Modeling and Controlling of an Integrated Distribution Supply Chain: Simulation Based Shipment Consolidation Heuristics

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Abstract

Increasing competition due to market globalization, product diversity and technological breakthroughs stimulates independent firms to collaborate in a supply chain that allows them to gain mutual benefits. This requires collective knowledge of the coordination and integration mode, including the ability to synchronize interdependent processes, to integrate information systems and to cope with distributed learning.

The Integrated Supply Chain Problem (ISCP) is concerned with coordinating the supply chain tires from supplier, production, inventory and distribution delivery operations to meet customer demand with an objective to minimize the cost and maximize the supply chain service levels. In order to achieve high performance, supply chain functions must operate in an integrated and coordinated manner. Several challenging problems associated with integrated supply chain design are: (1) how to model and coordinate the supply chain business processes; (2) how to analyze the performance of an integrated supply chain network; and (3) how to evaluate the dynamic of the supply chain to obtain a comprehensive understanding of decision-making issues related to supply network configurations. These problems are most representative in the supply chain theory's research and applications.

A particular real life supply chain considered in this study involves multi echelon and multi level distribution supply chains, each echelon with its own inventory capacities and multi product types and classes. Optimally solving such an integrated problem is in general not easy due to its combinatorial nature, especially in a real life situation where a multitude of aspects and functions should be taken into consideration.

In this dissertation, the simulation based heuristics solution method was implemented to effectively solve this integrated problem. A complex real life simulation model for managing the flow of material, transportation, and information considering multi products multi echelon inventory levels and capacities in upstream and downstream supply chain locations supported by an efficient Distribution Requirements Planning model (DRP) was modeled and developed named (LDNST) involving several sequential optimization phases. In calibration phase (0), the allocation of facilities to customers in the supply chain utilizing Add / Drop heuristics were implemented, that results in minimizing total distance traveled and maximizing the covering percentage. Several essential distribution strategies such as order fulfillment policy and order picking principle were defined in this

phase. The results obtained in this phase were considered in further optimization solutions.

The transportation function was modelled on pair to pair shipments in which no vehicle routing decision was considered, such an assumption generates two types of transportation trips, the first being Full Truck Load trips (FTL) and the second type being Less Truck Load trips (LTL). Three integrated shipment consolidation heuristics were developed and integrated into the developed simulation model to handle the potential inefficiency of low utilization and high transportation cost incurred by the LTL.

The first consolidation heuristic considers a pure pull replenishment algorithm, the second is based on product clustering replenishments with a vendor managed inventory concept, and the last heuristic integrates the vendor managed inventory with advanced demand information to generate a new hybrid replenishment strategy. The main advantage of the latter strategy, over other approaches, is its ability to simultaneously optimize a lot of integrated and interrelated decisions for example, on the inventory and transportation operations without considering additional safety stock to improve the supply chain service levels.

Eight product inventory allocation and distribution strategies considering different safety stock levels were designed and established to be considered as main benchmark experiments examined against the above developed replenishment strategies; appropriate selected supply chain performance measures were collected from the simulation results to distinguish any trading off between the proposed distribution strategies.

Three supply chain network configurations were proposed: the first was a multi-echelon distribution system with an installation stock reorder policy; the second proposed configuration was Transshipment Point (TP) with a modified (s,S) inventory; and the last considered configuration was a Sub-TP, a special case from the second configuration. The results show that, depending on the structure of multi-echelon distribution systems and the service levels targets, both the echelon location with installation stock policy and advanced demand information replenishment strategy may be advantageous, and the impressive results and service level improvements bear this out.

Considering the complexity of modeling the real life supply chain, the results obtained in this thesis reveal that there are significant differences in performance measures, such as

activity based costs and network service levels. A supply chain network example is employed to substantiate the effectiveness of the proposed methodologies and algorithms.

Keywords: Integrated Supply Chain Network Design Configuration, Simulation, Shipment Consolidation, Vendor Managed Inventory, Safety Stock.

