Coyle (1977), longer delays in a negative loop structure will reduce the ability of a system to dampen amplification. While in general a more stable system is desired by companies, delays in responding to changes in demand increases bottleneck. This result typically complies with the validation purpose.

The analysis of the push model in the test with the optimistic demand may not result in any significant instability in the system. At the end, a cost analysis will reveal the impact of the model's response towards the total costs and profit and cash balance, which can offer further understanding to managers about real consequences.

5.9 Model validation under hybrid push/pull model for optimistic demand

The hybrid push/pull model is a combination of push and pull process. For this reason, the assumption for the hybrid push/pull model's behaviour is that it will reflect both the performance of the push and pull model across the analysis. Figure 5.12 (a) and (b) illustrates the distributor inventory and dealer inventory of the hybrid push/pull model.



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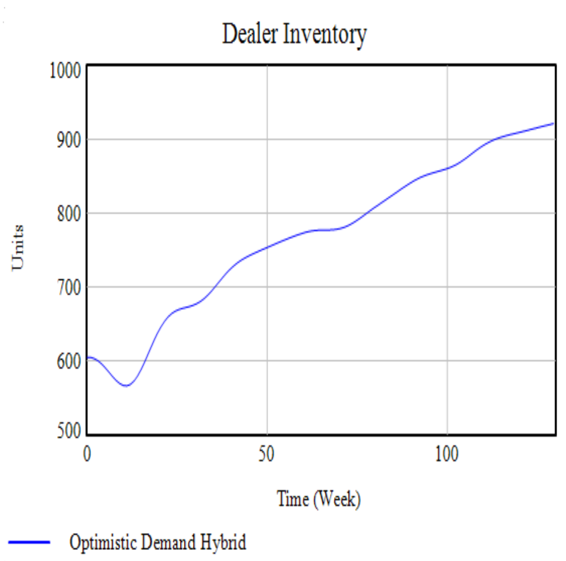

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FIGURE 5. 12. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER HYBRID PUSH/PULL MODEL

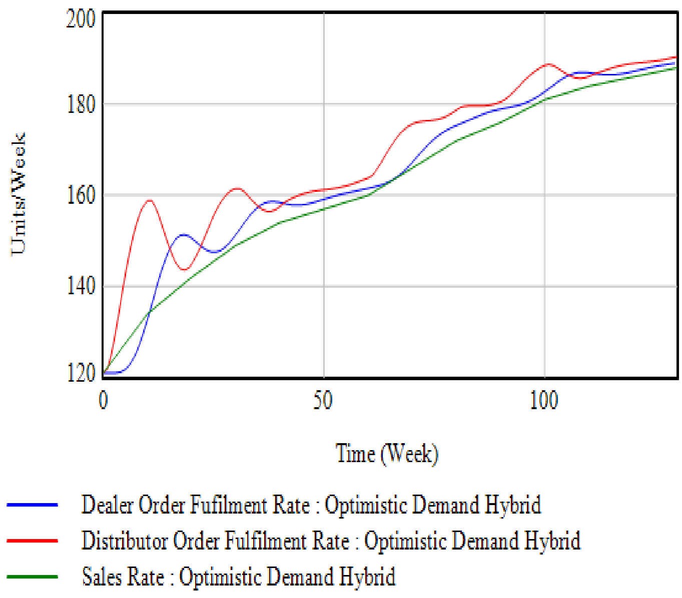

FIGURE 5. 13. EFFECT OF OPTIMISTIC DEMAND ON INFLOW AND OUTFLOW UNDER HYBRID PUSH/PULL MODEL

As seen in Figure 5.12 (b) the dealer inventory decreases after week 5 then gradually increases until the end of the simulation at week 130 the reason of this is the negative feedback. In Figure 5.12 (a) the distributor inventory increases after week 5 and keeps that pattern till the end of the simulation at week 130. The dealer order fulfilment rate is increased by the operation of push process from the distributor inventory that increases inventory in the system as shown in Figure 5.12 (a) and (b), and 5.13. The dealer order fulfilment rate is showing volatility as it is influenced by the dealer order cycle time. Despite the less oscillatory pattern in the distributor inventory and dealer inventory, the graphs show an increasing pattern and a slight jagged pattern all the way to the end of simulation. From the perspective of validation purpose for this research, the inflow and outflow rate does not exceed the inventories.

5.10 Direct structure tests for pessimistic demand

The third test is performed with a pessimistic demand pattern. It is worth observing the model behaviour under this test as well as validating the models in this case. When demand drops rapidly in the real world, the members of a supply chain tend to reduce inventory levels further to eliminate unnecessary costs for carrying inventories. Dooley et al. (2010), in their research to identify the bullwhip effect in the manufacturing sector during the recessionary period 2007-2009, conclude that the downstream is unresponsive to customer demand, which results in delays and drastic responses during the downturn period. This action caused further stress to cope with the uncertainties in the demand. During a recession, companies must cope with a sudden loss in sales as well as struggling with employee pay, which eventually can lead to massive layoffs. Many possible actions are considered during a depression period which can offer reduced costs and, most importantly, survival. Therefore, this test, although it may not reflect the exact response of the entire system, will provide some insights into how different policies can cope with an economic downturn. Figure 5.14 displays the pessimistic demand pattern and smoothed pessimistic demand in the analysis. In the next sections, the discussion of the analysis focuses on the validation of the behaviour against the validation purpose as outlined before. The model's response towards the pessimistic demand is also discussed.

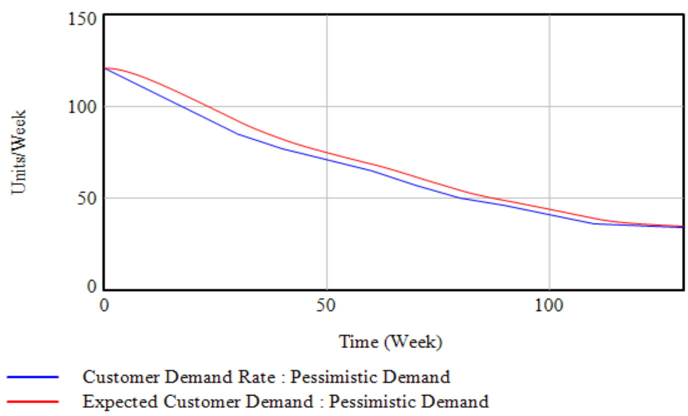

FIGURE 5. 14. PESSIMISTIC DEMAND AND SMOOTHED PESSIMISTIC DEMAND

5.11 Model validation under push system for pessimistic demand

The push model outputs show the effect of delays in the model. Adjustment time, commonly determined by managers to provide a time frame for inventory in order to adjust to changes in demand, results in unresponsiveness in the model therefore, the model outputs are insensitive to changes to adjustment time. The consequence of this action under pessimistic demand is a dramatic increase in the level of inventory in the dealer presented in Figure 5.15 (b). Conversely, in the test under optimistic demand pattern, the effect of this delay is insensitive. The response of the distributor and dealer to reducing demand is reflected in Figure 5.15 (a) and 5.15 (b), with the condition that the dealer order fulfilment cycle time is eight weeks and safety stock coverage three weeks. Commencing at about week five, the dealer order fulfilment rate is not responsive to a further decline in the sales rate.

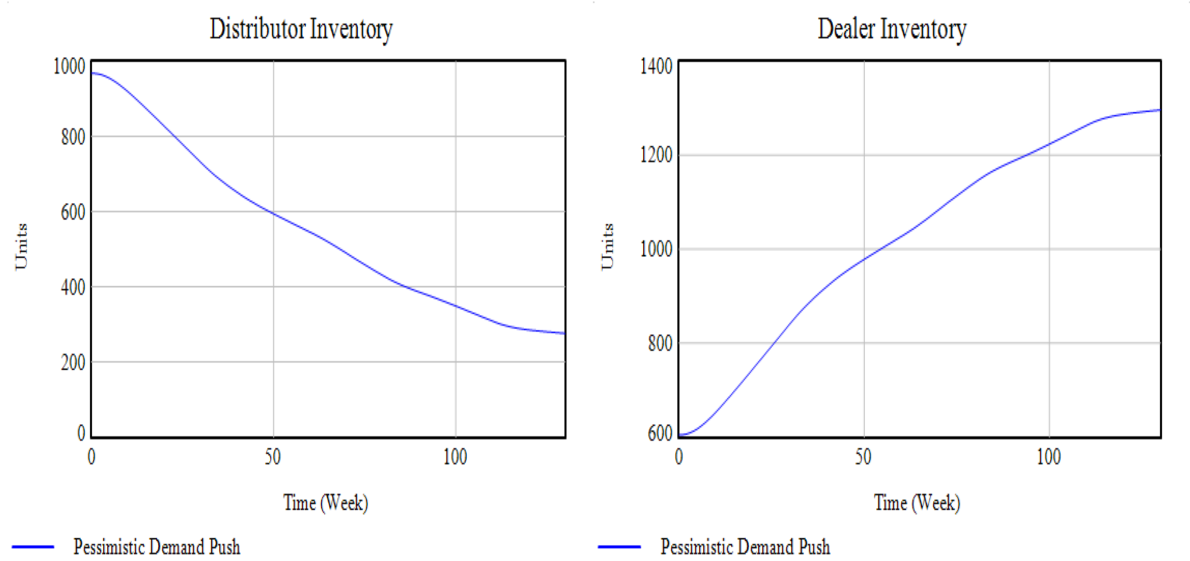

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FIGURE 5. 15. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER PUSH MODEL

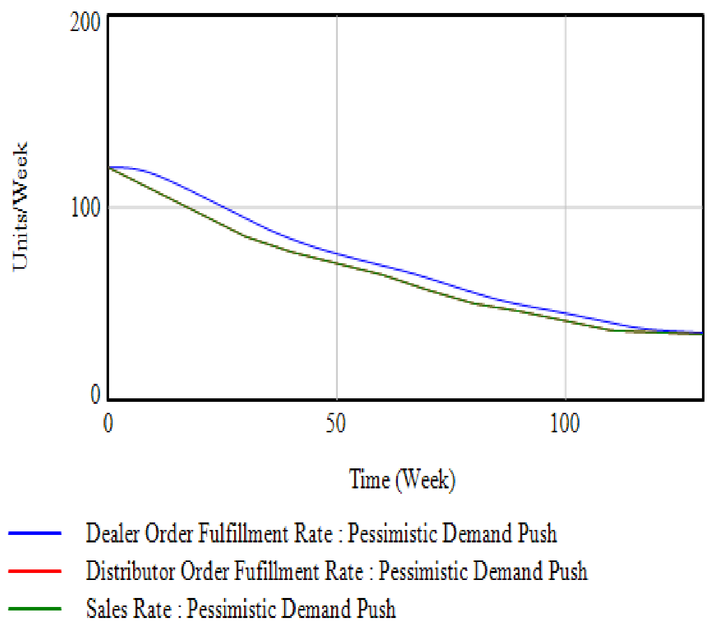


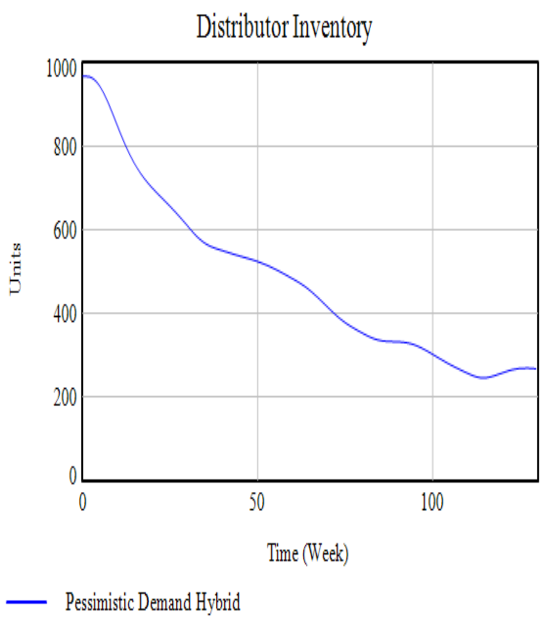
FIGURE 5. 16. EFFECT OF PESSIMISTIC DEMAND ON INFLOW AND OUTFLOW RATE UNDER PUSH MODEL

The amplification of the dealer order fulfilment rate during this period increases the dealer inventory level. As seen at the start of the simulation, the dealer inventory gradually increases far more than sales rate. Although the sales rate keeps reducing, the distributor order fulfilment rate declines at the same rate of sales rate, and gradually decreases below dealer order fulfilment rate depicted in Figure 5.16. This result is consistent with the findings of Morecroft (1980). He concluded that MRP installed within a typical business environment causes a fluctuation and instability in the rate and stock level. To reflect this observation, the dealer order fulfilment rate causes more instability to the dealer inventory compared to the sales rate.

Simultaneously, the reduction of sales rate does not exceed the dealer inventory level. The distributor is more responsive in comparison to the dealer resulting from the discrepancy. In conclusion, the behaviour of the push model under the analysis with pessimistic demand is less satisfactory but is in accordance with the validation purpose.

5.12 Model validation under hybrid push/pull model for pessimistic demand

Figures 5.17 (a), and (b), and 5.18 presents the effect of pessimistic demand on hybrid push/pull model. The results under pessimistic demand in the hybrid push/pull system are not like the findings in the push model. The underlying reason is that a pull structure is applied at the dealer. Nonetheless, different outcomes are observed in the system. As the dealer order fulfilment rate is almost at the same rate of distributor order fulfilment rate, the decline of inventory persist and visible. The dealer inventory level slightly increases after week five to about week twenty then inclines downward till the end of the simulation. This result is in contrast with the push model in the previous section, which justifies that pull process has a more dominant effect at this stage, despite push being applied.



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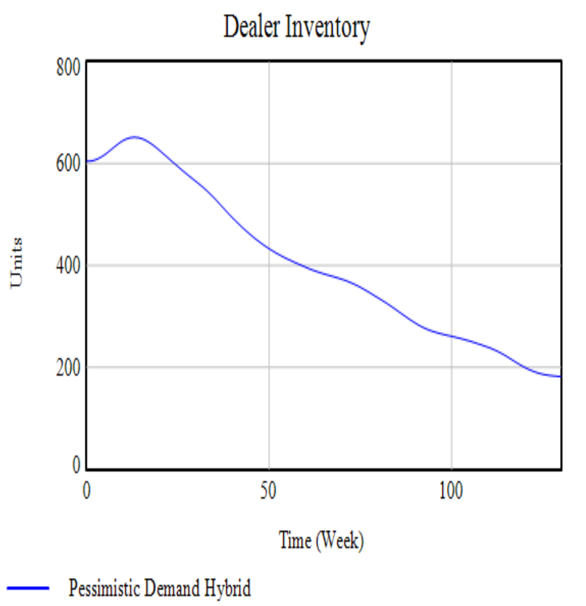

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FIGURE 5. 17. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR AND DEALER INVENTORY UNDER HYBRID PUSH/PULL MODEL

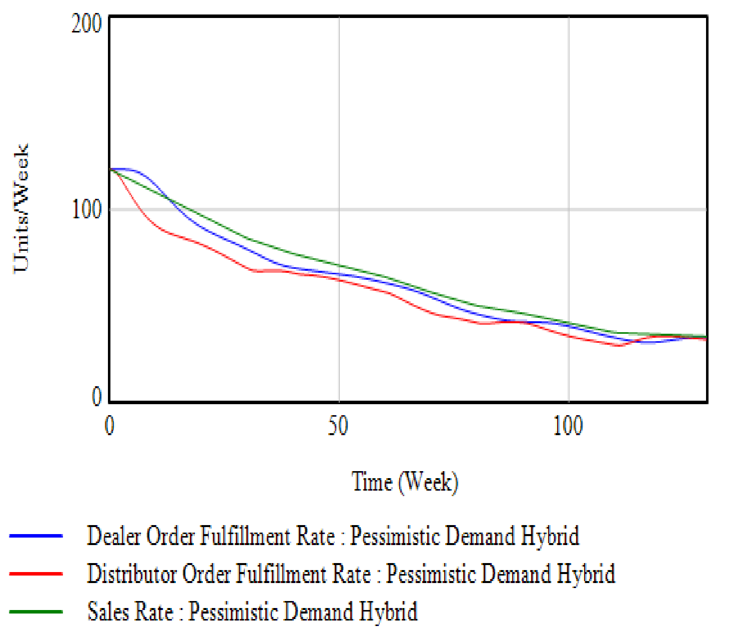


FIGURE 5. 18. EFFECT OF PESSIMISTIC DEMAND ON INFLOW AND OUTFLOW UNDER HYBRID PUSH/PULL MODEL

As depicted in the graphs the distributor order fulfilment rate, dealer order fulfilment rate and sales rate are consistently below both distributor and dealer inventory level. At this point it can be said that the model behaviour is in accordance with the validation purpose.

5.13 Comparative analysis of the push and hybrid push/pull inventory models

The focus of the discussion in this section is to interpret the results from a comparative analysis perspective in the two models. In the previous section, the behaviour of the two models at the distributor and dealer have been thoroughly discussed and validated for this research. Again, it is however important to stress that this research is performed on a case study basis to run a series of structure tests to build up confidence in the models for the managers. These tests validate that the structure of the model can produce the behaviour that emerges from a theoretical understanding of the system and real world. Now that the models have been validated, it is appropriate to continue the analysis on the inventory level of both the distributor and dealer in the two models to identify the impact on stock control and financial performance from the application of different supply chain policy alternatives.

The results of the first analysis are obtained from the simulation run with the smoothing parameter equal to six weeks. An extensive analysis has been performed to examine the behaviour of the models to a shorter smoothing parameter and this task was carried out with the agreement of the managers. In the second analysis, the smoothing parameter is set to only two weeks, which means that the demand is smoothed over one-third of the time the idea behind this is to create a quick response in smoothing any changes in the demand. This analysis is relevant in providing an insight into how the company might respond if managers tried to reduce the smoothing time in responding to customer demand. The results from the simulation runs are presented in the following sections for both values of the smoothing parameters.

5.14 Analysis of inventory levels of BAU demand

The inventory level has been presented at each stage of the distributor and dealer for each model in the analysis for validation purposes. However, it is difficult to compare the state of the inventories given the separate graphs. For this reason, the results from each model are now assembled in a single graph to provide a clear picture of how the models differ from one another. Figures 5.19 (a), and (b), and 5.20 (a) and (b) presents the results from the simulation with different smoothing parameter values. In the first graph, given the smoothing parameter equals six weeks, the distributor inventory and dealer inventory show a delay in adjusting to the desired level of inventory.

The hybrid push/pull model is imitating the behaviour of the pull system at dealer level, since pull is applied at the dealer while imitating push process at the distributor. The push model displays an uneven increase and with slightly less oscillatory pattern, whereas in the hybrid push/pull model the inventory level is more oscillatory in the distributor inventory compared to the push model but higher in the dealer.

In contrast, when the smoothing parameter is shortened to two weeks, the inventory level retains its pattern, with a slight a decrease of inventory levels as displayed in Figures 5.20 (a) and (b). The implication of this behaviour is that when the smoothing constant is increased companies may have the desired inventory level to fulfil customer demand but at the cost of increasing the oscillations in the system (Coyle, 1977). For this reason, the smoothing parameter was decreased for further simulation runs.

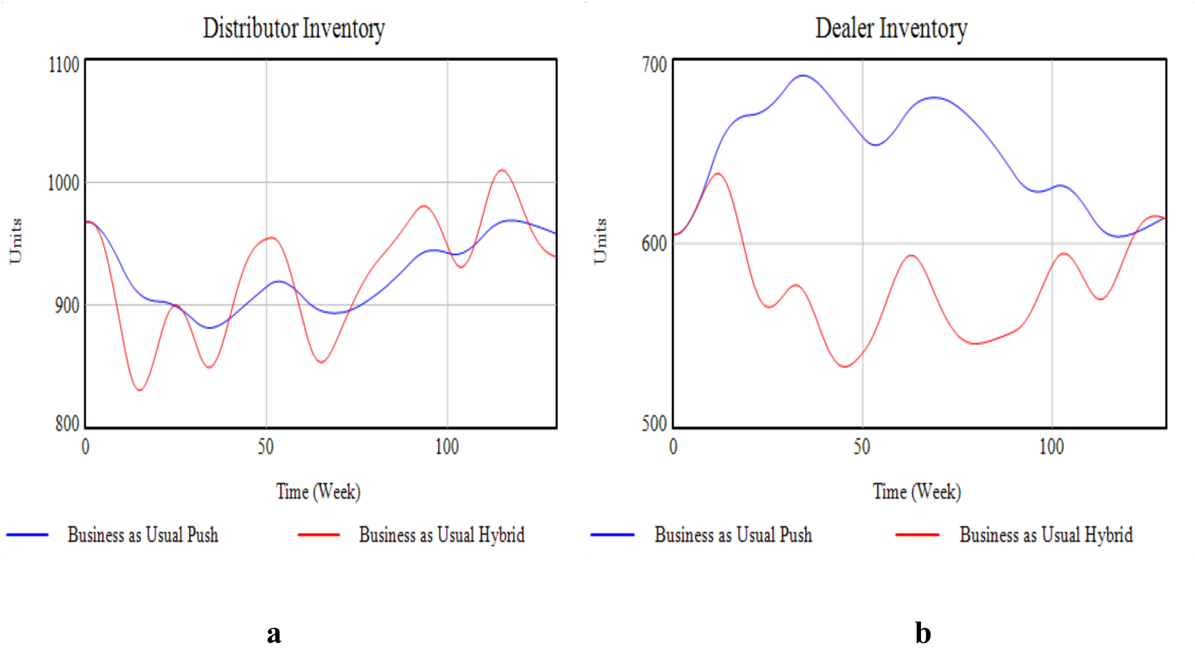
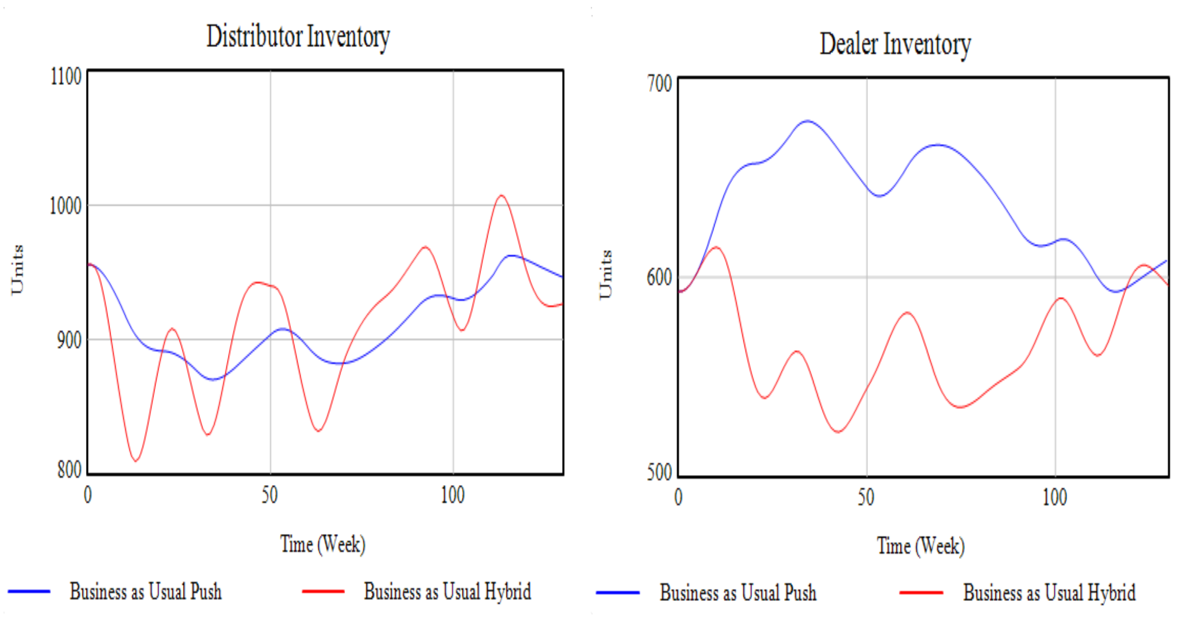


FIGURE 5. 19. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING VALUE OF SIX WEEKS



a **b**

FIGURE 5. 20. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING VALUE OF TWO WEEKS

The behaviour across the two models displays a slight difference at the distributor and dealer inventories in the level of oscillations, as shown in Figures 5.20 (a) and (b) as compared to Figures 5.19 (a) and (b). In Figure 5.19 (b), the push model holds higher dealer inventory. One of the main objectives in a push model operation is to increase the amount of inventory (Chang and Yih, 1994a; Monden, 1993). From this result, push model on its own, without policies that reflect the Just-In-Time philosophy, leads to excessive stock holding. Ohno (1988) emphasised the importance of level of inventory for a successful implementation of the JIT system. In this research, the push model is purposely synchronised with the hybrid push/pull model for a valid comparison.

The adjustments of inventory for the hybrid push/pull model, to determine the maximum inventory level at both the distributor and dealer are constantly varied in accordance with the adjustment of inventory in the push model. In addition to this, the safety stock coverage is also considered in determining the maximum inventory level. As a result, the dealer order fulfilment rate fluctuates and increases to achieve the changing level of desired inventory. This explains the higher level of dealer inventory in the push system as shown in Figures 5.19 (b) and 5.20 (b) above. For this reason, the policies on minimum inventory levels, safety stock coverage and delivery delays (cycle time) from suppliers need to be carefully considered by the managers to achieve the benefits of push and hybrid push/pull models.

5.15 Analysis of inventory levels for optimistic demand

In this section, the results from the simulation run with optimistic demand are discussed by highlighting the distinctions in the two models' behaviour and the sensitivity towards the changed smoothing parameter value. The model exhibits slight variations between the push and hybrid push/pull model as shown in Figures 5.21 (a) and (b), 5.22 (a) and (b). The hybrid push/pull model displays a slight unsteady pattern in both tests with smoothing parameter of six weeks and two weeks although more unsteady pattern in the distributor inventory than the dealer inventory. This result also reveals that the decision to reduce the response time to customer demand during a gradually increasing demand pattern does not trigger additional oscillations in the system.

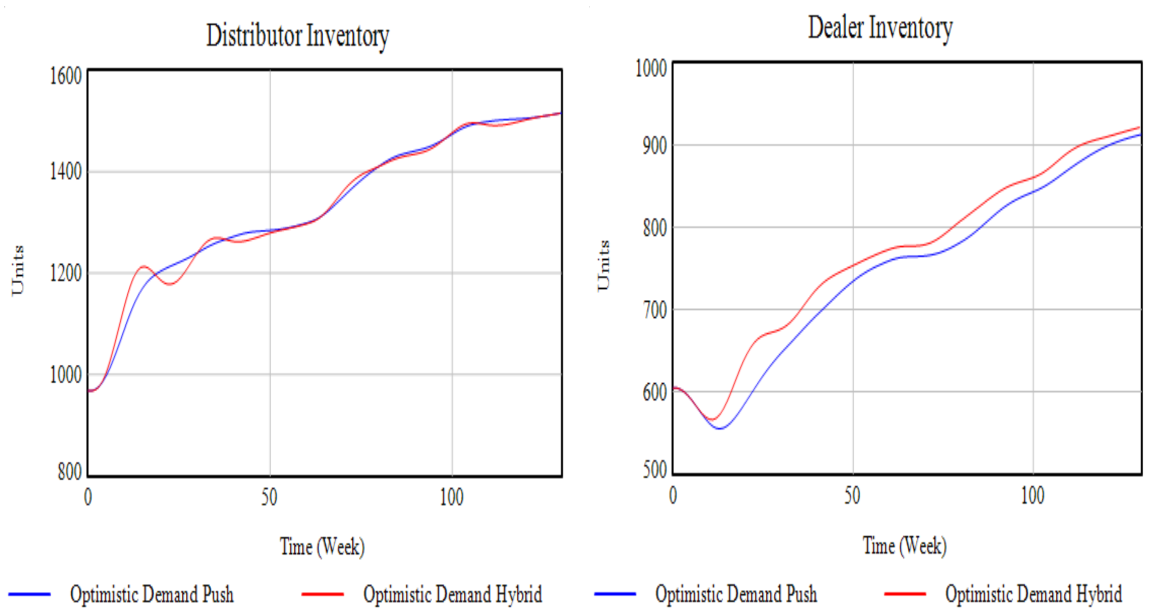


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FIGURE 5. 21. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF SIX WEEKS

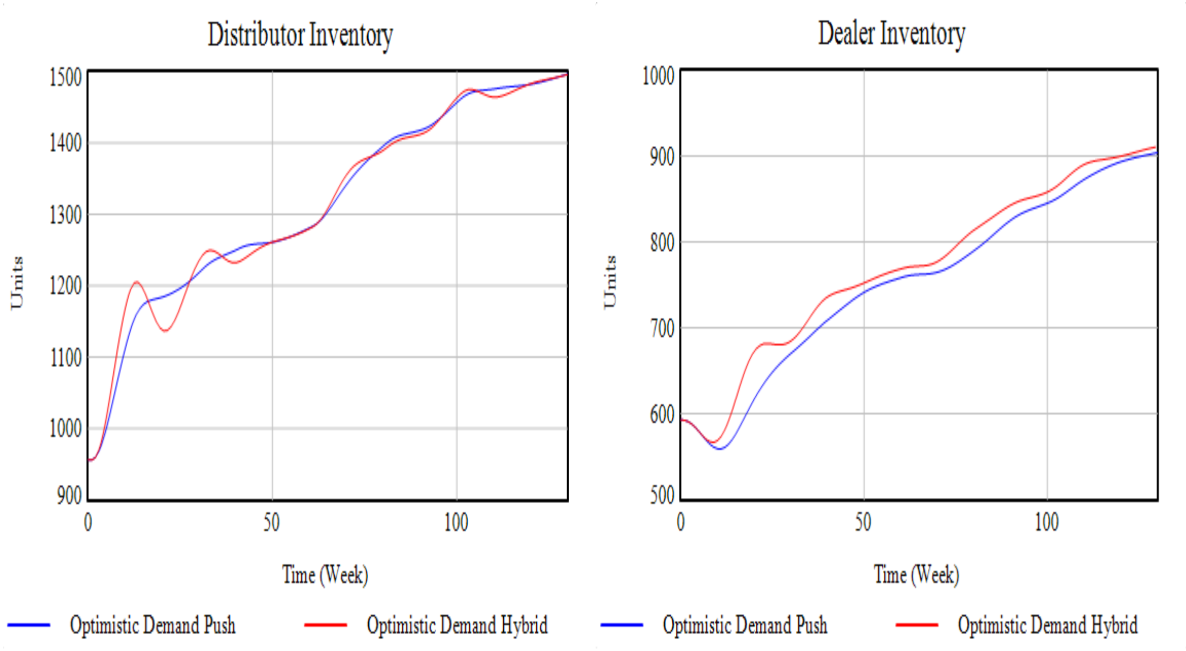

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FIGURE 5. 22. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF TWO WEEKS

In summary, a shorter smoothing time slightly decreases the time taken by the models to adjust to the desired inventory level i.e. insensitive. At this point, the managers should strive to act at the shortest time in adjusting and smoothing demand.

5.16 Analysis of inventory levels for pessimistic demand

Figures 5.23 (a), (b), and 5.24 (a), and (b) presents the inventory levels under pessimistic demand pattern with a different smoothing parameter. In the following graphs, the hybrid push/pull model has the lower inventory level. The major influence of the reduced smoothing parameter is a reduced difference in the inventory level in the graphs however in Figure 5.23 (b) there is a significant increase in inventory level at the dealer as seen in the push model.

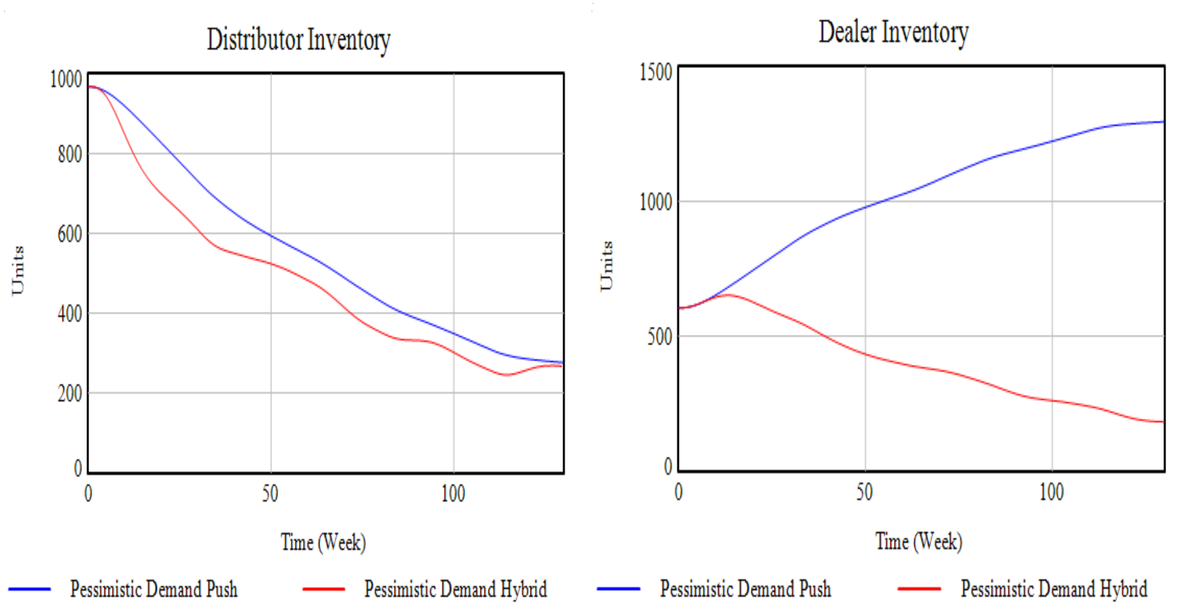

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FIGURE 5. 23. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF SIX WEEKS

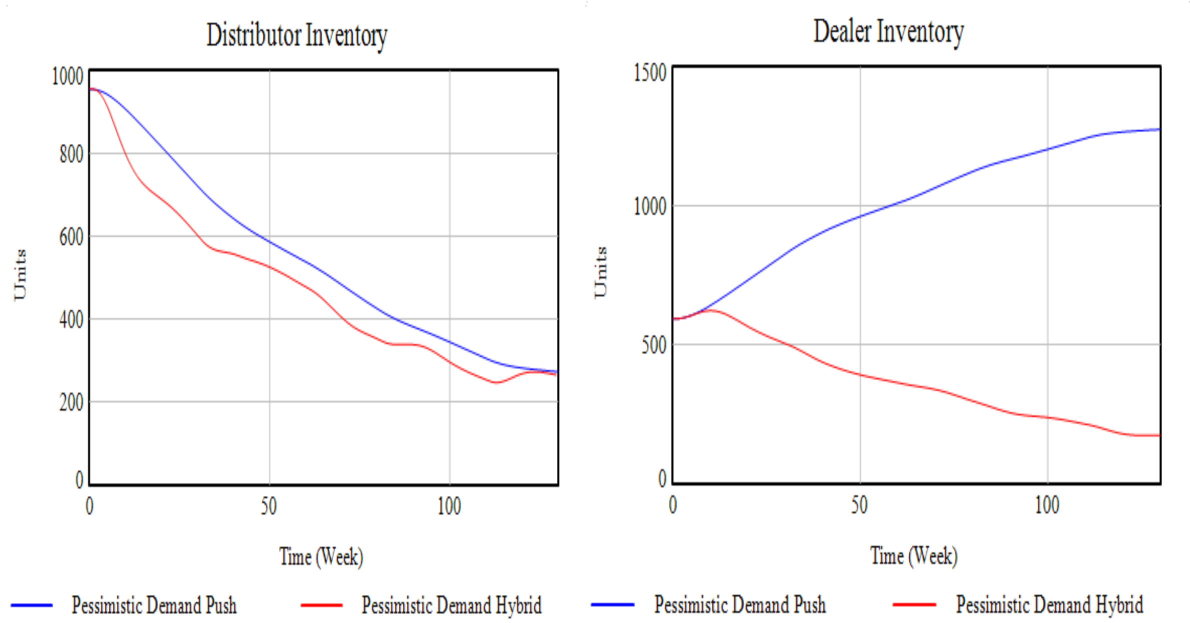

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FIGURE 5. 24. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF TWO WEEKS

As the delay is shortened in smoothing customer demand, the difference between the inventory levels is slightly affected as well as the time taken to adjust to the desired inventory level. A larger value for the smoothing parameter widens the gaps in the inventory levels in the two models, while the smaller smoothing parameter value slightly reduces this gap. Therefore, the hybrid push/pull system has lower inventory as compared to the push model.

A shorter smoothing parameter means that the hybrid push/pull model responds more quickly to customer demand especially in the dealer inventory. In other words, the replenishment discrepancy and the safety stock can be further reduced, almost being equivalent to the actual demand, which may result in a lower inventory level. This means that managers should consider carefully in reducing safety stock coverage because the ability of the company to fulfil customer demand in the hybrid push/pull model may decline, that can result in an unfilled order. On the other hand, the push model has a constant value for inventory coverage despite the demand pattern. This is beneficial for coping with changes during the period of increasing demand, allowing any possibility of unfilled order to be further reduced.

5.17 Summary of the inventory levels

This section summarises the graphical results from the simulation by presenting average inventory levels at the distributor and dealer. In the previous section, some of the results displayed minor differences in the two models between the distributor and dealer inventories. For this reason, the following numerical results provide a clearer picture of the performance of each of the models. Table 5.3 presents the test results of the business as usual demand of distributor and dealer inventory level. In test 1, where the smoothing parameter is equal to six weeks, the Hybrid push/pull model has slightly higher level of distributor and dealer inventories. Although the push model has lower average level of inventory, this result explains a possibility of insufficient inventories. Subsequently, the test with business as usual demand under the push model returns the best level of performance in the demand pattern. It responds slightly well to changes in demand and at the same time can keep inventories low.

Test 1: Business as Usual, smoothing parameter = 6 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	968	604
Hybrid Push/Pull	984	597
Test 2: Business as Usual, smoothing parameter = 2 weeks		
Push	1019	581
Hybrid Push/Pull	1024	586

TABLE 5. 2. EFFECT OF BAU ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

In the case where the managers decided to respond to changes in demand swiftly (Test 2) with a smoothing parameter of two weeks the inventory level is slightly reduced in the two results of the models with the hybrid push/pull model having slight more level of inventories as seen in Table 5.2. Under the test with optimistic demand with smoothing parameter of six weeks and two weeks, the results exhibit a similar pattern to the test under business as usual demand. Table 5.3 displays the push model still with a lower inventory level. These results also illustrate that the push model copes well with optimistic demand, showing slight lower inventories compared to the hybrid push/pull model therefore there is a close similarity between the results of the business as usual and optimistic under the push and hybrid push/pull model.

Test 3: Optimistic demand, smoothing parameter = 6 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	1518	894
Hybrid Push/Pull	1524	904
Test 4: Optimistic demand, smoothing parameter = 2 weeks		
Push	1501	889
Hybrid Push/Pull	1514	895

TABLE 5. 3. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

Contrary results emerge in the test with pessimistic demand in test 5. Table 5.4 demonstrates that the push model has higher level of distributor inventory and significant higher inventory level at the dealer when smoothing constant is at six weeks, which is opposite to the observation in the previous tests in experiment 1 to 4. Therefore, the effect of pessimistic demand pattern to the hybrid push/pull model is the lower inventory level in the distributor and dealer inventories. In previous tests, the push model copes well with business as usual and optimistic demand but performs poorly in pessimistic demand. In test six where the smoothing constant is equal to two weeks. Therefore, the result of Table 5.4 reveals that reducing the response time to demand changes under a pessimistic demand pattern still have significant higher dealer inventory level in the push model. Conversely, the hybrid push/pull model now has lower number of inventories in the distributor in comparison to the push model which displays significant higher inventory levels in test 6.

Test 5: Pessimistic Demand, smoothing parameter = 6 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	281	1291
Hybrid Push/Pull	253	189
Test 6: Pessimistic Demand, smoothing parameter = 2 weeks		
Push	278	1270
Hybrid Push/Pull	254	181

TABLE 5. 4. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

Tables 5.5 and 5.6 summarise the overall performance of the two models with smoothing parameter of six weeks and two weeks. The distributor inventory and dealer inventory are measured based on the average inventory level at the end of the simulation at week 130. From the tables, the model that has highest level of inventory is marked with H. Conversely, results having lowest level of inventory are marked with L. From these results, the model with the highest (H) level of inventory are highlighted with a blue background; this indicates that the model is not coping well with that particular demand pattern while the model with the greatest number of L (lowest) for the levels of inventory is highlighted with a light green background; this indicates that this particular system is performing better in comparison with the other models.

Demand Pattern	Business as Usual		Optimistic Demand		Pessimistic Demand	
Inventory Level	DIINV	DEINV	DIINV	DEINV	DIINV	DEINV
Push	L	L	L	L	H	H
Hybrid Push/Pull	H	H	H	H	L	L

DIINV- Distributor Inventory **DEINV-Dealer Inventory**

H-High L-Low

Best Performance Worst Performance

TABLE 5. 5. OVERALL PERFORMANCE OF THE PUSH AND HYBRID PUSH/PULL MODELS WITH SMOOTHING PARAMETER OF SIX WEEKS

Demand Pattern	Business as Usual		Optimistic Demand		Pessimistic Demand	
Inventory Level	DIINV	DEINV	DIINV	DEINV	DIINV	DEINV
Push	L	L	L	L	H	H
Hybrid Push/Pull	H	H	H	H	L	L

DIINV- Distributor Inventory **DEINV-Dealer Inventory**

H-High L-Low

Best Performance Worst Performance

TABLE 5. 6. OVERALL PERFORMANCE OF THE PUSH AND HYBRID PUSH/PULL MODELS WITH SMOOTHING PARAMETER OF TWO WEEKS

The results presented in this section portray the different responses of the push and hybrid push/pull models for the first case study under a series of tests using different customer demand patterns. However, perhaps more useful measures are the total costs, profit and cash balance incurred as a result of the responses of the two models to the different customer demand patterns. Although the models have been marked with the highest or the lowest inventory, the differences in the generated can be minimal. The analysis of financial metrics is discussed in the next sections.

5.18 Overview of financial measure

The analysis of costs is a continuation of the performance measurements on inventory levels for case study A. This part of the analysis focuses on the impact of the inventory level on total costs, profit and cash balance. The carrying cost of inventory for company A is NGN20, 000/unit. The costs are analysed to give insights about the total costs of carrying inventory over the period of 130 weeks. This analysis is performed under the different demand patterns. Moreover, the purpose of this analysis is to show that financial measures can vary, despite the performance being displayed as shown in section 5.5.

It is important to note that once again the analysis is performed with a varying smoothing parameter to represent the different expectations of managers in respect to changes in demand. This parameter is, as before explained, incorporated in the customer demand smoothing structure in the two models. The first results show the outcome from the simulation runs with a smoothing parameter of six weeks. This period represents the usual time for managers to respond to changes in demand. The second set of results display the outcome from a test with the demand smoothing parameter reduced to two weeks the outcome from these two tests is now described in the next section.

5.19 Costs analysis of BAU demand under push and hybrid push/pull models

Figures 5.25, to 5.30 present the total costs, profit and cash balance in the test with the business as usual demand. There is a clear distinction between the behaviour of the total costs, profit and cash balance across the two models, as seen in the figures. The total cost of the hybrid push/pull model is higher and oscillatory but with more profit in the push model. This is in line with the findings from the analysis of the levels of inventory. The push model has lower inventory level under business as usual demand, in comparison to the hybrid push/pull model. This results in a lower total cost and with more profit and cash balance. Holding high inventory leads to high total costs in the hybrid push/pull model.

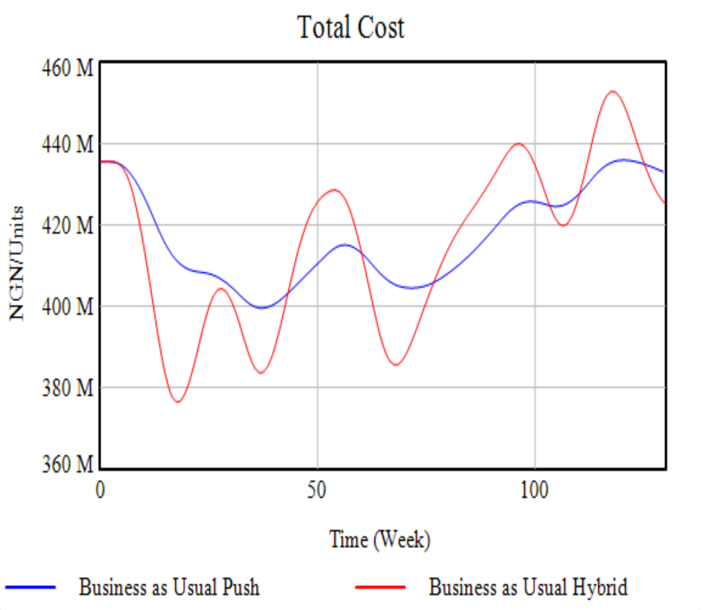


FIGURE 5. 25. EFFECT OF BAU DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER SIX WEEKS

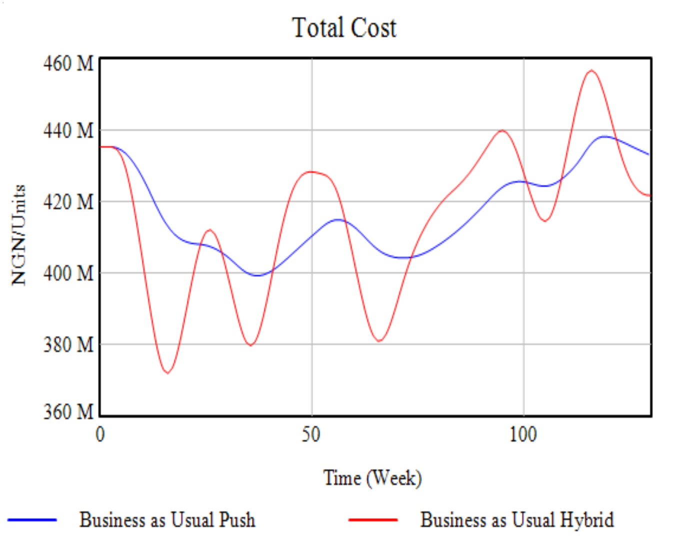


FIGURE 5. 26. EFFECT OF BAU DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER TWO WEEKS

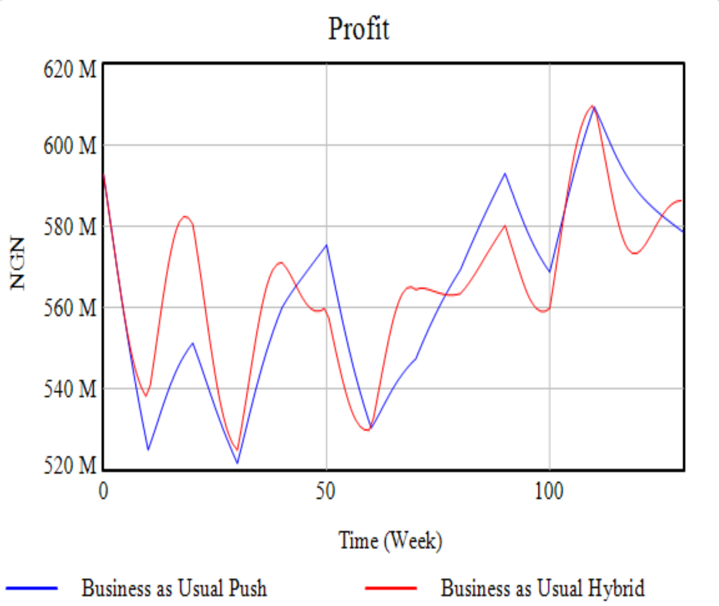


FIGURE 5. 27. EFFECT OF BAU DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

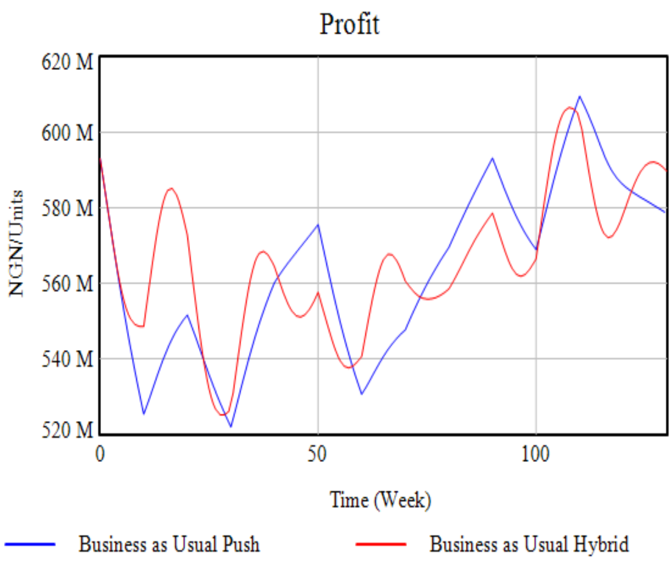


FIGURE 5. 28. EFFECT OF BAU DEMAND ON PROFIT WITH SMOOTHING PARAMETER TWO WEEKS

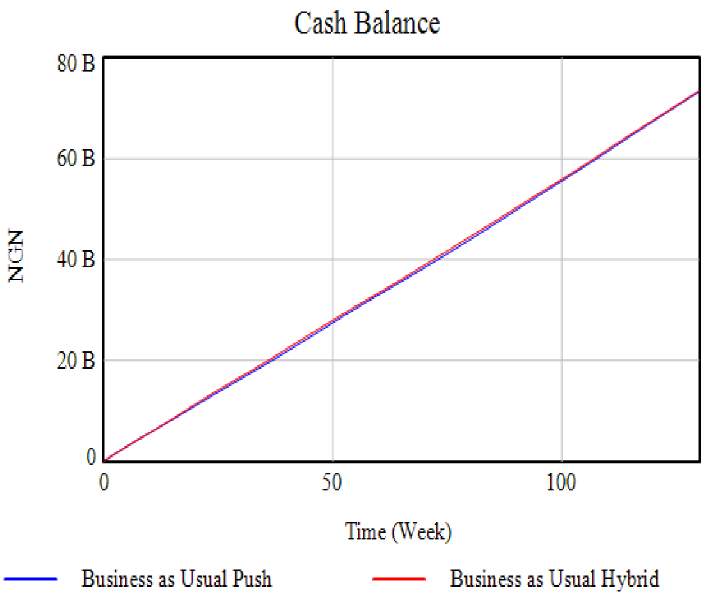


FIGURE 5. 29. EFFECT OF BAU DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

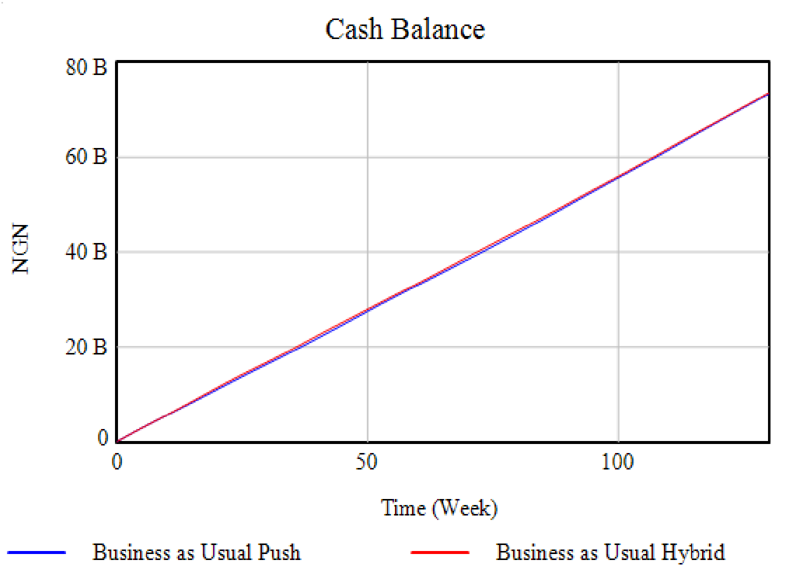


FIGURE 5. 30. EFFECT OF BAU DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

The final values of total costs, profit and cash balance in the push and hybrid push/pull models at week 130 are summarised in Table 5.8.

Business as Usual	Push	Hybrid Push/Pull
Smoothing Parameter = 6 Weeks		
Total Cost	445,785,000	447,653,000
Profit	623,347,000	607,696,000
Cash Balance	73,354,200,000	73,546,200,000
Smoothing Parameter = 2 weeks		
Total Cost	455,261,000	465,348,000
Profit	615,739,000	605,652,000
Cash Balance	73,363,200,000	73,595,300,000

TABLE 5. 7. EFFECT OF BAU DEMAND ON TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

From Table 5.7, the push model has slight lower total cost under the test with both a six weeks smoothing time and two weeks smoothing time with slightly more profit and cash balance. This result parallels the findings in the analysis of inventory levels. Therefore, the findings from this analysis suggest that a reduction in the smoothing value is that costs are lower when the managers respond faster to changes in customer demand.

5.20 Costs analysis of optimistic demand under push and hybrid push/pull models

Figures 5.31 to 5.36 illustrate the total costs, profit and cash balance of the models under optimistic demand pattern. Similar to the observation in the test with business as usual demand, the hybrid push/pull model has slight higher total costs, and slight lower cash balance and slight lower profit under optimistic demand in both test this result is similar to the findings of the business as usual in Figures 5.31, 5.33 and 5.35 and Table 5.8. The underlying reason is the lower level of inventory in the push model as compared to the hybrid push/pull model. The hybrid push/pull model exhibits slightly higher total costs. This is due to the lower level of inventory in Figure 5.32.

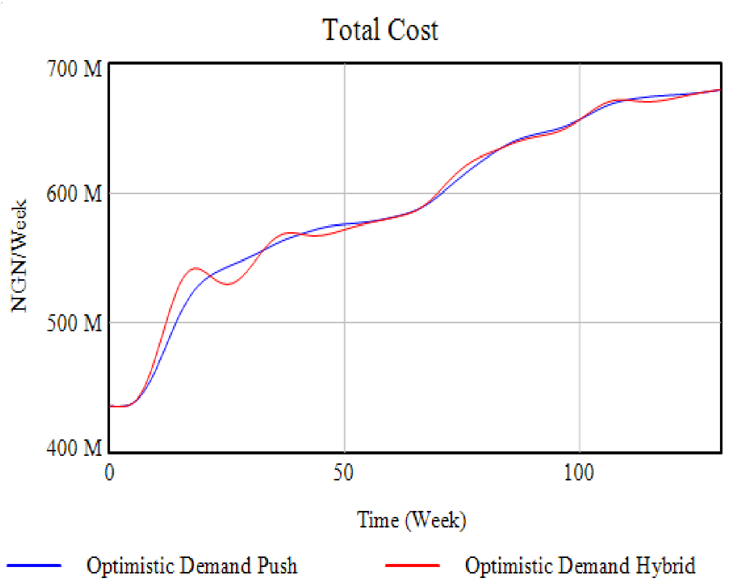


FIGURE 5. 31. EFFECT OF BAU DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

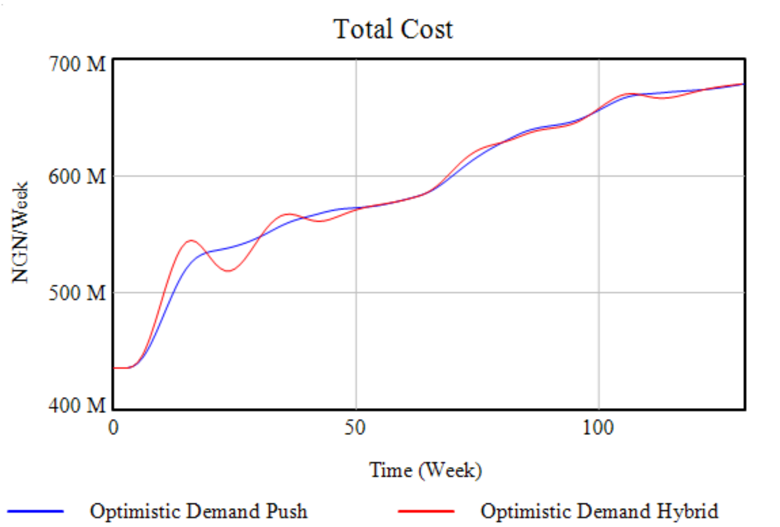


FIGURE 5. 32. EFFECT OF OPTIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER TWO WEEKS

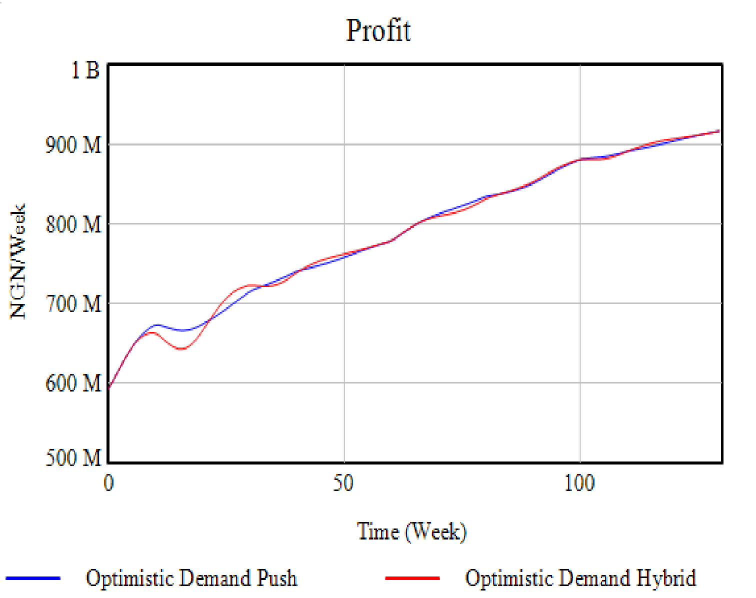


FIGURE 5. 33. EFFECT OF OPTIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

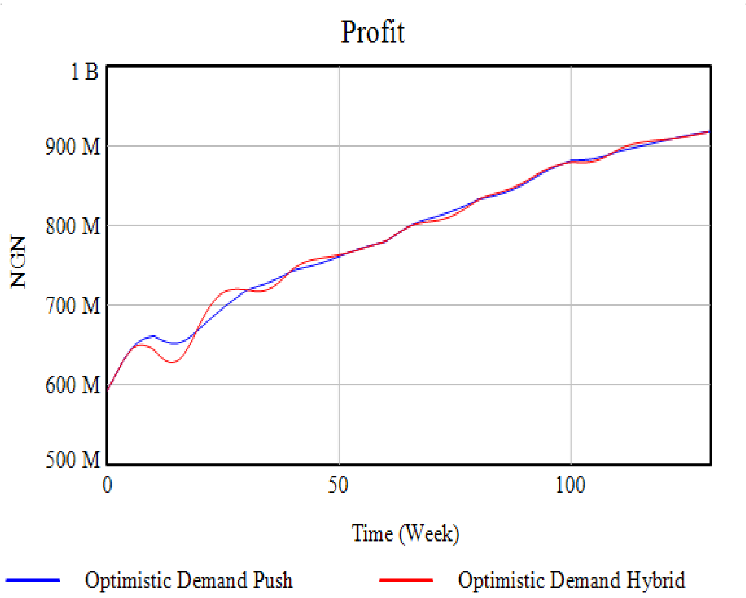


FIGURE 5. 34. EFFECT OF OPTIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER TWO WEEKS

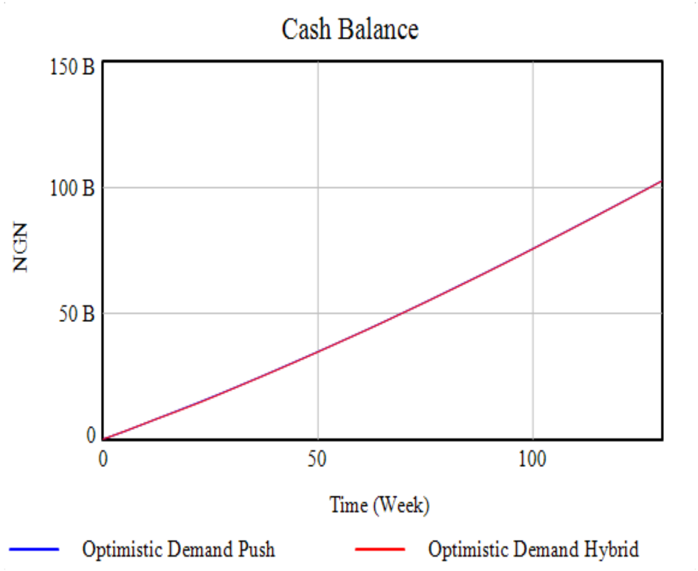


FIGURE 5. 35. EFFECT OF OPTIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

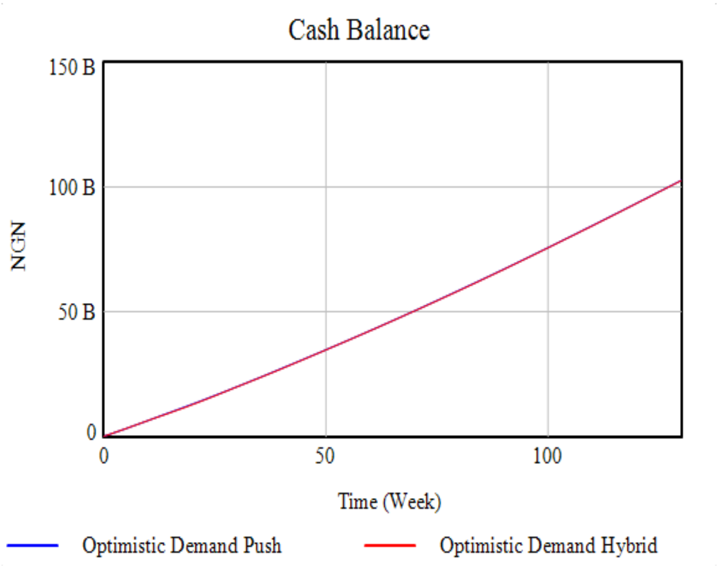


FIGURE 5. 36. EFFECT OF OPTIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER TWO WEEKS

Table 5.8 below portrays the numerical values from the simulation results of optimistic demand pattern under push and hybrid push/pull models. When the smoothing parameter is reduced to two weeks the hybrid push/pull model has slightly higher total cost with lower profit same as when the smoothing time is left at six weeks. However, the total costs in the two models are slightly reduced when the demand smoothing parameter is decreased to two weeks. This is as a result of the managers now responding faster to changes in customer demand.

Optimistic Demand	Push	Hybrid Push/Pull
Smoothing Parameter = 6 weeks		
Total Cost	676,309,000	678,871,000
Profit	918,402,000	917,840,000
Cash Balance	102,771,000,000	102,684,000,000
Smoothing Parameter = 2 Weeks		
Total Cost	677,839,000	679,884,000
Profit	917,872,000	915,827,000
Cash Balance	102,744,000,000	102,675,000,000

TABLE 5. 8. EFFECT OF OPTIMISTIC DEMAND ON TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

5.21 Costs analysis of pessimistic demand under push and hybrid push/pull models

Figures 5.37 to 5.42 and Table 5.9 illustrate the difference in the total costs, profit and cash balance of the two models for pessimistic demand. From these graphs and Table, the hybrid push/pull model has lower total costs with higher profit and cash balance. Moreover, in the hybrid push/pull model, dealer adjust the discrepancy on the amount of inventory sold from stock. This policy responds quickly to any changes in demand. Hence, during the pessimistic demand period, the distributor order fulfilment rate and dealer order fulfilment rate is further reduced as the smoothing time is decreased. For this reason, the level of inventory in the hybrid push/pull model is much lower in comparison to the push model.

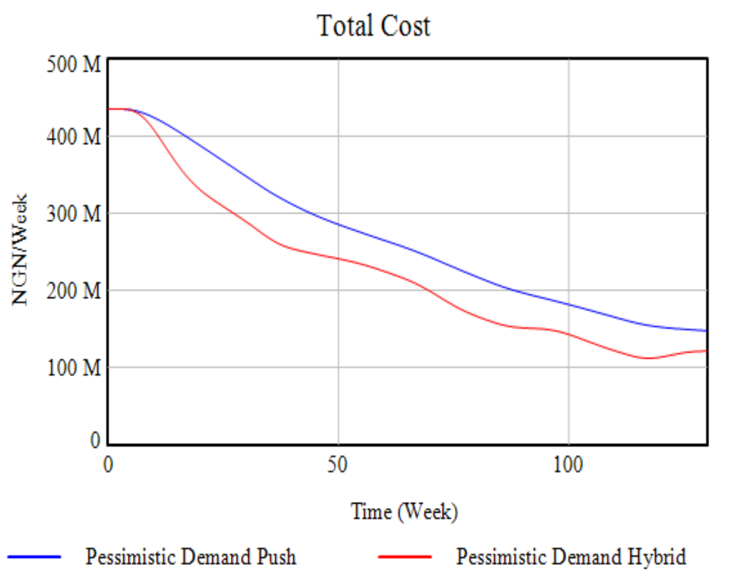


FIGURE 5. 37. EFFECT OF PESSIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER SIX WEEKS

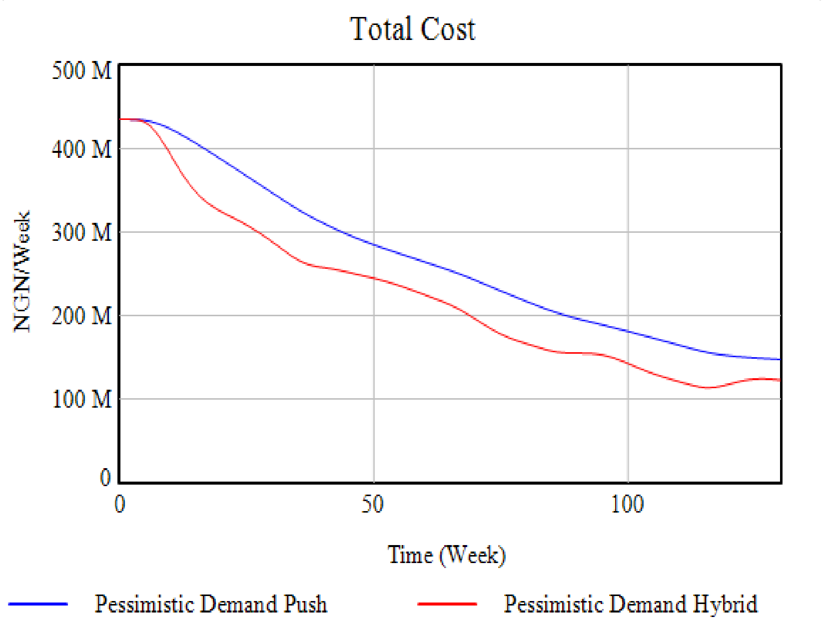


FIGURE 5. 38. EFFECT OF PESSIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER TWO WEEKS

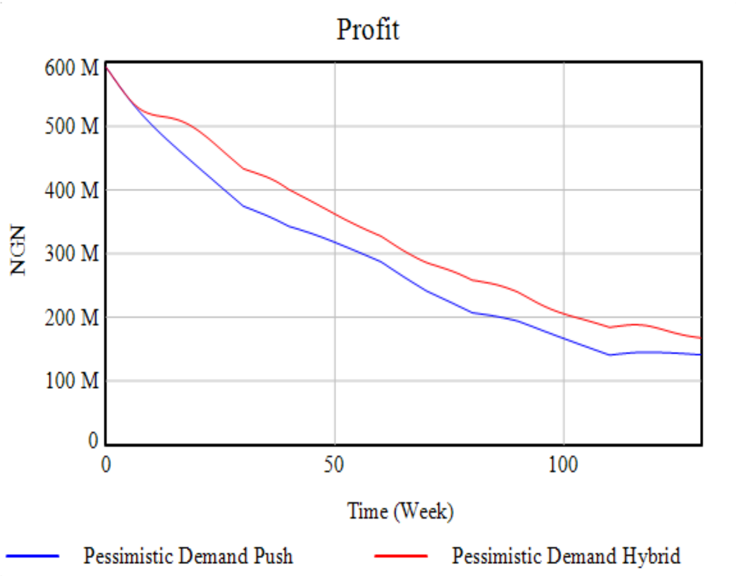


FIGURE 5. 39. EFFECT OF PESSIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

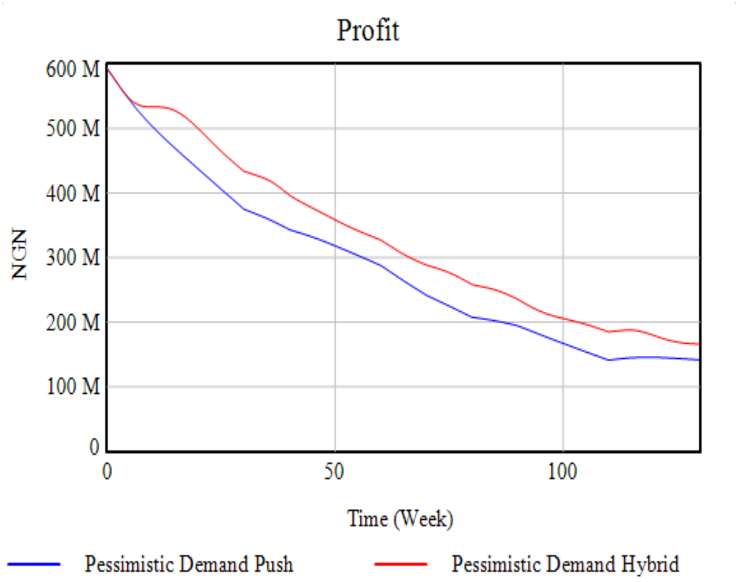


FIGURE 5. 40. EFFECT OF PESSIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

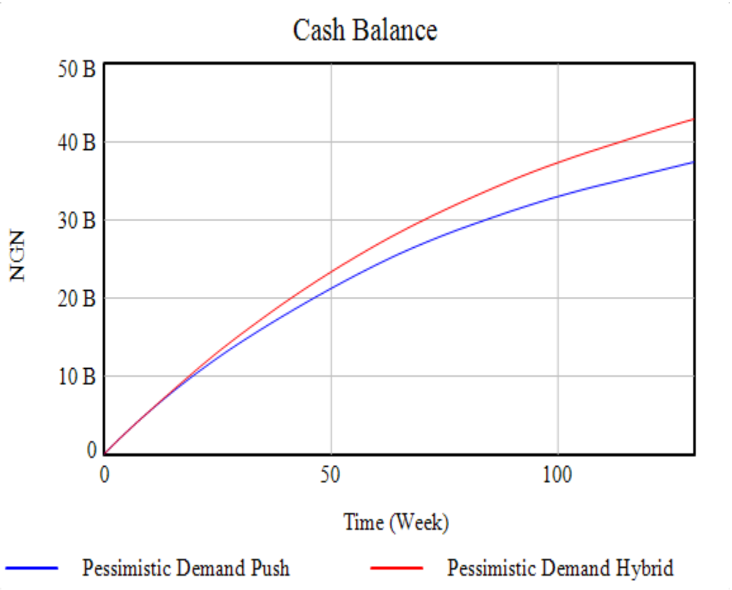


FIGURE 5. 41. EFFECT OF PESSIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

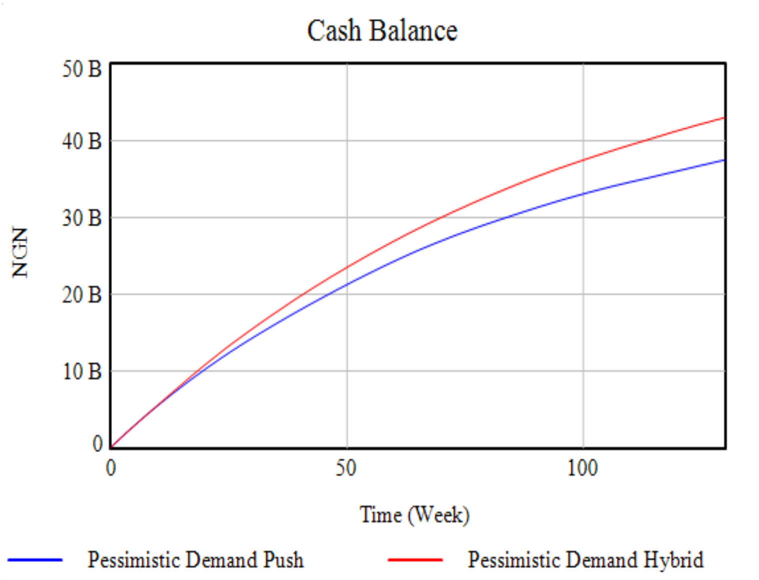


FIGURE 5. 42. EFFECT OF PESSIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER TWO WEEKS

In Table 5.9, the values reflect that the push model has higher total cost and lower profit and cash balance when the smoothing parameter equals six weeks. Also, when the smoothing constant is reduced, the push model has the higher total cost and lower profit and cash balance. These observations parallel the results of the analysis of stock carried in Tables 5.5 and 5.6.

Under the smoothing parameter, where the smoothing value is set to six weeks, the push model has higher total costs due to a high level of inventory at the distributor and dealer this indicates a higher cost of holding inventory. In other words, the costs of carrying safety stock in a push model are equivalent to those of another hybrid push/pull model but with different outcome (Table 5.6). Thus, the costs incurred holding excess inventory led to the push model with higher total cost, lesser profit and cash balance.

Pessimistic Demand	Push	Hybrid Push/Pull
Smoothing Parameter = 6 weeks		
Total Cost	151,539,000	111,360,00
Profit	137,461,000	177,640,00
Cash Balance	37,454,800,000	42,960,900,000
Smoothing Parameter = 2 weeks		
Total Cost	151,008,000	114,492,000
Profit	137,992,000	174,508,000
Cash Balance	37,529,000,000	43,043,600,000

TABLE 5. 9. EFFECT OF PESSIMISTIC DEMAND ON TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

Smoothing Parameter = 6 weeks									
Demand Pattern	**Business as Usual**			**Optimistic**			**Pessimistic**		
Push	TC (NGN)	Profit (NGN)	C B	TC (NGN)	Profit (NGN)	C B (NGN)	TC (NGN)	Profit (NGN)	C B
Final Values	445,785,000	623,347,000	73,354,200,000	676,309,000	918,402,000	102,771,000,000	151,539,000	137,461,000	37,454,800,000
Hybrid Push/Pull	TC	Profit		TC	Profit		TC	Profit	
Final Values	447,653,000	607,696,000	73,546,200,000	678,871,000	917,840,000	102,684,000,000	111,360,000	177,640,000	42,960,900,000
Smoothing Parameter = 2 weeks									
Demand Pattern	**Business as Usual**			**Optimistic**			**Pessimistic**		
Push	TC (NGN)	Profit (NGN)	C B	TC (NGN)	Profit (NGN		TC (NGN)	Profit (NGN	C B

Final Values	455,261,000	615,739,000	73,363,200,000	677,839,000	917,872,000	102,744,000,000	151,008,000	137,992,000	37,529,000,000
Hybrid Push/Pull	TC	Profit		TC	Profit		TC	Profit	
Final Values	465,348,000	605,652,000	73,595,300,000	679,884,000	915,827,000	102,675,000,000	114,492,000	174,508,000	43,043,600,000

Worst Performance   Best Performance

TABLE 5. 10. OVERALL SUMMARY OF COSTS WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

The final values for the total costs, profit and cash balance for the push model and hybrid push/pull model is summarised in Table 5.10. In this table, the highest values of total costs, profit, and cash balance are highlighted in yellow, which indicates the worst performance. The lowest values are represented by the green cells which represent the best performance. From table, the findings suggest that the hybrid push/pull model has higher total costs in four out of six tests, which indicates the worst performance and in terms of profit in four of the six tests. The model with the best performance is the hybrid push/pull model. The underlying reason is that this model manages to cope with variations in demand by having the lower total costs as a result of less inventories.

Analysis of the costs reveals the consequences of managerial decisions in responding to changes in customer demand. Increasing the delay causes the levels of inventories and the order fulfilment rates to fluctuate further, as discussed in previous section. For this reason, policy improvement by sensitivity analysis is introduced to search for the values of relevant parameters to reduce the inventory level, total costs, maximize profit and cash balance. Section 5.9 discusses the analysis in detail with more granulated scenarios tested in improving the model behaviour for case study A.

5.22 Policy improvement

Finding the best policy of a system dynamics model is performed either to improve the results of the model in some aspect of performance subject to a defined objective, or for calibration of the dynamics to fit (usually past) time series data (Hekimoğlu, 2010; Dangerfield, 2009; Dangerfield and Roberts, 1996). This method have been employed in system dynamics modelling for over twenty-five years but use of the techniques on teaching or generic models (as opposed to real-world models) is relatively rare (Dangerfield, 2009). Some of articles in the system dynamics literature by (Keloharju and Wolstenholme, 1989; Coyle, 1985) stress that sensitivity analysis can be utilised as an important tool to enhance understanding of the behaviour of a model under changing decisions or policies. The sensitivity analysis of the models in this section is concerned with improving the performance of the system by trying to optimise through experimentation (Coyle, 1996) to reduce the inventory levels and total costs as well as improving profit and cash balance.

There are a few elements of the sensitivity analysis that need to be clarified before starting the process. The parameters selected for improvement can be described as the process of improving the target behaviour generated from the model, for instance, maximisation of profits, reducing or minimisation of delivery delay. As a first step of sensitivity analysis, the parameter values and range of each parameter are determined the case companies' managers and company records. Typically, ± 20% of the parameter value are used for the simulation run. These parameter sensitivity test have been carried out extensively to analyse the best performance for the inventory level, total cost, profit and cash balance. Results from the sensitivity analysis portray the parameter values that successfully improve the system behaviour. With continuous sensitivity testing it was observed that dealer order fulfilment cycle time (DEOFCT) and safety stock coverage (SSC) have the most effect on the model behaviour to either increase or decrease the inventory levels.

The range of the value for the safety stock coverage is defined to reflect a minimum of 1 week, and a maximum of four weeks of safety stock. Morecroft (2008) defined safety stock coverage as being four weeks with expert. Hence, four weeks is the upper limit for the safety stock coverage in the push model and hybrid push/pull models. Morecroft (2008) defines cycle time as the average time to fill an order of a customer. The delay includes the time required to process an order, build the product and then ship the goods. In the models, the initial value of the cycle time is set to eight weeks. This means that the order is filled quickly from available distributor inventory. For the purpose of the test, the values for the simulations are tested in consultation with the managers between five to ten weeks to represent a shorter and longer cycle time. Table 5.11 summarises the parameter values.

Parameter Constant	Units	Values in the Model	Value Range
Push Model			
Dealer Order Cycle Time	Weeks	8	5-10
Safety Stock Coverage	Weeks	3	1-4
Hybrid Push/Pull Model			
Dealer Order Cycle Time	Weeks	8	5-10
Safety Stock Coverage	Weeks	3	1-4

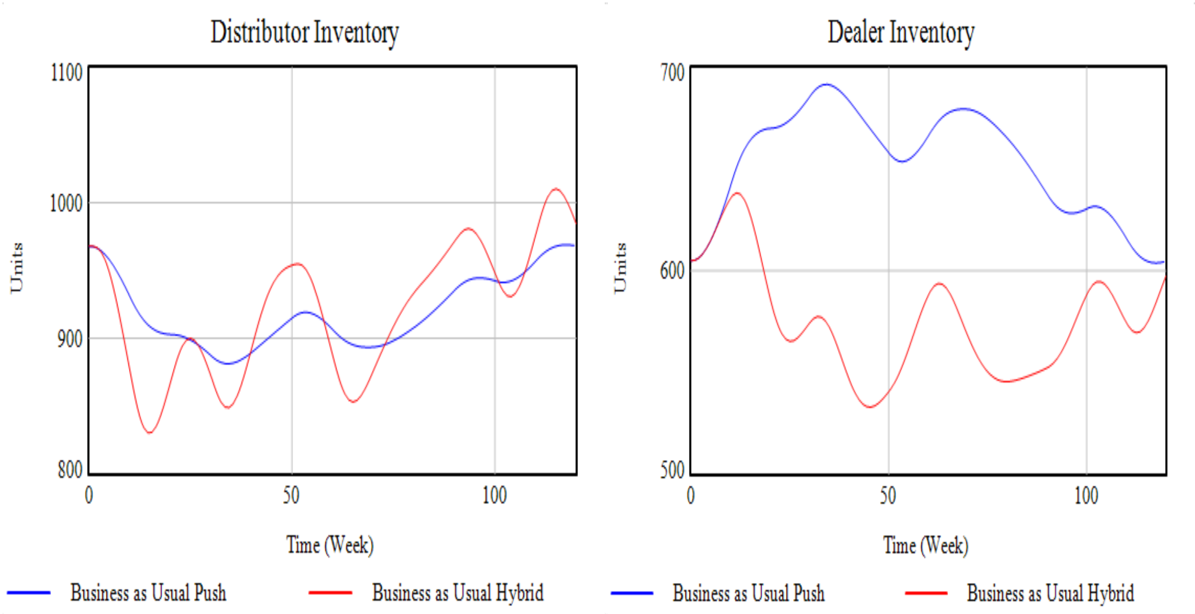
TABLE 5. 11. PARAMETER VALUES USED FOR PUSH AND HYBRID PUSH/PULL MODEL

In the next section, the results of the sensitivity analysis of the models for case company A are illustrated for each of the push and hybrid push/pull model under the different demand patterns that have the most effect of reducing inventory level and total costs at the same time improving profit and cash balance. Parameter values are rounded to one or two decimal places in the discussion.

5.23 Sensitivity analysis of business as usual

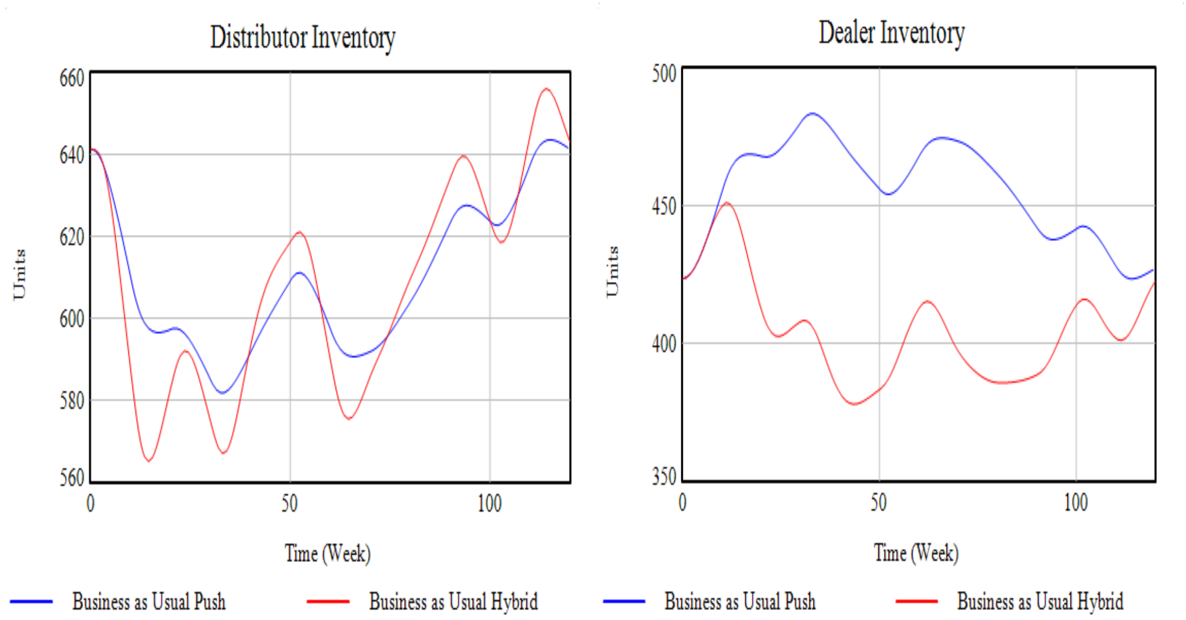
The first sensitivity analysis for the push model is performed for business as usual demand. Figures 5.43 (a) and (b), 5.44 (a) and (b) shows significant decrease in the distributor inventory and dealer inventory when the DEOFCT and SSC are reduced. Total costs can be lowered by reducing the safety stock coverage to 1.5 weeks and dealer order fulfilment cycle time to 5.3

weeks simultaneously. These parameter values have the ability of lowering the total costs and improving the profit in both the supply chain models.



a **b**

FIGURE 5. 43. EFFECT OF DEOFCT AND SSC OF BAU DEMAND



a **b**

FIGURE 5. 44. EFFECT OF DECREASING DEOFCT AND SSC OF BAU DEMAND

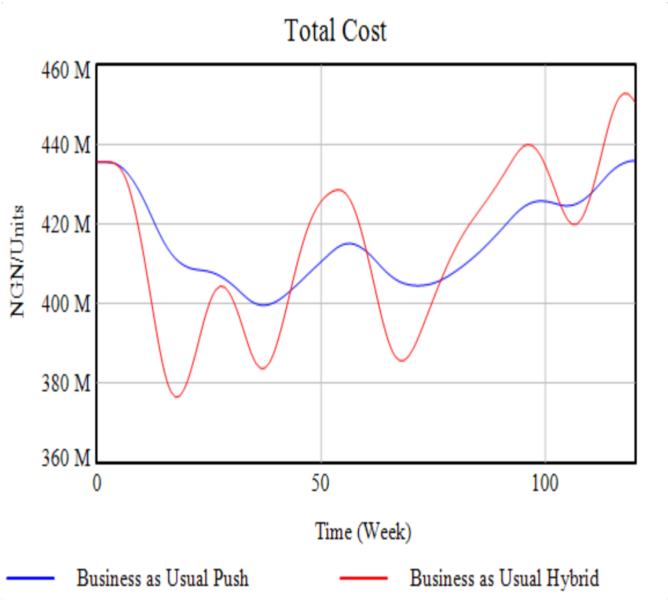


FIGURE 5. 45. EFFECT OF DEOFCT AND SSC ON TOTAL COST OF BUSINESS AS USUAL DEMAND

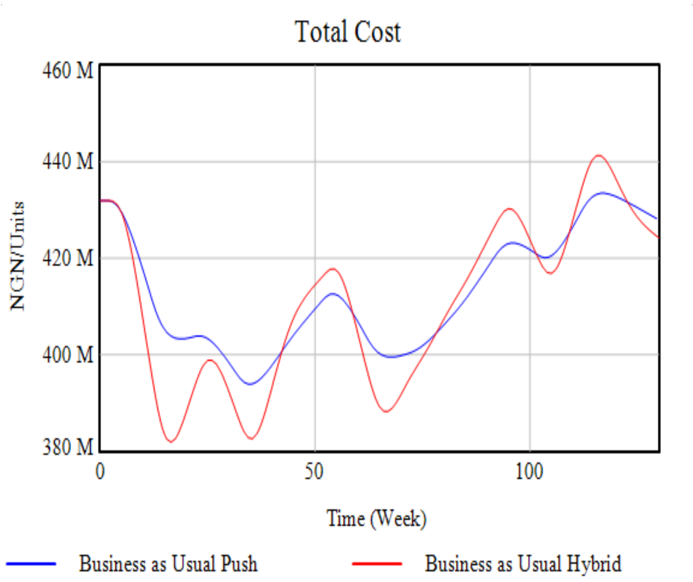


FIGURE 5. 46. EFFECT OF DECREASING DEOFCT AND SSC ON TOTAL COST OF BAU DEMAND

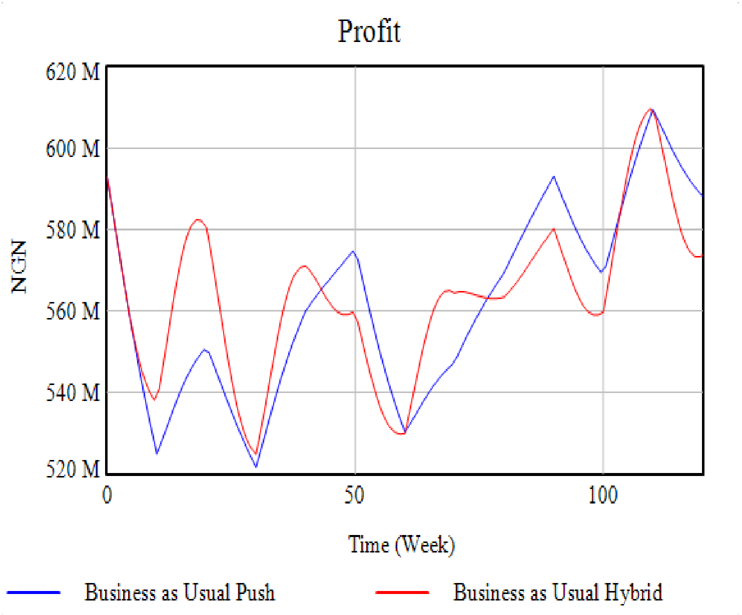


FIGURE 5. 47. EFFECT OF DEOFCT AND SSC ON PROFIT OF BAU DEMAND

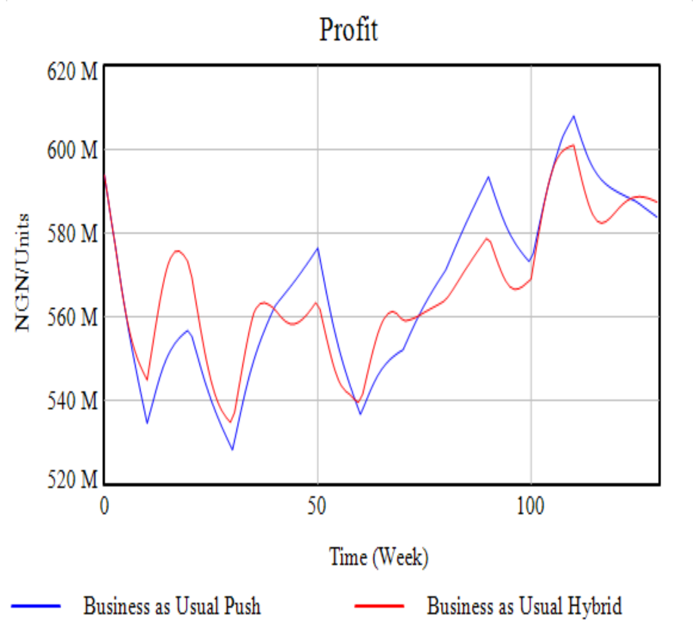


FIGURE 5. 48. EFFECT OF DECREASING DEOFCT AND SSC ON PROFIT OF BAU DEMAND

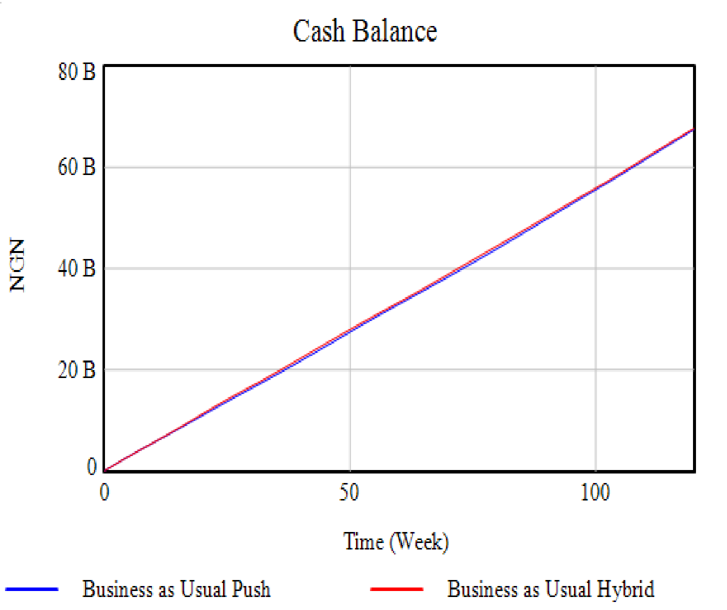


FIGURE 5. 49. EFFECT OF DEOFCT AND SSC ON CASH BALANCE OF BAU DEMAND

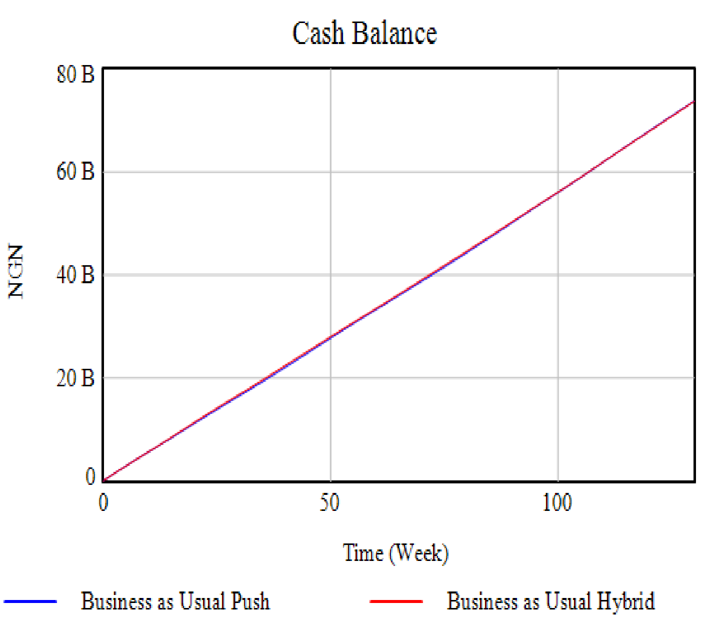


FIGURE 5. 50. EFFECT OF DECREASING DEOFCT AND SSC ON CASH BALANCE OF BAU DEMAND

The results of case study A of reducing dealer order fulfilment cycle time and safety stock coverage at week 130 are summarised in Table 5.12 and 5.13.

Test 2: Business as Usual, DEOFCT = 8weeks and SSC = 3 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	968	604
Hybrid Push/Pull	984	597
Test 3: Business as Usual, DEOFCT = 5.3 weeks and SSC = 1.5 weeks		
Push	641	427
Hybrid Push/Pull	643	422

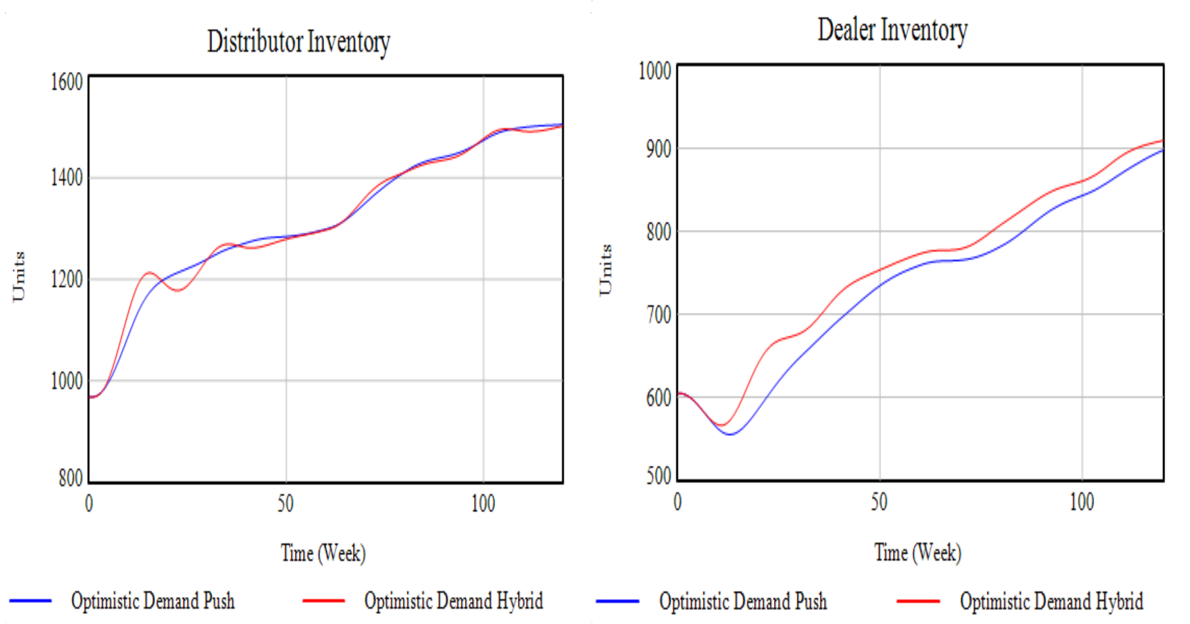
TABLE 5. 12. SUMMARY RESULT OF DISTRIBUTOR AND DEALER INVENTORIES ON BAU

Business as Usual	Push	Hybrid Push/Pull
DEOFCT = 8 weeks and SSC = 3 weeks		
Total Cost	436,011,000	450,573,000
Profit	588,239,000	573,677,000
CB	67,521,700,000	67,735,200,000
DEOFCT = 5.3 weeks and SSC = 1.5 weeks		
Total Cost	432,828,000	436,494,000
Profit	590,026,000	585,358,000
TC	67,961,900,000	67,894,700,000

TABLE 5. 13. SUMMARY RESULT OF FINANCIAL METRICS ON BAU

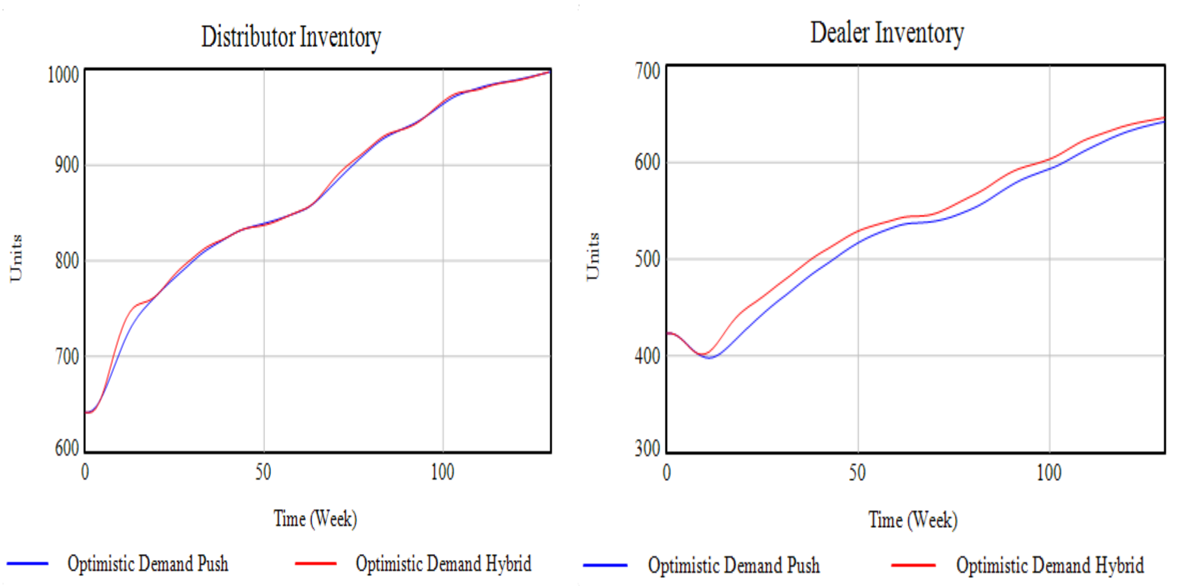
5.24 Sensitivity analysis of optimistic demand

The inventory level exhibits significant reduction in both models as shown in Figures 5.52 (a), and (b) for the distributor inventory and dealer inventory when the DEOFCT equals 5.3 and SSC equals 1.5.



a **b**

FIGURE 5. 51. EFFECT OF DEOFCT AND SSC OF OPTIMISTIC DEMAND



a **b**

FIGURE 5. 52. EFFECT OF DECREASING DEOFCT AND SSC OF OPTIMISTIC DEMAND

The results from the analysis of inventory level and total costs illustrate that the push model has slightly lower inventory under two out of the three demand patterns. However, the total costs and inventory level can be further reduced as the sensitivity analysis is carried out. Under optimistic demand, costs can be further improved by holding less safety stock coverage and a reduced dealer order fulfilment cycle time as shown in Figure 5.54 (b), 5.56, and 5.58.