This Thesis is dedicated to

My Mother

My Wife

My Daughter

and to

My late Father

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I would like to thank my mother and my wife for their love and affection and will never forget the values they have instilled in me and I will always strive to make them proud.

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Thesis Notation and Abbreviations

Notation	Description
i	Number of production plants i=(1,2,3)
j	Number of plant central warehouses (P_CW) j=(1,2,3)
K	Number of regional logistic center hubs (DC) k=(1,2,3….24)
l	Number of end demand point (Retailers, Wholesalers) l= (1, 2, 3…)
m	Number of end demand point served directly from j ; $m \subseteq l$ m=(1,2,3,…..l)
t	Time period (day)
p	Number of products / items / SKU's p=(1,2,3,……..)
Q_{pijt}	Shipment size in pallet from i to j of product type (p) on period (t)
Q_{pjkt}	Shipment size in pallet from j to k of product type (p) on period (t)
Q_{pklt}	Shipment size in pallet from k to l of product type (p) on period (t)
Q_{pjmt}	Shipment size in pallet from j to m of product type (p) on period (t) (direct shipments)
C_{ij}	Unit transportation cost per pallet from I to j (euro / Pallet)
C_{jk}	Unit transportation cost per pallet from j to k (euro / Pallet)
C_{kl}	Unit transportation cost per pallet from k to l (euro / Pallet)
C_{jm}	Unit transportation cost per pallet from j to m (euro / Pallet)
$I^{k}_{All,t}$	Multi product aggregated inventory level at the end of the period t at location k
h^{k}_{t}	Inventory holding and carrying cost per unit pallet per period time (t)
A^{j}	Plant central warehouses ordering cost (euro / order)
A^{k}	Logistic center hubs ordering cost (euro / order)
O_{klt}	Number of daily shipping orders from logistic center hubs to end demand points at time period (t)
O_{jmt}	Number of daily direct shipping orders from plant central warehouses to end demand points at time period (t)
MP^{jm}	Number of direct shipping mixed pallet forms from j to m , $MP^{jm} \subset Q_{pjmt}$
FP^{jm}	Number of direct shipping full pallet forms from j to m

MP^{kl}	Number of shipping mixed pallet forms from k to l
FP^{kl}	Number of shipping fixed pallet forms from k to l
OPK^{j}	Number of manual order-picking cartons in location j
OPK^{k}	Number of manual order-picking cartons in location k
$OPKC^{k \text{ or } j}$	Carton order-picking unit cost (euro/carton)
MPC	Mixed pallet order-picking cost
FPC	Full pallet order-picking cost
Inc^{j}	Shipment receiving cost at location j
Inc^{k}	Shipment receiving cost at location k
$Outc^{j}$	Shipping cost at location j
$Outc^{k}$	Shipping cost at location k
s_{p}^{k}	Product (p) reorder level at location k (min level)
S_{p}^{k}	Product (p) order up to level at location k (Max level)
Q_{p}^{k}	Nominal replenishment size of product (p) at location k (S_{p}^{k} - s_{p}^{k})
ψ^{k}	List of product type stocked in location k
ψ_{pull}^{k}	Pull replenishments products list $\psi_{\text{pull}}^{k} \subseteq \psi^{k}$
ψ_{push}^{k}	Extra pushed replenishments product list
ψ_{Hybird}^{k}	Hybrid replenishments product list = $\psi_{pull}^{k} \cup \psi_{Push}^{k}$
Q_{pt}^{k}	Normal pull replenishment quantity of product (p) at time (t) for location k based on ψ_{pull}^{k} list, in full pallet form.
$Q\_Push_{pt}^{k}$	Extra push replenishment quantity of product (p) at time (t) for location k based on ψ_{push}^{k} list, in full pallet form.
d_{plt}^{k}	Individual demand of product (p) at time (t) from customer l to location k
D_{pt}^{k}	Aggregated demand of product (p) at time (t) to location k
$\overline{D}_{pt}^{k}$	Average aggregated demand of product class (p) during L1 lead time