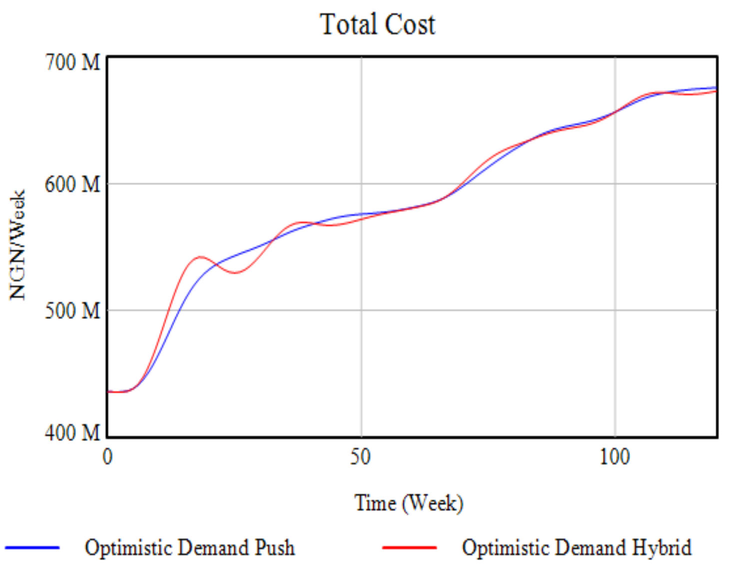


FIGURE 5. 53. EFFECT OF DEOFCT AND SSC ON TOTAL COST OF OPTIMISTIC DEMAND

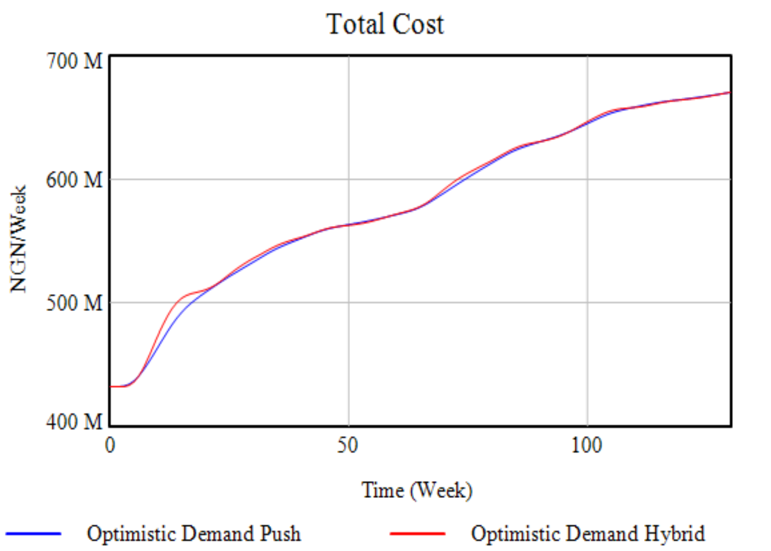


FIGURE 5. 54. EFFECT OF DECREASING DEOFCT AND SSC ON TOTAL COST OF OPTIMISTIC DEMAND

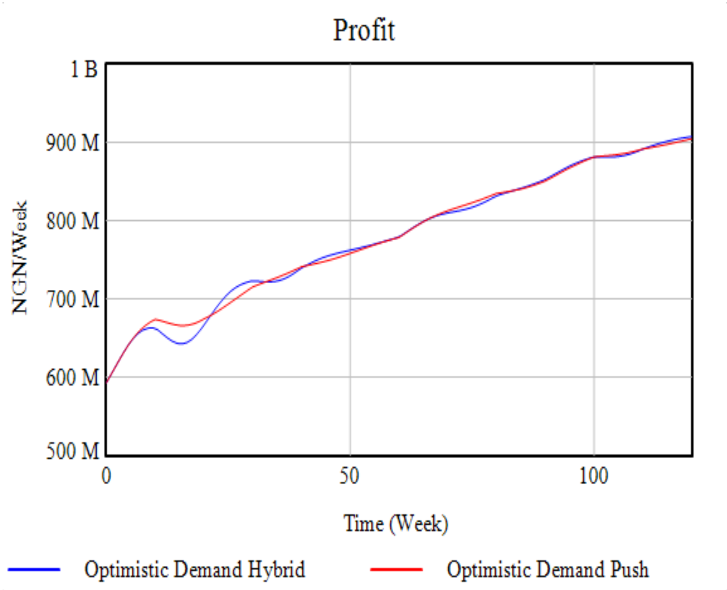


FIGURE 5. 55. EFFECT OF DEOFCT AND SSC ON PROFIT OF OPTIMISTIC DEMAND

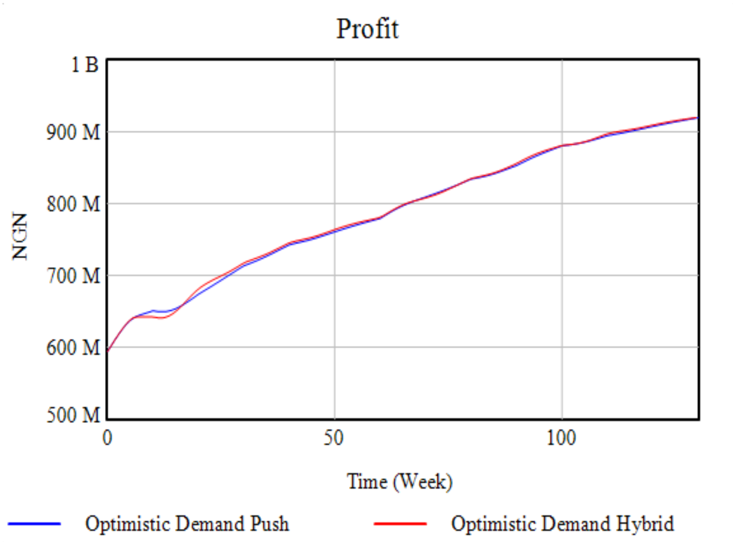


FIGURE 5. 56. EFFECT OF DECREASING DEOFCT AND SSC ON PROFIT OF OPTIMISTIC DEMAND

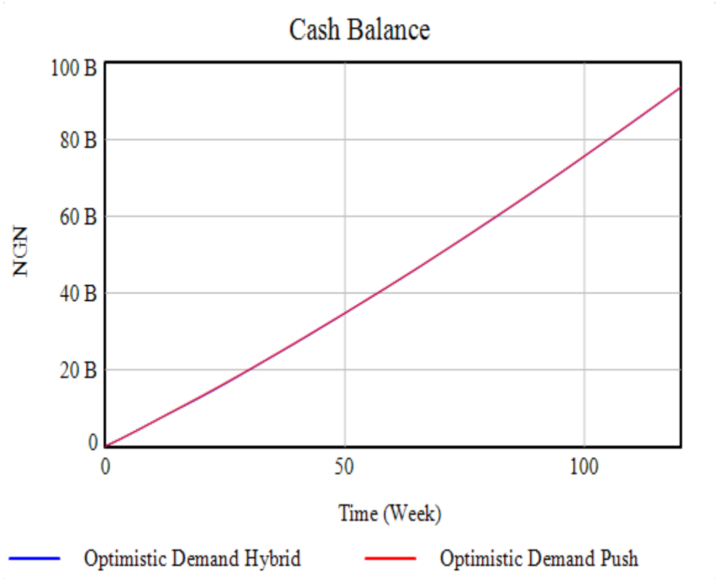


FIGURE 5. 57. EFFECT OF DEOFCT AND SSC ON CASH BALANCE OF OPTIMISTIC DEMAND

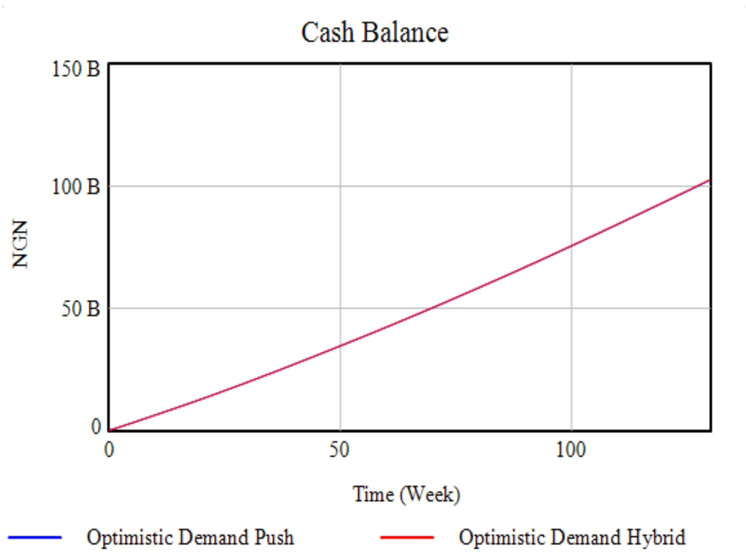


FIGURE 5. 58. EFFECT OF DECREASING DEOFCT AND SSC ON CASH BALANCE OF OPTIMISTIC DEMAND

Table 5.15 and 5.16 below portrays the numerical values from the simulation results in the tests with optimistic demand pattern in the push and hybrid push/pull models. When the DEOFCT and SSC is decreased the inventory, levels reduces significantly in the two models, total cost can be reduced at the same and with better profit in the two models. However, the push model slightly performs better than the hybrid push/pull model in this scenario.

Test 4: Optimistic demand, DEOFCT = 8 weeks and SSC = 3 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	1519	913
Hybrid Push/Pull	1516	922
Test 5:Optimistic demand, DEOFCT = 5.3 weeks and SSC = 1.5		
Push	998	642
Hybrid Push/Pull	997	646

TABLE 5. 14. SUMMARY RESULT OF DISTRIBUTOR INVENTORY AND DEALER INVENTORY OF OPTIMISTIC DEMAND

Optimistic Demand	Push	Hybrid Push/Pull
DEOFCT = 8 weeks and SSC = 3 weeks		
Total Cost	680,186,000	680,324,000
Profit	917,814,000	917,676,000
TC	102,771,000,000	102,684,000,000
DEOFCT = 5.3 weeks and SSC = 1.5 weeks		
Total Cost	670,791,000	670,933,000
Profit	919,888,000	920,656,000

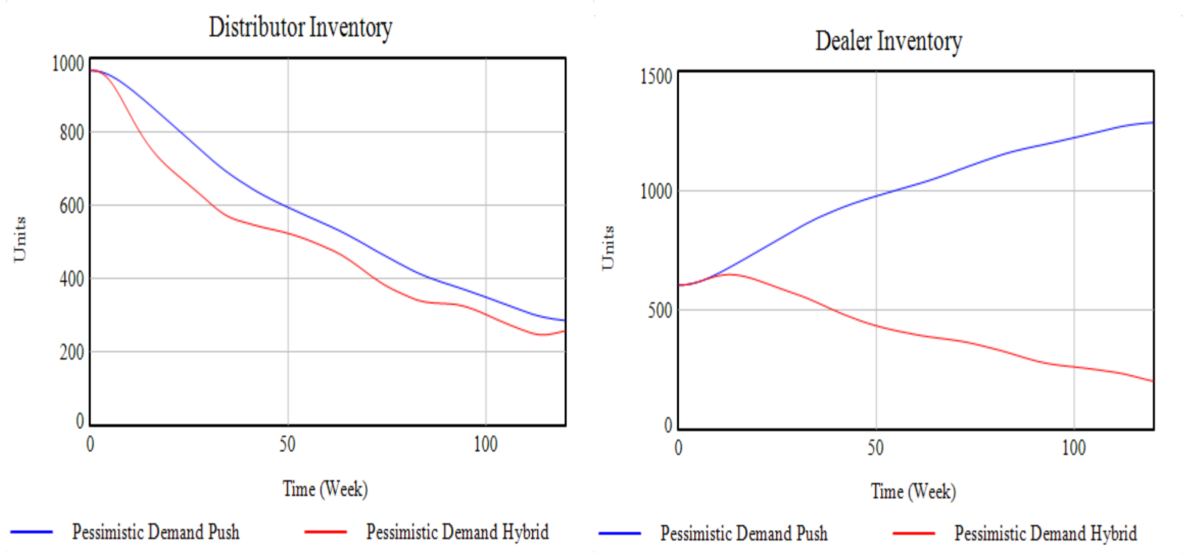
TC	102,625,000,000	102,815,000,000

TABLE 5. 15. SUMMARY RESULT OF FINANCIAL PERFORMANCE OF OPTIMISTIC DEMAND

In summary, a shorter time in adjusting these parameters (DEOFCT and SSC) are important for decision makers. At this point, the managers should strive to act at the shortest time in reducing their cycle time and safety stock coverage.

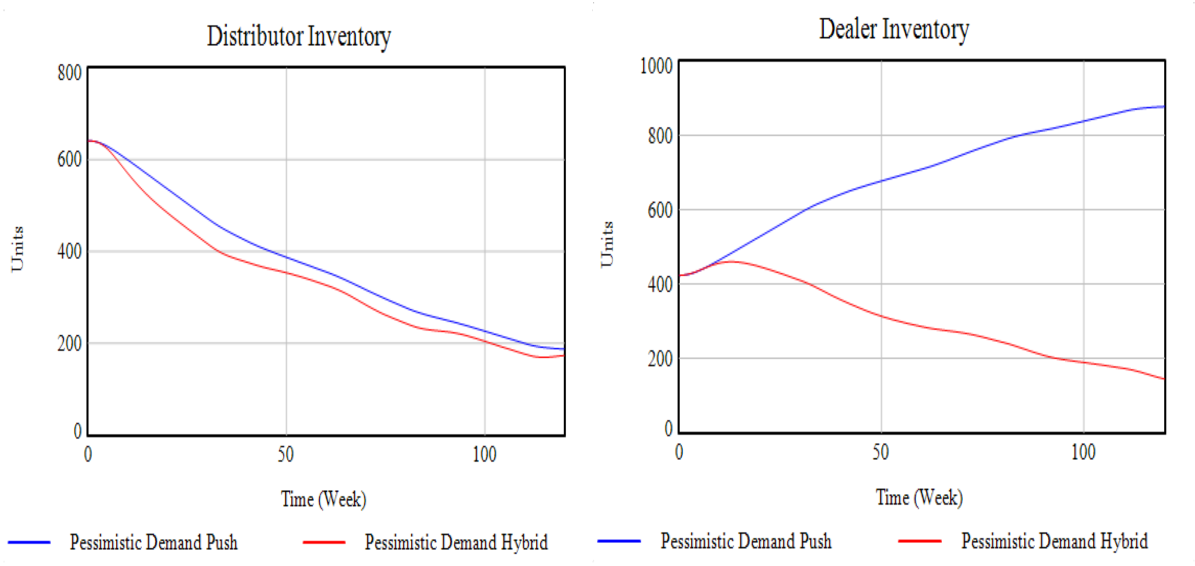
5.25 Sensitivity test of pessimistic demand

Figures 5.59 (a), (b), and 5.60 (a), and (b) display the inventory levels of pessimistic demand pattern DEOFCT equals 8 weeks and SSC equal 3 weeks and DEOFCT equals 5.3 weeks and SSC equals 1.5. In the following graphs, the hybrid push/pull model has lower inventory level. The major influence of the reduced parameter values is a reduced difference in the inventory level in both distributor inventory and dealer inventory. However, the push model performs poorly at the dealer inventory compared to the hybrid push/pull model as a result of excess inventory in stock as sales decreases over time.



a **b**

FIGURE 5. 59. EFFECT OF DEOFCT AND SSC OF PESSIMISTIC DEMAND



a **b**

FIGURE 5. 60. EFFECT OF DECREASING DEOFCT AND SSC OF PESSIMISTIC DEMAND

Figures 5.61 to 5.66 illustrate the difference in the total costs, profit and cash balance in the two models in the test of pessimistic demand by changing the values of DEOFCT and SSC. The hybrid push/pull model has lower inventory levels and total costs with a slightly higher cash balance and higher profit. In the hybrid push/pull model, the dealer adjusts the discrepancy on the amount of inventory sold from stock. This policy responds quickly to any changes in demand.

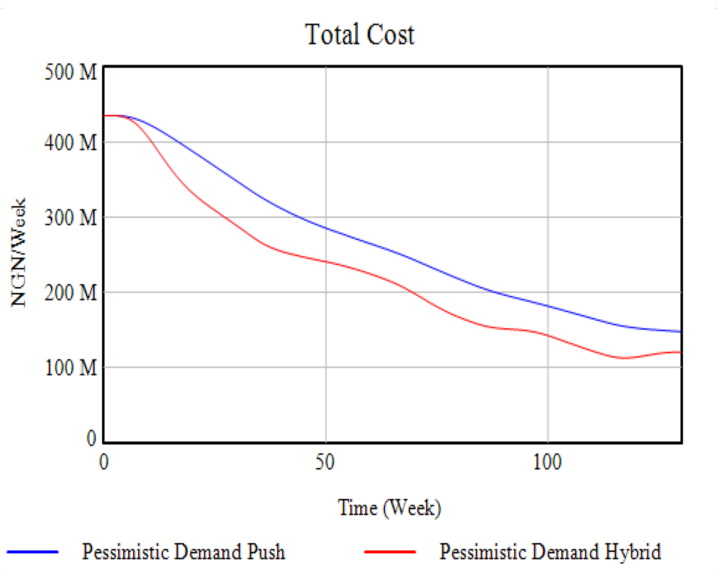


FIGURE 5. 61. EFFECT OF DEOFCT AND SSC ON TOTAL COST OF PESSIMISTIC DEMAND

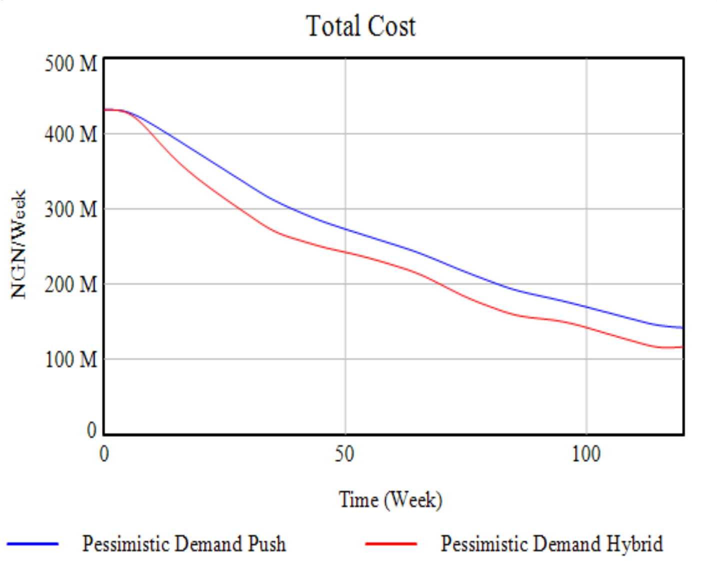


FIGURE 5. 62. EFFECT OF DECREASING DEOFCT AND SSC ON TOTAL COST OF PESSIMISTIC DEMAND

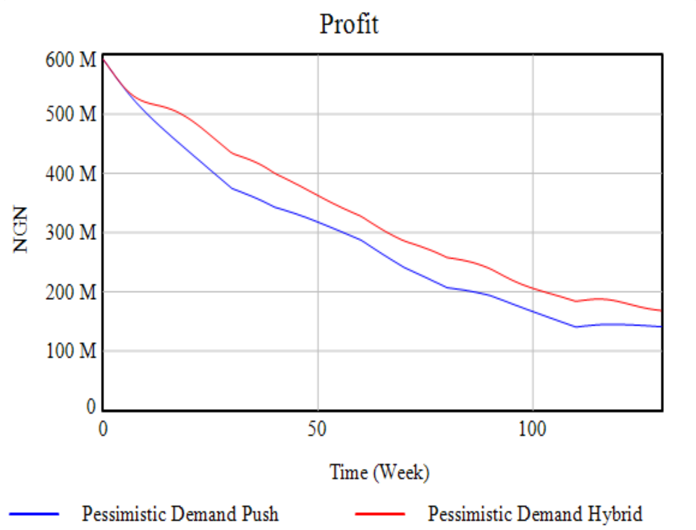


FIGURE 5. 63. EFFECT OF DEOFCT AND SSC ON PROFIT OF PESSIMISTIC DEMAND

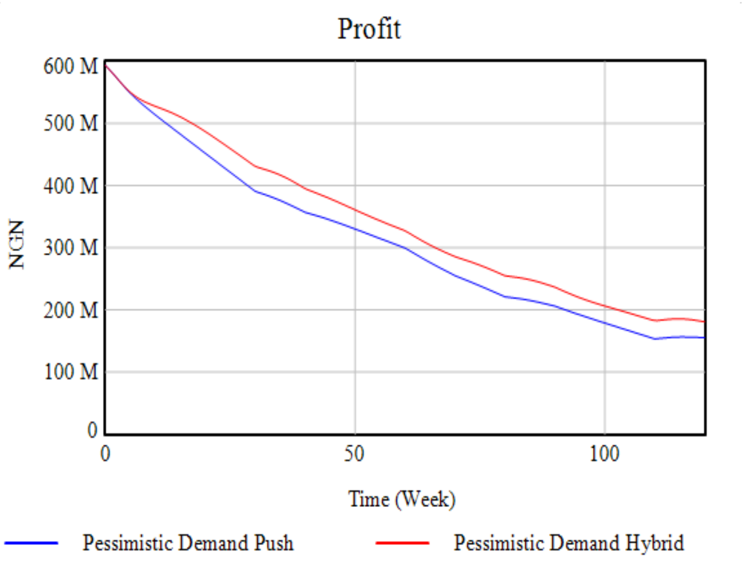


FIGURE 5. 64. EFFECT OF DECREASING DEOFCT AND SSC ON PROFIT OF PESSIMISTIC DEMAND

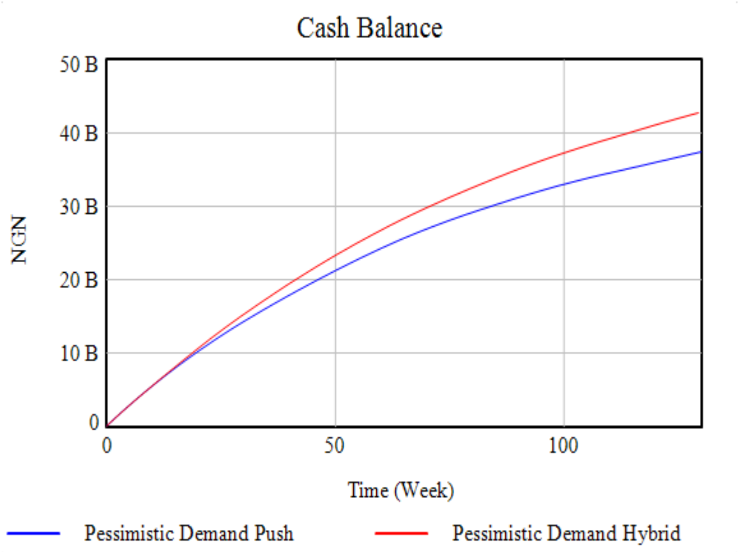


FIGURE 5. 65. EFFECT OF DEOFCT AND SSC ON CASH BALANCE OF PESSIMISTIC DEMAND

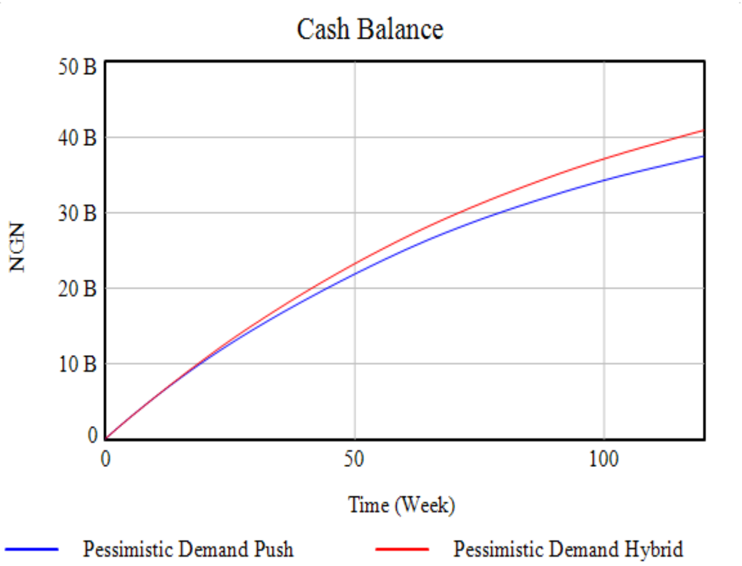


FIGURE 5. 66. EFFECT OF DECREASING DEOFCT AND SSC ON CASH BALANCE OF PESSIMISTIC DEMAND

The results of the pessimistic demand are summarized in Table 5.16 and 5.17, the values reflect that the push model has higher inventory levels and total cost with lower profit and cash balance. Thus, longer cycle time and safety stock coverage means that there would be high costs incurred by the company.

Experiment 6: Pessimistic Demand, smoothing constant = 6 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	281	1291
Hybrid Push/Pull	253	189
Experiment 7: Pessimistic Demand, smoothing constant = 2 weeks		
Push	278	1270
Hybrid Push/Pull	254	181

TABLE 5. 16. SUMMARY RESULT OF DISTRIBUTOR INVENTORY AND DEALER INVENTORY OF PESSIMISTIC DEMAND

Pessimistic Demand	Push	Hybrid Push/Pull
DEOFCT = 8 weeks and SSC = 3 weeks		
Total Cost	1,477,920,000	120,548,000
Profit	1,412,080,000	168,452,000
Cash Balance	37,454,800,000	42,879,700,000
DEOFCT = 5.3 weeks and SSC = 1.5 weeks		
Total Cost	1,385,190,000	119,171,000
Profit	1,504,810,000	169,829,000
CB	3,908,520,000	42,720,600,000

TABLE 5. 17. SUMMARY RESULT OF FINANCIAL METRICS ON PESSIMISTIC DEMAND

5.26 Conclusion

This chapter have presented the results of Case Study A to provide insights into the ideal policy supply chain structure to cope with the variations in demand at minimal costs in the automotive downstream supply chain. From the results it can be concluded that the ideal policy is to reduce the cycle time and safety stock coverage. Comparing the two models, the reports illustrate that the total costs are reduced when the cycle time equals 5.3 weeks and safety stock coverage 1.5 weeks. This result is the same across the different demand patterns. By decreasing these parameters, inventory levels are reduced with less safety stock coverage. Moreover, by decreasing the DEOFCT it leads to the minimisation of delays in fulfilling customer demand. Despite this unpredictability in customer demand, managers can still reduce costs by lowering these parameters to reduce inventory level. Various parameters values have been tested in the sensitivity test of the push and hybrid push/pull.

This chapter concludes all the analyses performed for case study A for the different demand patterns under push and hybrid push/pull model.

Chapter 6. Simulation Design and Analysis of Case Study B

6.1 Introduction

This chapter will investigate the effect of customer demand uncertainty on the downstream automobile push and hybrid push/pull system dynamics inventory models in Nigeria and the cost involved for case study B. The same processes of chapter five (case study A) will be used for chapter six (case study B). Discussion of the results is the perspective of simulating, validating and investigating the models and comparing the impact on the push and hybrid push/pull inventory models. Section 6.2 describes the simulation analysis and comparison of the push and hybrid push/pull inventory models. Section 6.17 discusses the effect of instability on cost under push and hybrid push/pull inventory models.

6.2 Analysis of inventory level of case study B

Chapter six for case study B is carried out to also achieve research objective three and four and answer the research questions by investigating the dynamics effects on the inventory level of the push and hybrid push/pull inventory models in the Nigeria downstream automobile supply chain inventory using different demand patterns and the costs incurred as a result of the fluctuations and instabilities. Figure 6.1 (a) displays the business as usual demand pattern agreed with the managers of the case companies. Figure 6.2 displays the second demand pattern optimistic demand and Figure 6.3 displays pessimistic demand pattern. In Figure 6.2, the demand increases from 18 to 45 units over 110 weeks. In Figure 6.3, the demand is reducing from 18 units per week to 5 units per week over 110 weeks.

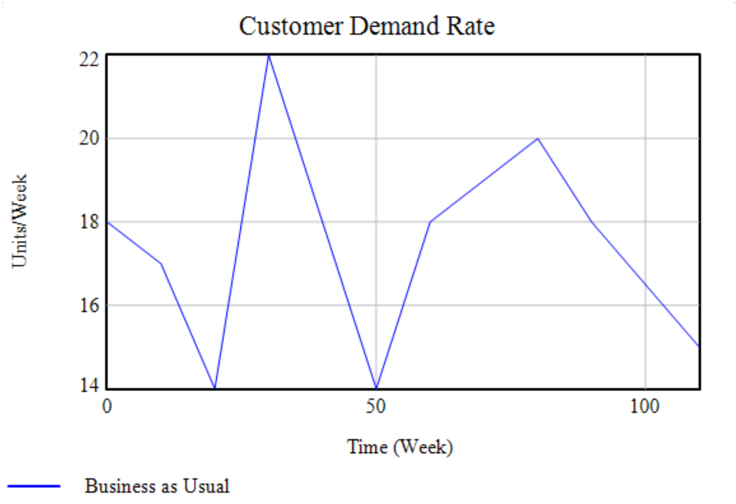


FIGURE 6. 1. BUSINESS AS USUAL DEMAND

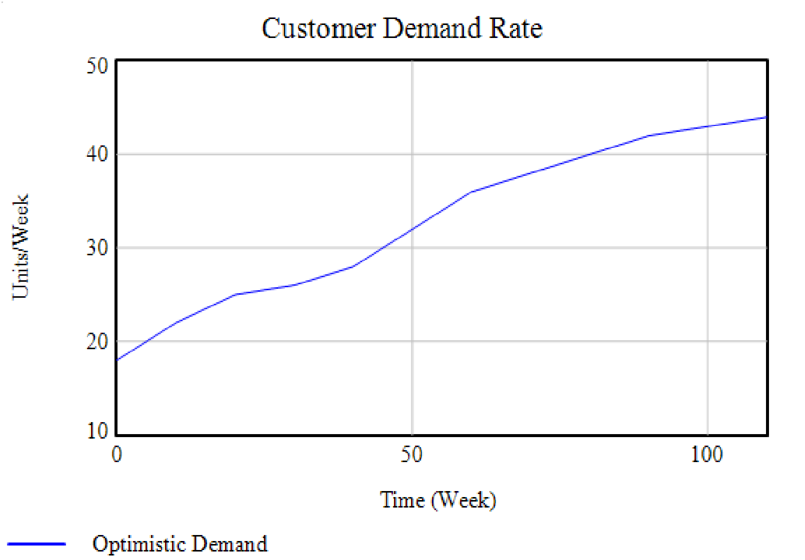


FIGURE 6. 2. OPTIMISTIC DEMAND

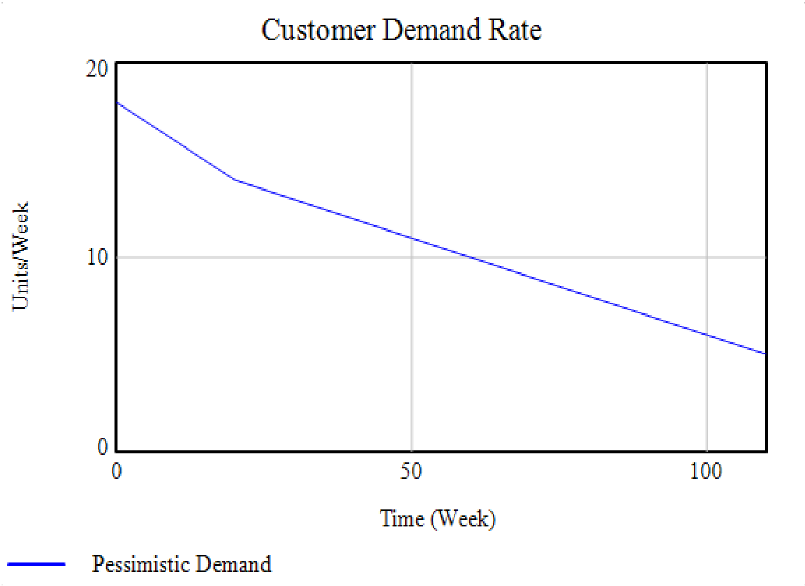


FIGURE 6. 3. PESSIMISTIC DEMAND

In each of the customer demand patterns, the changes start from week 0 and last until the end of the simulation at (110 weeks). In conducting the analysis, it is important to understand that the models represent the case company for this thesis. Similar parameter values are initialised in this model validation analysis for the push and hybrid push/pull models. By having consistent parameter values in the two models, it is possible to analyse the effect of the two models on the level of inventory and financial performance of the second case study.

The following sections discusses the results from the validation through direct structure tests for case study B as discussed with the managers as stated in Chapter Five. The results from the simulation runs are compared to logical perceptions of the modeller based on knowledge from the literature. The idea is to validate the models against the model purpose previously mentioned in Chapter Five, Table 5.2.

6.3 Direct structure tests for business as usual demand pattern

At this point of the analysis, the two-model output is compared in separate graphs, which is a more sensible way to portray the validation outputs. Figure 6.4 presents customer demand of business as usual (BAU). It is worth emphasising the differences in model behaviour in terms of distributor inventory, dealer inventory, distributor order fulfilment rate, dealer order fulfilment rate and sales rate.

The initial demand is at18 units/week; this demand then decreases to 14 at week 20 this trend continues fluctuating until the end of the simulation of 15 units/week at week 110. A smoothing structure is used to represent the expectation of managers concerning the customer demand. The objective of conducting the indirect structure this test is to validate the model's behaviour against the model purpose and analysing the model response towards changes in demand. The results from indirect structure tests with the push and hybrid push/pull models are discussed in the following sections.

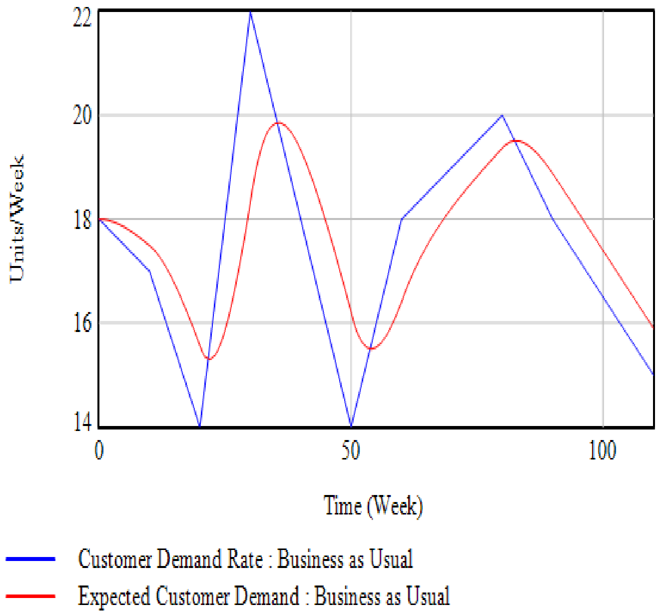
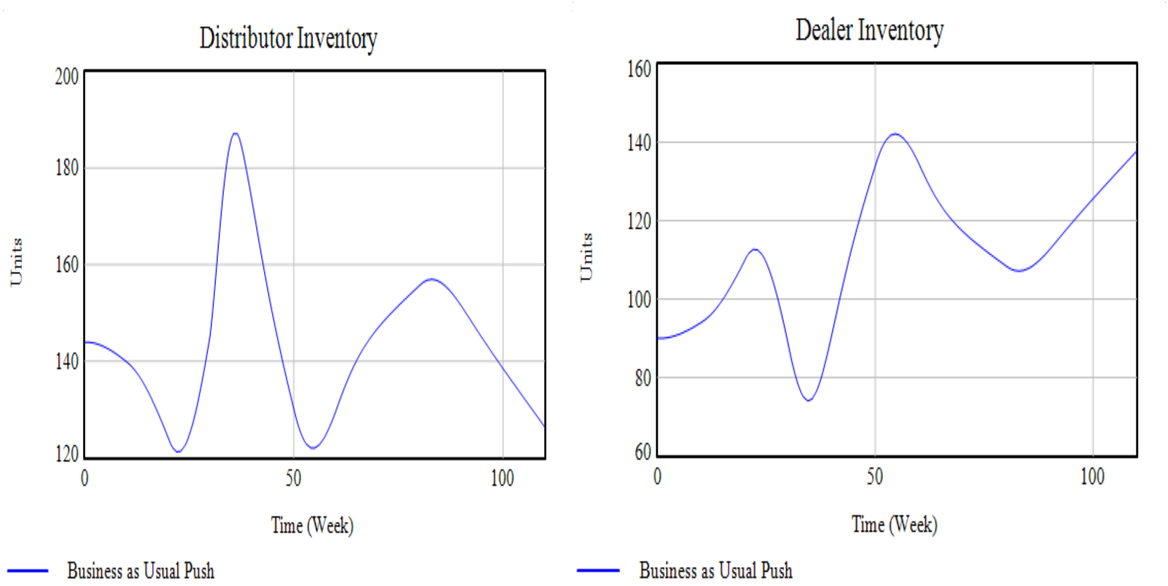


FIGURE 6. 4. CUSTOMER DEMAND AND SMOOTHED CUSTOMER DEMAND

6.4 Model validation under push model for BAU demand

In this analysis, the push model is simulated with a demand pattern given that the smoothing parameter for customer demand is equal to six weeks. Figures 6.5 (a), and (b), and 6.6 display the effect of the results under this pattern (business as usual). As the graphs suggest, the dealer order fulfilment rate, distributor order fulfilment rate and sales rate show sign of amplification and instability. In Figure 6.5 (a), the distributor inventory decreases after week 5 and increases after week 20 and oscillates till the end of the simulation at 110 weeks in converse, the dealer inventory increases at week 5 and oscillates upward till the end of the simulation when sales rate becomes unpredictable.

The demand continues fluctuating but the inflow and outflow as seen in the graphs does not exceed the levels of inventory of distributor and dealer. The underlying reason for this situation is the negative feedback and delay in the ability to fulfil their immediate partners demand at the shortest possible time. The inflow and outflow still remain below both distributor and dealer inventory level therefore follows the validation purpose.



a **b**

FIGURE 6. 5. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER PUSH MODEL

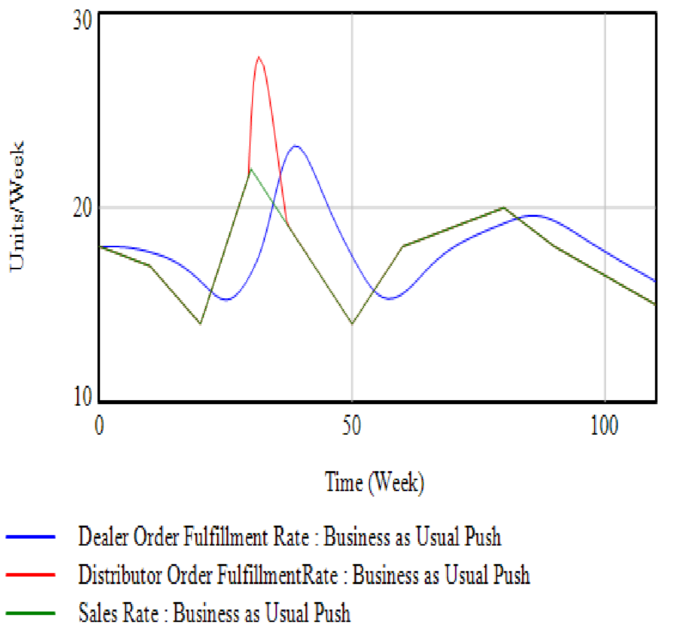
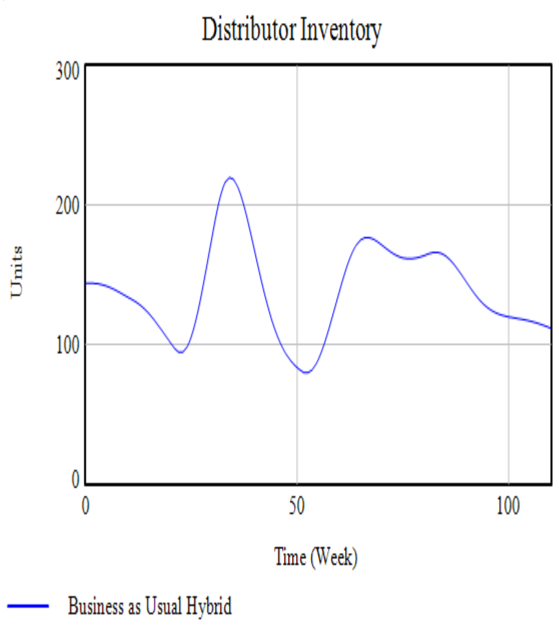


FIGURE 6. 6. EFFECT OF BAU DEMAND ON INFLOW AND OUTFLOW RATES UNDER PUSH MODEL

6.5 Model validation under hybrid push/pull model for BAU demand

The results from the simulation runs for the hybrid push/pull model for this demand pattern is depicted in Figures 6.7 (a) and (b). The oscillation and instability as seen in the distributor inventory and dealer inventory continues throughout the period of the simulation as a result of delays in fulfilling orders. The transition between the push and pull in this model has caused delays in adjusting the inventory level. Figure 6.8 shows that the inflow and the outflow is still below the inventory levels of distributor and dealer.



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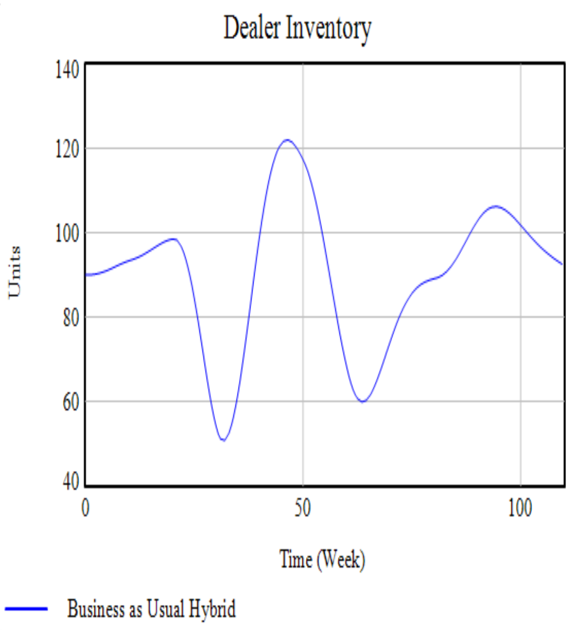

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FIGURE 6. 7. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY UNDER HYBRID PUSH/PULL

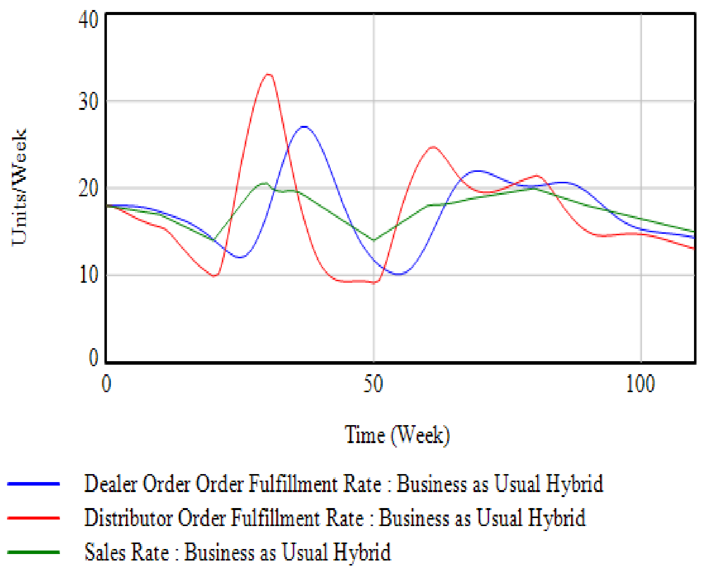


FIGURE 6. 8. EFFECT OF BAU DEMAND ON INFLOW AND OUTFLOW RATES UNDER HYBRID PUSH/PULL MODEL

6.6 Direct structure tests for optimistic demand

The second dynamic demand pattern for the analysis is the optimistic demand. The two models are analysed against the same model purpose as for the analysis for business as usual demand pattern. Figure 6.9 presents the optimistic demand and the smoothed optimistic demand used in the test. The expected observation is that the model will reproduce the increase in demand pattern in the initial period from 0 weeks of 18 units/week and continue increasing till the end of the simulation. The insights on the effect of delays and the instability of the model behaviour during a sudden rise in demand, may offer some help to managers.

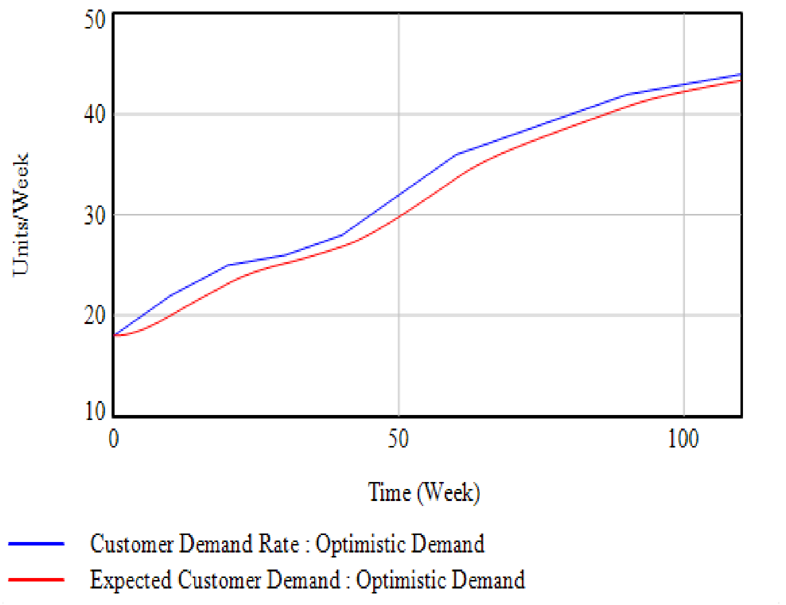


FIGURE 6. 9. OPTIMISTIC DEMAND AND SMOOTHED OPTIMISTIC DEMAND

6.7 Model validation under push model for optimistic demand

The optimistic demand in the model is discrete as shown in Figure 6.9. As the demand increases at week 0, the distributor inventory as shown in Figure 6.10 (a) gradually builds up until the end of the simulation. In Figure 6.10 (b) the dealer inventory gradually drops at week 10 and then starts to increase until the end of the simulation. With a policy of safety stock coverage in place in the model, which is set to three weeks, the inventory level shows an excess of three-week inventories in the dealer; three times the level of customer demand. As smoothing is applied, the demand pattern is smoother given the smoothing parameter is equal to six weeks. In Figure 6.11, distributor order fulfilment rate, dealer order fulfilment rate, and sales rate produce behaviour at almost the same level. However, the discrepancy between the inflow and the outflow rate has resulted in an increment in the distributor and dealer inventories, respectively.

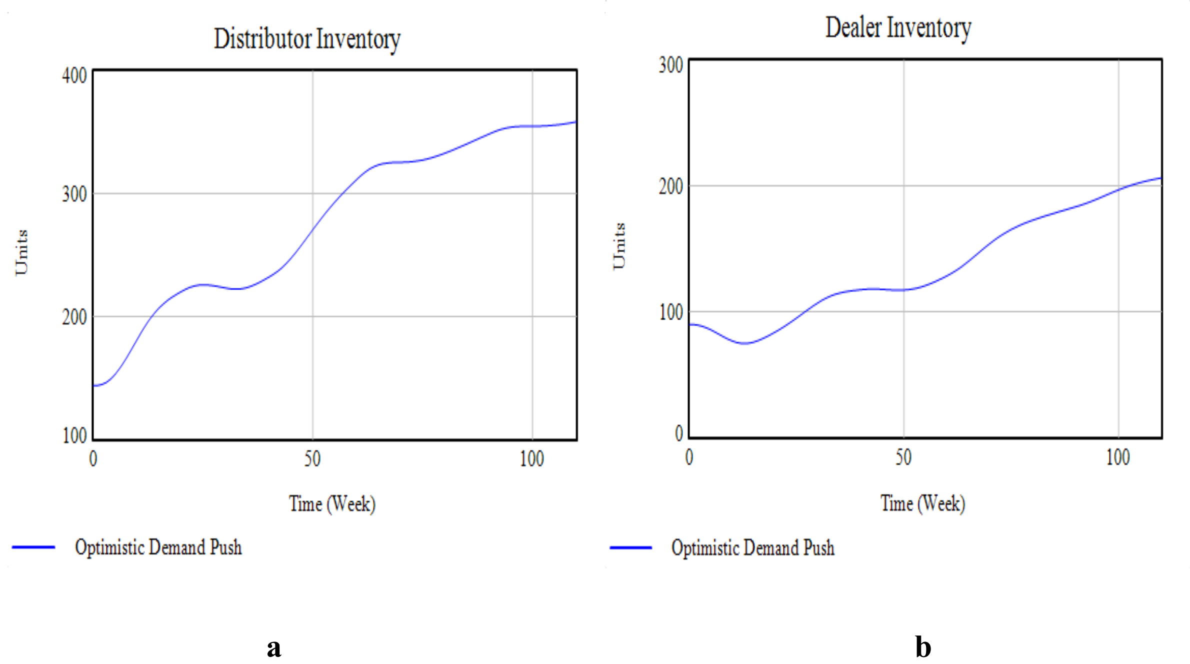


FIGURE 6. 10. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

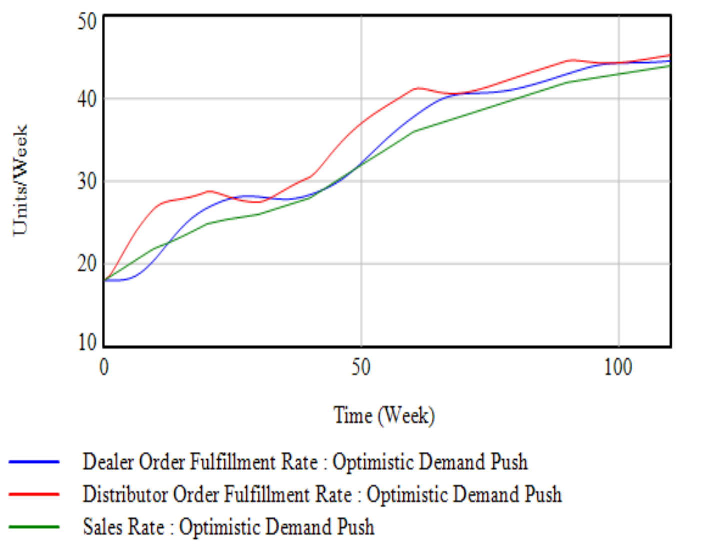
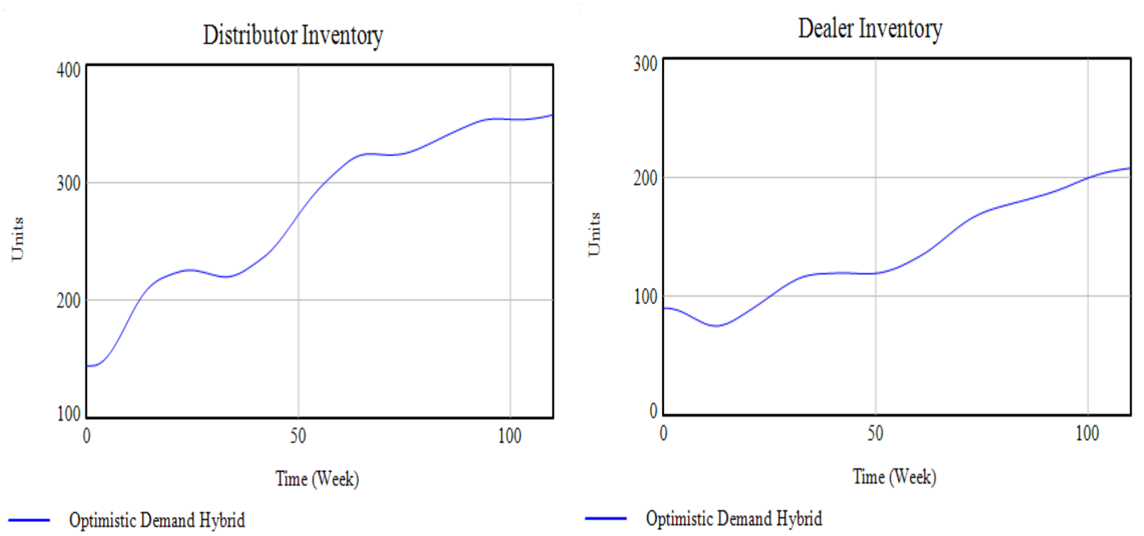


FIGURE 6. 11. EFFECT OF OPTIMISTIC DEMAND ON INFLOW AND OUTFLOW RATES UNDER PUSH MODEL

The behaviour displayed in the push model is a result of the number of inventories pushed down the supply chain this causes an increment in the number of inventories for the company. These values are up to the management to decide upon for their operations. As mentioned by Coyle (1977), longer delays will reduce the ability of a system to dampen amplification. While in general a more stable supply chain is desired by companies, delays in responding to changes in demand increases bottleneck. Nonetheless, the distributor order fulfilment rate, dealer order fulfilment rate and sales rate is persistently below the inventory. As such, it complies with the validation purpose.

6.8 Model validation under hybrid push/pull model for optimistic demand

The purpose for the hybrid push/pull model's behaviour is that it reflects both the performance of the push and pull model in the analysis. The behaviour of the hybrid push/pull model imitates a pull system at the dealer due to the structure of the model that applies pull process at the stage. The managers are unable to reduce the discrepancy of the desired inventory and actual inventory levels as a result of negative feedback in the system. Figure 6.12 (b) illustrates the dealer inventory of the hybrid push/pull model.



a **b**

FIGURE 6. 12. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

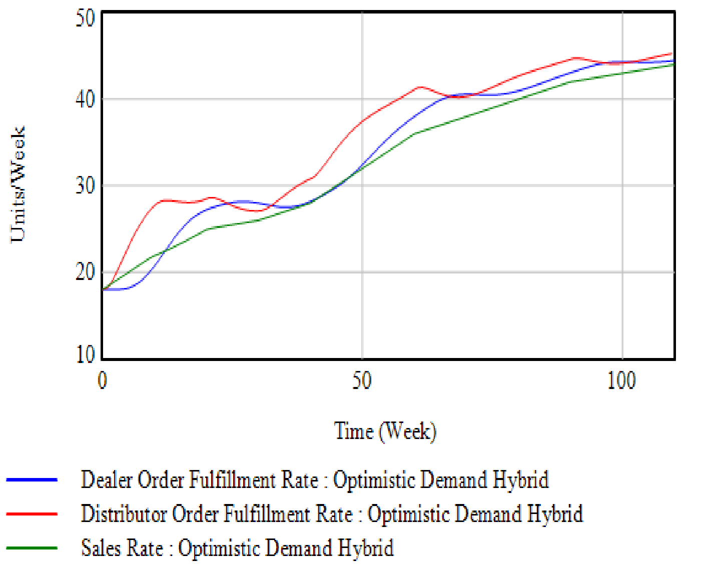


FIGURE 6. 13. EFFECT OF OPTIMISTIC DEMAND ON INFLOW AND OUTFLOW RATES

In Figure 6.12 (b), the dealer inventory decreases after week 5 then gradually increases to the end of the simulation at week 110. In Figure 6.12 (a) the distributor inventory increases after week 5 and keeps that pattern till the end of the simulation at 110 weeks. The dealer order fulfilment rate is increased by the distributor inventory making dealer inventory increase as shown till the end of the simulation as presented in Figure 6.12 (a) and (b), and 6.13. The dealer order fulfilment rate is showing volatility as it is influenced by the dealer order cycle time. Despite the less oscillatory pattern in the distributor inventory and dealer inventory, the graphs shows an increasing pattern and a slight unsteady pattern. From the perspective of the model validation purpose, the inflow and outflow rates does not exceed the inventories.

6.9 Direct structure tests for pessimistic demand

The third test is performed with a pessimistic demand pattern. Figure 6.14 displays the pessimistic demand pattern and smoothed pessimistic demand in the analysis. In the next sections, the discussion of the analysis focuses on the validation of the model's behaviour against the model purpose as previously outlined in Table 5.2 Chapter 5. The model's response towards the pessimistic demand is also discussed.

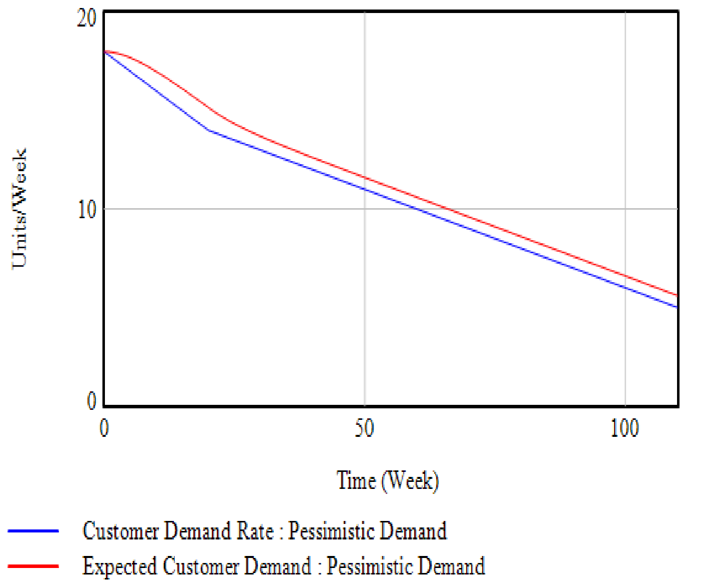
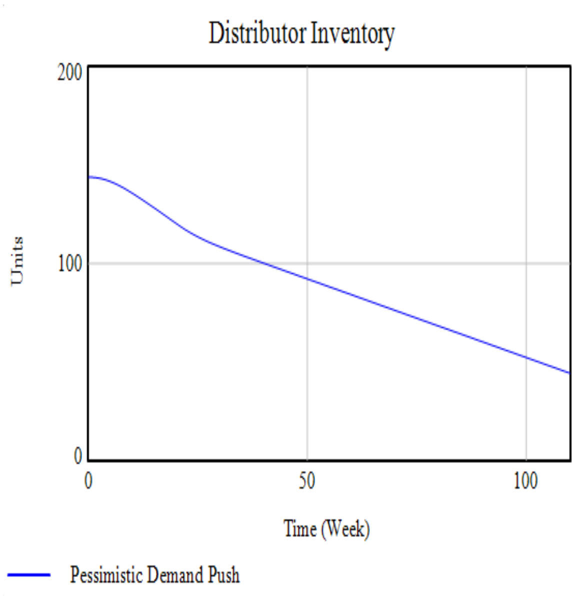


FIGURE 6. 14. PESSIMISTIC DEMAND AND SMOOTHED PESSIMISTIC DEMAND

6.10 Model validation under push model for pessimistic demand

As presented in Figures 6.15 (a), and (b) and 6.16 the consequence of the pessimistic demand is a dramatic increase in the level of inventory at the dealer inventory as seen in Figure 6.15 (b) with the condition that the dealer order fulfilment cycle time is 8 weeks and safety stock coverage 3 weeks and a decrease in distributor inventory level. Conversely, for optimistic demand pattern, the effect of this delay is only vaguely visible. Commencing at week 5, the dealer order fulfilment rate is not responsive to a further decline in the sales rate. This causes increase in the dealer inventory.



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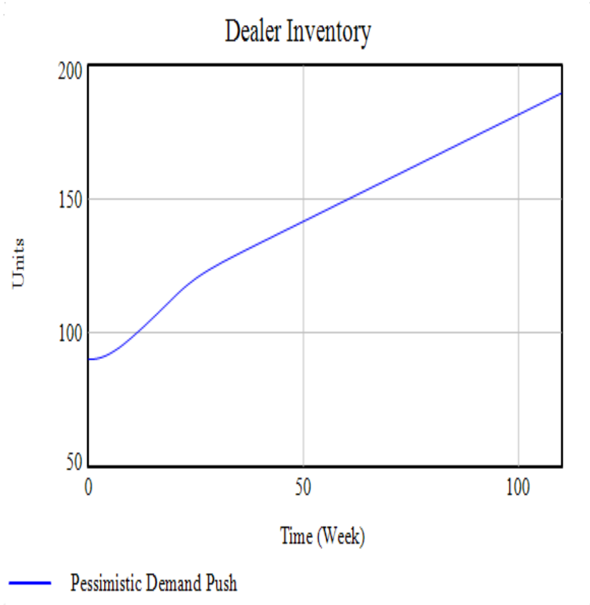

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FIGURE 6. 15. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

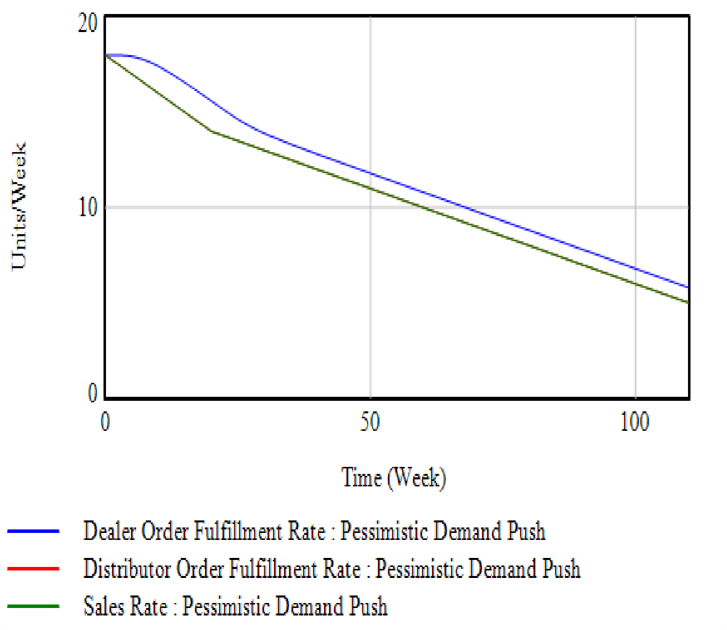

FIGURE 6. 16. EFFECT OF PESSIMISTIC DEMAND ON INFLOW AND OUTFLOW RATE

Although the sales rate gradually decreases, the distributor order fulfilment rate declines at the same rate of sales rate this is as a result of delays in the system to a decline in customer demand. This result is consistent with the findings of Morecroft (1980). He concluded that delay within a typical business environment causes instability in the rate and stock level. To reflect this observation, the dealer order fulfilment rate causes more instability to the dealer inventory than the sales rate. Simultaneously, the reduction of sales rate does not exceed the dealer inventory level. In this analysis, the dealer order fulfilment rate is higher than the distributor order fulfilment rate, which causes the distributor inventory to decrease gradually. However, the dealer order fulfilment rate is consistently below the distributor inventory level. Moreover, under push model, the order is placed based on a statement of requirements for inventory.

The delay from the distributor is inevitable as the supplier requires some time to produce or source for inventories. The distributor is more responsive in comparison to the dealer inventory level, resulting from the discrepancy. In conclusion, the behaviour of the push model under pessimistic demand is less satisfactory than the business as usual and optimistic demand patterns.

6.11 Model validation under hybrid push/pull model for pessimistic demand

As shown in Figure 6.17 (a) and (b) the analysis of pessimistic demand under the hybrid push/pull model are not similar to the push model. The underlying reason is that a push process is applied at the distributor inventory. Figure 6.17 (a) illustrates the behaviour of the distributor inventory under hybrid push/pull model as it decreases once the demand starts reducing. The distributor order fulfilment rate, dealer order fulfilment rate and sales rate also declines with an unsteady pattern. The dealer inventory level slightly increases after week 5 to about week 28 then inclines downward till the end of the simulation as seen in Figure 6.17 (b) this observation is in contrast with the push model in Section 6.4.1, which explains that pull process has a more dominant effect at the dealer's inventory.

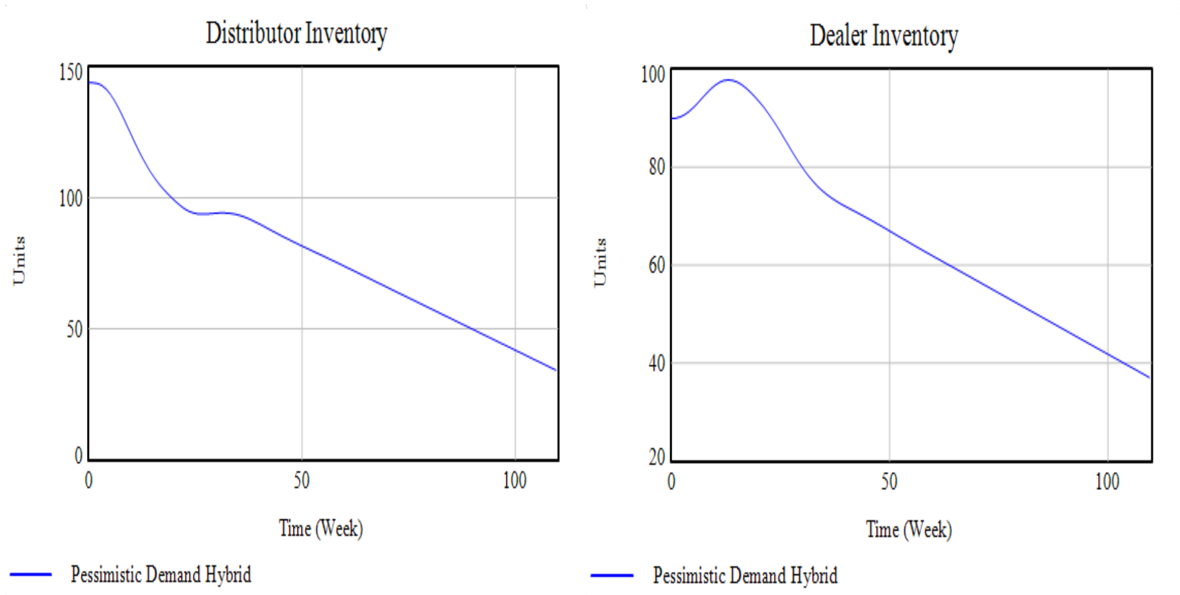

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FIGURE 6. 17. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

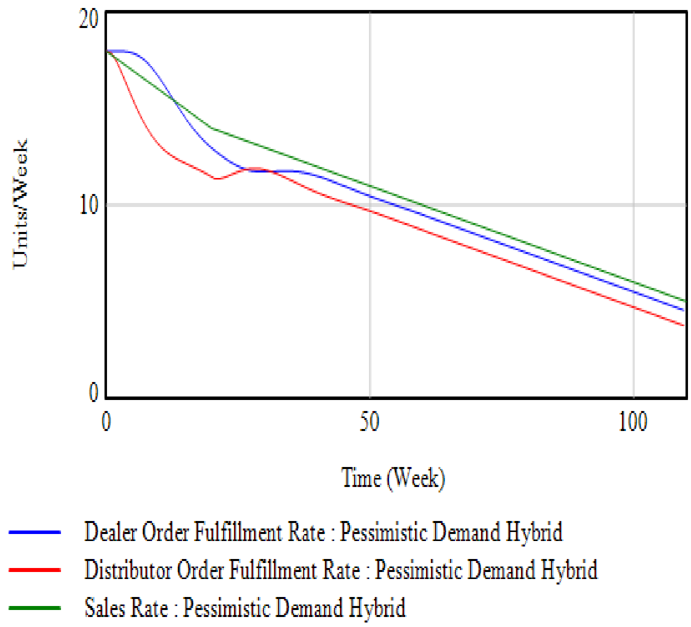

FIGURE 6. 18. EFFECT OF PESSIMISTIC DEMAND ON INFLOW AND OUTFLOW RATES

As seen in the graphs the distributor order fulfilment rate, dealer order fulfilment rate and sales rate are consistently below both distributor inventory and dealer inventory. At this point, the model behaviour is in accordance with the model validation purpose.

6.12 Comparative analysis

The focus of the discussion in this section is to interpret the results from a comparative analysis perspective for case study B. In the previous section, the behaviour of the two models for the distributor inventory and dealer inventory have been thoroughly discussed. As mentioned before, these analyses justify that the structure of the model is capable of producing the behaviour that emerges from a theoretical understanding of the system and real world. Now that the models have been validated, it is appropriate to continue the analysis on the level of inventory of the distributor and dealer in the two models. The results of the first analysis are obtained from a simulation run of the models with the smoothing constant equal to six weeks.

An extensive analysis has been performed to examine the sensitivity of the model to a shorter smoothing parameter. In the second analysis, the smoothing parameter is set to only two weeks, which means that the demand is smoothed over one-third of the time. The idea behind this is to create a quick response to any changes in the demand. This analysis is relevant in providing an insight of how the model might respond if the managers tried to reduce the smoothing times in responding to customer demand. The results from the simulation runs are presented in the following sections for both values of the smoothing parameter.

6.13 Analysis of inventory levels of BAU demand

The analysis for validation purposes have been presented at each model in the previous section. However, it is more difficult to compare the state of the inventories given the separate graphs. For this reason, the results from each model are now assembled in a single graph to provide a clear picture of how the models differ from one another. Figures 6.19 (a), and (b), and 6.20 (a), and (b) present the results from the simulation with different smoothing parameter values. In the first graph, given the smoothing constant equals 6 weeks, all the distributor and dealer show a delay in adjusting to the desired level of inventory.

The push model display oscillations and instabilities, whereas in the hybrid push/pull model the inventory level is more oscillatory in the distributor inventory compared to the push but less oscillatory in the dealer inventory. Similarly, when the smoothing parameter is shortened to 2 weeks, the inventory level retains its pattern, with slight adjustment to the desired level as displayed in Figure 6.20 (a) and (b). The implication of this behaviour is that when the smoothing parameter is increased company may have the desired inventory level to fulfil customer demand but at the cost of increasing the oscillations in the system. Therefore, the smoothing parameters was decreased for further simulation runs.

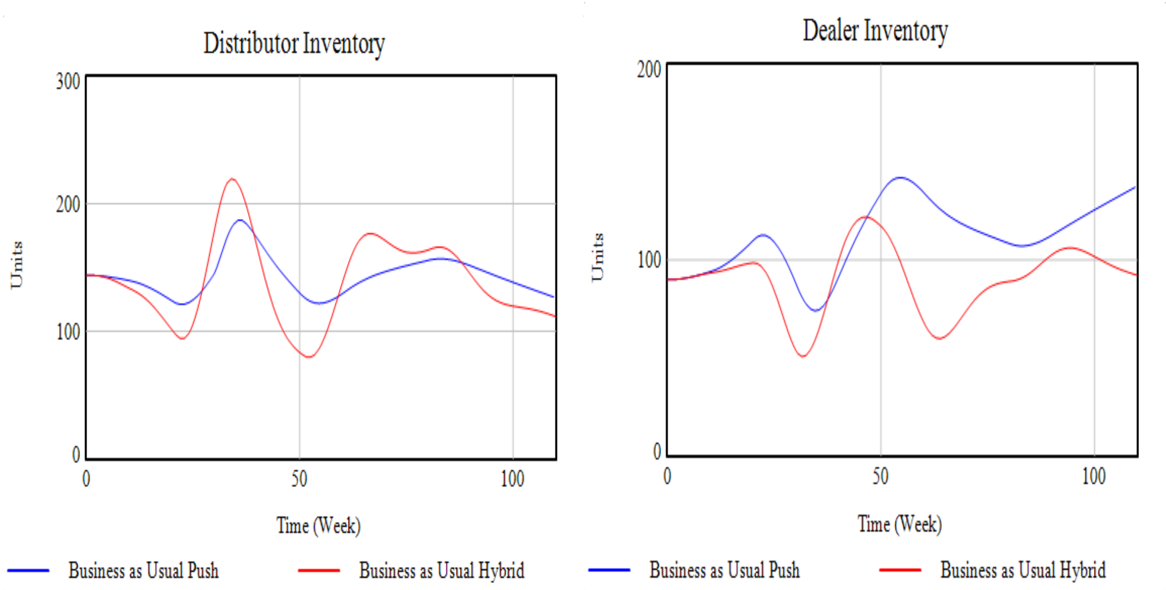

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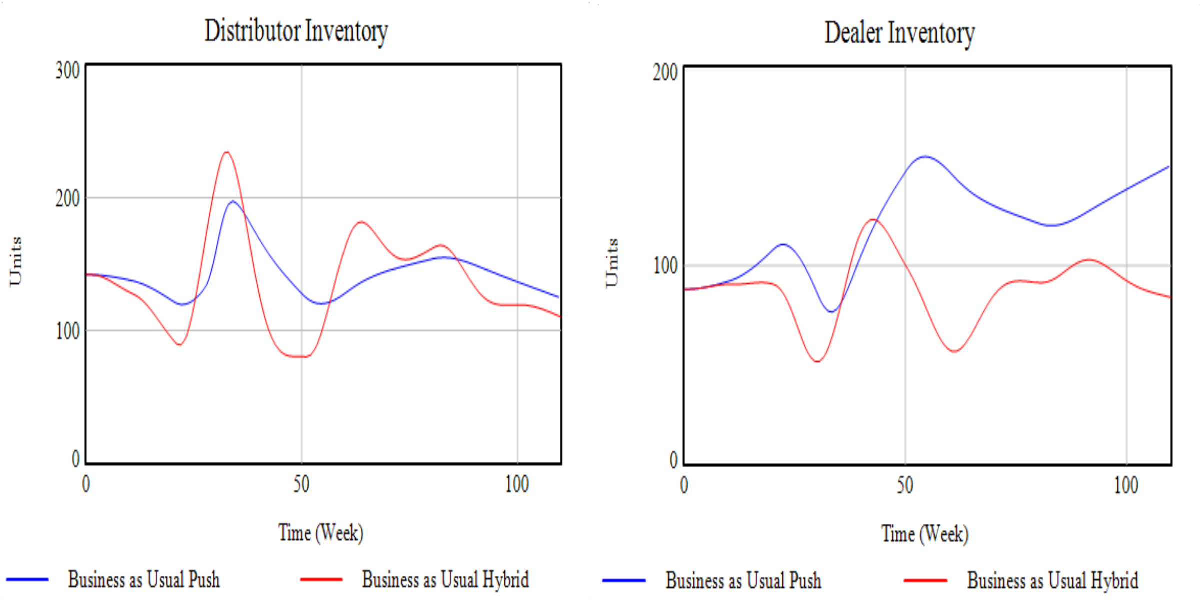
FIGURE 6. 19. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF SIX WEEKS



a **b**

FIGURE 6. 20. EFFECT OF BAU DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF TWO WEEKS

The behaviour in the two models displays a slight difference in the patterns of distributor and dealer inventories, as shown in Figures 6.20 (a) and (b) as compared to Figures 6.19 (a) and (b). In Figure 6.19 (b) the push model holds higher dealer inventory. One of the main objectives in a push operation is to increase the amount of inventory (Chang and Yih, 1994a; Monden, 1993). From this result, it can argue that push model on its own, without policies that reflect the Just-In-Time philosophy, leads to excessive stock holding. Ohno (1988) emphasised the importance of level production/inventory for a successful implementation of the JIT system. In this research, the push model is purposely synchronised with the hybrid push/pull model for a valid comparison.

As mentioned before, longer delays induce further oscillation and instabilities. Therefore, the rapid response to changes in demand can reduce the oscillation. In this situation, there will be trade-offs between costs generated by fluctuating inventory. These insights may offer some help for managers in balancing out the need for a prompt response to customer demand, and the costs incurred by such action.

6.14 Analysis of inventory levels of optimistic demand

In this section, the results from the simulation run with optimistic demand are discussed by highlighting the distinctions in the behaviour pattern of the two models' and the sensitivity towards the changed smoothing parameter. The two models exhibit slight variations between the push and hybrid push/pull model as shown in Figures 6.21 (a) (b), and 6.22 (a) (b). The models display a slightly jagged pattern in both test with smoothing parameters of 6 weeks and 2 weeks, respectively. This result also reveals that the decision to reduce the response time to customer demand during a gradually increasing demand pattern does not trigger additional or reduces oscillations in the models.

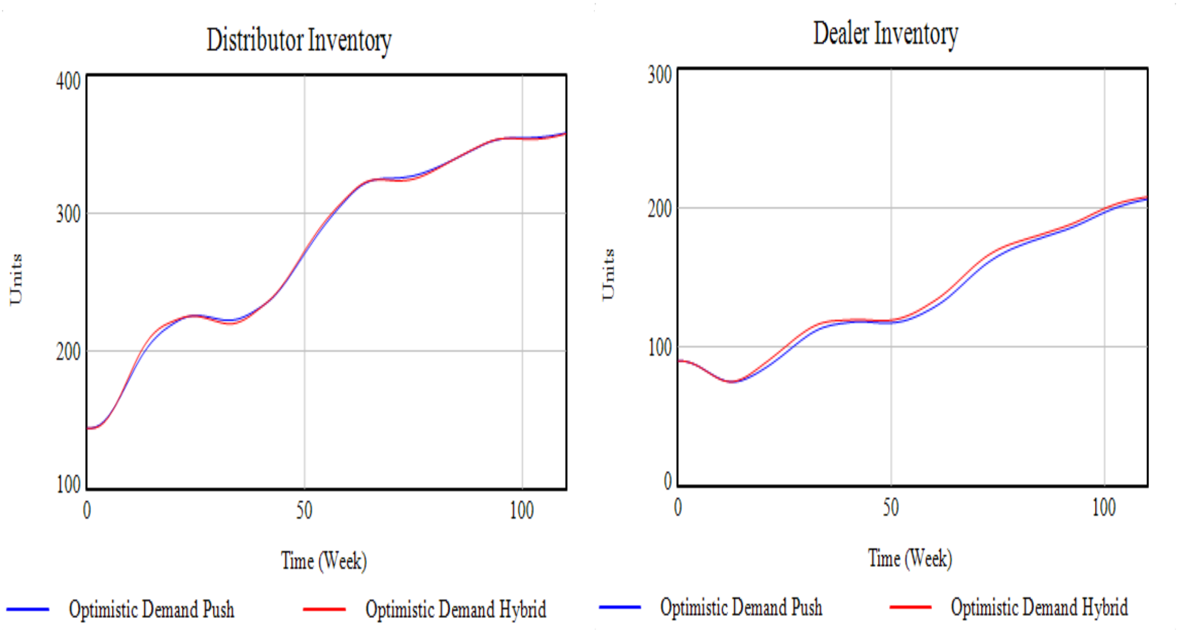


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FIGURE 6. 21. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF SIX WEEKS

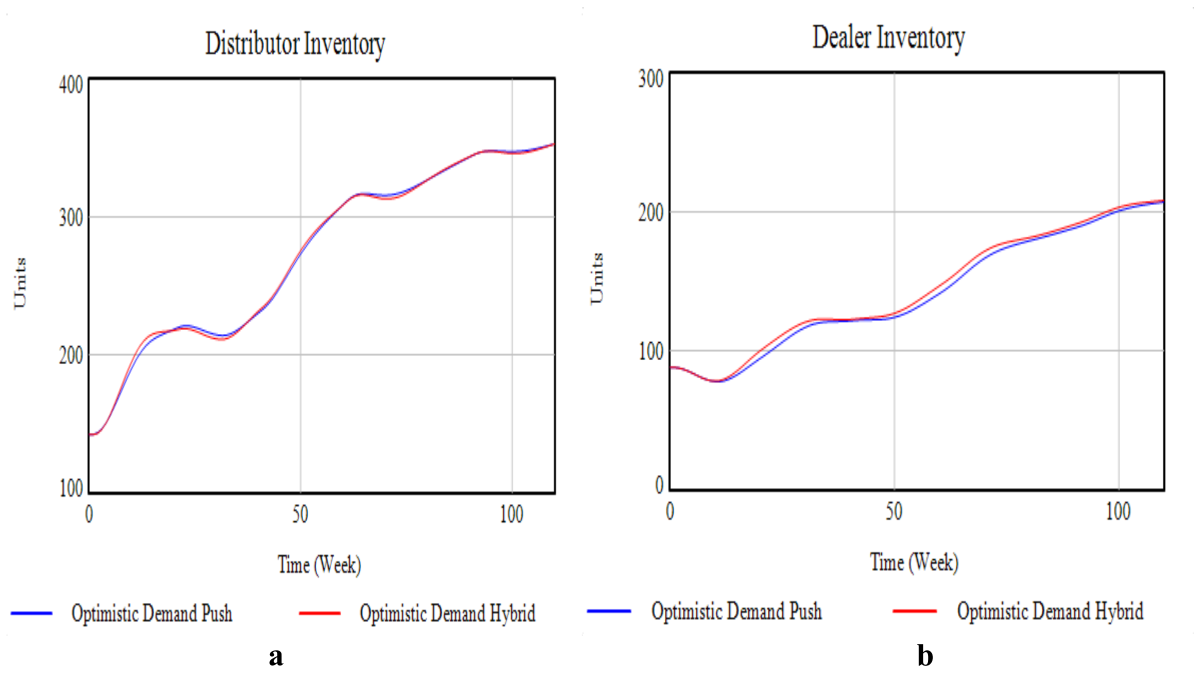


FIGURE 6. 22. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF TWO WEEKS

In summary, a shorter smoothing time reduces the time taken by the models to adjust to the desired inventory level. At this point, the managers should strive to act at the shortest time in adjusting and smoothing demand.

6.15 Analysis of inventory levels for pessimistic demand

Figures 6.23 (a) and (b), 6.24 (a) and (b) presents the effect of pessimistic demand pattern on the distributor and dealer inventory levels with a different smoothing parameter of six weeks and two weeks. In the following graphs, the hybrid push/pull model have lower inventory level on distributor inventory but surprisingly in Figure 6.23 (b) there is a significant increase in inventory level in the dealer inventory as seen in the push model. The major influence of the reduced smoothing parameter to two weeks is a slight reduced difference in the inventory level as seen in the graphs.

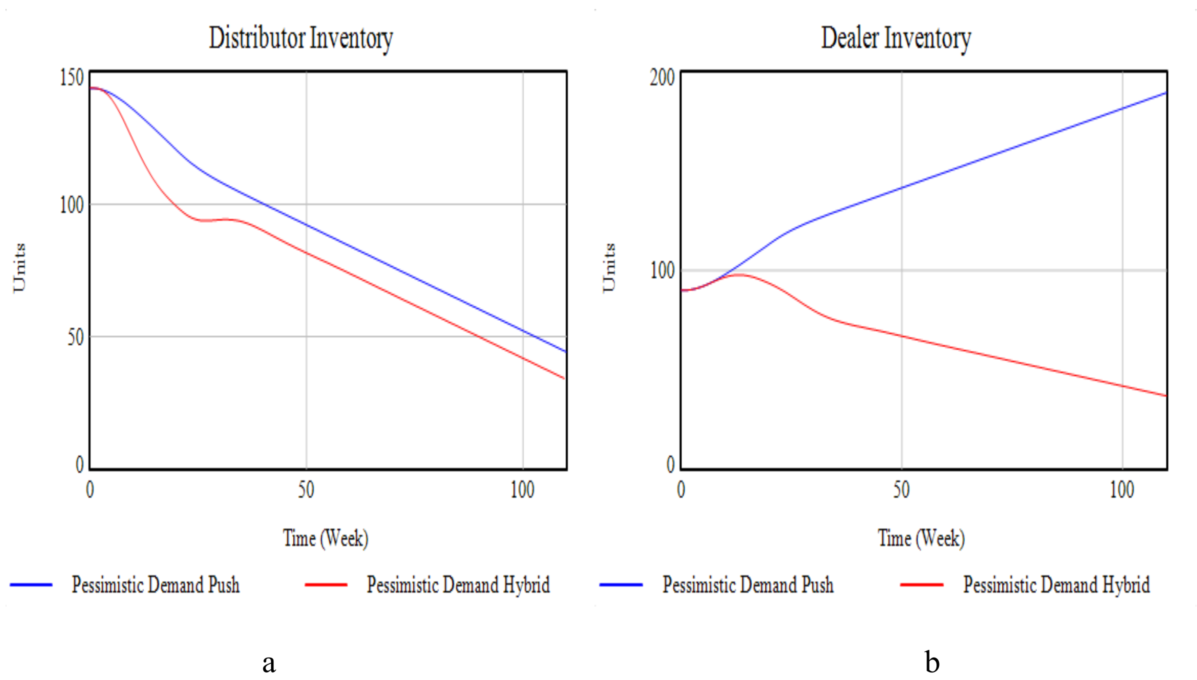


FIGURE 6. 23. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF SIX WEEKS

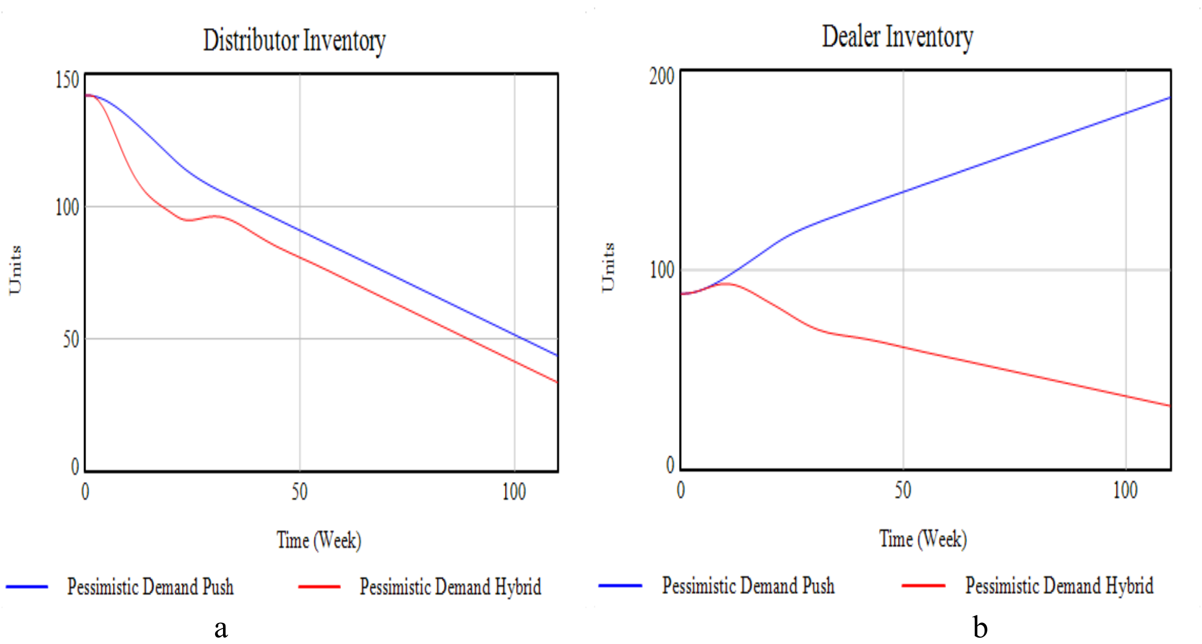


FIGURE 6. 24. EFFECT OF PESSIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY WITH SMOOTHING PARAMETER OF TWO WEEKS

As the delay is shortened in the smoothing parameter, the difference between the inventory levels is slightly affected as well as the time taken to adjust to the desired inventory level. A larger value for the smoothing parameter widens the gaps in the inventory levels across the models, while the smaller smoothing parameter slightly reduces this gap. Although, the hybrid push/pull system has lower inventory compared to the push model. A shorter smoothing parameter means that the hybrid push/pull model responds slightly quicker to customer demand especially in the dealer inventory.

6.16 Summary of the inventory levels

This section summarises the graphical results from the simulation by presenting average inventory levels at the distributor inventory and dealer inventory. In the previous section some of the results displayed minor differences in the two models between the distributor inventory and dealer inventory. For this reason, the following numerical results provide a clearer picture of the performance of each of the models. Table 6.1 presents the average distributor inventory and dealer inventory level in the analysis for business as usual demand pattern.

In test 1, where the smoothing parameter is equal to six weeks, the push model has higher level of distributor inventory and dealer inventory. Although the hybrid push/pull model has lower average level of inventory, this result explains a possibility of insufficient inventories. Under the test with business as usual the hybrid push/pull model returns the best level of performance for the demand pattern. It responds well to changes in demand and at the same time is capable of keeping inventories low.

Test 1: Business as Usual, smoothing parameter = 6 weeks		
	Distributor Inventory	**Dealer Inventory**

Push	132	131
Hybrid Push/Pull	104	106
Test 2: Business as Usual, smoothing parameter = 2 weeks		
Push	130	144
Hybrid Push/Pull	99	96

TABLE 6. 1. EFFECT OF BAU ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

In the case where the managers decided to respond to changes in demand swiftly (Test 2) with a smoothing parameter of two weeks the inventory level is slightly reduced in the two model results with the push model still with more level of inventories as depicted in Table 6.1.

For the test with optimistic demand, the results exhibit a contrary result to the test under business as usual demand. Table 6.2 presents the push model with slight lower inventory level as compared to the hybrid push/pull model with slightly higher inventory. These results illustrate that the push model copes well with optimistic demand, showing slight lower inventories than the hybrid push/pull model therefore there is no similarity between the results of the business as usual and optimistic against the push and hybrid push/pull model.

Test 3: Optimistic demand, smoothing parameter = 6 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	371	197
Hybrid Push/Pull	372	199

Test 4: Optimistic demand, smoothing parameter = 2 weeks		
Push	367	201
Hybrid Push/Pull	367	204

TABLE 6. 2. EFFECT OF OPTIMISTIC DEMAND ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

Contrary results emerge in the test with pessimistic demand in test 5. Table 6.3 demonstrates that the push model has higher level of inventory, which is opposite to the observation in the previous tests three and four but like tests one and two. Therefore, the effect of pessimistic demand pattern to the hybrid push/pull model is the lower inventory level in the distributor inventory. In previous tests, the push model copes well with optimistic demand but performs slightly poor in business as usual and significantly poor in pessimistic demand. Another interesting perspective is in test six where the smoothing parameter is equal to two weeks. Here, reducing the response time to demand changes under a pessimistic demand pattern still leaves the inventory level significantly high in the push model. Similarly, the hybrid push/pull model still have lower number of inventories in the distributor inventory in comparison to the push model which displays slight higher inventory levels in test six.

Test 5: Pessimistic Demand, smoothing parameter = 6 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	51	182
Hybrid Push/Pull	41	41

Test 6: Pessimistic Demand, smoothing constant = 2 weeks		
Push	50	179
Hybrid Push/Pull	41	35

TABLE 6. 3. EFFECT OF PESSIMISTIC ON DISTRIBUTOR INVENTORY AND DEALER INVENTORY

Tables 6.4 and 6.5 summarise the overall performance of the two models with smoothing parameter of six weeks and two weeks. The distributor inventory and dealer inventory are measured based on the average inventory level at the end of the simulation at week 110. From the tables, the model that has highest level of inventory is marked with H. On the other hand, results having lowest level of inventory is marked with L. From these results, the model with the highest (H) level of inventory are highlighted with a blue background; this indicates that the model is not coping well with that particular demand pattern while the model with the greatest number of L (lowest) for the levels of inventory is highlighted with a light green background; this indicates that this particular system is performing better in comparison with the other models.

Demand Pattern	**Business as Usual**		**Optimistic Demand**		**Pessimistic Demand**	
Inventory Level	DIINV	DEINV	DIINV	DEINV	DIINV	DEINV
Push	**H**	**H**	**L**	**L**	**H**	**H**
Hybrid Push/Pull	**L**	**L**	**H**	**H**	**L**	**L**

DIINV- Distributor Inventory **DEINV-Dealer Inventory**

H-High L-Low

Best Performance Worst Performance

TABLE 6. 4. OVERALL PERFORMANCE OF THE PUSH AND HYBRID PUSH/PULL MODELS WITH SMOOTHING PARAMETER OF SIX WEEKS

Demand Pattern	Business as Usual		Optimistic Demand		Pessimistic Demand	
Inventory Level	**DIINV**	**DEINV**	**DIINV**	**DEINV**	**DIINV**	**DEINV**
Push	H	H	L	L	H	H
Hybrid Push/Pull	L	L	H	H	L	L

DIINV- Distributor Inventory **DEINV-Dealer Inventory**

H-High L-Low

Best Performance Worst Performance

TABLE 6. 5. OVERALL PERFORMANCE OF THE PUSH AND HYBRID PUSH/PULL MODELS WITH SMOOTHING PARAMETER OF TWO WEEKS

The results presented in this chapter portray the different responses of the push model and hybrid push/pull model for the second case study under a series of tests using different customer demand patterns. However, perhaps more useful measures are the total costs, profit and cash balance incurred as a result of the responses to customer demand patterns. Although some of the model results have been marked with the highest or the lowest inventory, the differences in the generated volume measures can be minimal. For this reason, the analysis is now expanded to compare the financial metrics in the two models in the following sections.

6.17 Overview of financial measure

The focus of the analysis of financial measure is the impact the inventory level has on cost. The carrying cost of inventory for company B is NGN22, 000/unit and the financial metrics are analysed to give insights on the total costs of carrying inventory over the period of 110 weeks. This analysis is performed under the different demand patterns and the purpose is to show that financial measures can vary, despite the performance being displayed as shown in the previous sections.

It is important to note that once again the analysis is performed with a varying smoothing parameter to represent the different expectations by managers in respect of changes in demand. The first results present the outcome from the simulation runs with a smoothing parameter of six weeks. This period represents the usual time for managers to respond to changes in demand. The second set of results presents the outcome from a test with the demand smoothing parameter decreased to two weeks the outcome from these two tests is now described in the next section.

6.18 Costs analysis of BAU demand pattern under push and hybrid push/pull models

Figures 6.25 to 6.30 display the total costs, profit and cash balance for the test with business as usual demand pattern. Although the distinction between total costs, profit and cash balance in the two models is not obvious, it can be seen that the total cost of the of the models are oscillatory but with a slight higher profit compared in the hybrid push/pull model compared to the push model this would be as a result of the lower inventory level. This is in line to the findings from the analysis of the levels of inventory. The Hybrid push/pull model have better level of performance under business as usual demand, in comparison to the push model this causes higher total cost with less profit and cash balance. Holding high inventory lead to high total costs in the push model in this case.

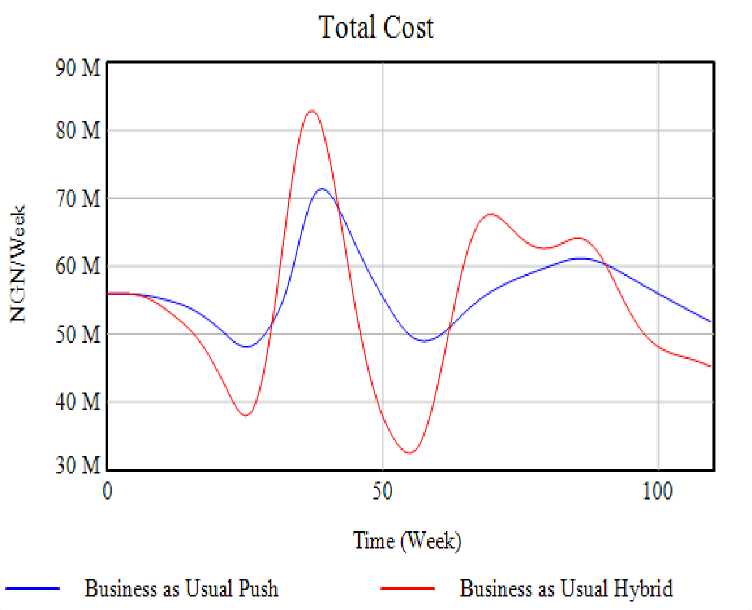


FIGURE 6. 25. EFFECT OF BAU DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER SIX WEEKS

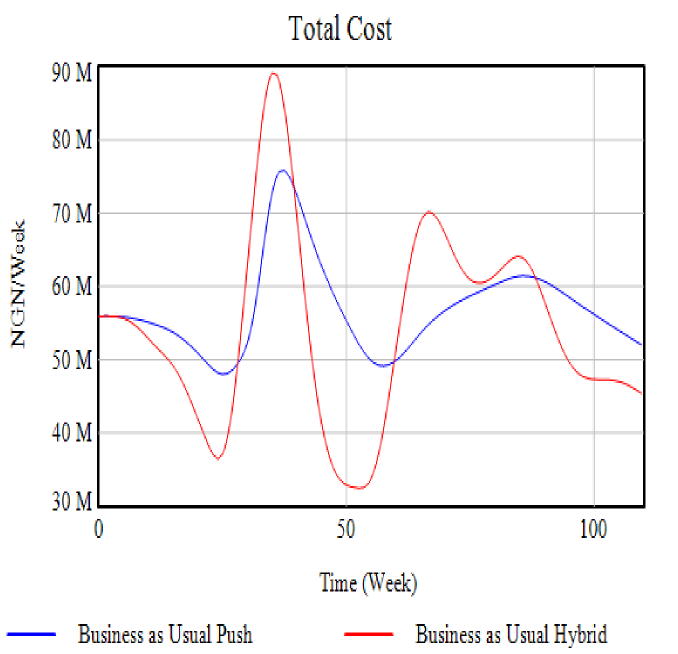


FIGURE 6. 26. EFFECT OF BAU DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER TWO WEEKS

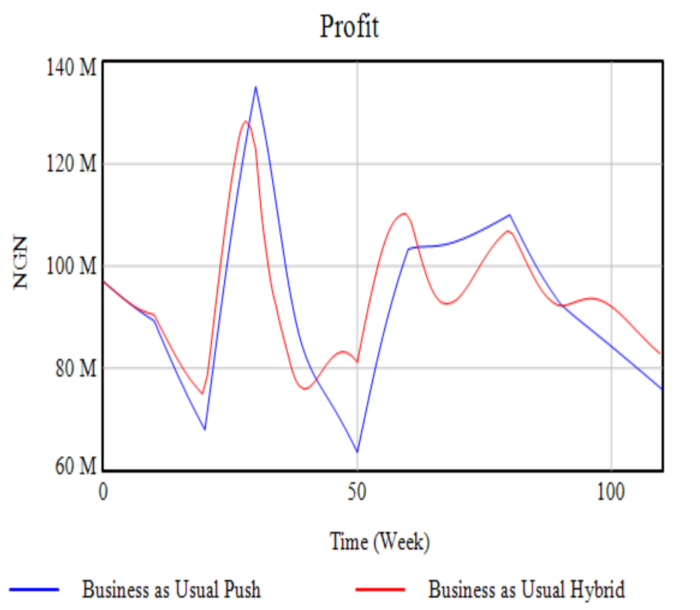


FIGURE 6. 27. EFFECT OF BAU DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

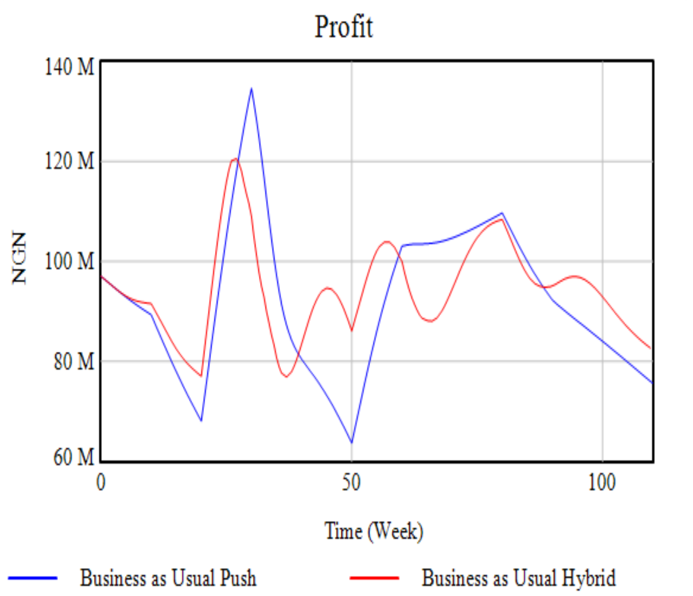


FIGURE 6. 28. EFFECT OF BAU DEMAND ON PROFIT WITH SMOOTHING PARAMETER TWO WEEKS

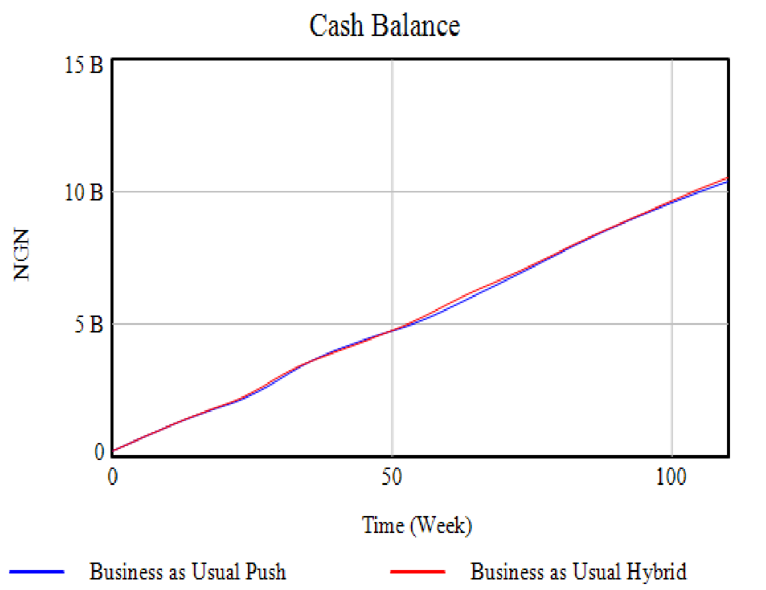


FIGURE 6. 29. EFFECT OF BAU DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

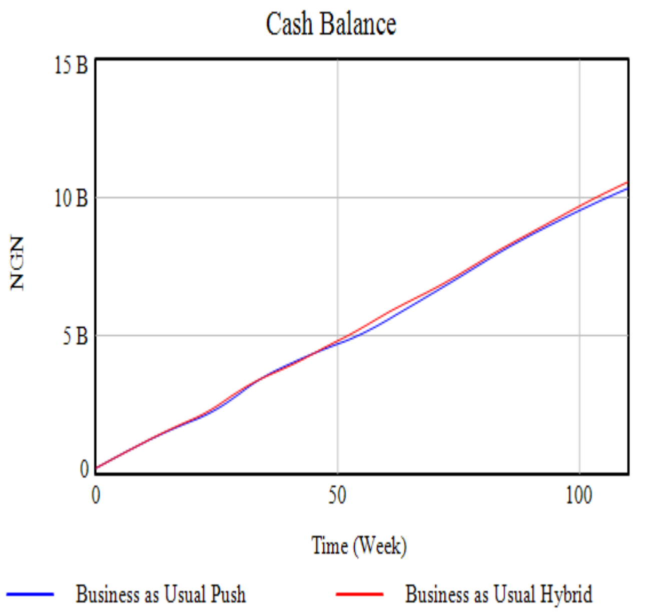


FIGURE 6. 30. EFFECT OF BAU DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER TWO WEEKS

The final values of total costs, profit and cash balance in the push and hybrid push/pull models at week 110 are summarised in Table 6.6.