σ_{pt}^{k}	Demand standard deviation of product (p)
SS	Product (p) safety stock
$C\psi_{t}^{jk}$	Consolidated list on time (t) at location j shipped to k
$C\psi_{t}^{kl}$	Consolidated list on time (t) at location k shipped to customer l
CQ_{t}^{jk}	Consolidated shipment size of product (p) on time (t) at location j shipped to k
CQ_{t}^{kl}	Consolidated shipment size at time (t) at location k shipped to customer l
$CQ_{new,t}^{jk}$	extra Pushed consolidated shipment size of product (p) on time (t) at location j shipped to k
$CQ_{pull,t}^{jk}$	Aggregated pull consolidated shipment size according to pure pull supply chain replenishment
$CQ_{Push,t}^{jk}$	Aggregated push consolidated shipment size according to proposed supply chain consolidation replenishment concept
$CQ_{hybird,t}^{jk}$	Aggregated new hybrid consolidated shipment size = $CQ_{pull,t}^{jk} + CQ_{Push,t}^{jk}$
I_{pt}^{k}	Inventory position of product (p) at time (t) in location k in pallets
$I_{new\,pt}^{k}$	Adjusted Inventory position of product (p) at time (t) in location k
B_{pt}^{k}	Backorder quantity of product (p) at time (t) in location k (Open Orders)
Q_{ip}^{FP}	Amount of units (SKU) from type (p) in standard production full pallet
Q_{lp}^{FP}	Amount of units (SKU) from type (p) in customer full pallet
β	Full pallet largest Integer β = 1 ,2 ,3,…..
δ	Largest integer transporters requirement δ = 1 ,2 ,3,…..
w_{jt}^{k}	Transportation truck capacity in pallets between j and k at time t
W_{jt}^{k}	Service Truck capacity in pallets $W_{jt}^{k} = \delta * w_{jt}^{k}$
$w_{LTL\,jt}^{k}$	Unused truck capacity where $w_{LTL\,jt}^{k} = 0$ in full truck load
η %	Truck filling degree Percentage
T_{pt}^{k}	In transit shipment quantity of product p to location k
n	Maximum allowed information horizon period or (ADI) advanced demand information period

L_0	Order transportation lead time in days between plants and central warehouses
L_1	Order transportation lead time in days between central warehouses and logistic center hubs
L_2	Order transportation lead time in days between logistic center hubs and end customers
P_{PCR}^{k}	Number of candidate clustered products in location k according to PCR algorithm
$v(d_p^k)$	Product demand coefficients of variation at location k
SCOR	Supply Chain Operations Reference model
WMS	Warehouse Management System
TMS	Transportation Management System
CPFR	Collaborative Planning, Forecasting and Replenishment
MRP	Material Requirements Planning
DRP	Distribution Requirements Planning
ERP	Enterprise Resource Planning
GIS	Geographical Information System
SKU	Stock Keeping Unit

1. Introduction

1.1 Background

Logistics is concerned with the organization, movement, and storage of materials and people. The term logistics was first used in its most narrow sense by the military to describe the activities associated with maintaining a fighting force in the field. The term gradually spread to cover business and service activities.

The Council of Logistics Management is a large association in the USA that promotes the practices and education of logistics and VDI - The Association of German Engineers share the definition of logistics as: *"Logistics is the combination of transport, storage, and control of material all the way from the suppliers, through the various facilities, to the customer, and the collection of all recyclable materials at each step".*

Logistics focuses on three types of flow: materials flow, information flow, and monetary flow. The most traditional is the physical "material flow", where the material can range from traditional products, through services, to livestock, and people.

The second is the information flow. The sharing of information on the status of the physical flows across the various organizations executing the logistics functions can dramatically decrease the magnitude of the physical materials flows. This has led to implementation of the Enterprise Resource Planning tool (ERP) that provides such information first within a single organization and now among all the organizations in a supply chain. Very closely related to logistics is the concept of a supply chain (SC) and supply chain management (SCM). The next section will provide a general introduction to supply chain management.

1.2 Introduction to the Supply Chain

In today's global marketplaces, individual companies no longer compete as independent entities with unique brand names, but rather as integral parts of supply chain links, where the introduction of products with shorter and shorter life cycles, and the heightened expectation of customers have forced business enterprises to invest in, and focus attention on, their supply chains. This, together with continuing advances in communications and transportation technologies, has contributed to the continuous evolution of the supply chain and of the techniques to manage it (Min and Zhou 2002, Simchi-Levi et al., 2003).

Supply chain is the term used to describe the management of materials and information across the entire supply chain, from suppliers to component producers to final assemblers to distributions (warehouses and retailers) and ultimately to the customer (Sliver at el., 1998).

1.2.1 Definition of Supply Chain Management (SCM)

A supply chain is a network of functional organizations that through their activities perform logistic functions. The most recent alternate definitions include as: "A supply chain is a network of organizations that are involved though upstream and downstream linkage in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customers" (Christopher, 1998). Stadtler and Kilger (2002) define supply chain management as "the task of integrating organizational units along a supply chain and coordinating materials, information, and financial flows in order to fulfill the demands of the ultimate customer with the aim of improving competitiveness of a supply chain as a whole". Simchi-Levi et al. (2003), define the supply chain as " a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements".

A typical supply chain is treated as an integrated system that synchronizes a series of inter-related business processes in order to perform the specific business processes mentioned in Min and Zhou (2002). There are three traditional stages in the supply chain: procurement, production, and distribution. Each stage may be composed of several facilities in different locations around the world as shown in Figure 1.1.

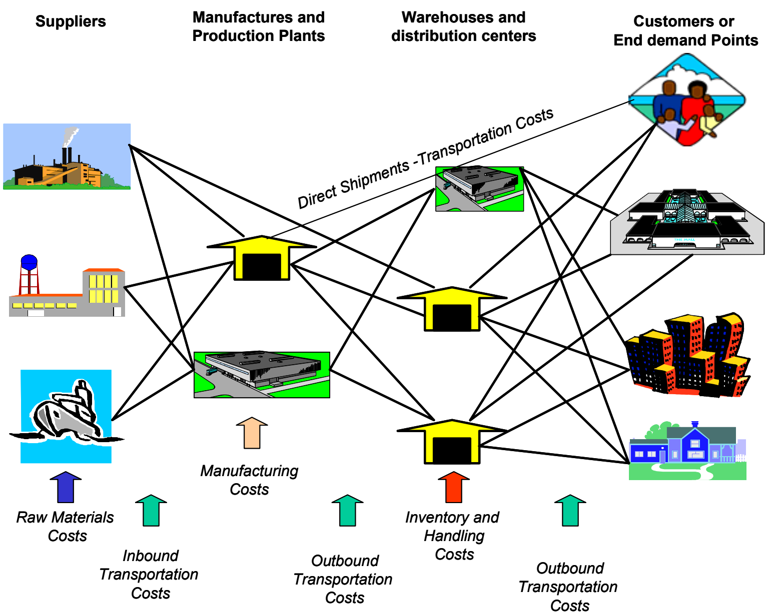


Figure 1.1 Generic Supply Chain Logistics Network (Simchi-Levi et al. 2003)

Min and Zhou (2002) characterized the flow in the supply chain to a forward flow of goods and a backward flow of information as shown in Figure 1.2. Figure 1.1 shows that a generalized supply chain is comprised of two main business process loops: materials management (inbound logistics), and physical distribution (outbound logistics).