Business as Usual	Push	Hybrid Push/Pull
Smoothing Parameter = 6 Weeks		
Total Cost	54,780,600	45,168,200
Profit	72,331,800	82,331,800
Cash Balance	10,405,800,000	10,547,700,000
Smoothing Parameter = 2 weeks		
Total Cost	54,990,800	42,775,200
Profit	72,509,200	84,724,800
Cash Balance	10,342,200,000	10,574,200,000

TABLE 6. 6. EFFECT OF BAU DEMAND ON TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

From Table 6.6, the hybrid push/pull model have lower total cost under the test with smoothing time six weeks and two weeks respectively with a higher profit and cash balance. This result parallels the findings in the analysis of inventory levels. Therefore, the findings from the test under business as usual demand pattern with different values for the smoothing constant is that there is a better performance when the smoothing parameter is slightly decreased resulting in the faster response by the managers to changes in customer demand.

6.19 Costs analysis of optimistic demand under push and hybrid push/pull models

Figures 6.31 to 6.36 illustrate the total costs, profit and cash balance of the two models under an optimistic demand pattern. Contrary, to the observation in the test with business as usual demand, the hybrid push/pull model has higher total costs with lower profit and cash balance under optimistic demand in both tests. The underlying reason is the higher level of inventory in the hybrid push/pull model as compared to the push model. The hybrid push/pull model exhibits slightly higher total costs as a result to the lower level of inventory.

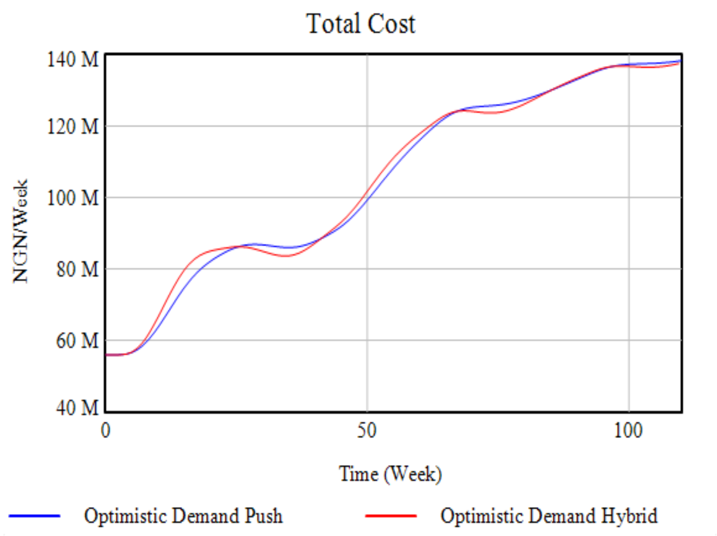


FIGURE 6. 31. EFFECT OF OPTIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER SIX WEEKS

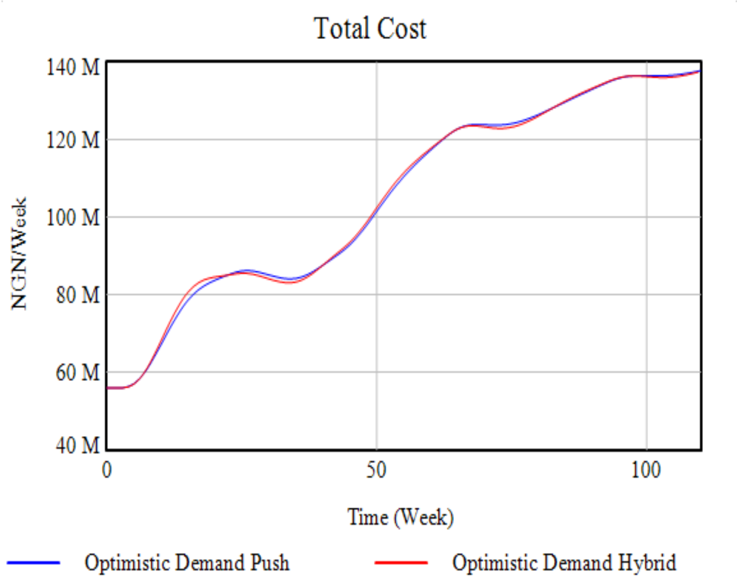


FIGURE 6. 32. EFFECT OF OPTIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER TWO WEEKS

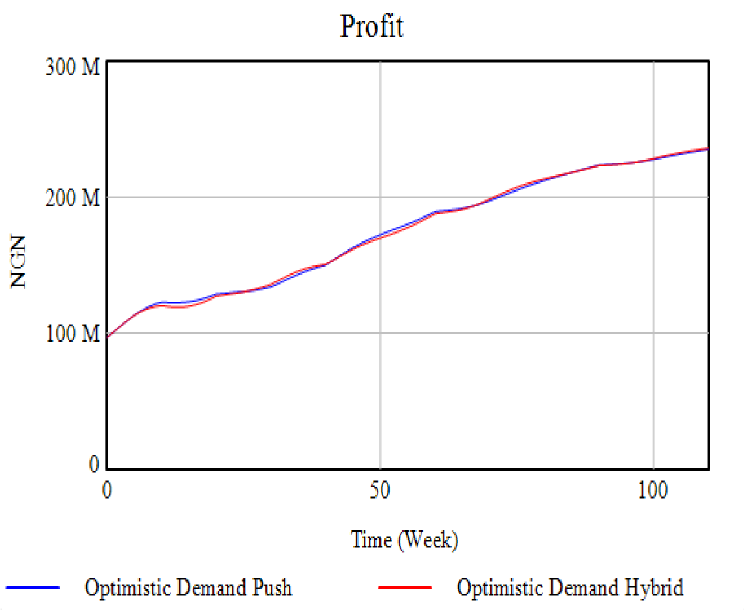


FIGURE 6. 33. EFFECT OF OPTIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

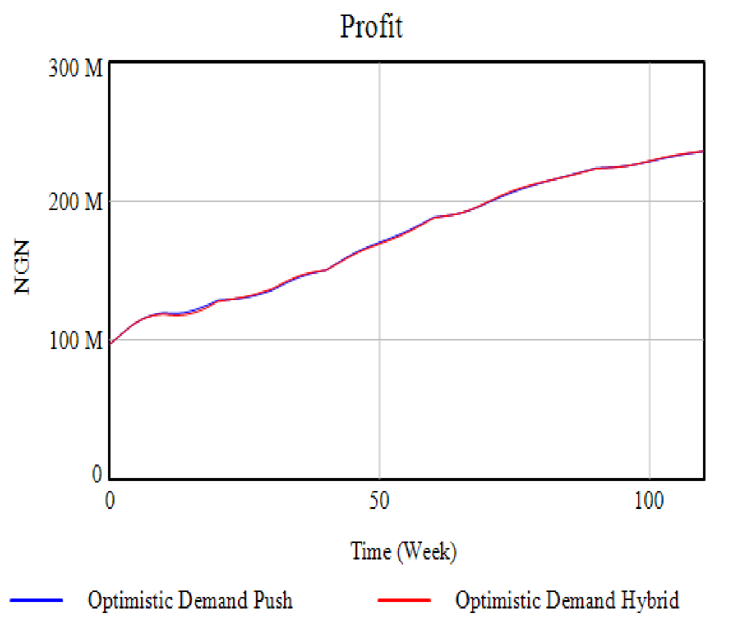


FIGURE 6. 34. EFFECT OF OPTIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER TWO WEEKS

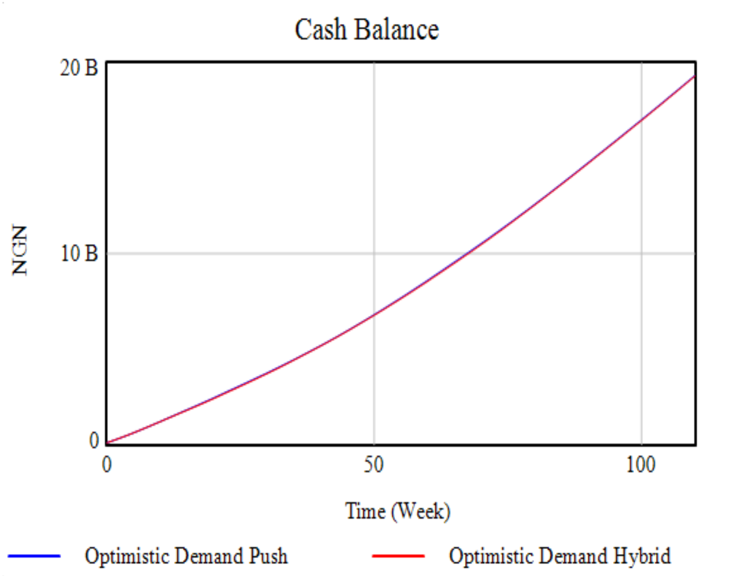


FIGURE 6. 35. EFFECT OF OPTIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

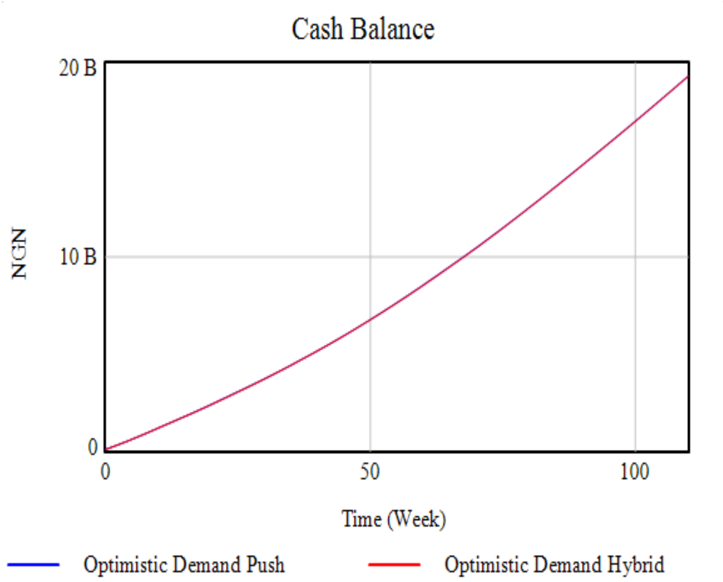


FIGURE 6. 36. EFFECT OF OPTIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER TWO WEEKS

Table 6.7 below portrays the numerical values from the simulation results in the tests conducted with optimistic demand pattern under push and hybrid push/pull models. When the smoothing parameter is decreased to two weeks the hybrid push/pull model still have slightly higher total cost with lower profit and cash balance like when the smoothing time is left at six weeks.

However, the total costs in the two models are slightly reduced when the demand smoothing parameter is decreased to two weeks. This is as a result of the managers now responding faster to changes in customer demand.

Optimistic Demand	Push	Hybrid Push/Pull
Smoothing Parameter = 6 weeks		
Total Cost	141,346,000	141,673,000
Profit	240,211,000	240,485,000
Cash Balance	19,330,700,000	19,343,300,000
Smoothing Parameter = 2 Weeks		
Total Cost	141,668,000	141,455,000
Profit	240,190,000	240,403,000
Cash Balance	19,327,800,000	19,338,400,000

TABLE 6. 7. EFFECT OF OPTIMISTIC DEMAND ON TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

6.20 Costs analysis of pessimistic demand under push and hybrid push/pull models

Figures 6.37 to 6.42 illustrate the difference in the total costs, profit and cash balance of the two models for the test of pessimistic demand. From these graphs, the hybrid push/pull model have lower total costs with higher profit and cash balance. In the hybrid push/pull model, dealer adjust the discrepancy on the amount of inventory sold from stock. This policy responds quickly to any changes in demand. Hence, during the pessimistic demand period, the distributor order fulfilment rate and dealer order fulfilment rate is further reduced as the smoothing time is decreased. For this reason, the level of inventory in the hybrid push/pull model is much lower in comparison to the push model.

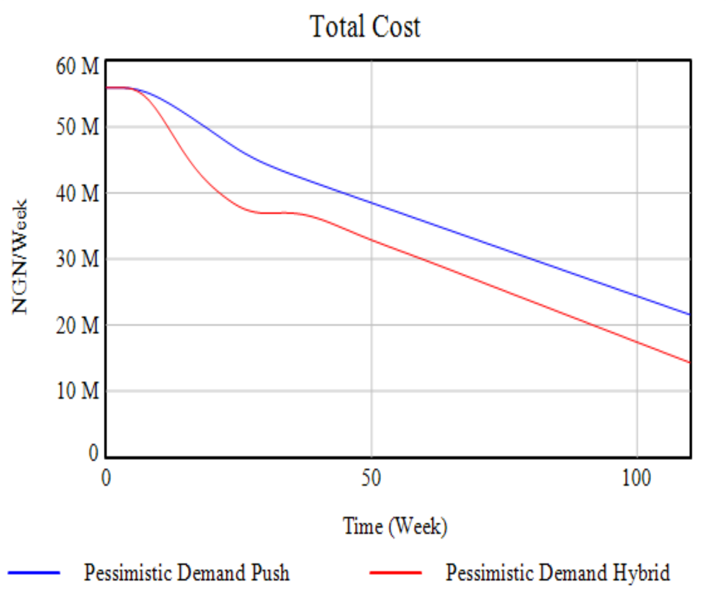


FIGURE 6. 37. EFFECT OF PESSIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER SIX WEEKS

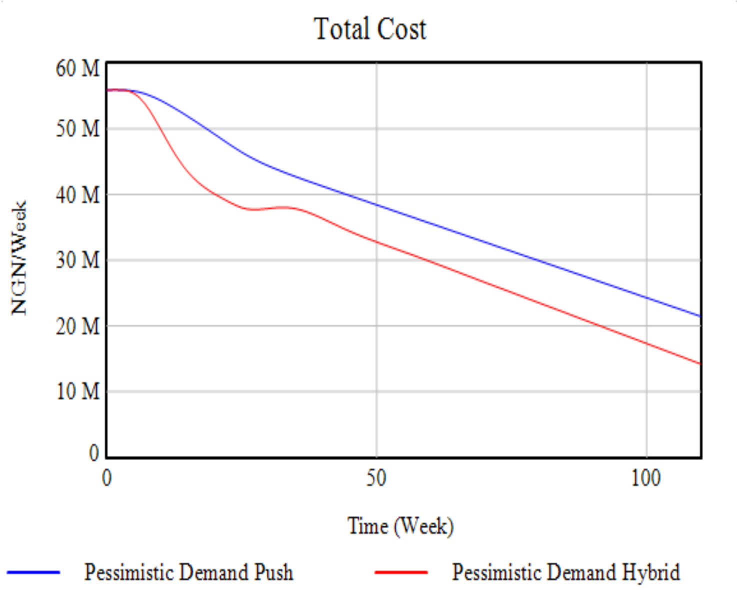


FIGURE 6. 38. EFFECT OF PESSIMISTIC DEMAND ON TOTAL COST WITH SMOOTHING PARAMETER TWO WEEKS

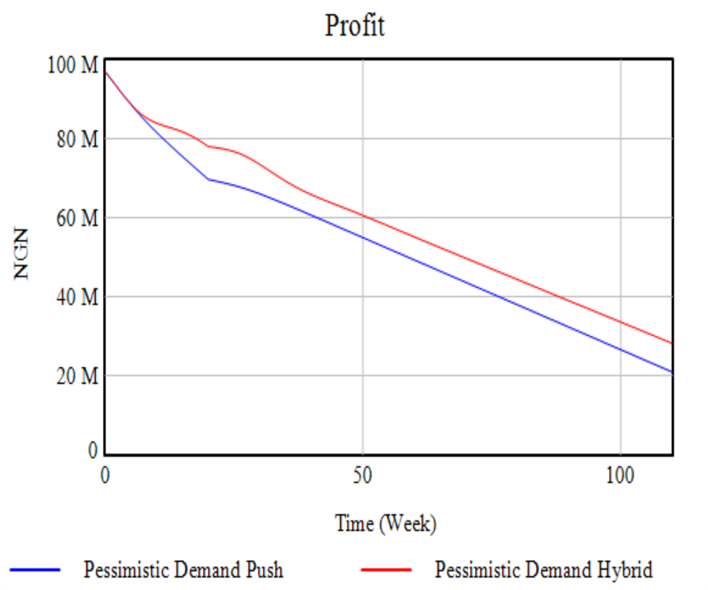


FIGURE 6. 39. EFFECT OF PESSIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER SIX WEEKS

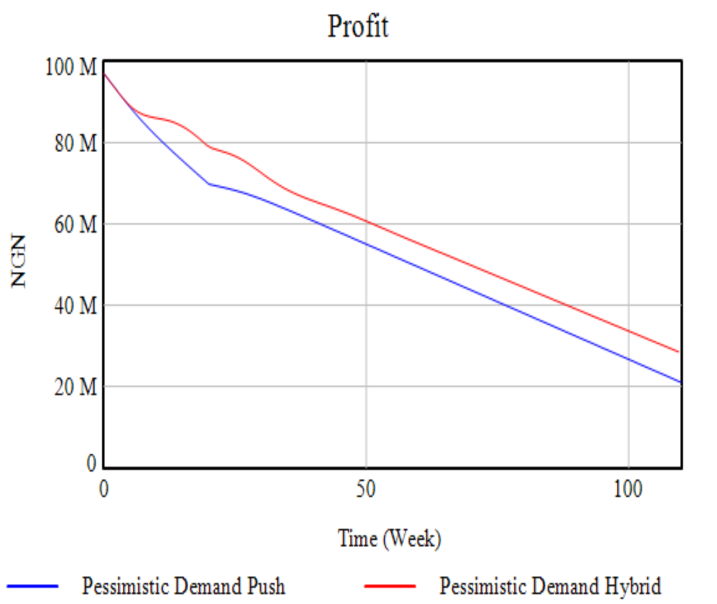


FIGURE 6. 40. EFFECT OF PESSIMISTIC DEMAND ON PROFIT WITH SMOOTHING PARAMETER TWO WEEKS

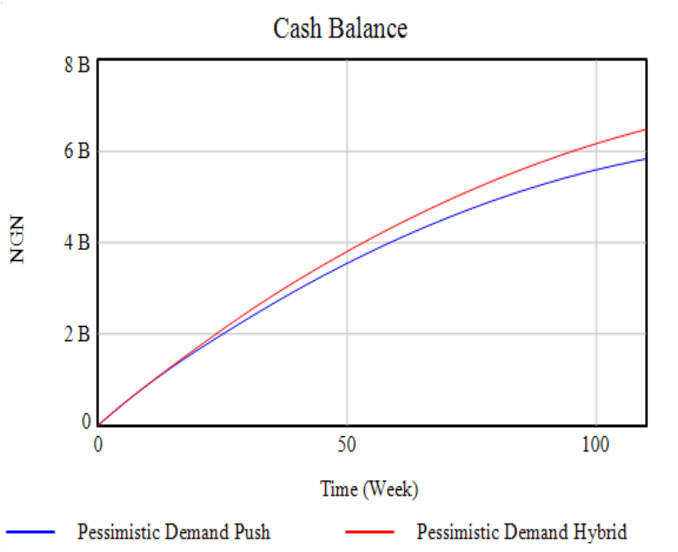


FIGURE 6. 41. EFFECT OF PESSIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER SIX WEEKS

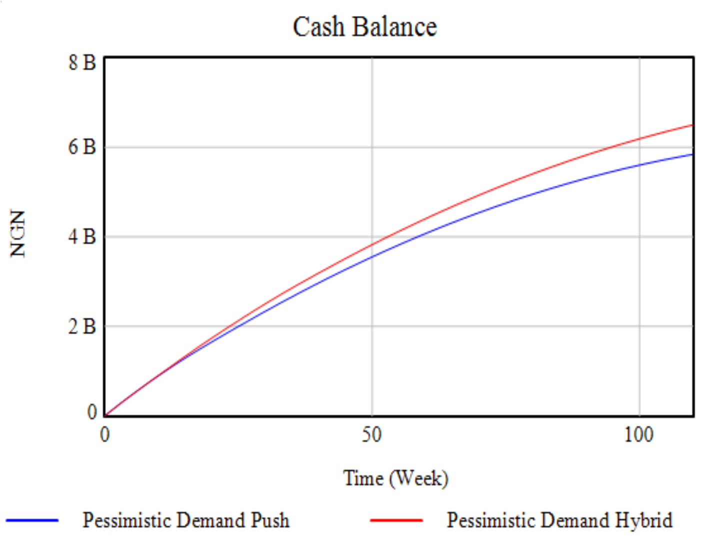


FIGURE 6. 42. EFFECT OF PESSIMISTIC DEMAND ON CASH BALANCE WITH SMOOTHING PARAMETER TWO WEEKS

In Table 6.8, the values reflect that the push model have higher total cost, with lower profit and cash balance when the smoothing constant equals six weeks. Also, when the smoothing constant is decreased to two weeks, the push model still has higher total cost with, lower profit and cash balance. These observations parallel the results of the analysis of the distributor inventory and dealer inventory level. Under the normal smoothing parameter, where the smoothing constant is set to six weeks, the push model has higher total costs due to a high level of inventory this indicates a higher cost of holding inventory. Thus, the costs incurred by the numbers of inventory results to the push model having higher total cost.

Pessimistic Demand	Push	Hybrid Push/Pull
Smoothing Parameter = 6 weeks		
Total Cost	24,135,700	16,965,000
Profit	26,475,100	33,645,800
Cash Balance	5,837,560,000	6,482,000,000
Smoothing Parameter = 2 weeks		
Total Cost	24,041,400	17,242,000
Profit	26,569,500	33,368,900
Cash Balance	5,846,970,000	6,505,710,000

TABLE 6. 8. EFFECT OF PESSIMISTIC DEMAND ON TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

Test With Smoothing Parameter = 6 weeks									
Demand Pattern	**Business as Usual**			**Optimistic**			**Pessimistic**		
Push	TC (NGN)	Profit (NGN)	CB (NGN)	TC (NGN)	Profit (NGN)	CB (NGN)	TC (NGN)	Profit (NGN)	CB(NGN)
Final Values	54,780,000	72,331,800	10,405,800,000	141,346,000	240,211,000	19,330,700,000	24,135,700	26, 475,100	5,864,970,000
Hybrid Push/Pull	TC	Profit		TC	Profit		TC	Profit	
Final Values	45,168,200	82,331,800	10,547,700,000	141,673,000	240,485,000	19,343,300,000	16,965,000	33,645,800	6,482,000,000
Test With Smoothing Parameter = 2 weeks									
Demand Pattern	**Business as Usual**			**Optimistic**			**Pessimistic**		
Push	TC (NGN)	Profit (NGN)		TC (NGN)	Profit (NGN		TC (NGN)	Profit (NGN	
Final Values	54,990,800	72,509,200	10,342,200,000	141, 668,000	240,190,000	19,327,800,000	24,041,400	26,569,500	5,846,970,000

Hybrid Push/Pull	TC	Profit		TC	Profit		TC	Profit	
Final Values	42,775,200	84,724,800	10,574,200,000	141,455,000	240,403,000	19,338,400,000	17,242,000	33,368,900	6,505,710,000

Worst Performance   Best Performance

TABLE 6. 9. OVERALL SUMMARY OF TOTAL COST, PROFIT AND CASH BALANCE WITH SMOOTHING PARAMETERS SIX AND TWO WEEKS

The final values for the total costs, profit and cash balance under push model and hybrid push/pull model with the different demand patterns is summarised in Table 6.9. In this table, the highest values of total costs, profit and cash balance are highlighted in yellow, which indicates the worst performance. The lowest values are represented by the green cells which represent the best performance. From results, the findings suggest that the push model have higher total costs in four out of six tests, which indicates the worst performance and in terms of profit and cash balance have worst performance in four of the six tests. The model with the best performance is the hybrid push/pull model. The underlying reason is that this model manages to cope with variations in demand with lower total costs.

Analysis of the total costs, profit and cash balance reveals the consequences of managerial decisions in responding to changes in customer demand. With the smoothing parameter it is obvious that the push model have higher total costs under varying demand patterns. However, when the delay in responding to changes in customer demand is decreased, the total costs slightly decreases, particularly under optimistic demand. On the other hand, increasing the delay causes the levels of inventories and the order fulfilment rates to fluctuate further as discussed in previous section. For this reason, policy improvement by sensitivity analysis is introduced to search for the values of relevant parameters to reduce the inventory level and total costs and maximize profit and cash balance. Section 6.9 discusses the analysis in detail with more refined scenarios tested to improve the model behaviour for case study B.

6.21 Policy improvement

The parameters selected for the model improvement can be described as the process of improving the target behaviour generated from the model, for instance, maximisation of profits, reducing or minimisation of delivery delay. As a first step of sensitivity test, the parameter values and range of each parameter for these test are determined from the literature and case company's managers for case study B. Typically, ± 20% of the parameter value are used for the simulation run (Sterman, 2000). These parameter sensitivity test has been carried out extensively to analyse the best performance for the inventory level, total cost and profit carried out manually by Vensim. Results from the sensitivity test portray the parameter values that successfully improve the model behaviour. With continuous sensitivity testing it was found that dealer order fulfilment cycle time (DEOFCT) and safety stock coverage (SSC) have the most impact on the model behaviour.

The value range for the safety stock coverage is defined to reflect a minimum of one week, and a maximum of four weeks of safety stock coverage. Hence, four weeks is the upper limit for the safety stock coverage in the push model and hybrid push/pull models and dealer order fulfilment cycle time is set to eight weeks. This means that the order is filled quickly from available distributor inventory. For the purpose of the analysis, the values for the simulations are tested between five to ten weeks to represent a shorter and longer dealer order fulfilment cycle time. Table 6.10 summarises the parameter values.

Parameter Constant	Units	Values in the Model	Value Range
Push Model			
Dealer Order Cycle Time	Weeks	8	5-10
Safety Stock Coverage	Weeks	3	1-4
Hybrid Push/Pull Model			
Dealer Order Cycle Time	Weeks	8	5-10
Safety Stock Coverage	Weeks	3	1-4

TABLE 6. 10. PARAMETER VALUES USED FOR PUSH AND HYBRID PUSH/PULL MODEL

In the next section, the results of the effect of the sensitivity test on the different demand patterns under push and hybrid push/pull models are illustrated to reduce inventory level and total costs at the same time improve profit and cash balance. Parameter values are rounded to one or two decimal places in the discussion.

6.22 Sensitivity analysis of BAU

The first sensitivity analysis is performed for business as usual demand under push model. As seen in Figures 6.44 (a) and (b). The graphs shows significant decrease in the distributor inventory and dealer inventory when the DEOFCT and SSC are decreased from Figures 6.43 a and b. Total costs can be decreased by reducing the safety stock coverage to 1.3 weeks and dealer order fulfilment cycle time to 5.1 weeks simultaneously. These parameter values can lower the total costs and improve the profit and cash balance by holding lesser inventory despite the different models.

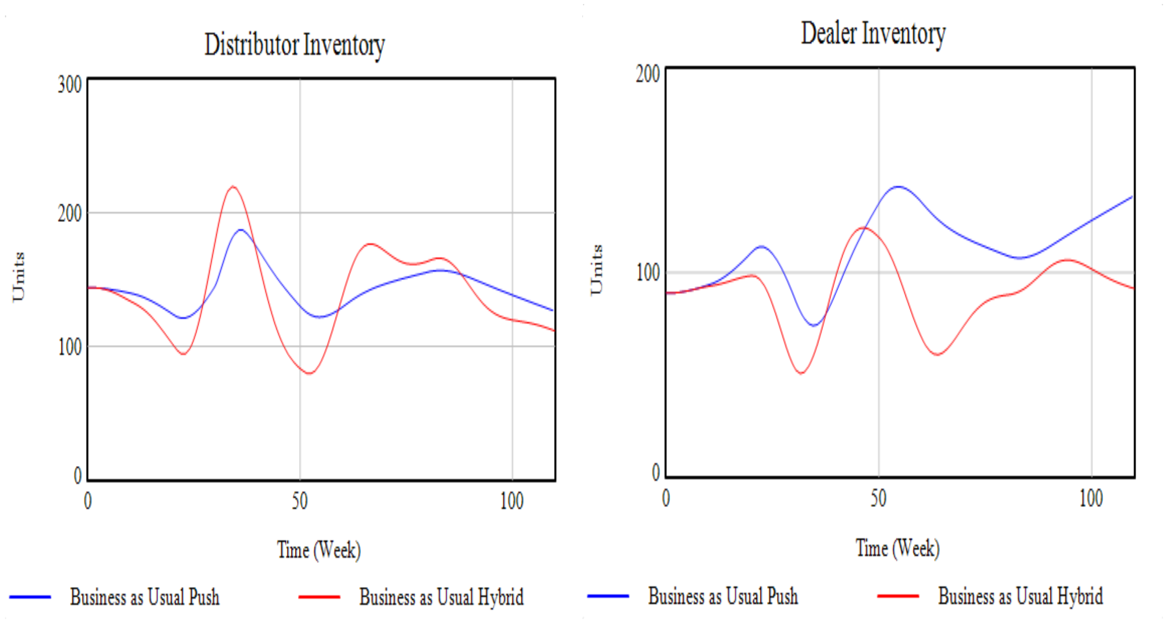
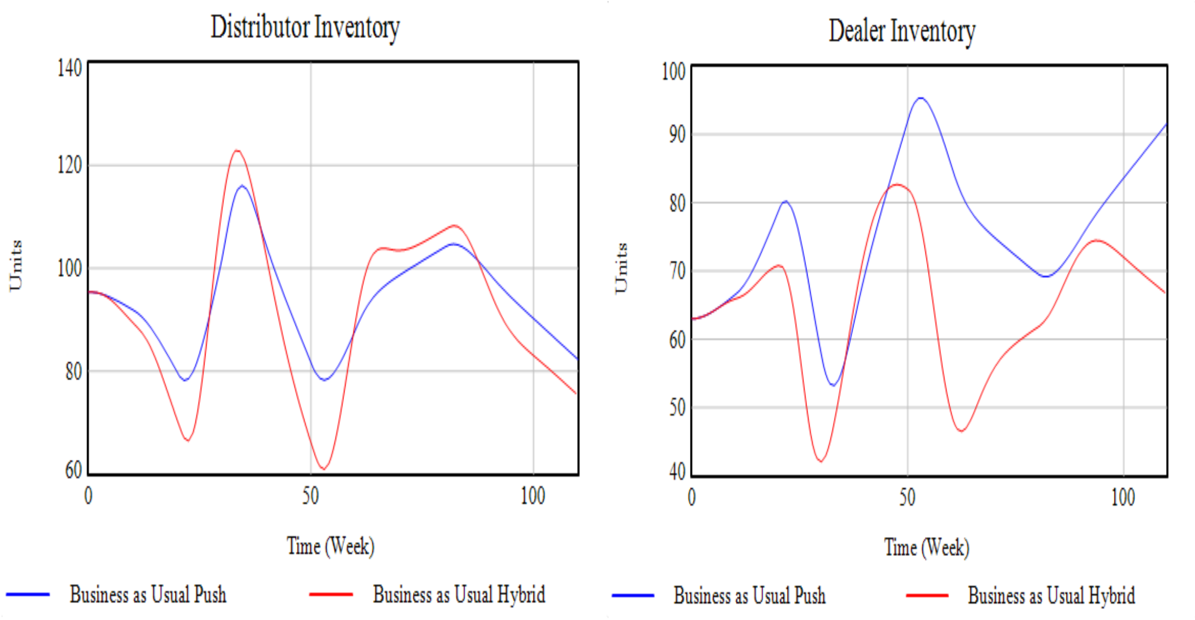


FIGURE 6. 43. EFFECT OF DEOFCT AND SSC OF BAU DEMAND



a b

FIGURE 6. 44. EFFECT OF DECREASING DEOFCT AND SSC OF BAU DEMAND

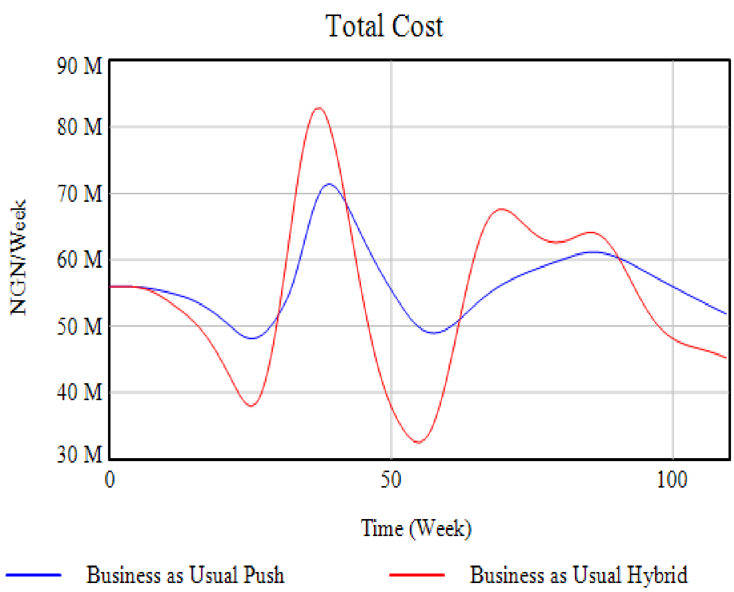


FIGURE 6. 45. EFFECT OF DEOFCT AND SSC ON TOTAL COST OF BUSINESS AS USUAL DEMAND

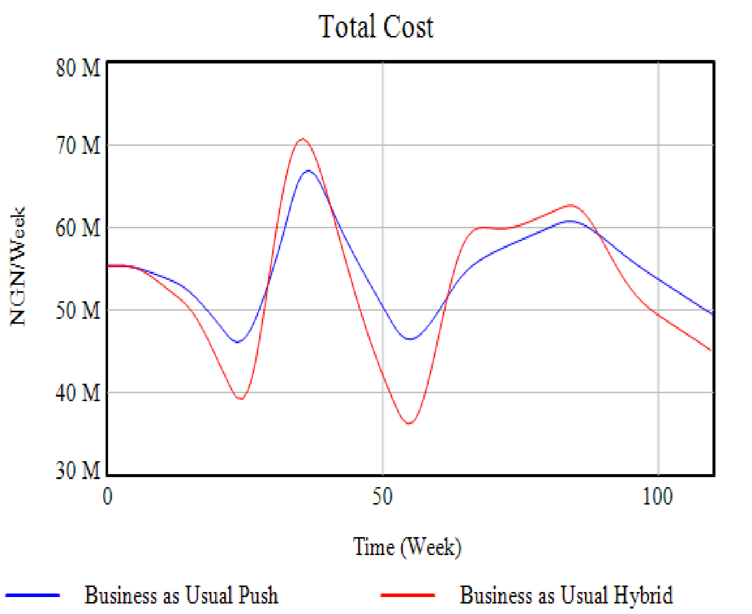


FIGURE 6. 46. EFFECT OF DECREASING DEOFCT AND SSC ON TOTAL COST OF BUSINESS AS USUAL DEMAND

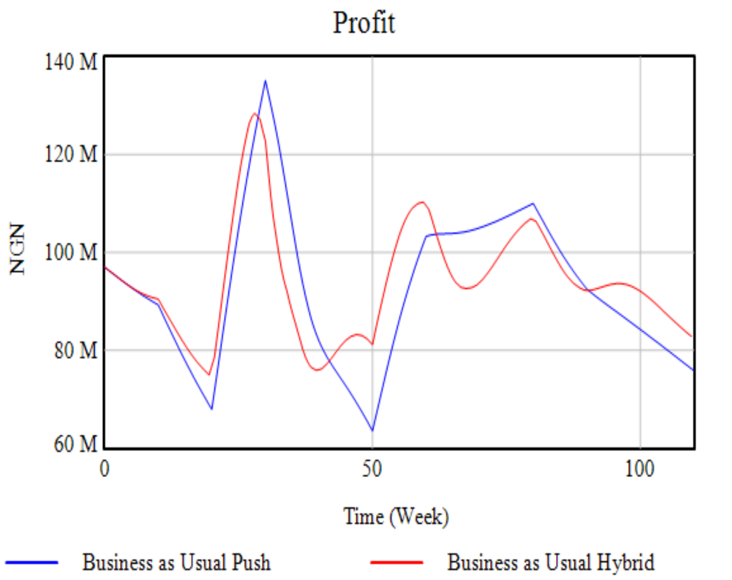


FIGURE 6. 47. EFFECT OF DEOFCT AND SSC ON PROFIT OF BUSINESS AS USUAL DEMAND

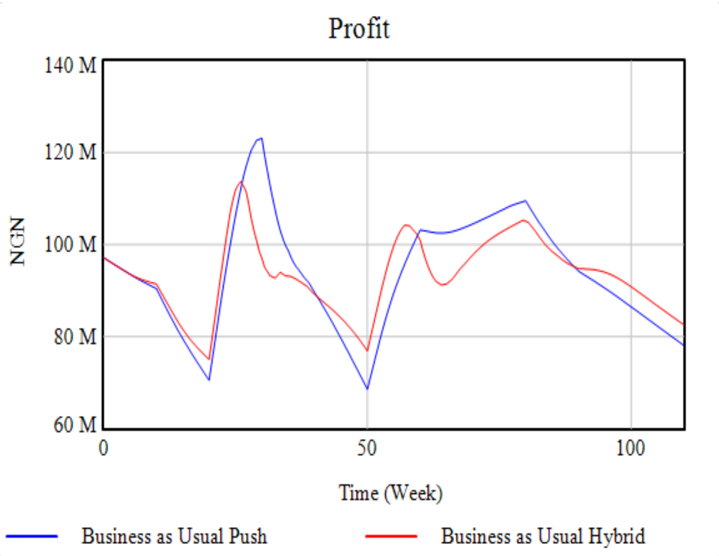


FIGURE 6. 48. EFFECT OF DECREASING DEOFCT AND SSC ON PROFIT OF BUSINESS AS USUAL DEMAND

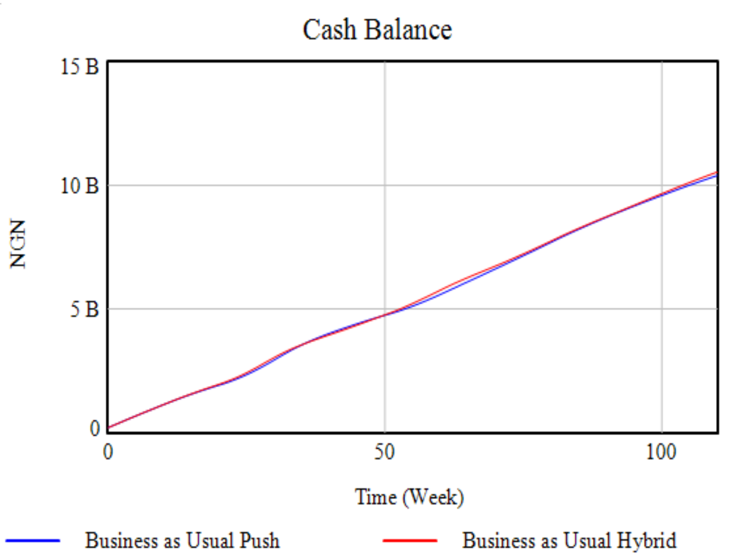


FIGURE 6. 49. EFFECT OF DEOFCT AND SSC ON CASH BALANCE OF BUSINESS AS USUAL DEMAND

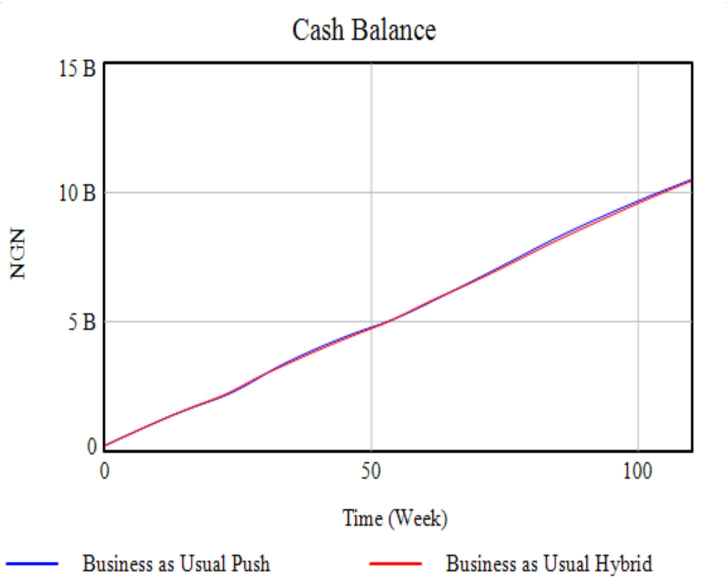


FIGURE 6. 50. EFFECT OF DECREASING DEOFCT AND SSC ON CASH BALANCE OF BUSINESS AS USUAL DEMAND

The results of case study A of reducing dealer order fulfilment cycle time and safety stock coverage at week 110 are summarised in Table 6.6 and 6.7.

Test 1: Business as Usual, DEOFCT = 8weeks and SSC = 3 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	126	137
Hybrid Push/Pull	111	92
Test 2: Business as Usual, DEOFCT = 5.1 weeks and SSC = 1.3 weeks		
Push	82	91
Hybrid Push/Pull	75	66

TABLE 6. 11. SUMMARY RESULT OF DISTRIBUTOR AND DEALER INVENTORIES ON BAU

Business as Usual	Push	Hybrid Push/Pull
DEOFCT = 8 weeks and SSC = 3 weeks		
Total Cost	51,636,500	45,037,700
Profit	75,863,500	82,462,300
TC	10,405,800,000	10,547,700,000
DEOFCT = 5.1 weeks and SSC = 1.3 weeks		
Total Cost	49,400,800	44,908,800
Profit	78,099,200	82,591,200
TC	10,506,900,000	10,461,400,000

TABLE 6. 12. SUMMARY RESULT OF FINANCIAL METRICS ON BAU

6.23 Sensitivity analysis of optimistic demand

The model exhibits significant reduction in the push and hybrid push/pull model as shown in Figures 6.52 (a) and (b) for the distributor inventory and dealer inventory when the DEOFCT equals 5.1 and SSC equals 1.3.

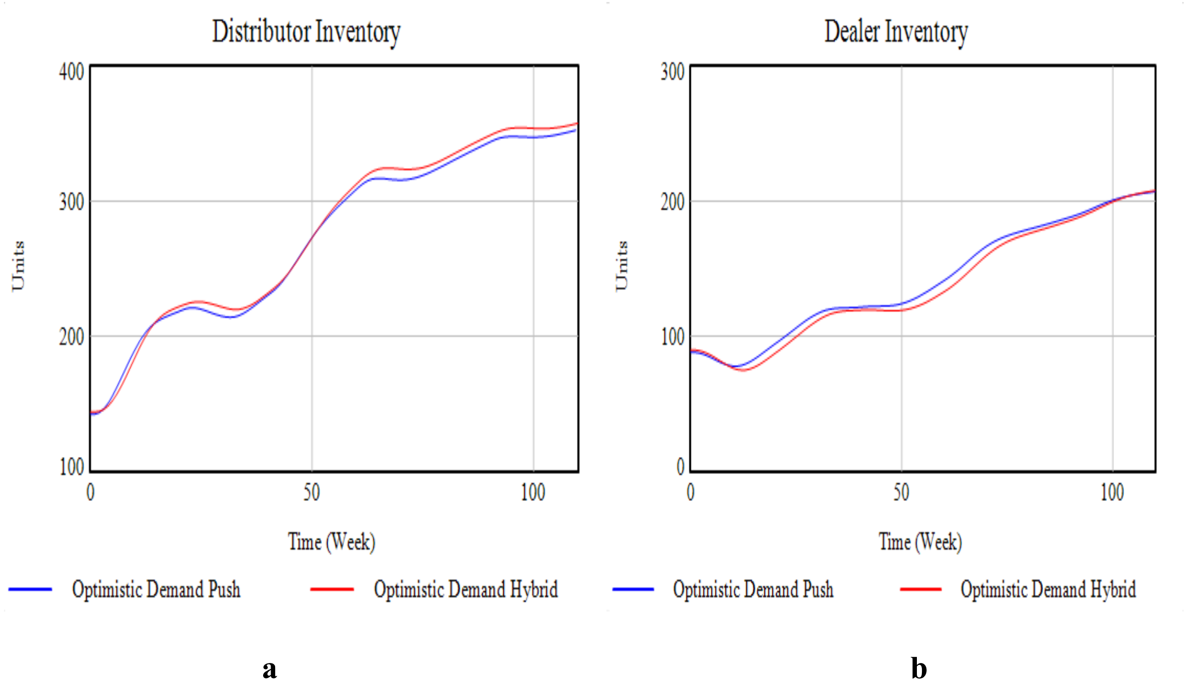


FIGURE 6. 51. EFFECT OF DEOFCT AND SSC OF OPTIMISTIC DEMAND

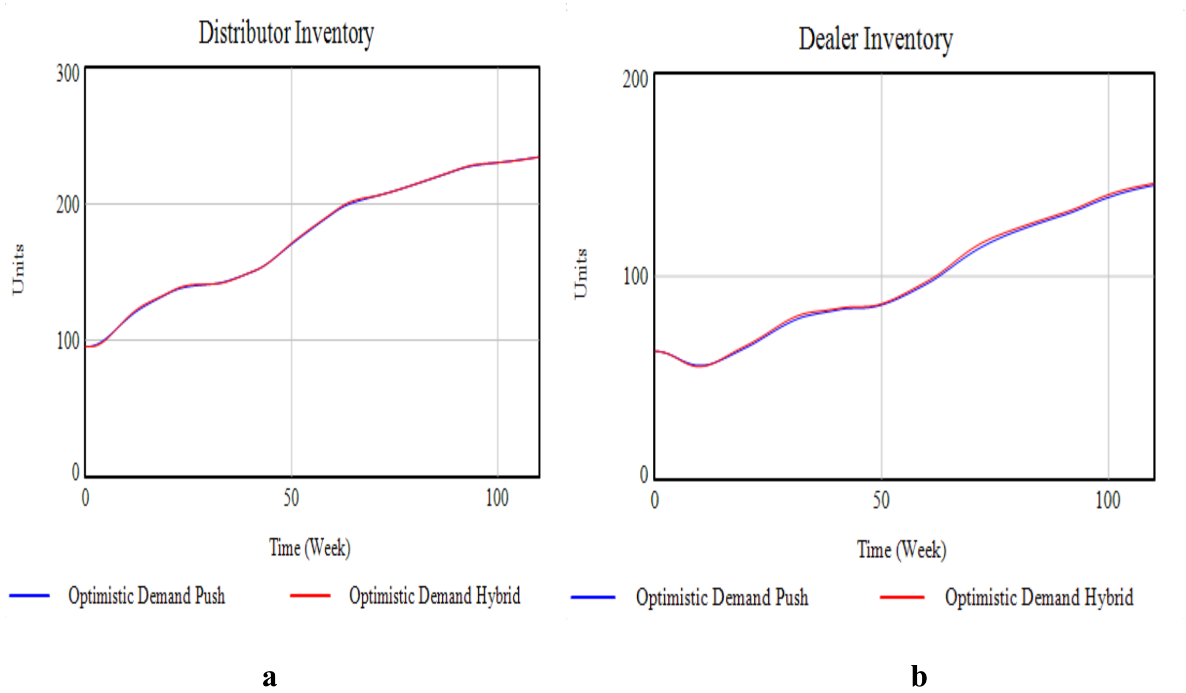


FIGURE 6. 52. EFFECT OF DECREASING DEOFCT AND SSC OF OPTIMISTIC DEMAND

The results from this test indicates that the oscillatory patterns of total costs can as well be reduced when DEOFCT and SSC is decreased simultaneously. Under optimistic demand, costs can be further improved by holding less safety stock coverage which means better profit and cash balance as shown in Figures 6.54, 6.56, and 6.58.