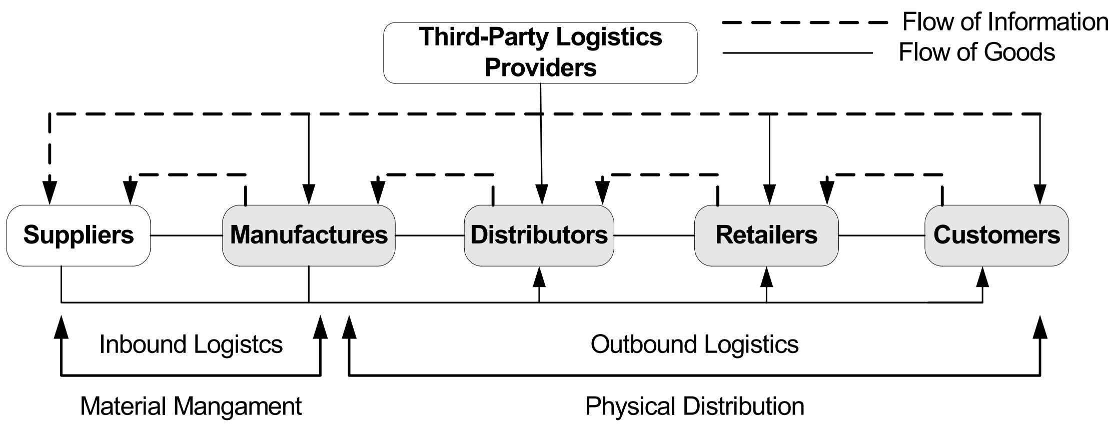


Figure 1.2 Generalized Supply Chain Process (Min and Zhou 2002)

1.2.1.1 Materials Managements (Inbound Logistics)

This inbound logistics loop is concerned with the acquisition and storage of raw materials, parts, and suppliers. To elaborate, materials management supports the complete cycle of material flow from the purchase, internal control of production to planning and controlling of work in process to the internal warehouses, shipping, and distribution of finished products.

1.2.1.2 Physical Distribution (Outbound Logistics)

This process encompasses all outbound logistics activities related to producing customer service, including order of receipts and processing, inventory deployment, storage and handling, outbound transportation, consolidation, pricing, promotional support, returned products, handling and life cycle support.

This thesis addresses the modeling and developing of the integration within the physical distribution loop (outbound logistics functions) focusing on integration of the transportation, inventory and warehousing supply chain functions.

Min and Zhou (2002) and Bemon (1989), classified the generalized supply chain decision variables that limit the range of the decision outcomes into several decisions based on their functionality to the supply chain performance measures; therefore, the performance measures and supply chain objectives are expressed as a function of one or more decision variables e.g. facility location, customer and facility allocation, network structuring, number of facilities and equipment, number of stages (echelons), service sequence, volume and capacity, facility inventory levels, size of workforce, outsourcing, number of product types and groups. In the real supply chain, more than one decision variable should be considered as those factors may complicate the decision making process. The decision level and phases present the second important issue that should be declared, namely to maximize the value along the supply chain where hundreds and thousands of planning decisions are made and integrated, and coordinated every minute (Simchi-Levi et al, 2003; Ballou, 2004a; Stadtler and Kilger, 2002).

Therefore, the supply chain may be viewed as an integrated approach to increase the effectiveness of the supply chain through improving coordinated efforts between upstream and downstream locations in the supply chain (see Van Der Vorst et al., 2000a; Frohlich and Westbrook, 2001; Korpela et al. 2001).

1.3 Overview of the Research Problem

This research work focuses on the following main specific problems:

1. Integration and coordination of inter-functional supply chain
2. Planning and controlling of supply chains considering multi product multi location with uncertain demand.
3. Modeling and simulation of supply chain network.
4. Integrated joint transportation and inventory decisions through shipment consolidation.
5. Effect of sharing demand information between supply chain locations implementing vendor-managed inventory (VMI) concepts.

Supply chain performance can be improved by reducing a number of uncertainties. It is clear that there is a need for some level of coordination of activities and processes within and between organizations in the supply chain to reduce uncertainties and add more value for customers. This requires that the interdependence relations between decision variables of different processes, stages and organizations have to be established and integrated. These relations may change with time and are very difficult to be analytically modeled. However, simulation-based heuristics approach supported by sharing demand information and implementing vendor managed inventory concepts provide much more flexible means to model the dynamic and controlling of complex networks. The simulation approach is considered the most reliable method today in studying the dynamic performance of supply chain networks when it is integrated with heuristics models. This methodology will be discussed through the proposed integrated transportation and inventory decisions utilizing a shipment consolidation.

1.4 Research Motivation and Objectives

The main objective of this research work is to model, design and develop an integrated and comparative distribution supply chain model that helps supply chain designers, logistics managers and planners to evaluate and improve the performance of the distribution supply chain strategy at any period of time.