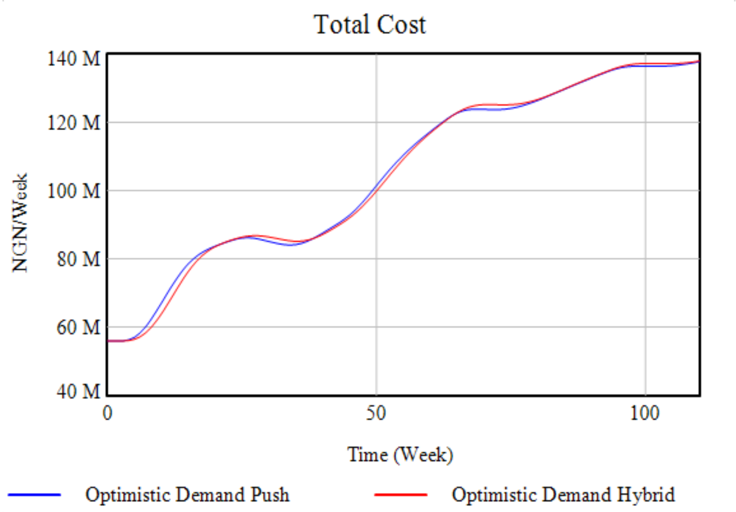


FIGURE 6. 53. EFFECT OF DEOFCT AND SSC ON TOTAL COST OF OPTIMISTIC DEMAND

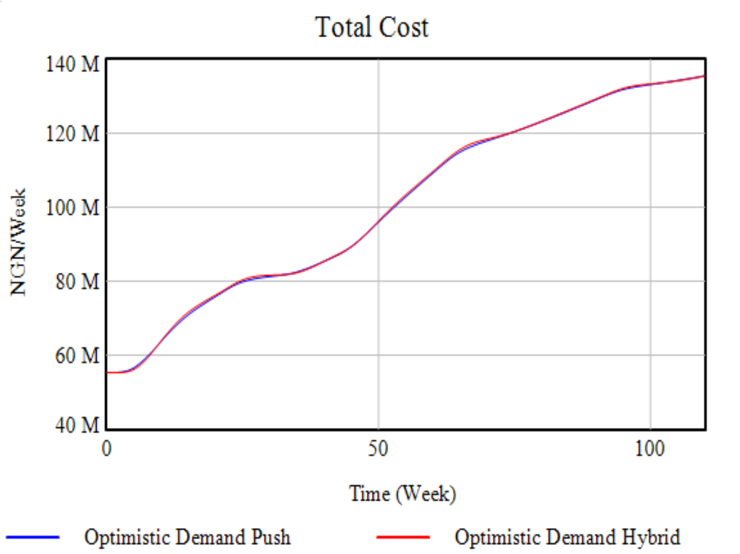


FIGURE 6. 54. EFFECT OF DECREASING DEOFCT AND SSC ON TOTAL COST OF OPTIMISTIC DEMAND

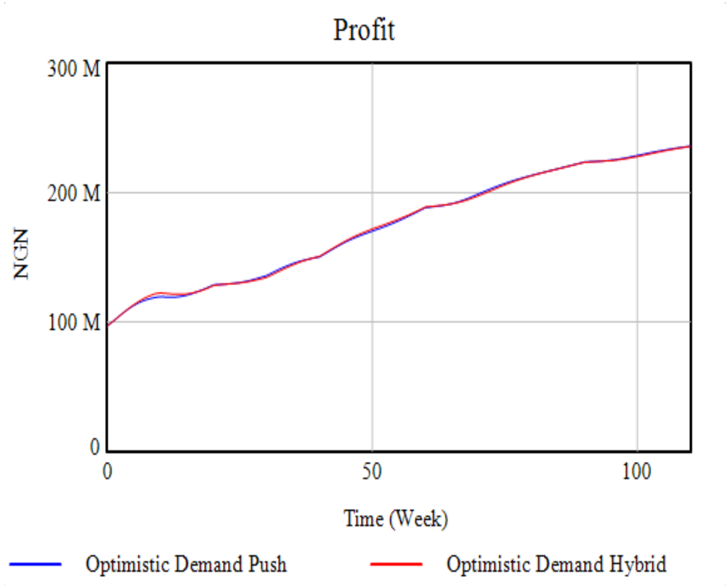


FIGURE 6. 55. EFFECT OF DEOFCT AND SSC ON PROFIT OF OPTIMISTIC DEMAND

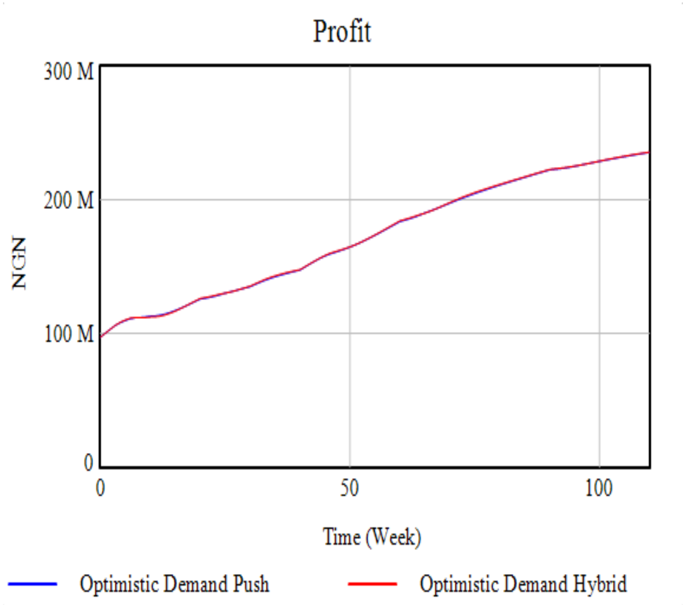


FIGURE 6. 56. EFFECT OF DECREASING DEOFCT AND SSC ON PROFIT OF OPTIMISTIC DEMAND

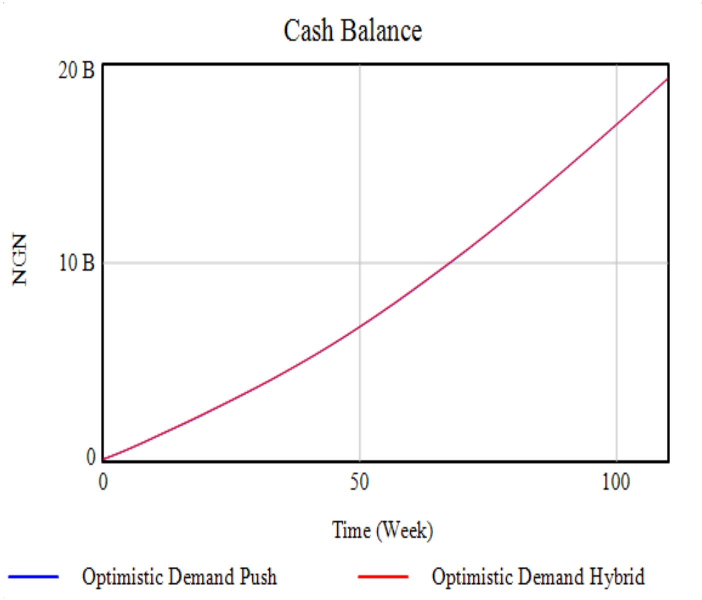


FIGURE 6. 57. EFFECT OF DEOFCT AND SSC ON CASH BALANCE OF OPTIMISTIC DEMAND

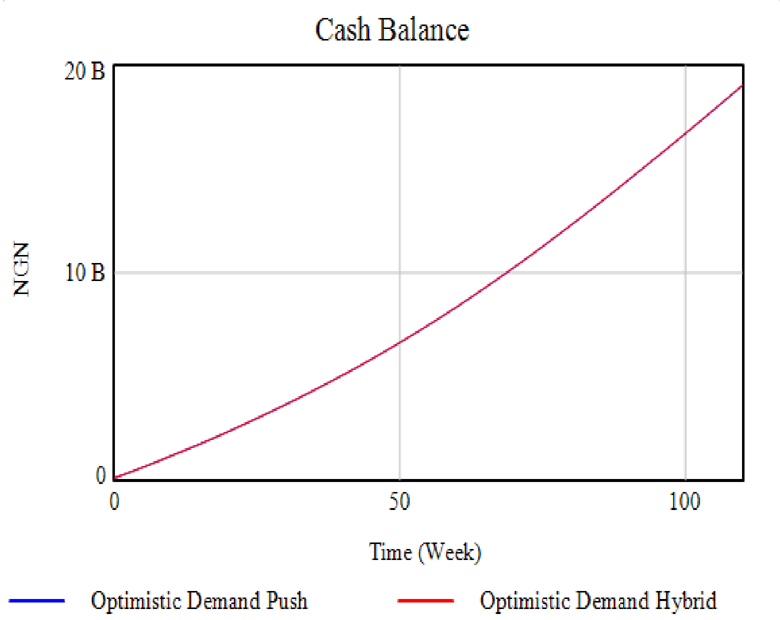


FIGURE 6. 58. EFFECT OF DECREASING DEOFCT AND SSC ON CASH BALANCE OF OPTIMISTIC DEMAND

Table 6.13 and 6.14 portrays the numerical values from the simulation results for the tests with optimistic demand pattern under push and hybrid push/pull models. When the DEOFCT and SSC is decreased the inventory, levels reduces significantly in the two models. Total cost can be reduced at the same and with better profit and cash balance in the two models. Nevertheless, push model slightly performs better compared to the hybrid push/pull model in this scenario.

Test 3: Optimistic demand, DEOFCT = 8 weeks and SSC = 3 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	353	207
Hybrid Push/Pull	357	208
Test 4:Optimistic demand, DEOFCT = 5.1 weeks and SSC = 1.3		
Push	234	145
Hybrid Push/Pull	237	148

TABLE 6. 13. SUMMARY RESULT OF DISTRIBUTOR INVENTORY AND DEALER INVENTORY OF OPTIMISTIC DEMAND

Optimistic Demand	**Push**	**Hybrid Push/Pull**
DEOFCT = 8 weeks and SSC = 3 weeks		
Total Cost	137,844,000	138,030,000
Profit	236,156,000	235,970,000
Cash Balance	19,337,800,000	19,333,300,000
DEOFCT = 5.3 weeks and SSC = 1.3 weeks		
Total Cost	135,563,000	135,510,000

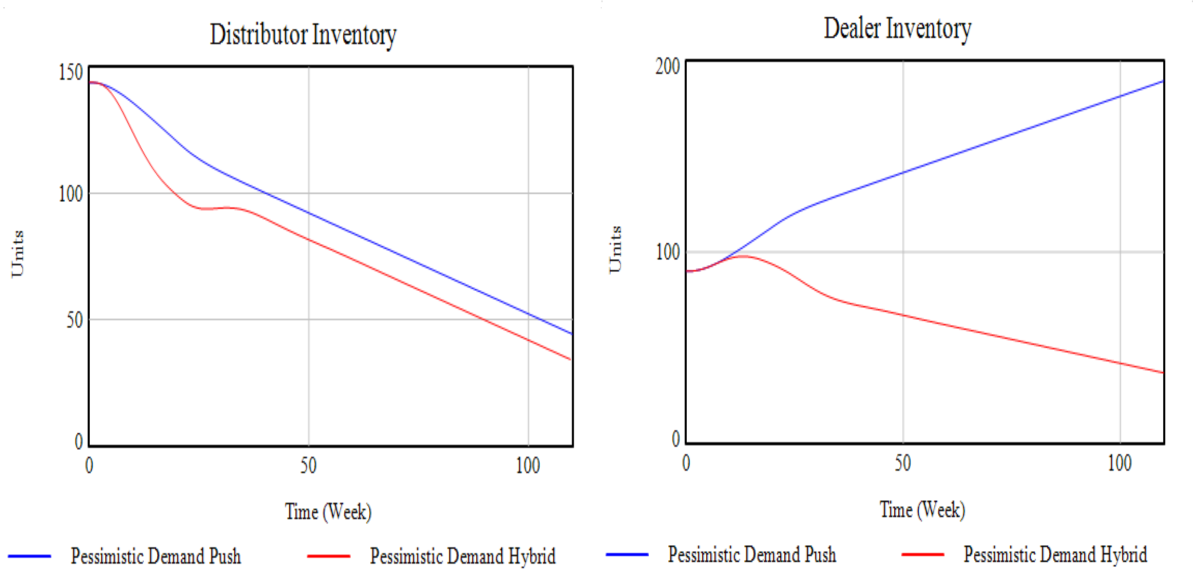
Profit	235,912,000	235,852,000
Cash Balance	19,095,600,000	19,083,300,000

TABLE 6. 14. SUMMARY RESULT OF FINANCIAL METRICS OF OPTIMISTIC DEMAND UNDER PUSH AND HYBRID PUSH/PULL MODEL

In summary, a shorter time in adjusting these parameters are important for decision makers. At this point, the managers should strive to act at the shortest time in reducing their cycle time and safety stock coverage.

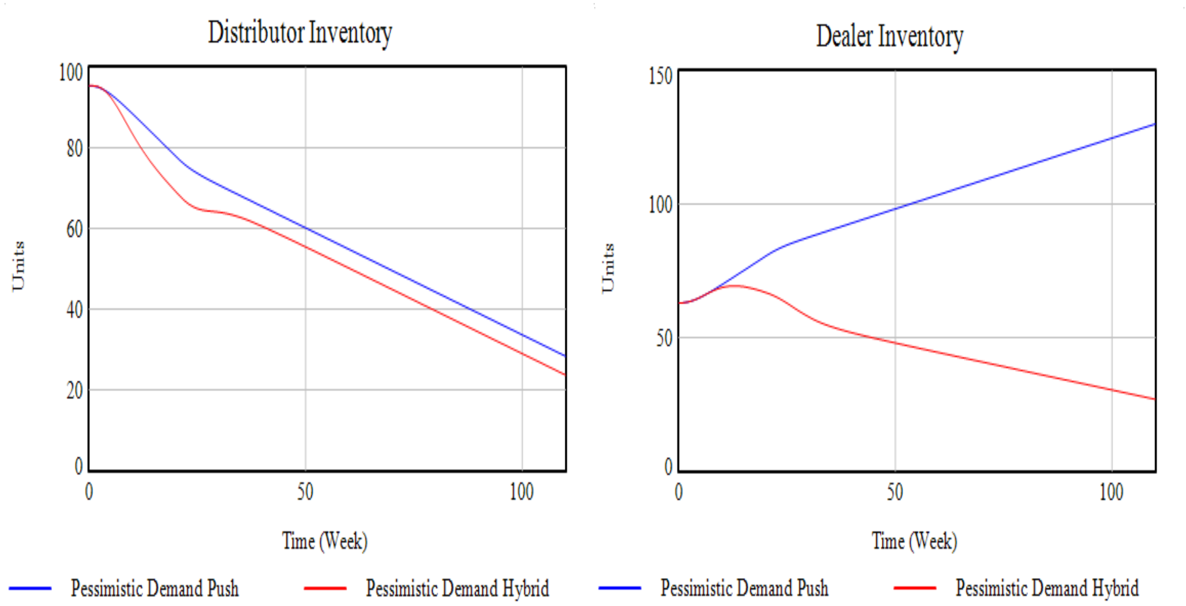
6.24 Sensitivity analysis of pessimistic demand

Figures 6.59 (a) and (b), and 6.60 (a) and (b) presents the inventory levels of pessimistic demand pattern with different DEOFCT of eight weeks and 5.1 weeks and SSC of three weeks and 1.3 weeks. In the following graphs, the hybrid push/pull model have lower inventory level. The major influence of the reduced parameter values is a reduced difference in the inventory level in both distributor inventory and dealer inventory. Nevertheless, the push model performs poorly compared to the hybrid push/pull model in this scenario.



a **b**

FIGURE 6. 59. EFFECT OF DEOFCT AND SSC OF PESSIMISTIC DEMAND



a **b**

FIGURE 6. 60. EFFECT OF DECREASING DEOFCT AND SSC OF PESSIMISTIC DEMAND

Figures 6.61 to 6.66 illustrate the difference in the total costs, profit and cash balance of pessimistic demand of different values of DEOFCT and SSC. Under this test, the hybrid push/pull model have lower inventory levels, total costs, slightly higher cash balance with higher profit. Under the hybrid push/pull model, dealer adjust the discrepancy on the amount of inventory sold from stock. This policy responds quickly to any changes in demand.

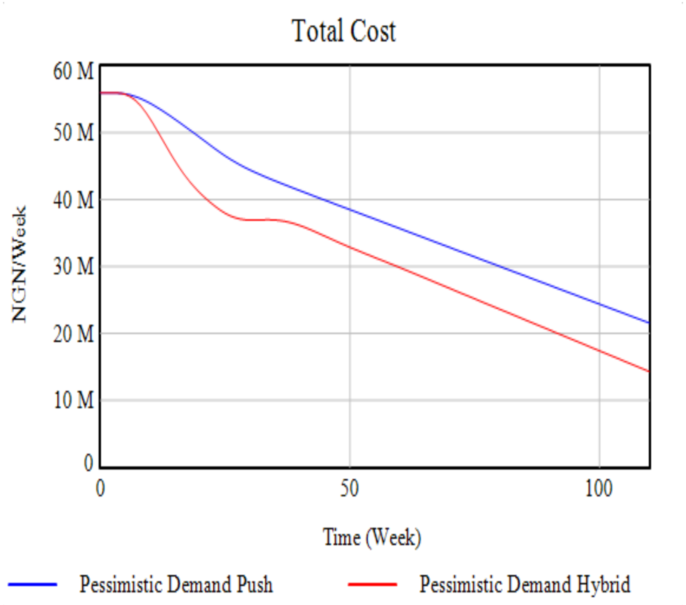


FIGURE 6. 61. EFFECT OF DEOFCT AND SSC ON TOTAL COST OF PESSIMISTIC DEMAND

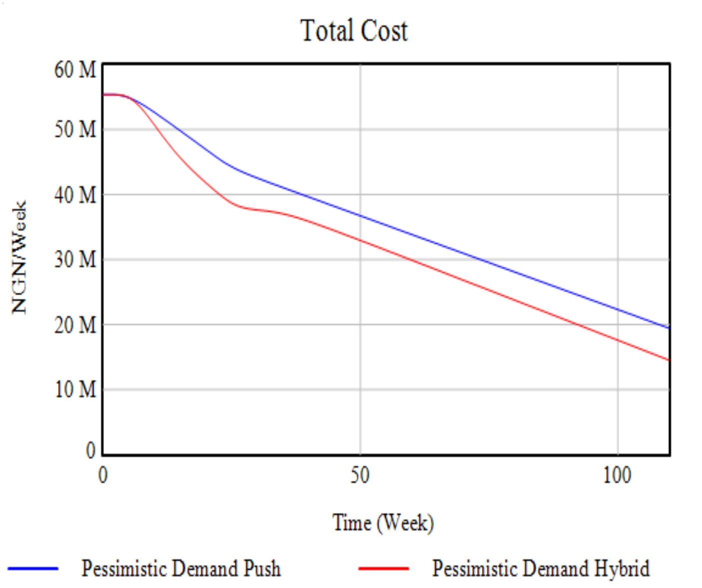


FIGURE 6. 62. EFFECT OF DECREASING DEOFCT AND SSC ON TOTAL COST OF PESSIMISTIC DEMAND

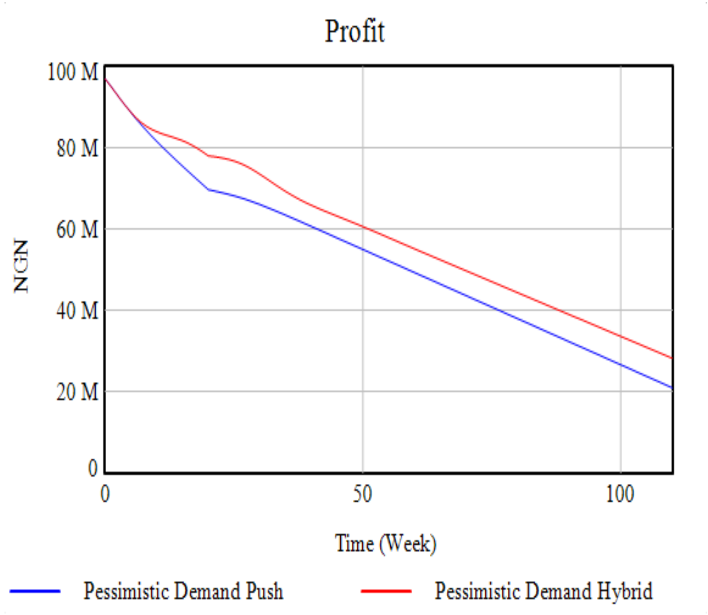


FIGURE 6. 63. EFFECT OF DEOFCT AND SSC ON PROFIT OF PESSIMISTIC DEMAND

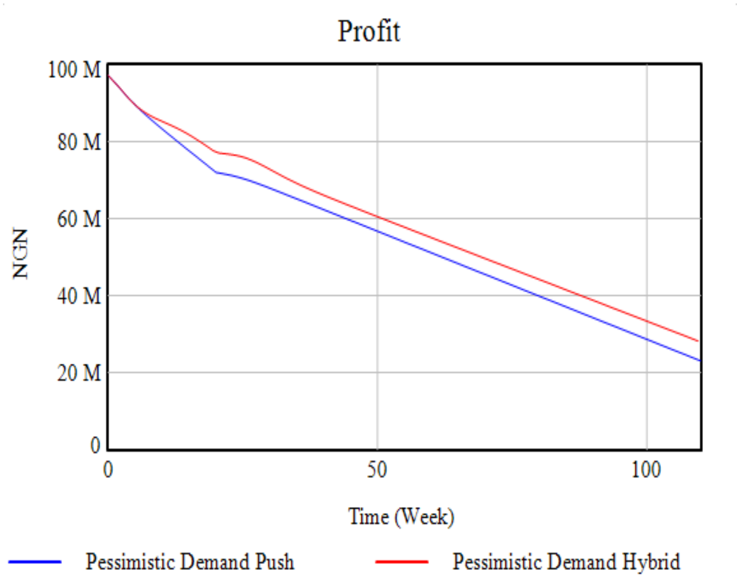


FIGURE 6. 64. EFFECT OF DECREASING DEOFCT AND SSC ON PROFIT OF PESSIMISTIC DEMAND

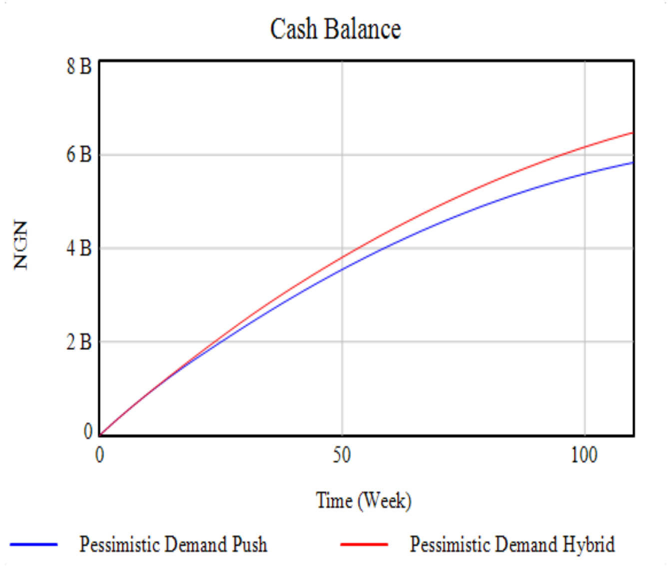


FIGURE 6. 65. EFFECT OF DEOFCT AND SSC ON CASH BALANCE OF PESSIMISTIC DEMAND

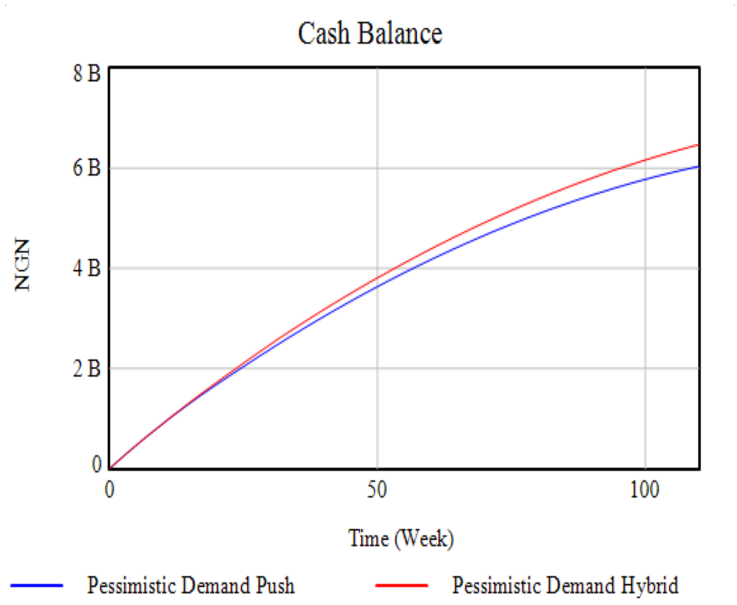


FIGURE 6. 66. EFFECT OF DECREASING DEOFCT AND SSC ON CASH BALANCE OF PESSIMISTIC DEMAND

The overall results is summarized in Table 6.15 and 6.16, the values reflects that the push model have higher distributor inventory, dealer inventory, higher total cost, and lower profit and cash balance. Thus, a longer cycle time and safety stock coverage means that there would be high costs incurred as a result of the numbers of inventory held by the company.

Experiment 5: Pessimistic demand, DEOFCT = 8 weeks and SSC = 3 weeks		
	Distributor Inventory	**Dealer Inventory**
Push	44	189
Hybrid Push/Pull	33	36
Experiment 6: Pessimistic Demand, DEOFCT = 5.1 weeks and SSC = 1.3 weeks		
Push	28	130
Hybrid Push/Pull	23	26

TABLE 6. 15. SUMMARY RESULT OF DISTRIBUTOR INVENTORY AND DEALER INVENTORY OF PESSIMISTIC DEMAND

Pessimistic Demand	Push	Hybrid Push/Pull
DEOFCT = 8 weeks and SSC = 3 weeks		
Total Cost	21,574,100	14,310,500
Profit	20,925,900	28,189,500
Cash Balance	5,837,560,000	6,482,000,000
DEOFCT = 5.1 weeks and SSC = 1.3 weeks		
Total Cost	19,451,900	14,542,700
Profit	23,048,100	27,957,300
TC	6,041,440,000	6,475,830,000

TABLE 6. 16. SUMMARY RESULT OF FINANCIAL METRICS ON PESSIMISTIC DEMAND

6.25 Conclusion

This chapter have presented the results of Case Study B. From the results it can be concluded that the ideal policy is to reduce the dealer order fulfilment cycle time and safety stock coverage simultaneously. Comparing the two models, the reports illustrate that the total costs are reduced when the cycle time equals 5.1 weeks and safety stock coverage 1.3 weeks. This result is the same across the different demand patterns. By decreasing these parameters, inventory levels are reduced with less safety stock coverage. Moreover, by decreasing the DEOFCT it leads to the minimisation of delays in fulfilling customer demand. Despite this unpredictability in customer demand, managers can still reduce costs by lowering these parameters to reduce inventory level. Various parameters values have been tested through sensitivity test of the push and hybrid push/pull. The final chapter discusses the overall findings and the contributions of this research and recommendations for further work.

Chapter 7. Discussion and Contributions

7.1 Introduction

The overall findings from the analysis is discussed in this chapter and the research contributions is provided. The findings offer insights on the effects of different demand patterns vs policy choices on the push and hybrid push/pull models when combined into managerial policy. The research boundaries are also discussed. The research contribution to the knowledge in the field of supply chains management and system dynamics is presented at the end of this chapter. The discussion starts by reviewing the research objectives and the research questions. From the discussion of the findings, the research questions are answered. The research contributions are outlined from the methodological perspective, practical and theoretical aspects. This thesis finally concludes with the recommendations for further research.

7.2 Review of the research purpose and originality of this study

This study presents the investigation of the bullwhip effect and instabilities using two system dynamics inventory models (push and hybrid push/pull models) for comparison in the downstream automobile supply chains in Nigeria by adapting and extending a well-established SD model. Although, other studies have conducted research of supply chain inventory models and bullwhip using system dynamics modelling methodology, this study employed a different approach employing the use of two case companies in Nigeria to investigate the effect of bullwhip and instabilities in the downstream automobile companies and the consequence on their financial performance by using three different demand patterns (business as usual, optimistic and pessimistic demand patterns to represent actual demand uncertainty. This was conducted to analyse the performance of the model by measuring the inventory level, total costs, profit and cash balance. In the final stage, sensitivity analysis was performed to search for the best policies to reduce costs and maximise profit and cash balance for both case studies these analyses were presented in chapters five and six.

7.3 Research objectives

The research objectives were designed to reflect the research purpose. As stated in chapter one, the objectives are summarised below:

1. Modelling the push and hybrid push/pull downstream automobile inventory in Nigeria using system dynamics methodology.
2. Testing the push and hybrid push/pull downstream automobile inventory policy interventions using different customer demand patterns to mimic the present increasing demand uncertainty.
3. To investigate the dynamic effects on the inventory level of the push and hybrid push/pull downstream automobile inventory in Nigeria given the different demand patterns.
4. To investigate the costs incurred as a result of fluctuations and instabilities in the inventory level of the downstream automobile companies based on different policy interventions.

The first objective is achieved by reviewing the literature on supply chain inventory and customer demand uncertainties to gain an understanding of the nature of policies implemented by experts and academics. The push and hybrid push/pull inventory models developed using the system dynamics methodology were also reviewed to enhance knowledge about system dynamics modelling. In this research, the models were developed by integrating policies as applied in the decision-making process by managers. Despite this, the models of the push and hybrid push/pull inventory models have shown that, although supply chain inventory model can be hard and complex to model, it is achievable and possible when using the system dynamics methodology.

The second objective was carried out by conducting tests with a series of different customer demand patterns (business as usual, optimistic and pessimistic demand patterns). Two types of tests were performed to represent the different manager's expectations about changes in customer demand. Modelling supply chain inventory using the system dynamics methodology is difficult in the sense that the models are developed through stock and flow diagram to replicate the feedback structure in the supply chain being addressed, and formulating hard and complex equations with rigorous tests. In order words, the time required in developing, executing and analysing the models is increased. As a result, the tests can be rigorous and extensive to provide more useful findings.

The third research objective was achieved by performing an extensive investigation from several perspectives. The first analysis involved the model validation to develop confidence in the system dynamics push and hybrid push/pull inventory models. In the second analysis, the inventory levels were analysed comparatively for the push and hybrid push/pull inventory models for case study A and case study B in Chapter Five and Chapter Six. The same analysis was repeated in the second test, with a different expectation for the changes in customer demand. The results from both tests were compared to analyse the consequences of different demand expectations.

The final objective was to analyse the total costs, profit and cash balance incurred as a result of any instability and fluctuations in the supply chain. In this case, the fluctuations were identified from the inventory levels of the distributor and dealer. The total costs of holding inventories were measured and the profit and cash balance realized. Sensitivity analysis of the models was carried out as an extended analysis to minimise the total costs and maximize profit and cash balance for both case studies. Discussion in this section has described how the research objectives were achieved in this thesis. The next section explains how the research questions is answered through the research findings.

7.4 Review of research questions

The research objective is achieved by demonstrating an extensive analysis of the push and hybrid push/pull inventory models by using system dynamics modelling. The research questions were derived from the research objectives as stated in the previous sections. The answers to these research questions are provided based on the research findings and are summarised below:

1) **What are the effects of customer demand uncertainties in the downstream automobile companies in Nigeria?**
   - Pessimistic demand has the effect of increasing the levels of inventory in the push model. However, the level of inventory is significantly reduced in the hybrid push/pull model.
   - The cost in the push model are normal under the business as usual and increases under optimistic demand and pessimistic demand patterns for both case studies.
   - The different policies yield various results under the different demand patterns. The hybrid push/pull model is a best system in coping with various demand patterns while the push model is at risk of a higher level of inventories under the different types demand.
2) **How does the customer demand uncertainties relate to the costs borne by the downstream automobile companies in Nigeria?**
   - The push model has higher total costs. This results from a higher level of inventories when responding to the pessimistic demand. The cost of holding inventory in the push model is the higher in the two models in both case studies.
   - The hybrid push/pull model slightly minimises total costs resulting from low levels of inventories, except under the optimistic demand pattern. The costs are slightly

higher under optimistic demand as compared to push model due to an increased inventory the results are similar in both case studies.

3) **Which of the two system dynamics inventory models is the most affected?**

- The push model has higher inventory level under two out of the three demand patterns and higher inventory level under the pessimistic demand pattern compared to business as usual and optimistic demand. This leads to higher total costs, lesser profit and cash balance in comparison to the hybrid push/pull model.

4) **What are the best policies to be implemented in order to reduce costs?**

- The cycle time must be reduced further in the different demand patterns to provide a swift response to fulfil customer orders, despite the different types of models i.e. push and hybrid push/pull models. This finding parallels the opinion of Fisher (1997), Bavin (2010) and Botha (2017) who stated that companies faced with uncertain customer demand should devise a responsive operation. Policy on the levels of safety stock coverage should be reduced to changes in customer demand.

7.5 Discussion of findings

The tests were conducted under three different demand patterns (business as usual, optimistic demand and pessimistic demand) which was a way of representing uncertainties in customer demand in the downstream automobile companies in Nigeria. These demands are adequate representation of the common demand patterns in the two case companies observed in the real world as it is based on the two companies future demand projection therefore, they serve the purpose of this research. The analysis of the demand patterns is shown in Chapter Five for case study A and Chapter Six case study B. Before moving onto the results from the tests in both chapters, it is important to note that the developed models incorporated "what if" assumptions, to enable a comparative analysis between the two models. The important assumptions are summarised below:

(1) The models were developed based on the case studies of automobile dealer companies in Nigeria.
(2) The push and hybrid push/pull models are driven by an expectation of managers for changes in customer demand.
(3) The values for cycle time and the safety stock coverage are synchronised in the two models to remove the effect of different policies on the comparative analysis.

There were two types of tests performed to represent the different manager's expectations in changes to customer demand. The first test signifies the normal discrepancy between the manager's expectation of the changes in demand and the actual demand. This has been carried out by setting the values of the smoothing parameter to six weeks as discussed in Chapter Five and Six. The results from the simulation runs with the demand patterns are summarised below:

(1) The business as usual and pessimistic customer demands have the effect of increasing the inventory level in the push model. There is a significant rise in inventory level in the pessimistic demand under dealer inventory.
(2) The hybrid push/pull model responds well to the business as usual and pessimistic demand pattern with smaller level of distributor inventory and dealer inventory, except under optimistic demand.
(3) Pessimistic demand has the undesirable effect of increasing the level of dealer inventory in the push model.

These results are important as they display that the test is sufficient to reveal the effect of the demand uncertainties under the different policies. The first test initiated further investigation to measure the performance of the model under the situation where the discrepancy between the expectation on demand and customer demand is reduced. The reason for the test is to reflect the reaction of the manager to the changes in the actual demand and its effect on the inventory level of both distributor and dealer. In the second test, the smoothing parameter was set to two weeks. The findings are therefore summarised from two different perspectives. The first perspective was on the effect of reducing the smoothing parameter, as described below:

(1) Reducing the discrepancy between the expected and actual demand from six weeks to two weeks have a slight effect of decreasing the level of inventory in the push and hybrid push/pull model under the three demand pattern but performs slightly better in the hybrid under business as usual and pessimistic demand pattern.

(2) Reducing the discrepancy between the expected demand and actual demand from six weeks to two weeks have a slight effect of decreasing the level of inventory in the push demand pattern under a pessimistic demand pattern. However, the level of inventory increases in push model. This demand pattern has the worst performance in all the different performance in both case studies.

(3) Reducing the discrepancy between the expected demand and actual demand six weeks to two weeks has no significant effect on the level of inventory in the push and hybrid push/pull models in both case studies under the different demand patterns.

From the second perspective the results are presented comparatively i.e. reducing the discrepancies between the expected customer demand and actual customer demand from six weeks to two weeks in Chapter Five and Chapter Six for both case studies. The major findings in the test with a reduced smoothing constant are summarised as:

(1) The push model still has the highest level of distributor and dealer inventories under the variations in demand types, as compared to the hybrid push/pull model when the smoothing constant is reduced in both case studies.

(2) The hybrid push/pull system dynamics inventory model maintains the best performance across the variations in demand types, except for pessimistic demand patterns in both cases.

(3) Pessimistic demand has the effect of increasing the level of inventories in the push model for both case studies which exhibits the worst performance under this demand pattern. Conversely, the hybrid push/pull model has the best performance under this demand pattern.

The results from the second tests illustrate that responding quicker to the changes in demand has a slight capability to reduce inventory under the three demand patterns. Holding a number of inventories in a supply chain introduces extra costs. This led to a cost analysis, where the total costs of holding inventory were analysed to find out the effect of reducing this parameter. The cost analysis revealed that reducing the discrepancy between the demand and its expectation only slightly minimises the total costs and slightly improves profit and cash balance under the business as usual and optimistic demand patterns. However, the costs rise under pessimistic demand in the push model under the two case studies because more stock of inventory is carried.

The findings from the cost analysis are very important in demonstrating the effect of the discrepancy between the managers' expectations of demand, and the actual demand. These analyses reflect the projection of future demand in the two case study companies. The discrepancy between the actual demand and its expectation in the model represents smoothing of the noise in the demand. In conclusion, reducing the discrepancy (smoothing demand) is slightly beneficial in responding to the different customer demand patterns. This observation initiated more test through sensitivity analysis to improve the model's performance by searching for the best policy to reduce inventory levels and total costs across the different demand patterns.

7.6 Summary of model boundaries

The results produced from the two models are confined to the model boundaries summarised below:

(1) The complete structure of the push and hybrid push/pull models were adapted and developed based on the existing knowledge in the literature and well-established inventory model in combination of the managers.

(2) The push and hybrid push/pull models consider inventory policies in the two automobile case companies in Nigeria. Customer demand is smoothed to represent how quickly the supply chain managers smooth any noise in customer demand. Sensitivity analysis was conducted to test the policy interventions.

(3) The policy interventions tested in the model are policies involving the safety stock coverage and the cycle time to deliver products.

Taking an overall view, it can be said that the push model is less responsive to changes in customer demand and this leads to a higher level of total costs. On the other hand, the hybrid push/pull model can be described as a robust model based on its capability to work under the variations of demand with a minimum inventory level and total costs in both case studies. However, the hybrid push/pull model consists of both push and pull process which means that the adjustment of policies is more difficult under the different demand patterns. All the major findings have been discussed in combination with their importance in the research progression. The research was conducted to answer questions relating to the performance of push and hybrid push/pull system dynamics inventory models using two case studies of downstream automobile companies in Nigeria. The next section discusses how the research questions are answered by the research findings, the research contributions and implications are also summarised below.

7.7 Discussion of policy improvement

The sensitivity analysis results of distributor inventory, dealer inventory, total costs, profit and cash balance posed a new question about the possible action that can be taken by managers to achieve the best policy in responding to the different demand pattern. In-depth sensitivity analysis of the models was carried out to search and find the best policy. The performance metrics employed in the models were based on financial and non-financial metrics. For this reason, the ideal policy was to reduce the level of safety stock coverage and the cycle time, to avoid holding excessive amount of inventory in the companies. The sensitivity results are summarised below:

(1) The cycle times should be reduced, ideally from 8 weeks to 5.3 weeks for case study A and 5.1 weeks for case study B this value applies to the push and hybrid push/pull models for all demand patterns. By reducing this value, the managers can fulfil customer demand faster.

(2) The safety stock coverage should be reduced ideally, from 3 weeks to 1.5 weeks for case study A and 1.1 weeks for case study B for all demand patterns under push and hybrid push/pull model. By reducing the SSC, the managers could hold the right amount of inventory and could avoid the risk of holding obsolete inventory which can have negative effect on total cost, less profit and cash balance.

(3) In the push model the policy on the safety stock coverage for dealer inventory needs to be adjusted carefully to the demand pattern especially the pessimistic demand pattern. The level of distributor inventory and dealer inventory should be kept high to a reasonable extent, except under pessimistic demand where the inventory level should be reduced.

(4) The hybrid push/pull model maintained better performance compared to the push model. This is because push model is based on a forecast of demand causing the companies to push more inventories to customers. The inability to forecast customer demand leads to companies holding larger number of inventories in order to absorb any unexpected changes in the customer demand (Lin, 2018). On the other hand, hybrid push/pull model hold a small number of inventories waiting to be ordered (Gonçalves 2003; Albrecht 2015).

The findings discussed in this chapter are very important to present the extensive analysis that has been performed to understand the effect of different demand patterns on the different models under different policies. Additional work on the sensitivity analysis to improve the model's performance was carried out to provide insights in suggesting the best policies for managers for implementation in order to reduce the costs incurred because of responding to demand uncertainties. This research emphasises that even though there is a solid body of knowledge and well developed theory around the demand amplification issue, the bridge between theory and practice is fragile in developing countries. Behind this, there is the lack of study on system dynamics model on supply chain inventory management in Nigeria capable of capturing sensitivities of the bullwhip effect origins arising from the specifics of each actual case, which prevents systematic performance from practitioners.

7.8 Research contributions

Based on the research motivation, the literature review and findings, the research contributions can be summarised into subject contribution, theory contribution, and practical contribution which is described below:

Methodological contribution

The main contribution of this research is the supply chain inventory models developed using the system dynamics methodology in the setting of downstream automobile companies in Nigeria. The development of these models, from the work of Sterman (2000), and also Morecroft (1983) Minnich and Maier (2007), Yasarcan, 2003, and Shin et al 2010 for the push and hybrid push/pull models, extends the existing work on supply chain inventory models in the field of system dynamics. Baines and Harrison (1999) and Botha, (2017) stipulated that there are few studies of supply chain inventory models in the system dynamics field. They suggest that research in inventory models should be encouraged as system dynamics can be important and a beneficial policy design tool for managers. In response to these statements, the push and hybrid push/pull models and the sensitivity analysis for policy implementation in this study can assist managers in the policy process who work under customer demand uncertainties. Furthermore, these models illustrate that the technical complexity in modelling supply chains, as argued by Fowler and Rose (2004), can be reduced by using the system dynamics methodology. The benefit is given by an extensive analysis of the models by the reduced amount of work in the model development.

Theoretical contribution

A great interest in supply chain inventory management has arisen from the issues of demand uncertainty at the beginning of the 21st century (Kov´acs and Spens, 2007; Alsop and Armstrong, 2010; Lin, 2018). More research has focused mainly on positioning of supply chain parties and strategic planning so as to improve responses to uncertainties. In contrast, the management of uncertainties that occurs from operational level has become very important because of the recent trends in the dynamics of business environment. Sheffi, (2005b) stipulate that in global supply chains there is more likelihood of operational problems when there is long distances between partners and the more resources involved. Moreover, demand uncertainty causes instability in operational level which affects company performance.

System dynamics is an important method in managing this operational problem by identifying and managing the flow of material and information (Mason-Jones and Towill, 1998) and can be classified as an important technique in identifying bullwhip effect (Lin, 2018). As there are limited literature in this field this research addressed the effect of bullwhip and oscillations on supply chain inventory level using system dynamics methodology. In Chapter Four, the general concept of supply chain inventory given by Sterman (2000) has been extended and the literature on supply chain inventory management and bullwhip effect has been further explored using system dynamics modelling approach. In summary the steps taken to build the system dynamic inventory model for investigating the bullwhip effect and oscillations was:

Identifying properties of bullwhip effect and oscillations

Three properties of bullwhip effect and oscillations have been identified and expanded as follows:

• Readiness: implies whether the downstream automobile companies in Nigeria can effectively manage their inventory even under demand uncertainty.

• Response: implies not only reducing bullwhip effect and oscillations but also suggests that, in times of demand uncertainty, supply chains should minimise the time to react quickly and recover.

• Recovery: implies the return to stable or reduce the bullwhip.

Finding an appropriate supply chain performance metric

What the work of Shin et al (2010) did not specify was which supply chain performance metric should be used. By stating that the objective of the supply chain is reducing the bullwhip effect and oscillations, and hence, satisfying customers at a low cost, it was established in Chapters Five and Six that responses to bullwhip effect and oscillations on inventory level and cost should be considered as the performance indicators.

Adapting a well-established system dynamics inventory structure

A system dynamics inventory model has been constructed based on the works of Sterman 2000. The research used different customer demand patterns to compare the different performance matrix on the models. The analysis was carried out in Chapter five and Chapter six via simulation. These analyses can be used to understand the system responses and consequently they provide a qualitative insight into the effect of different parameter values on the supply chain's performance. In Chapter Five and Chapter Six, analyses of the effect of bullwhip effect and oscillations on inventory levels, total cost, profit, cash balance were undertaken. The analysis draws attention to the fact that the company may not achieve all business objectives at the same time. For instance, it has been demonstrated that a system with reduced cycle time and safety stock will improve costs. However, it was also demonstrated that although reducing these parameters is achieved with improved cost, there is a limit that a supply chain can reach. Therefore, reducing these parameters beyond this point will only incur costs and no further improvements in fulfilling customer demand. Finally, Chapter 7 provided a context for the steps necessary to improve the supply chains system dynamics inventory models based on the insights gained during the research process. This structure, which has been adapted and extended from Sterman (2000), starts from observing the real supply chain system to generate conceptual models that can be analysed using system dynamics, computer simulation and statistical techniques. After the validation and dynamics analysis steps, tuning existing parameters, and using 'what if?' scenarios can be used to investigate the supply chains according to their business objective: to reduce bullwhip effect and oscillations. In summary, answering the research questions and the contribution to theory involves consideration of the following points:

1. Supply chain dynamics play an important role in inventory management due to delays and feedback information in the system. For a given policy intervention this study suggest that the choice of decision parameters affects the degree of robustness that the system has. The study adapted a well-established system dynamics inventory model that enable the identification of important variables and parameters to test and identify strategies in an industrial context.

2. By investigating different policy interventions, simultaneously reducing the cycle time and safety sock coverage has been explored as a strategy to reduce bullwhip on inventory level and cost. The study suggests ways which yield decreased total costs, increased profit, cash balance

and robust system responses. Moreover, no previous system dynamics research on bullwhip effect and oscillations in downstream automobile supply chain in Nigeria has been found. Hence, this research has filled this gap in the literature.

3. Theoretical contribution was exhibited throughout the consideration of the push and hybrid push/pull inventory models under different demand patterns as discussed in Chapters Four, Five and Six which can be used for analytical generalization as this research used case study approach. In the downstream automobile companies in Nigeria, amplification of demand is observed because of the customer demand information and ordering actions of the managers. This effect is known to cause instability in the inventory level, which affects performance. This claim is similar to Geary *et al.* 2002; Yasarcan, 2003; Deif and Elmaraghy, 2010 who suggested that the transparency of customer demand information and the ordering actions by the managers in the supply chain is necessary for understanding the causes of bullwhip effect.

Practical contribution

The inventory model developed using system dynamics are a beneficial tool in the policy-making process. The model can be used as an operational and strategic management tool in the design and implementation of effective supply chain management initiatives to improve financial performance necessary for downstream automobile companies' growth. System dynamics model addresses an issue or structure of a system to reduce the complexity in the modelling process. In the light of this, the time needed to develop, execute and analyse a model is less. This is ideal for helping managers in the decision-making process who work in a fast-changing environment. Sensitivity analysis of the models' parameters demonstrates the capability of system dynamics to search for a best policy, based on the input range from managers. The improved behaviour of the models can exhibit the effect of different policies on the models, reducing the risk of poor decisions in a real-life scenario. This observation extends the view of Coyle (1985) Sermiento (2010) Wee *et al.* (2014) in their study suggests that system dynamics model can be developed to incorporate model improvement to provide further benefits in the policy-making process.

Lin (2018) conducted research using system dynamics modelling for hybrid push/pull, pull and push strategy to investigate performance and critical success factors of businesses for managing inventory. In the research, Lin stated that one of the important decisions to be made in a system dynamics hybrid push/pull, push and pull process is to find a suitable policy. These policies includes finding the balance between reducing uncertainties of orders and finding appropriate inventory levels and this can be a very complex process and procedure. The push and hybrid push/pull SD inventory models aimed at reducing instabilities and fluctuations presented in this research work is a more general and simpler approach than other methods for example mathematical methods. Due to the simplicity of system dynamics in solving policy problem, SD method can be understood not only by academics but also by practitioners.

Therefore, this study is an important practical contribution to knowledge because managers frequently avoid the use of complex approaches that is difficult to understand they prefer simple approaches to understand and easy to communicate with people. Additionally, this study adds to practical contribution as it fits well in a in a real-world context to assess policies on inventory levels that minimise the costs, as described in Chapter Five and Chapter Six for both case studies.

7.9 Research limitations

The research limitations of this thesis are concerned with the structure of the supply chain represented by the system dynamics models. The results presented in Chapter five and six are bound to serial supply chain operations. The structure is selected to analyse the complex model, so as to gain further understanding of the effects in different demand patterns on the distributor and dealer (downstream players). This means that suppliers and manufacturers (upstream players) are outside the boundary. The downstream automobile case study companies in Nigeria represents the distributor and dealer. The end-user is indirectly involved through the variety essential in the final customer demand, where the patterns reflect the purchasing behaviours of the customer.

The models assume a single product of automobile. This assumption is made to simplify the model structure to provide insights on the effect of uncertainties in customer demand towards the performance of the two inventory models. However, the models can be adjusted to suit operations of an organisation. The tests and analysis conducted on the two models use different types of demand pattern but in uniform and continuous patterns. For this reason, the behaviour of the two models projected is subject to these demand patterns. This obviously implies that the models could be expanded to include more different customer demand patterns to gain more insight for different scenario.

7.10 Direction for future research

This research was conducted based on the knowledge of the case study companies and from the literature. The models were developed to allow a comparative analysis of the performance of the push and hybrid push/pull system dynamics inventory models (downstream supply chain). Further work can be performed to extend the boundary of the model by modelling other important material flow and information flow. For instance, the allocation of physical capacity constraint and workforce can be modelled to gain a more knowledge of the effect of these policies on performance on the supply chain SD inventory models. Therefore, the boundaries of the supply chain system dynamics inventory models can be extended further at the distributor and dealer by providing further insights on the effects of instabilities in the companies' supply chain.