Several operational and strategic decision aspects and strategies will be examined and investigated. Modeling practical and value added cost drives should be considered, also integrating both transportation and inventory decisions to search for opportunities to improve the logistics distribution network performance measures.

The following are the specific aspects that motivated this research work based on the recommendation of several contemporary researchers and by examining a survey of supply chain models.

1.4.1 Thesis Motivation

Increased attention in recent years has been placed on performance, design, and control of the supply chain; however, given its complexity it is difficult to analyze the performance of the supply chain and determine the appropriate controls and distribution strategy mechanisms. A real life food supply chain network optimization project motivated this thesis, specifically, to investigate and construct several integrated distribution strategies that improve the supply chain performance measures.

Min and Zhou (2002) and Sarmiento and Nagi (1999) conclude that new lines of research for further supply chain modeling efforts should be focused on those techniques related to general/inter-functional integration (e.g. production-distribution, production-sourcing, location-inventory, inventory-transportation, etc.) to be controlled by exploring multi-echelon, multi-period, multi-product aspects. That was the second motivation of this thesis. The third motivation issue was related to the complexity of managing the supply chain network with conflicting objectives that open a new research direction. Simchi-Levi et al. (2003); Ballou (2004a); Chopra and Meindl, (2002) were focusing on those inter-model deals with multi objective treatments of joint functions and decisions and considered the trade-offs between them.

The fourth motivator was the complexity and difficulty of modeling real life logistics business processes and obtaining optimizing solutions to encourage the researchers to construct simulation models that are needed to evaluate dynamic decision rules for many inter-relations. Chen (2004) believes that the integrated production distribution (IPD) with stochastic demand deserves more research work, whereas most of the existing researchers consider deterministic models where the demand for products is known in advance; that was the fifth research motivation issue that will be discussed in detail later in this thesis.

1.4.2 Thesis Objectives

The following objectives of this thesis have to be accomplished:

1. Development of an efficient modeling method of the real supply chain business processes. This problem is still under study in the area of integrated supply chains, as shown in the literature today.
2. Identification and assessment of the effects of several practical cooperative distribution strategies on supply chain performance measurer.
3. Implementation of the developed supply chain simulation model to assist in estimating and evaluating the supply chain performance measures and indicators using a simulation-based heuristics approach.
4. Examination of the effect of implementing a pull, and hybrid pull-push replenishment strategy on the supply chain performance measures, considering several product safety stock allocation strategies and supply chain configurations.
5. Development of an efficient integrated joint transportation inventory strategy that incorporates a replenishment policy for the outgoing materials for the performance analysis and optimization of an integrated supply network with an (s,S) inventory control at all sites. This dissertation extends the previous work done on the pull supply network model with control and service requirements. Instead of a pure pull stock policy, a hybrid stock policy and lot-sizing problems will be considered.
6. Investigation and examination of several multi products safety stock allocation strategies determining the effect of the safety stock levels and product type order quantity during a finite period horizon to obtain an acceptable delivery performance at reasonable total cost for the whole supply chain network.
7. Development of cooperative supply chain replenishment heuristics algorithms that utilize developing trends in information technology such as implementing Advanced Demand Information (ADI) or Early Order Commitment (EOC) policy.
8. Integration of the developed model with an appropriate data exchange interface to be linked with supply chain Enterprise Resource Planning (ERP) and forecasting tools.

1.5 Organization of the Thesis

There are nine chapters in this thesis. The content of each chapter is summarized below. Chapter 1 presents a generalized introduction to the thesis, an overview of research problems, motivation, objectives, and organization. In chapter 2, reviews of existing literature in related research problems were presented. The first section in chapter 2 reviews types of supply chain coordination and integration frameworks followed by a distinction between mathematical and analytical models, which have been used to carry out simulation-based techniques in integrating and coordinating the supply chain. Finally, the effect of advanced demand information as an advanced supply chain coordination methodology is also reviewed.