System dynamics can be applied in numerous possible supply chain issues and this thesis has suggested one of many applications by modelling the supply chain inventory issues for comparative analysis. Widespread research to address various operational and strategic issues in downstream supply chain, for instance the deployment of capacity, or workforce lay off, is suggested to utilise the versatility of the system dynamics methodology. Research on the framework for modelling supply chain inventory can be beneficial by providing guidelines on how future research in system dynamics in this area should be conducted. On a closing note, it is hoped that this research provides some additional knowledge in the field of system dynamics and in supply chain management.

References

Aastrup, J. and Halldórsson, Á. (2008). Epistemological role of case studies in logistics. *International Journal of Physical Distribution & Logistics Management*, 38(10), pp.746-763.

Adams, G.R. and Schavaneveldt, J.D., 1991.Understanding Research Methods. *2ndLondon: Longman.*

Adamides, E., Papachristos, G. and Pomonis, N. (2012). Critical realism in supply chain research. *International Journal of Physical Distribution & Logistics Management*, 42(10), pp.906-930.

Aeppel, T., (2010). 'Bullwhip' hits firms as growth snaps back. *Wall Street Journal – Eastern Edition* 255 (21): A1–A6.

Agrawal, S., Sengupta, R. and Shanker, K. (2009). Impact of information sharing and lead time on bullwhip effect and on-hand inventory. *European Journal of Operational Research*, 192(2), pp.576-593.

Ahmadi, T., Atan, Z., de Kok, T. and Adan, I. (2019). Optimal control policies for assemble-to-order systems with commitment lead time. *IISE Transactions*, pp.1-18.

Akan, O., Allen, R., Helms, M. and Spralls, S. (2006). Critical tactics for implementing Porter's generic strategies. *Journal of Business Strategy*, 27(1), pp.43-53.

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(3), pp.173-186.

Albrecht, J., Laleman, R. and Vulsteke, E. (2015). Balancing demand-pull and supply-push measures to support renewable electricity in Europe. *Renewable and Sustainable Energy Reviews*, 49, pp.267-277.

Alsop, R. and Armstrong, D., (2010). Resilient supply chain in time of uncertainty. *The economist*, May, http://www.m2mevolution.com/conference/miami-13/ presentations /oracle_supply_chain_web.pdf [Accessed 10 Aug 2020], 1–12.

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

Ancarani, A., Di Mauro, C., & D'Urso, D. (2013). A human experiment on inventory decisions under supply uncertainty. *International Journal of Production Economics,* 142(1), 61–73.

Anderson, E., Fine, C. and Parker, G. (2009). Upstream Volatility in the Supply Chain: The Machine Tool Industry as a Case Study. *Production and Operations Management*, 9(3), pp.239-261.

Angerhofer, BJ & Angelides, MC 2000, 'System Dynamics Modelling in Supply Chain Management: Research Review', paper presented to 2000 *Winter Simulation Conference*, UK. (2019).

Anne, K.R. (2009). Contribution of Modelling and Simulation of Supply Chain Networks from a Nonlinear Dynamics Perspective, *PhD thesis*, *Alpen-Adria-Universit¨at Klagenfurt.*

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), 22–40.

Ashayeri, J., Keij, R. and Bröker, A. (1998). Global business process re-engineering: a system dynamics-based approach. *International Journal of Operations & Production Management*, 18(9/10), pp.817-831.

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

Atan, Z., Ahmadi, T., Stegehuis, C., Kok, T. and Adan, I. (2017). Assemble-to-order systems: A review. *European Journal of Operational Research*, 261(3), pp.866-879.

Axsater, S. (1985). Control theory concepts in production and inventory control. *International Journal of Systems Science*, 16(2), pp.161-169.

Azfar, K., Khan, N. and Gabriel, H. (2014). Performance Measurement: A Conceptual Framework for Supply Chain Practices. *Procedia - Social and Behavioral Sciences*, 150, pp.803-812.

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

Baines, T. and Harrison, D. (1999). An opportunity for system dynamics in manufacturing system modelling. *Production Planning & Control*, 10(6), pp.542-552.

Barlas, Y. (1989). Multiple tests for validation of system dynamics type of simulation models. *European Journal of Operational Research*, 42(1), pp.59-87.

Barlas, Y. and Carpenter, S. (1990) Philosophical roots of model validation: two paradigms. *System Dynamics Review,* 6(2), 148-166.

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

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.

Bazin, N.E.N. (2010). An Analysis of the Performance of Push, Pull, Hybrid Production Systems in Manufacturing Supply Chain, PhD Thesis, *University of Salford*.

Beamon, B. (1998). Supply chain design and analysis: *International Journal of Production Economics*, 55(3), pp.281-294.

Benton, T., (1977). The philosophical foundation of the three sociologies. London: *Routledge*.

Benton, W. J. (2007). Purchasing and Supply Management. *USA: McGraw-Hill/Irwin*.

Benton, T. and Craib, I., (2001). Philosophy of social science. *1st New York: Palgrave*.

Bezemer, J.J. and Akkermans, H. (2003). Not with a start bang, but with a whimper: Understanding delays in semiconductor supply chain dynamics, *International System Dynamics Conference.*

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

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

Billington, C., Callioni, G., Crane, B., Ruark, J., Rapp, J., White, T. and Willems, S. (2004). Accelerating the Profitability of Hewlett-Packard's Supply Chains. *Interfaces*, 34(1), pp.59-72.

Bijulal, D. and Venkateswaran, J. (2008). Closed-Loop Supply Chain Stability under Different Production-Inventory Policies. In Proceedings of the 26th International Conference of the System Dynamics Society. *System Dynamics Society*.

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*.

Blinder, A.S. (1986) Can production smoothing model of inventory behaviour be saved?. *The Quarterly Journal of Economics,* 101(3), 431-453.

Blinder, A. S., and Maccini, L. J. (1991). Taking stock: a critical assessment of recent research on inventories. *Journal of Economic Perspectives*, 5(1), 73-96.

Bonney, M.C., 1994. Trends in inventory management. *International Journal of Production Economics* 35 (1-3): 107–114.

Borshchev, A. and Filippov, A. (2004). From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, and Tools. *In Proceedings of the 22nd International Conference of the System Dynamics Society*. System Dynamic Society.

Bossert, J. and Willems, S. (2007). A Periodic-Review Modelling Approach for Guaranteed Service Supply Chains. *Interfaces*, 37(5), pp.420-436.

Botha, A. (2017). A system Dynamics Simulation for Strategic Inventory Management in the South African Automotive Industry, PhD Thesis, *University of Pretoria*.

Boute, R., Disney, S., Lambrecht, M. and Van Houdt, B. (2007). An integrated production and inventory model to dampen upstream demand variability in the supply chain. *European Journal of Operational Research*, 178(1), pp.121-142.

Boute, R., Disney, S., Lambrecht, M. and Van Houdt, B. (2010). Coordinating Lead-Time and Safety Stock Decisions in a Two-Echelon Supply Chain with Auto-correlated Consumer Demand. *SSRN Electronic Journal*.

Bowen, J.T. and Sparks, B.A., 1998. Hospitality marketing research: A content analysis and implications for future research. International Journal of Hospitality Management, 17 (2), 125–144.

Bradl, P. (2003). The Use of System Dynamics in Management: Reasons and Applications. *In Proceedings of the 26th International Conference of the System Dynamics Society*. The System Dynamics Society.

Bray, R. L., and Mendelson, H. (2015). Production smoothing and the bullwhip effect. *Manufacturing and Service Operations Management*, 17(2), 208-220.

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

Bryman, A. (2012), Social Research Methods (4th Ed.), *Oxford University Press*.

Burbidge, J.L. and Halsall, J. (1994) Group technology and growth at Shalibane. *Production Planning and Control,* 5(2), 213-218.

Burbidge, J. L. (1961). The new approach to production. *Production Engineer*, 40(12), 769-784.

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), 703–729.

Cachon G.P. (1999), "Quantitative models for supply chain management," *Kluwer Academic Publishers*, Boston, 111–146.

Cachon, G., T. Randall, G. Schmidt. (2007). In search of the bullwhip effect. *Manufacturing and Service Operation Manage.* 9(4): 457–479.

Calle, M., González-R, P. and Pierreval, H. (2016). Impact of the customer demand on order fulfilment strategies based on floating decoupling point: a simulation analysis. *International Journal of Production Research*, 54(24), pp.7359-7373.

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

Camm, J., Chorman, T., Dill, F., Evans, J., Sweeney, D. and Wegryn, G. (1997). Blending OR/MS, Judgment, and GIS: Restructuring P&G's Supply Chain. *Interfaces*, 27(1), pp.128-142.

Cannella, S., Ashayeri, J., Miranda, P. and Bruccoleri, M. (2013). Current economic downturn and supply chain: the significance of demand and inventory smoothing. *International Journal of Computer Integrated Manufacturing*, 27(3), pp.201-212.

Cannella, S., Dominguez, R., Ponte, B. and Framinan, J. (2018). Capacity restrictions and supply chain performance: Modelling and analysing load-dependent lead times. *International Journal of Production Economics*, 204, pp.264-277.

Cantor, D.E. and. MacDonald J.R. (2008), "Decision making in the supply chain: Examining problem solving approaches and information availability," *Journal of Operations Managements*, 26:461-556.

Cantor, D. E., and Katok, E. (2012). Production smoothing in a serial supply chain: a laboratory investigation. *Transportation Research Part E*, 48(4), 781-794.

Cavana, R. Y. and Maani, K. E. (2000). A Methodological Framework for Integrating Systems Thinking and System Dynamics. *In Proceedings of the 18th International Conference of the System Dynamics Society*. System Dynamics Society.

Chang, T.M. and Yih, Y. (1994a) Generic kanban systems for dynamic environment. *International Journal of Production Research,* 32 (4), 889-902.

Chang, T.M. and Yih, Y. (1994b) Determining the number of kanbans and lot sizes in a generic kanban system: a simulated annealing approach. *International Journal of Production Research,* 32 (8), 1991 - 2004.

Chen, F., Drezner, Z., Ryan, J. 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.

Chen, F., Ryan, J. K., and Simchi-Levi, D. (2000b). The impact of exponential smoothing forecasts on bullwhip effect. *Naval Research Logistics*, 47, 269-286.

Chen, L., and H. L. (2012). Bullwhip effect measurement and its implications. *Operations Research*. 60, 771-784.

Cheng, F., Ettl, M., Lu, Y. and Yao, D. (2012). A Production-Inventory Model for a Push-Pull Manufacturing System with Capacity and Service Level Constraints. *Production and Operations Management*, 21(4), pp.668-681.

Childerhouse, P. and Towill, D. (2003). Simplified material flow holds the key to supply chain integration. *Omega*, 31(1), pp.17-27.

Childerhouse, P. and Towill, D. (2004). Reducing uncertainty in European supply chains. *Journal of Manufacturing Technology Management*, 15(7), pp.585-598.

Childerhouse, P., Hermiz, R., Mason-Jones, R., Popp, A. and Towill, D. (2003). Information flow in automotive supply chains – present industrial practice. *Industrial Management & Data Systems*, 103(3), pp.137-149.

Childerhouse, P., Lewis, J., Naim, M. and Towill, D. (2003). Re-engineering a construction supply chain: a material flow control approach. *Supply Chain Management: An International Journal*, 8(4), pp.395-406.

Chopra, S. and Meindl, P., (2007). Supply chain management – *strategy, planning, & operation. 3rd ed*. Upper Saddle River: Pearson Prentice Hall.

Chopra, S. and Meindl, P. (2010) 'Supply chain performance: achieving strategic fit and scope', Supply Chain Management, Strategy, Planning and Operation, pp.40–43, *ISBN: 9780131730427.*

Christopher, M. and Holweg, M. (2011). "Supply Chain 2.0": managing supply chains in the era of turbulence. *International Journal of Physical Distribution & Logistics Management*, 41(1), pp.63-82.

Chow, C.W. and Van der Stede, W. A. (2006). The use and usefulness of nonfinancial performance measures. *Management Accounting Quarterly,* 7(3), 1-8.

Choy, M., & Cheong, M. L. (2012). Identification of Demand through Statistical Distribution Modelling for Improved Demand Forecasting. *Business Intelligence Journal, 5*(2), 260-266.

Clark Jr., T. D. and Kurono, H. (1995). A Conversion Table of DYNAMO into STELLA II. *In Proceedings of the 13th International Conference of the System Dynamics Society*, pages 424-433. System Dynamics Society.

Cohen, M. and Moon, S. (1990). "Impact of production scales economies, manufacturing complexity and transportation cost on supply chain facility network," *Journal of Manufacturing and Operations Management*, 3:269-292.

Cooper, M. and Ellram, L. (1993). Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy. *The International Journal of Logistics Management*, 4(2), pp.13-24.

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

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

Collis, J. and Hussey, R. (2009), Business Research - A Practical Guide for Undergraduates and Postgraduate Students (3rd Ed.), *Palgrave Macmillan*.

Coppini, M., Rossignoli, C., Rossi, T., Strozzi, F., (2010). Bullwhip effect and inventory oscillations analysis using the beer game model. *International Journal of Production Research* 48 (13): 3943–3956.

Corinna Cagliano, A., DeMarco, A., Rafele, C. and Volpe, S. (2011). Using system dynamics in warehouse management: a fast-fashion case study. *Journal of Manufacturing Technology Management*, 22(2), pp.171-188.

Corry, P. and Kozan, E. (2004). Meta-heuristics for a complex push–pull production system. *Journal of Intelligent Manufacturing*, 15(3), pp.381-393.

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

Coyle, R.G., (1985). The use of optimization methods for policy design in system dynamics model. *System Dynamics Review,* 1(1), 81-91.

Coyle, G. (1998). The practice of system dynamics: milestones, lessons and ideas from 30 years' experience. *System Dynamics Review*, 14(4), pp.343-365.

Coyle, R.G. and Exelby, D. (2000). The validation of commercial system dynamics models. *System Dynamics Review* 16(1):27-41.

Croson, R., Donohue, K., (2003). Impact of POS data sharing on supply chain management: an experimental study. *Production and Operations Management* 12 (1): 1–11.

Croson, R., Donohue, K., (2006). Behavioural causes of the bullwhip effect and the observed value of inventory information. *Management Science* 52 (3): 323–336.

Dangerfield, B.C. (2009). System dynamics models, optimization of, in: Meyers, R. A. *Encyclopedia of Complexity & Systems Science.* Springer, New York, USA.

Dangerfield, B.C. and Roberts, C. (1996). An overview of strategy and tactics in system dynamics optimisation. *Journal of the Operational Research Society,* 47, 405 -423.

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

Davis, T. (1993) Effective supply chains management. *Shan Management Review,* 34 (4), 35-46.

Deif, A.M. and ElMaraghy, H.A. (2009). Modelling and analysis of dynamic capacity complexity in multi-stage production, *Production Planning & Control,* 20(8), 737-749.

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

Dejonckheere, J., Disney, S., Lambrecht, M. and Towill, D. (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.

Delhoum, S., and Scholz-Reiter, B. (2009). The Influence of Decision Patters of Inventory Control on Bullwhip Effect Based on a Simulation Game of a Production Network. *Production Planning and Control*, 20(8), 666-677.

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

Disney, S. and Grubbström, R. (2004). Economic consequences of a production and inventory control policy. *International Journal of Production Research*, 42(17), pp.3419-3431.

Disney, S. and Towill, D. (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.

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

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

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

Disney, S.M., Naim, M.M., Potter, A., (2004). Assessing the impact of e-business on supply chain dynamics. *International Journal of Production Economics*, 89 (2), 109–118.

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

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

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

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

Disney, S.M., Towill, D.R., Warburton, R.D.H., (2006). Taming the bullwhip effect whilst watching customer service in a single echelon of a supply chain. *European Journal of Operational Research*, 173 (1), 151–172.

Dooley, K., Yan, T., Mohan, S. and Gopalakrihnan, M. (2010). Inventory management and the Bullwhip Effect During the 2007â2009 recession: Evidence from the manufacturing sector. *Journal of Supply Chain Management*, 46(1), pp.12-18.

Doyle, J. and Ford, D. (1998). Mental models concepts for system dynamics research. *System Dynamics Review*, 14(1), pp.3-29.

Doyle, J. and Ford, D. (1999). Mental models concepts revisited: some clarifications and a reply to Lane. *System Dynamics Review*, 15(4), pp.411-415.

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

Duc, T. T. H., Luong, H. T., and Kim, Y. D. (2008). A measure of Bullwhip Effect in Supply Chains with a Mixed Autoregressive-moving Average Demand Process. *European Journal of Operational Research*, 187, 243-256.

Duc, T. T. H., Luong, H. T., and Kim, Y. D. (2008b). A Measure of Bullwhip Effect in Supply Chains with Stochastic Lead Time. *International Journal of Advanced Manufacturing Technology*, 38, 1201-1212.

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), 145–172.

Durkheim, E., (1964). The rules of sociological methods. Glencoe: *The Free Press.*

Easton, G. (2010). Critical realism in case study research. *Industrial Marketing Management*, 39(1), pp.118-128.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (2002), Management Research: An Introduction (2nd Ed.), London, *SAGE*.

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

Eberlein, R. and Peterson, D. (1992). Understanding models with Vensim™. *European Journal of Operational Research*, 59(1), pp.216-219.

Eisenhardt, K.M. (1989). Building theories from case study research, *Academy of Management Review*, 14(4): 532-550.

Elkady, G., Moizer, J. and Liu, S., (2014). A Decision Support Framework to Assess Grocery Retail Supply Chain Collaboration: A System Dynamics Modelling Approach. *International Journal of Innovation, Management and Technology*, 5(4), 232-238.

Ellram, L.M. (1996). The use of case study method in logistics research: *Journal of Business Logistics*, 17(2): 93-138.

Ewaldt, J. W. (2000). A System Dynamics Analysis of the Effects of Capacity Limitations in A Multi-Level Production Chain. *In Proceedings of the 18th International Conference of the System Dynamics Society*. System Dynamics Society.

Farasyn, I., Humair, S., Kahn, J., Neale, J., Rosen, O., Ruark, J., Tarlton, W., Van de Velde, W., Wegryn, G. and Willems, S. (2011). Inventory Optimization at Procter & Gamble: Achieving Real Benefits through User Adoption of Inventory Tools. *Interfaces*, 41(1), pp.66-78.

Fellows, R.F.F. (1997). The culture of Partnering, Proceeding of the CIB W-92 Procurement Systems Symposium. *University of Montreal, Montreal*, Canada pp 193-202

Feng, Y. (2012). System Dynamics Modelling for Supply Chain Information Sharing. *Physics Procedia*, 25, pp.1463-1469.

Fisher, M. L. (1997). What is the right supply chain for your product? *Harvard Business Review,* March/April, 105-116.

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

Forrester, J. (1961). *Industrial Dynamics.* Cambridge: MIT Press.

Forrester, J. (1965). Industrial Dynamics. MIT Press, 4th Ed., MA, USA.

Forrester, J. (1969). *Urban Dynamics.* Cambridge MA: Productivity Press.

Forrester, J. (1973). *World Dynamics.* Cambridge MA: Productivity Press.

Forrester, J. (1975). Industrial dynamics after the first decade. Chapter 8 in "Collected papers of Jay W. Forrester", *Wright-Allen Press, Inc*.

Forrester, J. W. and Senge, P.M. (1980). Test for building confidence in System Dynamics models. In: Legasto A.A. Jr, Forrester J. W., Lyneis J.M. (eds) System Dynamics. *North-Holland Publishing Company*. Amsterdam, 209 -208.

Forrester, J. W. (1987). Lessons from system dynamics modelling. *System Dynamics*

Review, 3(2):136-149.

Forrester, J. (1994). System Dynamics, Systems Thinking and Soft OR. *System Dynamics Review, 10*(2).

Forrester, J. W. (1995). The beginning of system dynamics. *McKinsey Quarterly*, 17(4):4-17.

Forrester, J. (2003). Dynamic models of economic systems and industrial organizations. *System Dynamics Review*, 19(4), pp.329-345.

Fowler, A. (1999). Feedback and feedforward as systemic frameworks for operations control. *International Journal of Operations & Production Management*, 19(2), pp.182-204.

Fowler, J., Kim, S. and Shunk, D. (2019). Design for customer responsiveness: Decision support system for push–pull supply chains with multiple demand fulfilment points. *Decision Support Systems*, 123, p.113071.

Fox, M. S., Barbuceanu, M., and Teigen, R., (2000). Agent-oriented supply-chain management, *International Journal of Flexible Manufacturing Systems*, 12, 165−188.

Francesco, A. (2015). Managing the Bullwhip Effect in Multi-Echelon Supply Chains. *Industrial Engineering and Management*, 04(02).

Fu, K., Hsu, V. and Lee, C. (2006). Inventory and Production Decisions for an Assemble-to-Order System with Uncertain Demand and Limited Assembly Capacity. *Operations Research*, 54(6), pp.1137-1150.

Gaalman, G., and Disney, S.M. (2012). Bullwhip behaviour in order-up-to-policy with ARIMA demand. *In 4th World Conference on Production and Operations Management*. Amsterdam.

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

Garcia Salcedo, C., Ibeas Hernandez, A., Vilanova, R. and Herrera Cuartas, J. (2013). Inventory control of supply chains: Mitigating the bullwhip effect by centralized and decentralized Internal Model Control approaches. *European Journal of Operational Research*, 224(2), pp.261-272.

Gary, M., Kunc, M., Morecroft, J. and Rockart, S. (2008). System dynamics and strategy. *System Dynamics Review*, 24(4), pp.407-429.

Gattorna, J. (2010). Dynamic Supply Chains - Delivering Value Through People. UK: *Pearson Education Limited*.

Geary, S., Childerhouse, P., Towill, D.R., (2002) Uncertainty and the seamless supply chain. *Supply Chain Management Review,* July/August, 52- 61.

Geary, S., Disney, S. and Towill, D. (2006). On bullwhip in supply chains—historical review, present practice and expected future impact. *International Journal of Production Economics*, 101(1), pp.2-18.

Georgiadis, P. and Vlachos, D. (2004). The effect of environmental parameters on product recovery. *European Journal of Operational Research*, 157(2), pp.449-464.

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

Geraghty, J. and Heavey, C. (2004). A comparison of Hybrid Push/Pull and CONWIP/Pull production inventory control policies. *International Journal of Production Economics*, 91(1), pp.75-90.

Geraghty, J. and Heavey, C. (2005). A review and comparison of hybrid and pull-type production control strategies. *OR Spectrum*, 27(2-3), pp.435-457.

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), 27–37.

Gilbert, K., 2005. An ARIMA supply chain model. *Management Science*, 51 (2): 305–310.

Goldratt, E.M. and Cox, J. (1984). *The goal- a process of ongoing improvement.* 3rd ed. Aldershot: Gower.

Golicic, S.L., Davis, D.F. and McCarthy, T.M., (2005). A Balanced Approach to Research in Supply Chain Management. In: H. Kotzab, S. Seuring, M. Muller and ¨ G. Reiner, eds. Research Methodologies in Supply Chain Management. Germany: *Physica-Verlag Heiedlberg*.

Gonclaves, P.M. (2003). Demand Bubbles and Phantom Orders in Supply Chains, PhD Thesis, *Massachusetts Institute of Technology*.

Gonçalves, P., Hines, J. and Sterman, J. (2005). The impact of endogenous demand on push-pull production systems. *System Dynamics Review*, 21(3), pp.187-216.

Goncalves, P. (2010). Supplier Capacity Decisions Under Retailer Competition and Delays: Theoretical and Experimental Results. In Proceedings of the 28th International Conference of the System Dynamics Society. *System Dynamics Society*.

Graves, S. and Willems, S. (2000). Optimizing Strategic Safety Stock Placement in Supply Chains. *Manufacturing and Service Operations Management*, 2(1), 68-83.

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

Gunasekaran, A., Patel, C. and Tirtiroglu, E., (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management*, 21 (1/2), 71–87.

Guo, H., Marston, S. and Chen, Y. (2015). Push or Pull? Design of Content Delivery Systems. *Decision Sciences*, 46(5), pp.937-960.

Guojun, J. and Caihong, Z. (2008) 'Study on supply chain disruption risk management strategies and model', *2008 International Conference on Service Systems and Service Management*, pp.1–6.

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

Harrison, A. (1992) Just-In-Time manufacturing in perspective, *Prentice Hall International*, Hertfordshire.

Haslett, T. and Osborne, C. (1999). Local rules: the theory, the application, and the chances of success. In: *The Online Proceedings of the 17th International Conference of the System Dynamics Society and the 5 the Australian and New Zealand Systems Conference,* 1999, Wellington, New Zealand.

Helal, M. (2008). A Hybrid System Dynamics-Discrete Event Simulation Approach to Simulating the Manufacturing Enterprise, *PhD Thesis, University of Central Florida*.

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

Hidaka, S., Cavana, R. Y., Vennix, J. A. M., Rouwette, E. A. J. A., Stevenson-Wright, M., and Candlish, J. (1999). System Dynamics: A New Tool for TQM. In Proceedings of the 17th International Conference of the System Dynamics Society. *System Dynamics Society*.

Higgins, P., Le Roy, P., and Tierney, L. (1996). Manufacturing Planning and Control Beyond MRPII*, Chapman and Hall*, London.

Higuchi, T. and Troutt, M. (2004). Dynamic simulation of the supply chain for a short life cycle product—Lessons from the Tamagotchi case. *Computers and Operations Research*, 31(7), pp.1097-1114.

Hillier, S., & Liberman, G. (2005). Introduction to Operations Research (8^{th} ed.). USA: *McGraw Hill*.

Hodgson, T. and Wang, D. (1991a). Optimal hybrid push/pull control strategies for a parallel multistage system: Part I. *International Journal of Production Research*, 29(6), pp.1279-1287.

Hodgson, T. and Wang, D. (1991b). Optimal hybrid push/pull control strategies for a parallel multistage system: Part II. *International Journal of Production Research*, 29(7), pp.1453-1460.

Homer, J. (1996). Why we iterate: scientific modelling in theory and practice. *System Dynamics Review*, 12(1), pp.1-19.

Homer, J. (1997). Structure, data, and compelling conclusions: notes from the field. *System Dynamics Review*, 13(4), pp.293-309.

Homer, J. and Oliva, R. (2001). Maps and models in system dynamics: a response to Coyle. *System Dynamics Review*, 17(4), pp.347-355.

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

Hopp, W.J. and Spearman, M.L. (2004). To pull or not to pull: What is the question? *Manufacturing and Service Operations Management,* 6(2), 133-148.

Hosoda, T., and Disney, S.M. (2006a). On variance amplification in a three-echelon supply chain with minimum mean square error forecasting. *Omega*, 34(4), 344-358.

Hosoda, T., and Disney, S.M. (2012). On the replenishment policy when the market demand information is lagged. *International Journal of Production Economics*, 135(1), 458-467.

Hua, Z. and Li, S. (2008). Impacts of demand uncertainty on retailer's dominance and manufacturer-retailer supply chain cooperation. *Omega*, 36(5), pp.697-714.

Huang, C. and Kusiak, A. (1996). Overview of Kanban systems. *International Journal of Computer Integrated Manufacturing*, 9(3), pp.169-189.

Huang, S., Uppal, M. and Shi, J. (2002). A product driven approach to manufacturing supply chain selection. *Supply Chain Management: An International Journal*, 7(4), pp.189-199.

Humair, S. and Willems, S. (2006). Optimizing Strategic Safety Stock Placement in Supply Chains with Clusters of Commonality. *Operations Research*, 54(4), pp.725-742.

Humair, S. and Willems, S. (2011). Technical Note—Optimizing Strategic Safety Stock Placement in General Acyclic Networks. *Operations Research*, 59(3), pp.781-787.

Hunter, M. (2002). Rethinking epistemology, methodology, and racism: or, is White sociology really dead?. *Race and Society*, 5(2), pp.119-138.

Ishfaq, R. and Raja, U. (2017). Evaluation of Order Fulfillment Options in Retail Supply Chains. *Decision Sciences*, 49(3), pp.487-521.

Ishii, K., Takahashi, K. and Muramatsu, R. (1988). Integrated production, inventory and distribution systems. *International Journal of Production Research*, 26(3), pp.473-482.

Ivanov, D., Mason, S. and Hartl, R. (2016). Supply chain dynamics, control and disruption management. *International Journal of Production Research*, 54(1), pp.1-7.

Jaipuria, S. and Mahapatra, S. (2014). An improved demand forecasting method to reduce bullwhip effect in supply chains. *Expert Systems with Applications*, 41(5), pp.2395-2408.

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

Janamanchi, B. and Burns, J. (2013). Control Theory Concepts Applied to Retail Supply Chain: A System Dynamics Modelling Environment Study. *Modelling and Simulation in Engineering,* 2-14.

Jeong, S. and Maday, C. (1996). Dynamic information control for multi-echelon production-distribution systems with constrained production capacity. *System Dynamics Review*, 12(4), pp.331-343.

Jones, T.C. and Riley, D.W. (1987). 'Using inventory for competitive advantage through supply chain management', *International Journal of Physical Distribution and Logistics Management*, Vol. 15, No. 5, pp.16–26.

Joshi, Y. (2000). Information visibility and its effect on supply chain dynamics. Master Thesis, *Massachusetts Institute of Technology*, Cambridge, MA.

Juerging, J. and Milling, P.M. (2006). Manufacturing stat-ups in the automobile industry. In: The Online Proceedings of the 2006 International Conference of the System Dynamics Society, 2006, *Nijmigen, Netherlands*.

Kahn, J.A. (1987). Inventories and volatility of production. *The American Economic Review,* 77(4), 667-679.

Kaplan, R.S. (Ed.) (1990). Measures for manufacturing excellence. *Harvard Business School Press.*

Karabakal, N., Günal, A. and Ritchie, W. (2000). Supply-Chain Analysis at Volkswagen of America. *Interfaces*, 30(4), pp.46-55.

Karmarkar A. and N.R. Patel (1977), "The one-period, n-location distribution problem," *Naval Research Logistics Quarterly*, 24:559–575.

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

Kelle, P., and Milne, A. (1999). The effect of (s S) ordering policy on the supply chain *International Journal of Production Economics,* 59(1-3), 113-122.

Keloharju, R. and Wolstenholme, E. F. (1989). A case study in system dynamics optimisation. *Journal of the Operational Research Society,* 40 (3), 221-230.

Kothari, C.R., (1997), Research Methodology methods & Techniques, *Wisha Prakashan*, New Delhi, India.

Kibira, D., Jain, S., and McLean, C. R. (2009). A System Dynamics Modeling Framework for Sustainable Manufacturing. In Proceedings of the 27th International Conference of the System Dynamics Society. *System Dynamics Society*.

Kim, J. G., Chatfield, D., Harrison, T. P. and Hayya, J. C. (2006). Quantifying the bullwhip effect in a supply chain with stochastic lead time. *European Journal of Operational Research*, 173, 617-636.

Kim, D. H. and Burchill, G. (1992). System Archetypes as a Diagnostic Tool: A Field-based Study of TQM Implementation. In Vennix, J. A. M., Faber, J., Scheper, W. J., and Takkenberg, C. A. T., editors, Proceedings of the 10th International Conference of the System Dynamics Society. *System Dynamics Society*.

Kim, S., Fowler, J., Shunk, D. and Pfund, M. (2012). Improving the push–pull strategy in a serial supply chain by a hybrid push–pull control with multiple pulling points. *International Journal of Production Research*, 50(19), pp.5651-5668.

Kleijnen, J.P.C. and Smits, M.T. (2003). Performance metrics in supply chain management. *The Journal of the Operational Research Society,* 54(5), 507-514.

Klug, F. (2013). The internal bullwhip effect in car manufacturing. *International Journal of Production Research*, 51(1), pp.303-322.

Kortelainen, S. and Lattila, L. (2009). Modeling Strategic Technology Management with a Hybrid Model. In Proceedings of the 27th International Conference of the System Dynamics Society. *System Dynamics Society*.

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

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.

Lambert, D.M. and Cooper, M.C. (2000) Issues in supply chain management. *Industrial Marketing Management,* 29, 65-83.

Lambert, D. and Enz, M. (2017). Issues in Supply Chain Management: Progress and potential. *Industrial Marketing Management*, 62, pp.1-16.

Lane, D. (2000a). Diagramming conventions in system dynamics. *Journal of the Operational Research Society*, 51(2), pp.241-245.

Lane, D. (2000b). Should system dynamics be described as a 'hard' or 'deterministic' systems approach? *Systems Research and Behavioural Science*, 17(1), pp.3-22.

Lane, D. (2001a). Rerum cognoscere causas: Part I – How do the ideas of system dynamics relate to traditional social theories and the voluntarism/determinism debate? *System Dynamics Review* 17 (2), 97–118

Laugen, B.T., Acur, N., Boer, H., Frick, J. (2005). Best manufacturing practices What do the best-performing companies do? *International Journal of Operations & Production Management,* 25(2), 131-150.

Lee, L. (1989). A Comparative Study of the Push and Pull Production Systems. *International Journal of Operations & Production Management*, 9(4), pp.5-18.

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

Lee, H.L., Padmanabhan, V., Whang, S., (1997b). The bullwhip effect in supply chains. Sloan Management Review 38 (3): 93–102.

Lee, H., Padmanabhan, V. and Whang, S. (2004). Comments on "Information Distortion in a Supply Chain: The Bullwhip Effect". *Management Science*, 50(12_supplement), pp.1887-1893.

Lee, H., Padmanabhan, V. and Whang, S. (2004). Information Distortion in a Supply Chain: The Bullwhip Effect. *Management Science*, 50(12_supplement), 1875-1886.

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

Lee, H. L., and Whang, S. (2000). Information sharing in a supply chain. *International Journal of Technology Management*, 20(3/4), 373-387.

Lertpattarapong, C. (2002). Applying System Dynamics Approach to the Supply Chain Management Problem. *MSc Dissertation, Massachusetts Institute of Technology*.

Li, Q., Disney, S.M. and Gaalman, G. (2014). Avoiding the bullwhip effect using Damped Trend forecasting and Order-up-to replenishment policy. *International Journal of Production Economics*, 149, 3-16.

Lin, J. and Yueliang, S. (2016). Research on Order Financing System Dynamics in the Chain Finance Model, *Cross-Cultural Communication*, 12(8), pp25-30.

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

Listl, A. and Notzon, I. (2000). An operational application of system dynamics in the automotive industry: Inventory management at BMW. *Online Proceedings of the 18th International Conference of the System Dynamics Society,* Bergen, Norway, August 6-8, 2000.

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

Luis F L Reyes and Deborah L Andresen, (2004), Collecting and analyzing qualitative data for system dynamics: methods and models, *System Dynamics review*, (19)4, 271-296.

Lyneis, J. (1980). Corporate planning and policy design: A system dynamics approach. *The MIT Press*, Cambridge, MA, USA

Lyneis, J., Cooper, K. and Els, S. (2001). Strategic management of complex projects: a case study using system dynamics. *System Dynamics Review*, 17(3), 237-260.

Ma, D. (2015). Push or Pull? A Website's Strategic Choice of Content Delivery Mechanism. *Journal of Management Information Systems*, 32(1), 291-321.

Mayberry, M., Hoxsey, K., Me Cracken, K., and Rendell, C. (1996). Using systems thinking and dynamics simulations to reengineer manufacturing processes at silicon graphics. In: *The Online Proceedings of the I4l International Conference of the System Dynamics Society,* 1996, Cambridge, Massachusetts.

MacCarthy, B., Blome, C., Olhager, J., Srai, J. and Zhao, X. (2016). Supply chain evolution – theory, concepts and science. *International Journal of Operations & Production Management*, 36(12), 1696-1718.

Malone, T., Gonçalves, P., Hines, J., Herman, G., Quimby, J., Rice, J., Murphy-Hoye, M., Patten, J. and Ishi, H. (2009). Construction by Replacement: A New Approach to Simulation Modeling. *SSRN Electronic Journal*.

Manary, M. and Willems, S. (2008). Setting Safety-Stock Targets at Intel in the Presence of Forecast Bias. *Interfaces*, 38(2), 112-122.

Marquez, A.C., Usano, R. R., Torres, J. M. F., and De Castro, Z. (1996). The pull control system: a system dynamics perspective. In: *The Online Proceedings of the 14 the International Conference of the System Dynamics Society,* 1996, Cambridge, Massachusetts.

Mason-Jones, R. and Towill, D., 1998. Shrinking the supply chain uncertainty circle. *Control*, 24 (7), 17–23.

Mason-Jones, R. and Towill, D. (1999). Total cycle time compression and the agile supply chain. *International Journal of Production Economics*, 62(1-2), 61-73.

Mason-Jones, R. and Towill, D. (2000). Coping with Uncertainty: Reducing "Bullwhip" Behaviour in Global Supply Chains. *Supply Chain Forum: An International Journal*, 1(1), 40-45.

Mason-Jones, R. and Towill, D. (1998). Time compression in the supply chain: information management is the vital ingredient. *Logistics Information Management*, 11(2), 93-104.

Mason-Jones, R., Naylor, B. and Towill, D. (2000). Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research*, 38(17), 4061-4070.

Mentzer, J.T., DeWitt, W.J., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D., Zacharia, Z.G., (2001). Defining supply chain management. Journal of Business Logistics 22 (2), 1–25.

N¨aslund, D., (2002). Logistics needs qualitative research: especially action research. *International Journal of Physical Distribution & Logistics*, 32 (5), 321–38.

McCullen, P. and Towill, D. (2001). Achieving lean supply through agile manufacturing. *Integrated Manufacturing Systems*, 12(7), 524-533.

Meadows, D. and J. Robinson (1985). *The Electronic Oracle. Computer Models and Social Decisions.* Chichester: John Wiley & Sons.

Mentzer, J. and Kahn, K., (1995). A framework of logistics research. *Journal of Business Logistics,* 16 (1), 231–50.

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), 1–25.

Monden, Y. (1993). *Toyota production system.* 2nd ed. Norcross, Georgia: *Industrial Engineering and Management Press*.

Morrison, J. B. (2010). Managing the Dynamics of Process Improvement: Production, Improvement, and Learning. In Proceedings of the 28th International Conference of the System Dynamics Society. *System Dynamics Society*.

Min, H. and Zhou, G. (2002). Supply chain modeling: past, present and future. *Computers & Industrial Engineering*, 43(1-2), 231-249.

Minegishi, S. and Thiel, D. (2000). System dynamics modeling and simulation of a particular food supply chain. *Simulation Practice and Theory*, 8(5), 321-339.

Mingers, J. (2000). The Contribution of Critical Realism as an Underpinning Philosophy for OR/MS and Systems. *The Journal of the Operational Research Society*, 51(11), 1256– 1270.

Mingers, J. and J. Rosenhead (2001). Rational Analysis for a Problematic World Revisited. Problem Structuring Methods for Complexity, Uncertainty and Conflict (2nd ed.)., Chapter An Overview of Related Methods: *VSM, System Dynamics, and Decision Analysis*, pp. 267–288. Chichester: John Wiley and Sons, Ltd.

Mingers, J. (2004a). Critical realism and information systems: brief responses to Monod and Klein. *Information and Organisation* 14, 145–153. 28

Mingers, J. (2004b). Realizing information systems: critical realism as an underpinning philosophy for information systems. *Information and Organization* 14, 87–103.

Minnich, D. and Maier, F.H. (2007) Responsiveness and efficiency of pull based and push based planning systems in the high-tech electronics industry. In: *Online Proceedings of the 50th International Conference of the System Dynamics Society,* Boston, Massachusetts, USA, July 29- August 2 2007.

Morecroft, J.D.W. (1980). An evaluation of materials requirements planning using industrial dynamics. *Twelfth Annual Meeting of the American Institute of Decision Sciences.*

Morecroft, J. (1985). Rationality in the Analysis of Behavioural Simulation Models. *Management Science*, 31(7), 900-916.

Nag, R., Hambrick, D. and Chen, M. (2007). What is strategic management, really? Inductive derivation of a consensus definition of the field. *Strategic Management Journal*, 28(9), 935-955.

Nagaraja, C., Thavaneswaran, A. and Appadoo, S. (2015). Measuring the bullwhip effect for supply chains with seasonal demand components. *European Journal of Operational Research*, 242(2), 445-454.

Naim, M., Spiegler, V., Wikner, J. and Towill, D. (2017). Identifying the causes of the bullwhip effect by exploiting control block diagram manipulation with analogical reasoning. *European Journal of Operational Research*, 263(1), 240-246.

Naim, M., Wikner, J. and Grubbström, R. (2007). A net present value assessment of make-to-order and make-to-stock manufacturing systems. *Omega*, 35(5), 524-532.

Negahban, A. and Smith, J. (2016). The effect of supply and demand uncertainties on the optimal production and sales plans for new products. *International Journal of Production Research*, 54(13), 3852-3869.

Neubacher, D. (2012). System Dynamics as Tool for Strategic Decision Making with Enterprises, *Diploma Thesis*, Graz University of Technology.

Ng, T., Sy, C. and Lee, L. (2012). Robust parameter design for system dynamics models: a formal approach based on goal-seeking behaviour. *System Dynamics Review*, 28(3), 230-254.

Noblesse, A. M., Boute, R. N., Lambrecht, M. R., and Houdt, B. (2014). Characterizing order processes of continuous revie *(s, S)* and *(r, nQ)* policies. *European Journal of Operational Research*, 236, 534-547.

Nozick, L. and Turnquist, M. (2001). Inventory, transportation, service quality and the location of distribution centers. *European Journal of Operational Research*, 129(2), 362-371.

Ohno, T. (1988). Toyota production system: beyond large scale production. Portland: *OR productivity press.*

Olhager, J. and Östlund, B. (1990). An integrated push-pull manufacturing strategy. *European Journal of Operational Research*, 45(2-3), 135-142.

Oliva, R. (2003). Model calibration as a testing strategy for system dynamics models. *European Journal of Operational Research*, 151(3), 552-568.

Ouyang, Y. and Li, X. (2010). The bullwhip effect in supply chain networks. *European Journal of Operational Research*, 201(3), 799-810.

Özbayrak, M., Papadopoulou, T. and Akgun, M. (2007). Systems dynamics modelling of a manufacturing supply chain system. *Simulation Modelling Practice and Theory*, 15(10), 1338-1355.

Paich, M., Peck, C. and Valant, J. (2011). Pharmaceutical market dynamics and strategic planning: a system dynamics perspective. *System Dynamics Review*, 27(1), 47-63.

Panov, S.A. and Shiryaev, V. I. (2003). Manufacturing supply chain adaptive management under changing demand conditions. In: *The Online Proceedings of the 21st International Conference of the System Dynamics Society,* 2003, New York City, New York.

Patton, M.Q., 2002. Qualitative research and evaluation methods. *3rd London: Sage*.

Perry, C. (1998). Processes of case study methodology for postgraduate research in marketing. *European Journal of Marketing*, 32(9), 785-802.

Perry, C. and Coote, L. (1994), Process of a case study research methodology; Tool for Management Development, *Proceedings of Australian and New Zealand Association for Management ANZAM Conference*, December, Victoria University of Wellington, New Zealand.

Persson, F. and Olhager, J. (2002) Performance simulation of supply chain design. *International Journal of Production Economics, (*77), 231-245.

Peterson, D. and Eberlein, R. (1994). Reality check: A bridge between systems thinking and system dynamics. *System Dynamics Review*, 10(2-3), pp.159-174.

Petrovic, D. (2001). Simulation of supply chain behaviour and performance in an uncertain environment. *International Journal of Production Economics*, 71(1-3), pp.429-438.

Petrovic, R. and Petrovic, D. (2001). Multicriteria ranking of inventory replenishment policies in the presence of uncertainty in customer demand. *International Journal of Production Economics*, 71(1-3), pp.439-446.

Poles, R. (2010). System Dynamics Modelling of Closed Loop Supply Chain System for Evaluating System Improvement Strategies, *PhD Thesis, RMIT University*.

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.

Politou, A. and Georgiadis, P. (2008). Production planning and control in flow shop operations using drum buffer rope methodology: a system dynamics approach. In: *The Online Proceedings of the 26th International Conference of the System Dynamics Society,* 2008, Athens, Greece.

Ponte, B., Wang, X., de la Fuente, D. and Disney, S. (2016). Exploring nonlinear supply chains: the dynamics of capacity constraints. *International Journal of Production Research*, 55(14), pp.4053-4067.

Poornikoo, M. (2017). Fuzzy Logic Decision Making in Supply Chain Systems; an Approach to Mitigate the Bullwhip Effect, *PhD Thesis, University of Bergen*.

Poornikoo, M. and Qureshi, M. (2019). System dynamics modelling with fuzzy logic application to mitigate the bullwhip effect in supply chains. *Journal of Modelling in Management*, pp.610-627

Potter, A. and Lalwani, C. (2008). Investigating the impact of demand amplification on freight transport. *Transportation Research Part E: Logistics and Transportation Review*, 44(5), pp.835-846.

Prasad P.S.S, and Shankhar C., (2011). Cost optimization of supply chain networks using Ant Colony Optimization, *International Journal of Logistics systems and management*, 9 (2).

Pruyt, E. (2006). What is System Dynamics? A Paradigmatic Inquiry, Universiteit Brussel, Business School Solvay (Internet). *Available from 2006 July (cited 2019 October 15)*; pp1-29 http://www.researchgate.net/publication/228925617

Pyke, D. and Cohen, M. (1990). Push and pull in manufacturing and distribution systems. *Journal of Operations Management*, 9(1), pp.24-43.

Pyke, D. and Cohen, M. (1993). Performance characteristics of stochastic integrated production-distribution systems. *European Journal of Operational Research*, 68(1), pp.23-48.

Richardson, G. (2011). Reflections on the foundations of system dynamics. *System Dynamics Review*, 27(3), pp.219-243.

Richmond, B. (1993). Systems thinking: Critical thinking skills for the 1990s and beyond. *System Dynamics Review*, 9(2), pp.113-133.

Riddalls, C. and Bennett, S. (2002). The stability of supply chains. *International Journal of Production Research*, 40(2), pp.459-475.

Romano, C. (1989), Research strategies for small business: a case study, *International Business Journal* 7(4), p35-43.

Rodríguez-Ulloa, R and Paucar-Caceres, A. (2005). Soft system dynamics methodology (SSDM): A Combination of soft systems methodology (SSM) and System Dynamics (SD). *System Practice and Action Research*, pp 1-36.

Saleh, M., Oliva, R., Kampmann, C. and Davidsen, P. (2010). A comprehensive analytical approach for policy analysis of system dynamics models. *European Journal of Operational Research*, 203(3), pp.673-683.

Sandberg, M. (2011). Soft Power, World System Dynamics, and Democratization: A Bass Model of Democracy Diffusion 1800-2000. *Journal of Artificial Societies and Social Simulation*, 14(1).

Sargent, R. G. (2005). Verification and validation of simulation models. In Proceedings of the 37th conference on winter simulation, WSC '05, pages 130-143. *Winter Simulation Conference.*

Sarmiento, A.T. (2010). A Methodology to Stabilize the Supply Chain, PhD Thesis, University of Central Florida.

Saunders, M.N.K., Lewis, P. and Thornhill, A., (2009). *Research Methods for Business Students*. 5th Harlow, England: Pearson Education Limited.

Sayer, A., (2000). *Realism and Social Science*. 1st London: Sage.

Schieritz, N. and Milling, P. M. (2003). Modeling the Forest or Modeling the Trees: A Comparison of System Dynamics and Agent-Based Simulation. *In Proceedings of the 21st International Conference of the System Dynamics Society*. System Dynamics Society.

Senge, P. (2006). The Fifth Discipline: The Art and Practice of the Learning Organization. *Doubleday/Currency*.

Shapiro, J.F. (2000). Modelling the Supply Chain. *South-Western College Pub*, Illustrated Ed.

Sheffi, Y., (2005b). Building a Resilient Supply Chain. *Harvard Business Review*, 1 (8), 1–5.

Shin, K. H., Kwon, I., Lee, J., and Kim, C.O. (2010). Performance trajectory-based optimised supply chain dynamics. *International Journal of Computer Integrated Manufacturing*, (23)1, pp.87-100

Sidwell A.C. (1982), A critical study of project team organizational forms within the building process. PhD thesis, *Department of Construction and Environmental Health*, University of Aston in Birmingham.

Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2002). Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies. *New York, NY: McGraw-Hill*.

Simchi-Levi, D. and Zhao, Y. (2005). Safety Stock Positioning in Supply Chains with Stochastic Lead Times. *Manufacturing & Service Operations Management*, 7(4), pp.295-318.

Sipahi, R. and Delice, I. (2010). Stability of inventory dynamics in supply chains with three delays. *International Journal of Production Economics*, 123(1), pp.107-117.

Soshko, O., Vjakse, V. and Merkuryev, Y. (2010). Modelling inventory management system at Distribution Company: case study, *Scientific Journal of Riga Technical University: Computer Sciences*, Vol. 42, No. 1, pp.87–93.

Spearman, M. and Zazanis, M. (1992). Push and Pull Production Systems: Issues and Comparisons. *Operations Research*, 40(3), pp.521-532.

Spengler, T. and Schröter, M. (2003). Strategic Management of Spare Parts in Closed-Loop Supply Chains—A System Dynamics Approach. *Interfaces*, 33(6), pp.7-17.

Spiegler, V. and Naim, M. (2017). Investigating sustained oscillations in nonlinear production and inventory control models. *European Journal of Operational Research*, 261(2), pp.572-583.

Spiegler, V. L. 2013. Designing supply chains resilient to nonlinear system dynamics, *PhD thesis, Cardiff University*.

Sprague, L. and Callarman, T. (2010). Supply Chain Management is not a Beer Game. *Journal of Supply Chain Management*, 46(1), pp.9-11.

Steckel, J. H., Grupta, S., and Banerji, A. (2004). Supply chain decision making: will shorter cycle times and shared point-of-sale information necessarily help? *Management Science*, 50(4), 458-464.

Sterman, J. (1989). Misperceptions of feedback in dynamic decision making. *Organizational Behavior and Human Decision Processes*, 43(3), pp.301-335.

Sterman, J. (1989). Modelling Managerial Behaviour: Misperceptions of Feedback in a Dynamic Decision Making Experiment. *Management Science*, 35(3), pp.321-339.

Sterman, J. (1994). Learning in and about complex systems. *System Dynamics Review*, 10(2-3), pp.291-330.

Sterman, J., Repenning, N. and Kofman, F. (1997). Unanticipated Side Effects of Successful Quality Programs: Exploring a Paradox of Organizational Improvement. *Management Science*, 43(4), pp.503-521.

Sterman, J. D. (2000). Business dynamics - systems thinking and modelling: for a complex world. *McGraw-Hill Higher Education*.

Stevens, G. (1989). Integrating the Supply Chain. *International Journal of Physical Distribution & Materials Management*, 19(8), pp.3-8.

Suck. E, (2009). The bullwhip effect in supply chains- An overestimated problem? *International Journal of Production Economics*, 118, 311-322.

Suryani, E., Chou, S. and Chen, C. (2010). Air passenger demand forecasting and passenger terminal capacity expansion: A system dynamics framework. *Expert Systems with Applications*, 37(3), pp.2324-2339.

Swaminathan M. and C. Tayur (1999). "Stochastic programming models for managing product variety," Quantitative Models for Supply Chain Management, *Kluwer Academic Publishers*, Boston, 585–622.

Schwaninger, M. and Groessser, S. (2009). System dynamics modelling: validation for quality assurance, in: Meyers, R. A. Encyclopaedia of Complexity & Systems Science. *Springer*, New York, USA.

Takahashi, K. and Nakamura, N. (2004). Push, pull, or hybrid control in supply chain management. *International Journal of Computer Integrated Manufacturing*, 17(2), pp.126-140.

Talluri, S. (2000). An IT/IS acquisition and justification model for supply-chain management. *International Journal of Physical Distribution & Logistics Management*, 30(3/4), pp.221-237.

Taylor, M. (2016). A Critical Evaluation of Empirical Non-Linear Control System and System Dynamics Modeling Theories for Mitigating Risks Arising From Bullwhip Effect. *International Journal of Management & Information Systems (IJMIS)*, 20(1), p.1.

Thiel, D. (1996) Instabilities and deterministic chaos in Just in Time production systems: comparison between neural networks simulation and continuous simulation. . In: *The Online Proceedings of the 14 the International Conference of the System Dynamics Society,* 1996, Cambridge, Massachusetts.

Thomas, A.B., (2004). Research Skills for management studies. *1st London: Routledge*.

Torres, O. and Maltz, A. (2010). Understanding the Financial Consequences of the Bullwhip Effect in a Multi-Echelon Supply Chain. *Journal of Business Logistics*, 31(1), pp.23-41.

Towill, D.R., (1991). Supply chain dynamics. *International Journal of Computer Integrated Manufacturing*, 4 (4), 197–208.

Towill, D. (1996). Time compression and supply chain management - a guided tour. Supply Chain Management: *An International Journal*, 1(1), pp.15-27.

Towill, D. (1997). FORRIDGE - Principles of good practice in material flow. *Production Planning & Control*, 8(7), pp.622-632.

Towill, D. (1997). The seamless supply chain - the predator's strategic advantage. *International Journal of Technology Management*, 13(1), p.37.

Towill, D. (1982). Dynamic analysis of an inventory and order based production control system. *International Journal of Production Research*, 20(6), pp.671-687.

Towill, D. (1991). Supply chain dynamics. *International Journal of Computer Integrated Manufacturing*, 4(4), pp.197-208.

Towill, D., Naim, 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.

Usano, R. R., Marquez, A.C., and Torres, J. M. F. (1995). Advanced manufacturing system dynamics: The lean production approach. In: *The Proceedings of the 13 the International Conference of the System Dynamics Society,* 1995, Tokyo.

Van Ackere, A., Larsen, E.R., Morecroft, J.D.W., (1993). Systems thinking and business process redesign: an application to the Beer Game. *European Management Journal,* 11 (4): 412–423.

Venkateswaran, J. (2005). Production and Distribution Planning for Dynamic Supply Chains using Multi-Resolution Hybrid Models, *PhD Thesis*, University of Arizona.

Vensim, (2007). User's Guide Version 5. Ventana Simulation Environment, *Ventana Systems, Inc.*

Vennix, J. A. (1996). Group model building: Facilitating team learning using system dynamics, *Wiley Chichester*.

Villegas, F. and Smith, N. (2006). Supply chain dynamics: analysis of inventory vs. order oscillations trade-off. *International Journal of Production Research*, 44(6), pp.1037-1054.

Vosniadou, S. and Brewer, W. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24(4), pp.535-585.

Vrat, P. (2014). Basic concepts in inventory management, Materials Management, *Springer* pp.21–36.

Walker, D. T. (1994), An Investigation Into Factors That Determine Building Construction Time Performance, *PhD Thesis*, *Department Of Building And Construction Economics, Royal Melbourne Institute Of Technology*, Australia.

Wang, W. and Cheong, F. (2005). A framework for the system dynamics (SD) modelling of the mobile commerce market. In ModSim05 (International Congress on Modelling and Simulation 2005): Advances and Applications for Management and Decision Making, *Modelling and Simulation Society of Australia and New Zealand*. 1787-1793.

Wang, N., Fang, X., Gou, Q. and Liang, L. (2016). Supply chain performance under pull or push contracts in the presence of a market disruption. *International Transactions in Operational Research*, 24(4), pp.713-736.

Wang, X., Disney, S. and Wang, J. (2012). Stability analysis of constrained inventory systems with transportation delay. *European Journal of Operational Research*, 223(1), pp.86-95.

Wang, X., Disney, S. and Wang, J. (2014). Exploring the oscillatory dynamics of a forbidden returns inventory system. *International Journal of Production Economics*, 147, pp.3-12.

Wang, X. and Disney, S. (2016). The bullwhip effect: Progress, trends and directions. European, *Journal of Operational Research*, 250, pp.691-701.

Wang, Z., Wang, X. and Ouyang, Y. (2015). Bounded growth of the bullwhip effect under a class of nonlinear ordering policies. *European Journal of Operational Research*, 247(1), pp.72-82.

Wanphanich, P. (2008). A simulation Model for Quantity and Reducing the Bullwhip Effect, *PhD Thesis*, University of New South Wales.

Wanphanich, P., Kara, S., and Kayis, B. (2010). Analysis of the bullwhip effect in multi-product, multi-staged supply chain systems- a simulation approach. *International Journal of Production Research*, 48(15), 4501-4517.

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.

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.

Warburton, R., Disney, S., Towill, D. and Hodgson, J. (2004). Technical Note: Further insights into ‘the stability of supply chains’. *International Journal of Production Research*, 42(3), pp.639-648.

Wee, H., Peng, S., Yang, C. and Wee, P. (2014). The Influence of Production Management Practices and Systems on Business Performance: From the Perspective of the Push-pull Production Systems. *Operations and Supply Chain Management*, 2(1), pp. 11-23.

Wei, Y., Wang, H. and Qi, C. (2013). On the stability and bullwhip effect of a production and inventory control system. *International Journal of Production Research*, 51(1), pp.154-171.

West, K.D. (1986). A variance bounds test of the linear quadratic inventory model. *Journal of Political Economy,* 94(2), 374-401.

Wieland, B., Mastrantonio, P., Willems, S. and Kempf, K. (2012). Optimizing Inventory Levels within Intel's Channel Supply Demand Operations. *Interfaces*, 42(6), pp.517-527.

Wikner, J. (2003). Continuous-time dynamic modelling of variable lead times. *International Journal of Production Research*, 41(12), pp.2787-2798.

Wikner, J. (2014). On decoupling points and decoupling zones. *Production & Manufacturing Research*, 2(1), pp.167-215.

Wikner, J. and Noroozi, S. (2016). A modularised typology for flow design based on decoupling points – a holistic view on process industries and discrete manufacturing industries. *Production Planning & Control*, 27(16), pp.1344-1355.

Wikner, J., Naim, M., Spiegler, V. and Lin, J. (2017). IOBPCS based models and decoupling thinking. *International Journal of Production Economics*, 194, pp.153-166.

Wikner, J., Towill, D. and Naim, M. (1991). Smoothing supply chain dynamics. *International Journal of Production Economics*, 22(3), pp.231-248.

Wikner, J., Yang, B., Yang, Y. and Williams, S. (2017). Decoupling thinking in service operations: a case in healthcare delivery system design. *Production Planning & Control*, 28(5), pp.387-397.

Williams, T., 2008. Management Science in Practice. *West Sussex: John Wiley*

Winston, W. (1994). Operations Research, Applications and Algorithms (3rd ed.). USA: *Duxbury Press*.

Wolf, J., (2008). The nature of supply chain management research. *Frankfurt: GablerVerlag*.

Wolstenholme, E. F. (1990). System enquiry: a system dynamics approach, *John Wiley & Sons, Inc.*

Wolstenholme, E. (1999). Qualitative vs quantitative modelling: the evolving balance. *Journal of the Operational Research Society* 50 (4), 422–428.

Wolstenholme, E. (1997). System dynamics in the elevator (sd1163). e-mail communication. system-dynamics@world.std.com.

Wright, D., and Yuan, X. (2008). Mitigating the bullwhip effect by ordering policies and forecasting methods. *International Journal of Production Economics*, 113(2), 587-597.

Wu, K., Tseng, M., Chiu, A. and Lim, M. (2017). Achieving competitive advantage through supply chain agility under uncertainty: A novel multi-criteria decision-making structure. *International Journal of Production Economics*, 190, pp.96-107.

Yamashina, H. (1987). Proceedings of the Second International Conference on Just-in-Time, *IPS, Bedford*.

Yan, M.R. (2009). The Market Competitive Behaviour in the Project-based Industries. In Proceedings of the 27th International Conference of the System Dynamics Society. *System Dynamics Society.*

Yang, T. and Fan, W. (2014). Information management strategies and supply chain performance under demand disruptions. *International Journal of Production Research*, 54(1), pp.8-27.

Yaşarcan, H. (2003). Feedback, Delays and non-linearities in Decision Structures, *PhD Thesis, Boğaziçi University.*

Yim, N., Kim, S., Kim, H. and Kwahk, K. (2004). Knowledge based decision making on higher level strategic concerns: system dynamics approach. *Expert Systems with Applications*, 27(1), pp.143-158.

Yin, R., (1984), Case Study Research: Design and Methods (Second Edition), *Sage, Beverly Hills, CA*.

Yin, R.K. (2009), Case Study Research – Design and Methods (4th Ed.), *Sage Publication*.

Zahn, E., Dillerup, R. and Schmid, U. (1998). Strategic evaluation of flexible assembly systems on the basis of hard and soft decision criteria. *System Dynamics Review*, 14(4), pp.263-284.

Zapata, G.E.P. and Marquez, A.C. (2003) A qualitative analysis of push and pull models. In: *The Proceedings of the Twenty-first International Conference of the System Dynamics Society,* July 20-24 2003.

Zemzam, A., Maataoui, M.E., Hlyal, M., Alami, J.E., and Alami, N.E. (2017). Inventory management of supply chain with robust control theory: literature review. *International Journal of Logistics Systems and Management*, 27(4), 438-465.

Zhang, X. (2004a). The impact of forecasting methods on the bullwhip effect. *International Journal of Production Economics*, 88, pp.15-27.

Zhao, X., Xie, J. and Leung, J. (2002). The impact of forecasting model selection on the value of information sharing in a supply chain. *European Journal of Operational Research*, 142(2), pp.321-344.

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.

Zhou, L., Naim, M. and Disney, S. (2017). The impact of product returns and remanufacturing uncertainties on the dynamic performance of a multi-echelon closed-loop supply chain. *International Journal of Production Economics*, 183, pp.487-50

AppendixA Equations

The equations used for the push and hybrid push/pull SD models have originated from Sterman 2000 with some modifications. However, more equations have been added for performance measurement (financial performance) for analysis purpose and policy recommendations.

Equations for Push Model:

Adjusted Unit Price: The adjusted unit price (AUP) specifies that the prices are adjusted by the company in regards to the differences in customers and situations.

Units: NGN/Units

Average Dwell Time: The average dwell time (ADT) indicates the time it takes for the distributor to fulfil dealer order.

ZIDZ (Distributor Inventory, Dealer Order Fulfilment Rate)

Units: Week

Cash Balance: The cash balance (CB) represents the amount of money owned by the company or has in its bank account.

INTEG (Sales Revenue-Total Cost)

Units: NGN

Customer Demand: Customer demand (CD) which is the only and main exogenous variable. The customer demand rate in this study has been used to input the different customer demand patterns, which includes business as usual, optimistic and pessimistic demand.

Demand Cycles (Time)

Units: Units/Week

Dealer Adjustment Time: The dealer adjustment time (DAT) indicates the time or period the dealer adjust his/her inventory to get their inventory in balance with the company's desired level.

Units: Week

Dealer Inventory: The level of dealer inventory (DI) is the number or vehicles ready for sales to fulfil their customer requirement and it is increased by dealer order fulfilment rate.

INTEG (Dealer Order Fulfilment Rate-Sales Rate, Desired Dealer Inventory)

Units: Units

Dealer Inventory Adjustment: The desired distributor order is adjusted by the distributor either above or below the forecast centred on the inventory position and needs of customer. I.e. When desired dealer inventory > dealer inventory, desired distributor order is increased (and vice versa). Dealer inventory gaps are corrected over the dealer adjustment time.

(Desired Dealer Inventory-Dealer Inventory)/Dealer Adjustment Time

Units: Units/Week

Dealer Order Fulfilment Cycle Time: The DOFCT indicates the average delay between the start of order and the final completion of order or fulfilment of order.

Units: Week

Dealer Order Fulfilment Rate: Dealer order fulfilment rate (DOFR) represents a third order delay of the distributor order fulfilment rate and the delay time is determined by the dealer order fulfilment cycle time (DOFCT).

DELAY3 (Distributor Order Fulfilment Rate, Dealer Order Fulfilment Cycle Time)

Units: Units/Week

Dealer Safety Stock Coverage: Safety stocks coverage (SSC) represents the number of weeks the dealer would like to maintain in their stock or warehouse that is over and above the company's normal sales processing time. In order word, the safety stocks coverage (SSC) guards against any possibility of unforeseen variations or uncertainty in customer demand that may cause sales to fall below orders and ultimately cause loss of sales.

Units: Week

Demand Cycles: the demand cycles (DC) represents a downward and/or upward flow of gross domestic product (GDP) in the company around its long-term growth trend. It also represents the customer demand behaviour over a period of time. The demand cycle in this study has been used to project and analyse the effect of customer demand on the company's inventory level.

Units: Units/Week

Desired Dealer Inventory: The desired dealer coverage (DDI) is determined by the dealer. The dealer maintains a certain coverage of quantity of stocks, estimated by the customer demand forecast.

Expected Customer Demand * Desired Dealer Inventory Coverage

Units: Units

Desired Dealer Inventory Coverage: The desired Dealer inventory coverage (DDIC) represents the number of weeks the dealer seeks to maintain inventory level determined by the demand forecast. This dealer inventory coverage is required by the company to sustain delivery reliability by buffering the dealer inventory against unforeseen discrepancies in customer demand. It contains the sales processing time (SPT) plus the safety stocks coverage (SSC).

Min Sales Processing Time + Dealer Safety Stock Coverage

Units: Week

Desired Distributor Inventory: The desired distributor coverage (DDI) is determined by the distributor. The distributor maintains a certain coverage of quantity of stocks, estimated by the customer demand forecast.

Dealer Order Fulfilment Cycle Time * Desired Distributor Order

Units: Units

Desired Distributor Order: Desired Distributor Order (DDO) represents the expected customer demand adjusted or corrected to bring the company's inventory in line with the target inventory level.

MAX (0, Expected Customer Demand + Dealer Inventory Adjustment)

Units: Units/Week

Desired Push Rate: The desired push rate (DPR) represents the quantity/volume of inventory that needs to be sent/pushed through the chain.

Units: Units/Week

Desired Sales Rate: The desired sales rate (DSR) equals the customer demand. The company has no backlog of unfilled orders as the unfilled orders are lost as customers seek another place to purchase.

Customer Demand Rate

Units: Units/Week

Distributor Inventory Adjustment Time: The distributor inventory adjustment time (DIAT) represent the time period in which the distributor brings or adjust their inventory to reduce any discrepancy in inventory level.

Units: Week

Distributor Indicated Order: The distributor indicated order (DIO) equals the desired rate of the distributor order fulfilment rate.

Distributor Inventory Adjustment + Desired Distributor Order

Units: Units/Week

Distributor Inventory: The level of distributor inventory (DI) is the number or vehicles ready for sales to fulfil their dealer requirement and it is increased by distributor order fulfilment rate.

INTEG (Distributor Order Fulfilment Rate - Dealer Order Fulfilment Rate)

Units: Units

Distributor Inventory Adjustment: The distributor adjustment time (DAT) indicates the time or period the distributor adjust his/her inventory to get their inventory in balance with the company's desired level. In order word, the distributor inventory adjustment amends distributor order fulfilment rate to keep the distributor inventory in line with the desired level.

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

Units: Units/Week

Distributor Order Fulfilment Rate: The distributor order fulfilment rate (DOFR) is the distributor indicated order rate, constrained or should be nonnegative.

MAX (0, Distributor Indicated Order)

Units: Units/Week

Expected Customer Demand: Expected customer demand (ECD) implies that there is a delay for the firm in forecasting or smoothing changes or gaps in actual demand when the dealer detects any discrepancy.

SMOOTH (Customer Demand Rate, Time to Average Customer Demand)

Units: Units/Week

Final Time: The final time (FT) the time final time period for the simulation. The final time for the simulation of case study A is 130 week and 110 weeks for case study B.

Units: Week

Initial Time: The initial time (IT) represents the initial simulation starting from week 0.

Units: Week

Inventory Carrying Cost: Inventory carrying cost (ICC) represents a certain percentage of the value of the company's inventory, and it also represents the cost the company incurs when they hold inventory in their warehouse.

Units: NGN/Week

Max Sales Rate: The maximum sales rate (MSR) represents the rate of sales the company can accomplish given their present inventory level and the company's minimum sales processing time.

Dealer Inventory/Min Sales Processing Time

Units: Units/Week

Min Sales Processing Time: The sales processing time (MSPT) represents the minimum time required by the dealer to process and sell their products to their customer.

Units: Week

Profit: Profit (P) represents the company financial benefit that is realized when the amount of revenue achieved from the company's sales of vehicles to customers is more than the expenses, costs, and taxes required to run the company.

Sales Revenue-Total Cost

Units: NGN

Sales Fulfilment Ratio: Sales fulfilment ratio (SFR) represents the ratio of the maximum to desired sales rate. Maximum sales ratio less than one show that sales are constrained below the desired level.

ZIDZ (Max Sales Rate, Desired Sales Rate)

Units: Dimensionless

Sales Price: The sales price (SP) represents the price of the vehicles that is being offered with or without discount to their customers.

Units: NGN/Week

Sales Rate: The sales rate (SR) represents the company's desired sales rate which is multiplied by the fractions of sales filled (the sales fulfilment ratio). Sales to customers can fall below desired sales when the possible sales rate fall below the desired rate, indicating that some stocks are unavailable causes loss of sales thereby loosing customer.

Desired Sales Rate * Sales Fulfilment Ratio

Units: Units/Week

Sales Revenue: The sales revenue (SR) represents the amount realized by the company from the sale of vehicles to customers.

Sales Rate * Sales Price

Units: NGN/Week

SAVEPER: The SAVEPER represents the frequency with which output is stored (0.5) for both case studies.

Units: Week

TIME STEP: The TIMESTEP represent the time step for the simulation (0.5) for both case studies.

Units: Week [0]

Total Cost: The total cost (TC) represents the economic measure that sums all expenses paid to purchase inventory, store inventory, carry inventory and other expenses incurred by the company before selling the product.

Unit Cost + (Inventory Carrying Cost*Dealer Inventory)

Units: NGN/Week

Total Dwell Time: The total dwell time (TDT) represents or determines the time for the dealer to finally fulfil their customer demand requirement.

ZIDZ (Dealer Inventory, Sales Rate)

Units: Week

Unit Cost: The unit cost (UC) represents the total expenditure incurred by the company to hold and sell one unit of vehicle to their customer.

Adjusted Unit Price * Dealer Order Fulfilment Rate

Units: NGN/Week

Equations for Hybrid Push/Pull Model:

Adjusted Unit Price: The adjusted unit price (AUP) specifies that the prices are adjusted by the company in regards to the differences in customers and situations.

Units: NGN/Units

Average Dwell Time: The average dwell time (ADT) indicates the time it takes for the distributor to fulfil dealer order.

ZIDZ (Distributor Inventory, Dealer Order Fulfilment Rate)

Units: Week

Cash Balance: The cash balance (CB) represents the amount of money owned by the company or has in its bank account.

INTEG (Sales Revenue-Total Cost)

Units: NGN

Customer Demand: Customer demand (CD) which is the only and main exogenous variable. The customer demand rate in this study has been used to input the different customer demand patterns, which includes business as usual, optimistic and pessimistic demand.

Demand Cycles (Time)

Units: Units/Week

Dealer Adjustment Time: The dealer adjustment time (DAT) indicates the time or period the dealer adjust his/her inventory to get their inventory in balance with the company's desired level.

Units: Week

Dealer Inventory: The level of dealer inventory (DI) is the number or vehicles ready for sales to fulfil their customer requirement and it is increased by dealer order fulfilment rate.

INTEG (Dealer Order Fulfilment Rate-Sales Rate, Desired Dealer Inventory)

Units: Units

Dealer Inventory Adjustment: The desired distributor order is adjusted by the distributor either above or below the forecast centred on the inventory position and needs of customer. I.e. When desired dealer inventory > dealer inventory, desired distributor order is increased (and vice versa). Dealer inventory gaps are corrected over the dealer adjustment time.

(Desired Dealer Inventory-Dealer Inventory)/Dealer Adjustment Time

Units: Units/Week

Dealer Order Fulfilment Cycle Time: The DOFCT indicates the average delay between the start of order and the final completion of order or fulfilment of order.

Units: Week

Dealer Order Fulfilment Rate: Dealer order fulfilment rate (DOFR) represents a third order delay of the distributor order fulfilment rate and the delay time is determined by the dealer order fulfilment cycle time (DOFCT).

DELAY3 (Distributor Order Fulfilment Rate, Dealer Order Fulfilment Cycle Time)

Units: Units/Week

Dealer Safety Stock Coverage: Safety stocks coverage (SSC) represents the number of weeks the dealer would like to maintain in their stock or warehouse that is over and above the company's normal sales processing time. In order word, the safety stocks coverage (SSC) guards against any possibility of unforeseen variations or uncertainty in customer demand that may cause sales to fall below orders and ultimately cause loss of sales.

Units: Week

Demand Cycles: the demand cycles (DC) represents a downward and/or upward flow of gross domestic product (GDP) in the company around its long-term growth trend. It also represents the customer demand behaviour over a period of time. The demand cycle in this study has been used to project and analyse the effect of customer demand on the company's inventory level.

Units: Units/Week

Desired Dealer Inventory: The desired dealer coverage (DDI) is determined by the dealer. The dealer maintains a certain coverage of quantity of stocks, estimated by the customer demand forecast.

Expected Customer Demand * Desired Dealer Inventory Coverage

Units: Units

Desired Dealer Inventory Coverage: The desired Dealer inventory coverage (DDIC) represents the number of weeks the dealer seeks to maintain inventory level determined by the demand forecast. This dealer inventory coverage is required by the company to sustain delivery reliability by buffering the dealer inventory against unforeseen discrepancies in customer demand. It contains the sales processing time (SPT) plus the safety stocks coverage (SSC).

Min Sales Processing Time + Dealer Safety Stock Coverage

Units: Week

Desired Distributor Inventory: The desired distributor coverage (DDI) is determined by the distributor. The distributor maintains a certain coverage of quantity of stocks, estimated by the customer demand forecast.

Dealer Order Fulfilment Cycle Time * Desired Distributor Order

Units: Units

Desired Distributor Order: Desired Distributor Order (DDO) represents the expected customer demand adjusted or corrected to bring the company's inventory in line with the target inventory level.

MAX (0, Expected Customer Demand + Dealer Inventory Adjustment)

Units: Units/Week

Desired Sales Rate: The desired sales rate (DSR) equals the customer demand. The company has no backlog of unfilled orders as the unfilled orders are lost as customers seek another place to purchase.

Customer Demand Rate

Units: Units/Week

Distributor Inventory Adjustment Time: The distributor inventory adjustment time (DIAT) represent the time period in which the distributor brings or adjust their inventory to reduce any discrepancy in inventory level.

Units: Week

Distributor Indicated Order: The distributor indicated order (DIO) equals the desired rate of the distributor order fulfilment rate.

Distributor Inventory Adjustment + Desired Distributor Order

Units: Units/Week

Distributor Inventory: The level of distributor inventory (DI) is the number or vehicles ready for sales to fulfil their dealer requirement and it is increased by distributor order fulfilment rate.

INTEG (Distributor Order Fulfilment Rate - Dealer Order Fulfilment Rate)

Units: Units

Distributor Inventory Adjustment: The distributor adjustment time (DAT) indicates the time or period the distributor adjust his/her inventory to get their inventory in balance with the company's desired level. In order word, the distributor inventory adjustment amends distributor order fulfilment rate to keep the distributor inventory in line with the desired level.

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

Units: Units/Week

Distributor Order Fulfilment Rate: The distributor order fulfilment rate (DOFR) is the distributor indicated order rate, constrained or should be nonnegative.

MAX (0, Distributor Indicated Order)

Units: Units/Week

Expected Customer Demand: Expected customer demand (ECD) implies that there is a delay for the firm in forecasting or smoothing changes or gaps in actual demand when the dealer detects any discrepancy.

SMOOTH (Customer Demand Rate, Time to Average Customer Demand)

Units: Units/Week

Final Time: The final time (FT) the time final time period for the simulation. The final time for the simulation of case study A is 130 week and 110 weeks for case study B.

Units: Week

Initial Time: The initial time (IT) represents the initial simulation starting from week 0.

Units: Week

Inventory Carrying Cost: Inventory carrying cost (ICC) represents a certain percentage of the value of the company's inventory, and it also represents the cost the company incurs when they hold inventory in their warehouse.

Units: NGN/Week

Max Sales Rate: The maximum sales rate (MSR) represents the rate of sales the company can accomplish given their present inventory level and the company's minimum sales processing time.

Dealer Inventory/Min Sales Processing Time

Units: Units/Week

Min Sales Processing Time: The sales processing time (MSPT) represents the minimum time required by the dealer to process and sell their products to their customer.

Units: Week

Profit: Profit (P) represents the company financial benefit that is realized when the amount of revenue achieved from the company's sales of vehicles to customers is more than the expenses, costs, and taxes required to run the company.

Sales Revenue-Total Cost

Units: NGN

Sales Fulfilment Ratio: Sales fulfilment ratio (SFR) represents the ratio of the maximum to desired sales rate. Maximum sales ratio less than one show that sales are constrained below the desired level.

ZIDZ (Max Sales Rate, Desired Sales Rate)

Units: Dimensionless

Sales Price: The sales price (SP) represents the price of the vehicles that is being offered with or without discount to their customers.

Units: NGN/Week

Sales Rate: The sales rate (SR) represents the company's desired sales rate which is multiplied by the fractions of sales filled (the sales fulfilment ratio). Sales to customers can fall below desired sales when the possible sales rate fall below the desired rate, indicating that some stocks are unavailable causes loss of sales thereby loosing customer.

Desired Sales Rate * Sales Fulfilment Ratio

Units: Units/Week

Sales Revenue: The sales revenue (SR) represents the amount realized by the company from the sale of vehicles to customers.

Sales Rate * Sales Price

Units: NGN/Week

SAVEPER: The SAVEPER represents the frequency with which output is stored (0.5) for both case studies.

Units: Week

TIME STEP: The TIMESTEP represent the time step for the simulation (0.5) for both case studies.

Units: Week [0]

Time to Average Customer Demand: The time to average customer demand (TACD) represents the time the company uses to smooth or adjust actual customer demand over a time period.

Units: Week

Total Cost: The total cost (TC) represents the economic measure that sums all expenses paid to purchase inventory, store inventory, carry inventory and other expenses incurred by the company before selling the product.

Unit Cost + (Inventory Carrying Cost*Dealer Inventory)

Units: NGN/Week

Total Dwell Time: The total dwell time (TDT) represents or determines the time for the dealer to finally fulfil their customer demand requirement.

ZIDZ (Dealer Inventory, Sales Rate)

Units: Week

Unit Cost: The unit cost (UC) represents the total expenditure incurred by the company to hold and sell one unit of vehicle to their customer.

Adjusted Unit Price * Dealer Order Fulfilment Rate

Units: NGN/Week

AppendixB Data collection request

1. **Research Project Title:**

   Using system dynamics modelling to enable supply chain collaboration in an automotive supply chain.

2. **Research Interview Invitation**

   You are being asked to take part in a research study on inventory management and financial performance in your company automotive supply chain. Before deciding whether or not to participate, you should understand the reason for undertaking this research and what this research would involve. If you need me to further clarify anything or you would need more information, please don't hesitate to ask me. Your involvement is completely voluntary.

3. **What is the aim of this research?**

   The main aim of this research is to study downstream automotive supply chain management in the context of improving supply chain financial performance in automotive supply chain in Nigeria.

4. **Why have I been selected for this research?**

   You have been chosen because we believe that you have the right expertise and experience of automotive dealership supply chain here in Nigeria. We also believe that the findings from this will have useful influences for automotive supply chain which you might be interested in.

5. **Do I have to be involved for this research?**

   No. it is up to you to decide whether or not you want to participate in this study. Your involvement is entirely voluntary.

6. What will happen to me if I am involved?

If you choose to take part in this study, we will be asking for your opinion on automotive supply chain processes through interview, which will last about an hour. There are not any right or wrong answers because we just want to hear about your opinion.

7. What are the benefits of participating for this research?

By participating in this study you will help to improve our understanding of the automotive supply chain in Nigeria. You will have the opportunity to provide your expert opinion on current supply chain processes. The information we collect from you will contribute to the research findings about improving downstream automotive supply chain systems in Nigeria. If you are interested, we would be happy to provide you with a summary of research findings.

8. Will my participation in this research be kept confidential and will the company profile be kept confidential?

All information collected about you during the project will be kept strictly confidential. You will not be able to be identified in any reports or publications. Moreover, the name of your company will be anonymous so identifying you would be impossible.

9. Will I be recorded during the interview?

You will be recorded if you agree to be recorded using voice recorder and transcript can be provided if you wish.

10. Contact for further information

If you have any further questions, please do not hesitate to contact PhD student Jindu Chizea: Jindu.chizea@plymouth.ac.uk or stepo4real@yahoo.com. If you are dissatisfied how the research is carried out, please contact the Director of Studies in the first instance: jonathan.moizer@plymouth.ac.uk. If in your mind the problem is still unsolved please contact the faculty of business Research Ethics Committee: FOBResearch@plymouth.ac.uk.

AppendixC Interview Guide for Data Collection

The main focus of the interview is to gain an in-depth understanding of how the supply chain of the downstream automotive supply chain in Nigeria is managed. The interview will provide the researcher with the opportunity to explore every aspect of the company's supply chain, with the main objective of answering these questions. The company's relationship with channel partners and how inventory is managed in the company will also be investigated.

Grasping an overview of the company's supply chain;

- Can you provide a detailed account of the company supply chain?
- Do you have any system in place that guaranties that vehicles flow just the way you described?
- What is the flow of inventory like for imported vehicles?
- What are the source(s) of distribution and how does it get to your company?

Knowing the channel partners, why they exist, and the roles they play;

- Can you please mention who your key partners are?
- Can you explain as detailed as possible their roles and significance to your company?

Understanding how inventory is managed, ordered and forecasted in the supply chain;

- Can you describe the flow of inventory from the point of order to the point of fulfilling customer demand?
- What method and means by which inventory are transported to customers?
- Why do you think there is delay in flow of inventory and information from your partners?
- What method do you use in making orders and forecasts?
- How do you share order information with your partners?

- What measures do you have in place to counteract in case of delays?

Understanding how the supply chain delays can affect supply chain performance.

- At what point(s) of the supply chain do you realize that there would be delay of orders?
- In your opinion why do you think they are mostly detected as those point(s)?
- What measure(s) can be used at each point?
- What do you understand as supply chain delays?
- What level of collaboration do you have with your partners to reduce delays?
- What, in your opinion can be done to make the supply chain respond to uncertainties in customer demand?
- How can these changes affect your operations and how will your key partners react to these changes?
- What are the possible barriers to these changes?

AppendixD Ethical approval

RESEARCH WITH PLYMOUTH UNIVERSITY

Ref: FREC1617.54
Date: 7 August, 2017

Dear Jindu,

Ethical Approval Application No: FREC1617.54
Title: Using system dynamics modelling to enable supply chain collaboration in an automotive supply chain

The Faculty Research Ethics Committee, has considered the ethical approval form 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.

We would like to wish you good luck with your research project.

Yours sincerely

(Sent as email attachment)

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AppendixE Data Collected Table

Data Collected Table								
Category of Data	**Operational Definition**	**Model Equations**	**Unit**	**Type**	**Data Availability**	**Data Source**	**Data Quality**	**Notes Summary**
Profit (P)	Denote the amount of money made after costs have been incorporated (Revenues – Costs)	Total Sales-Sales Revenue	NGN	Auxiliary variable	Unknown	Company report	Data not found	This data is fact which is available in the company.
Dealer Inventory (DI)	Denote the current amount of inventory the dealer has in stock ready for shipment to customer	Dealer Order Fulfilment Rate-Sales Rate	Units	Stock variable	Fully available	Company report	Good	This data is fact which is available in the company.
Expected Customer Demand (ECD)	Stands as the value of the expected order rate in this model	(Changes in Demand Expectation, Expected Customer Demand)	Units	Stock variable	Equation	Data not required	Data not required	Non
Distributor Order Fulfilment Rate (DOFR)	Distributor order to replace expected outflow from the stock and reduce any discrepancy between the desired and actual stock	MAX(Distributor Target Inventory, Distributor Indicated Order)	Units/Week	Flow variable	Equation	Data not required	Data not required	Non

Dealer Order Fulfilment Rate (DOFR)	Dealership order's to replace expected sales from the stock and reduce any discrepancies between the desired and actual stock	DELAY3(Distributor Inventory, Dealer Order Fulfilment Cycle Time)	Units/Week	Flow variable	Equation	Data not required	Data not required	Non
Changes in Demand Expectation (CDE)	Denotes changes in incoming orders	(Customer Demand-Expected Customer Demand)/Time to Average Customer Demand	Units/Week	Flow variable	Equation	Data not required	Data not required	Non
Distributor Indicated Order (DIO)	The distributor indicated order is expressed as an anchoring and adjustment process	Desired Distributor Order + Distributor Inventory Adjustment	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Distributor Inventory Adjustment (DIA)	The distributor maintains an adequate inventory of unfilled orders by adjusting it so that ordering are closed to the desired state	(Desired Distributor Inventory-Distributor Inventory)/Distributor Adjustment Time	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Dealer Order Fulfilment Cycle Time (DOFCT)	Denotes the average transit time for all items aggregated together	Data Required	Week	Auxiliary variable	Equation	Company record	Good	This data is fact which is available in the company.
Dealer Inventory Adjustment (DIA)	The dealer try to maintain an adequate inventory of unfilled orders by adjusting it so that ordering are closed to the desired state	(Desired Inventory-Dealer Inventory)/Dealer Adjustment Time	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non

Max Sales Rate (MSR)	Denotes the company current inventory level and the minimum order fulfilment time	Dealer Inventory/Min Sales Processing Time	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Sales Fulfilment Ratio (SFR)	Denotes the function of the ratio of the maximum sales rate to the desired sales rate	(Max Sales Rate/Desired Sales Rate)	Dimensionless	Auxiliary variable	Equation	Data not required	Data not required	Non
Desired Sales Rate (DSR)	Indicates that the firm can sell what it wants or what it can sell	Customer Demand	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Min Sales Processing Time (MSPT)	Indicates minimum order fulfilment time is determined by the firms order fulfilment process	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Distributor Adjustment Time (DAT)	Indicates the time it takes to correct the records of the distributor to bring them into agreement with the findings of the actual (physical) inventory from the desired	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	All these data are more or less facts which are available in the company.

Desired Distributor Inventory (DDI)	This variable provides a level of inventory to yield the desired rate of order given the current dealer order cycle time	Dealer Order Fulfilment Cycle Time*Desired Distributor Order	Units	Auxiliary variable	Equation	Data not required	Data not required	Non
Dealer Adjustment Time (DAT)	Indicates the time it takes to correct the records of the dealer to bring them into agreement with the findings of the actual (physical) inventory from the desired	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Desired Inventory (DI)	Indicates the preferred amount of inventory	Desired Inventory Coverage*Expected Customer Purchases	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Desired Inventory Coverage (DIC)	Denotes the preferred amount of time for which inventory is able to fulfil customer demand	Min Sales Processing Time + Safety Stock Coverage	Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Safety Stock Coverage (SSC)	(Also called buffer stock) is a level of extra stock (cars) in this model that is maintained to mitigate risks of stock out due to uncertainties in demand and sales	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.

Customer Demand (CD)	Is the percentage of customer orders satisfied from stock at hand and a measure of an inventory's ability to meet demand	Data Required	Vehicle	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Desired Distributor Order (DDO)	This is an anchor which is then adjusted by an amount designed to bring the distributor inventory of unfilled orders in line with its goal	MAX(0, Expected Customer Demand + Dealer Inventory Adjustment)	Units/Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Time to Average Customer Demand (TACD)	This is the time required, on average, for expectations to respond to change in actual conditions in this model	Data Required	Week	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Average Dwell Time (ADT)	Calculates the time it takes for the distributor to fulfil dealer order	Distributor Inventory/Dealer Order Fulfilment Rate	Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Total Dwell Time (TDT)	Determines the time it takes for the dealer to finally fulfil customer demand	Data Required	Week	Auxiliary variable	Equation	Data not required	Data not required	Non
Desired Push Rate (DPR)	The number of inventory push down the supply chain	Data Required	Unit/Week	Auxiliary variable	Available	Company report	Good	This data is fact which is available in the company.

Adjusted Unit Price (AUP)	Denotes the **cost of** the company's vehicles which may be **adjusted** up by adding the initial cash basis used to purchase the asset to the **costs** associated with increasing the value of the asset	Data Required	NGN	Auxiliary variable	Available	Company report	Average	This data is fact which is available in the company.
Unit Cost (UC)	Denotes the total expenditure incurred by the company to produce, store and sell one unit of vehicle.	Adjusted Unit Price	NGN	Auxiliary variable	Equation	Data not required	Data not required	Non
Inventory Cost (IC)	Denotes the cost of holding inventory	Distributor Unit Carrying Cost	NGN	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Sales Price (SP)	Denotes the price of the company's vehicles for sales.	Data Required	NGN	Auxiliary variable	Fully available	Company report	Good	This data is fact which is available in the company.
Sales Revenue (SR)	Denotes the income from sales of goods and services, minus the cost associated with things like returned or undeliverable merchandise	Sales Price*Sales Rate	NGN/Units	Flow variable	Equation	Data not required	Data not required	Non

Cash Balance (CB)	Denotes the amount of money the company has in the bank at a particular period	Sales Revenue-Total Sales	NGN	Stock variable	Equation	Data not required	Data not required	Non
Total Cost (TC)	Denotes the total expense incurred in reaching a particular level of output by the firm	Unit Cost+(Inventory Cost*Dealer Inventory)	NGN/Unit	Flow variable	Equation	Data not required	Data not required	Non
Distributor Inventory (DI)	Denotes the current amount of inventory the distributor has in stock ready for shipment to dealer	Distributor Order Fulfilment Rate-Dealer Order Fulfilment Rate	Units	Stock variable	Available	Company report	Good	This data is fact which is available in the company.

AppendixF Collected Data

Case study A sales Rate

Period	Sales	Simulated	St. Dev S	St. Dev F	Error	ABS Error	%Error	Sq. Error	ME	MAE	MAPE
Feb-16	108	106									
Apr-16	112	108	10.12296197	10.98892216	4	4	3.57%	16	0.4167	7.916667	7.41%
Jun-16	96	113	10.55146119	11.42133835	-17	17	17.71%	289	0.0909	8.272727	7.76%
Aug-16	98	93	11.05276601	11.96206124	5	5	5.10%	25	1.8	7.4	6.76%
Oct-16	113	99	10.54303351	12.56803706	14	14	12.39%	196	1.4444	7.666667	6.95%
Dec-16	99	116	9.96800437	11.7686023	-17	17	17.17%	289	-0.125	6.875	6.27%
Feb-17	95	96	10.65615181	11.51086443	-1	1	1.05%	1	2.2857	5.428571	4.71%
Apr-17	112	95	9.719886341	12.37509019	17	17	15.18%	289	2.8333	6.166667	5.32%
Jun-17	118	115	4.324349662	10.83820403	3	3	2.54%	9	0	4	3.35%
Aug-17	117	119	3.271085447	4.324349662	-2	2	1.71%	4	-0.75	4.25	3.55%
Oct-17	121	117	3.593976442	3.915780041	4	4	3.31%	16	-0.333	5	4.16%
Dec-17	125	122	3.511884584	4.509249753	3	3	2.40%	9	-2.5	5.5	4.59%
Feb-18	118	126	4.949747468	2.828427125	-8	8	6.78%	64	-8	8	6.78%

Alpha	R^2	MSE	RMSE	RMPSE	U^M	U^S	U^c
1.2							
	0.55	100.5833	10.029	9.29%	0.00548	0.0075	0.9927
	Mean	110.1538	109.62				

Case Study A Distributor Inventory

Period	Actual	Simulated	St. Dev A	St. Dev S	Error	ABS Error	%Error	Sq. Error	ME	MAE	MAPE
Feb-16	224	220									
Apr-16	217	224	7.1924105	6.148796	-7	7	3.23%	49	-1.583333	7.25	3.34%
Jun-16	225	216	7.3252366	6.4220265	9	9	4.00%	81	-1.090909	7.2727273	3.35%
Aug-16	228	226	7.6716716	6.5933851	2	2	0.88%	4	-2.1	7.1	3.29%
Oct-16	227	228	7.7466839	6.8443001	-1	1	0.44%	1	-2.555556	7.6666667	3.56%
Dec-16	214	227	7.2648316	6.8819409	-13	13	6.07%	169	-2.75	8.5	3.95%
Feb-17	226	213	6.541079	6.436503	13	13	5.75%	169	-1.285714	7.8571429	22.00%

Apr-17	219	227	7.0440789	5.7362672	-8	8	3.65%	64	-3.666667	7	3.29%
Jun-17	210	218	5.7850382	6.0221812	-8	8	3.81%	64	-2.8	6.8	3.22%
Aug-17	219	209	5.7706152	4.1593269	10	10	4.57%	100	-1.5	6.5	3.07%
Oct-17	215	220	6.448514	4.5	-5	5	2.33%	25	-5.333333	5.3333333	2.57%
Dec-17	215	215	6.350853	2.8867513	0	0	0.00%	0	-5.5	5.5	2.70%
Feb-18	204	215	7.7781746	0	-11	11	5.39%	121	-11	11	5.39%

Alpha	**R^2**	**MSE**	**RMSE**	**RMPSE**	**U^M**	**U^S**	**U^c**
1.1							
	0.22	70.58333333	8.401388774	3.75%	0.003053653	0.015430431	0.983025658

Case study A Dealer Inventory

Period	**Actual**	**Simulated**	**St. Dev A**	**St. Dev S**	**Error**	**ABS Error**	**%Error**	**Sq. Error**	**ME**	**MAE**	**MAPE**
Feb-16	144	142									
Apr-16	145	143	2.87339699	2.12735541	2	2	1.38%	4	0	2.6666667	1.88%

Jun-16	146	144	2.95803989	2.22076973	2	2	1.37%	4	-0.181818	2.7272727	1.92%
Aug-16	144	145	2.96647939	2.31595258	-1	1	0.69%	1	-0.4	2.8	1.98%
Oct-16	143	144	2.7968236	2.3570226	-1	1	0.70%	1	-0.333333	3	2.12%
Dec-16	146	143	2.82842712	2.23606798	3	3	2.05%	9	-0.25	3.25	2.30%
Feb-17	141	145	2.94897076	2.19983766	-4	4	2.84%	16	-0.714286	3.2857143	2.33%
Apr-17	138	142	2.37045304	2.26778684	-4	4	2.90%	16	-0.166667	3.1666667	2.25%
Jun-17	144	139	2.5819889	1.64316767	5	5	3.47%	25	0.6	3	2.12%
Aug-17	139	143	2.58843582	1.64316767	-4	4	2.88%	16	-0.5	2.5	1.78%
Oct-17	140	140	2.1602469	1.73205081	0	0	0.00%	0	0.6666667	2	1.42%
Dec-17	138	140	2.51661148	0.57735027	-2	2	1.45%	4	1	3	2.12%
Feb-18	143	139	3.53553391	0.70710678	4	4	2.80%	16	4	4	2.80%

Alpha	**R^2**	**MSE**	**RMSE**	**RMPSE**	**U^M**	**U^S**	**U^c**
0.7							
	0.26	9.3333333	3.0550505	2.12%	0.0275276	0.079933	0.9733337

Case Study B Sales Rate

Time	Sales	Simulated	St. Dev A	St. Dev S	Error	ABS Error	% Error	Sq. Error	ME	MAE	MAPE
Sep-16	17	18									
Nov-16	15	17	1.85292561	2.5927249	-2	2	13.33%	4	0.5556	2.5556	14.33%
Jan-17	20	14	1.93649167	2.7436796	6	6	30.00%	36	0.875	2.625	14.45%
Mar-17	19	22	1.68501802	2.9277002	-3	3	15.79%	9	0.1429	2.1429	12.23%
May-17	15	18	1.67616342	2.7688746	-3	3	20.00%	9	0.6667	2	11.64%
Jul-17	17	14	1.78885438	2.3380904	3	3	17.65%	9	1.4	1.8	9.97%
Sep-17	19	18	1.14017543	2.5884358	1	1	5.26%	1	1	1.5	8.05%
Nov-17	20	19	0.81649658	2.1602469	1	1	5.00%	1	1	1.6667	8.98%
Jan-18	19	20	1	2.6457513	-1	1	5.26%	1	1	2	10.96%
Mar-18	18	15	0.70710678	3.5355339	3	3	16.67%	9	3	3	16.67%

Alpha	R^2	MSE	RMSE	RMPSE	U^M	U^S	U^C

1.3							
	0.15	8.77777778	2.96273147	17.43%	0.01712663	0.06235097	0.9300541

Case Study B Distributor Inventory

Time	Actual	Simulated	St. Dev A	St. Dev S	Error	Abs Error	%Error	Sq-Error	ME	MAE	MAPE
Sep-16	52	50									
Nov-16	53	52	4.0055517	3.5730473	1	1	0.0188679	1	-0.777778	4.1111111	0.0847144
Jan-17	46	53	4.055175	3.7749172	-7	7	0.1521739	49	-1	4.5	0.0929452
Mar-17	46	47	3.8890873	3.8521793	-1	1	0.0217391	1	-0.142857	4.1428571	0.0844839
May-17	45	46	4.1403934	3.6968455	-1	1	0.0222222	1	0	4.6666667	0.0949414
Jul-17	48	45	4.445972	4.0207794	3	3	0.0625	9	0.2	5.4	0.1094852
Sep-17	44	48	4.6583259	4.3358967	-4	4	0.0909091	16	-0.5	6	0.1212315
Nov-17	55	44	5.3541261	4.4347116	11	11	0.2	121	0.6666667	6.6666667	0.131339
Jan-18	52	54	5.1316014	5.2915026	-2	2	0.0384615	4	-4.5	4.5	0.0970085
Mar-18	45	52	4.9497475	1.4142136	-7	7	0.1555556	49	-7	7	0.1555556

Alpha	R^2	MSE	RMSE	RMPSE	U^M	U^S	U^C
0.9							
	2.64%	27.888889	5.2809932	10.16%	0.0009465	0.006707	0.999269

Case Study B Dealer Inventory

Time	Actual	Simulated	St. Dev A	St. Dev S	Error	Abs Error	%Error	Sq. Error	ME	MAE	MAPE
Sep-16	33	32									
Nov-16	37	34	1.3333333	3.107339	3	3	8.11%	9	-0.222222	2.8888889	8.14%
Jan-17	36	39	1.2018504	3.0867099	-3	3	8.33%	9	-0.625	2.875	8.14%
Mar-17	34	34	1.069045	3.2486261	0	0	0.00%	0	-0.285714	2.8571429	8.11%
May-17	35	34	1.069045	3.1847853	1	1	2.86%	1	-0.333333	3.3333333	9.47%
Jul-17	34	36	1.0954451	3.4448028	-2	2	5.88%	4	-0.6	3.8	10.79%
Sep-17	35	32	1.2247449	3.7815341	3	3	8.57%	9	-0.25	4.25	12.01%
Nov-17	34	37	1.2583057	4.3588989	-3	3	8.82%	9	-1.333333	4.6666667	13.16%
Jan-18	37	32	1.5275252	4.5092498	5	5	13.51%	25	-0.5	5.5	15.33%
Mar-18	35	41	1.4142136	6.363961	-6	6	17.14%	36	-6	6	17.14%

Alpha	**R^2**	**MSE**	**RMSE**	**RMPSE**	**U^M**	**U^S**	**U^C**
1.8							
	0.00%	11.3333333	3.36650165	10.20%	0	0.27768495	0.73113858

Parameter data case study A

Parameter	Value
Distributor Adjustment Time	2
Dealer Adjustment Time	6
Dealer Order Fulfilment Cycle Time	8
Minimum Sales Processing Time	2
Safety Stock Coverage	3
Time to Average Customer Demand	6

Parameter data case study B

Parameter	Value
Distributor Adjustment Time	2
Dealer Adjustment Time	6
Dealer Order Fulfilment Cycle Time	8
Minimum Sales Processing Time	2
Safety Stock Coverage	3
Time to Average Customer Demand	6

Case Study A financial data

	Value (NGN)
Inventory carrying cost	20,000
Sales Price	8,300,000
Adjusted Unit Cost	3,500,000

Case study B financial data

	Value (NGN)
Inventory carrying cost	22,000
Sales Price	8,500,000
Adjusted Unit Cost	3,000,000