Chapters 3 and 4 present the fundamentals of modeling the developed supply chain simulation model (LDNST), considering the proposed generalized conceptual modeling methodology based on Use Case Map (UCM) notations and Supply Chain Operations Reference model SCOR Ver.6.1 that assists in building the details of the supply chain simulation model. The overall architecture of the development LDNST features, and base supply chain library is present. A thesis motivated supply chain case study is also presented in chapter 4 with associated data input and network characteristics. The initial supply chain performance measures (reference mode) are carried out utilizing the developed tool; several utilized supply chain policies were conducted and modeled in chapter 4.

Chapter 5 summarizes the main research experiments accomplished in this thesis and the implemented methodology that describes the anticipated impact of the identifying directions of future research in the supply chain. Starting from chapter 6, the first proposed distribution strategy of distinguishing between a pure hub and spoke transportation network and hybrid hub and spoke network with a direct shipment strategy was implemented in two simulation experiments, performance measures were estimated and discussed. Chapter 7, discusses, explains, and analyzes the settings of the proposed main simulation benchmark experiments conducted in this thesis, eight selected safety stock inventory allocation and distribution strategies were examined and analyzed. The supply chain performance measures have been estimated, and averages and standard deviations for the various performance measures have been calculated. Chapter 8, describes the simulation experiment and supply chain performance measures of two developed integrated long-haul shipment consolidation heuristics named SF-PCR-VMI1 and SF-ADI-VMI2. Utilizing the vendor managed inventory distribution concept, general summarized recommendations and conclusions are made. Two other proposed hybrid supply chain configurations were developed and modeled. The first model shows the concept of the transshipment points logistic center hubs, as one of the well-known distribution supply chain network structures. The second proposed configuration was sub-transshipment hubs network. Several supply chain distribution strategy models were evaluated at the end of chapter 8. Appropriate and efficient distribution strategies were evaluated and presented. Finally, this thesis concludes findings and future research directions summarized in Chapter 9.

2.0 Literature Review of Related Research Work

2.1 Introduction

Increasing competition due to market globalization, product diversity and technological breakthroughs stimulates independent companies to collaborate in a supply chain that allows them to gain mutual benefits. This requires the collective know-how of the coordination and integration modes, including the ability to synchronize interdependent processes, to integrate information systems and to cope with distributed learning. However, research into coordination has paid some attention to acknowledging different modes of coordination (Remano, 2003). Supply chain coordination and integration frameworks have been reviewed and are discussed in section 2.2.

A large body of literature exists on different aspects and problems related to supply chain management systems integration and coordination models. Those models were classified into mathematical and analytical methods that have been developed to integrate two or more activities and functions; an outline of the literature reviewed for the purposes of this work will be found in section 2.3. Others have utilized the simulation based techniques in integrating and coordinating the supply chain. Section 2.4 reviews and discusses different recent proposed supply chain simulation frameworks. Section 2.5 deals with research related to implementation of information technology on the supply chain integration such as implementation of the Advanced Demand Information

(ADI) as an advanced supply chain coordination methodology. A summary of the review is given in section 2.6.

2.2 Supply Chain Integration and Coordination Classification Framework

Stadtler and Kilger (2002) stated that there are two broad means for improving the competitiveness of a supply chain. One is a closer integration of the organizations involved, and the other is a better coordination of material, information and financial flows. To ensure efficient performance of the supply chain, decisions having a significant impact on each other must be coordinated together. Contemporary review conducted by Bhatnagar et al. (1993); Sarmiento and Nagi (1999); Schwarz (2004) and Chen (2004) addressing the issue of supply chain coordination and integration types, refer to Bhatnagar et al. (1993). There are two types of coordination as follows:

1. Coordination within the same functions at different echelons in the supply chain ,and
2. Coordination between functions,

The first type is called Multi-Plant Coordination Problem (MPCP), and the second type is named General Coordination Problem (GCP). The following sections will present and explain the main difference between those two types of coordination problems.

2.2.1 Multi-Plant Coordination Problem (MPCP)

Bhatnagar et al. (1993); Chandra (1994) and Schwarz (2004) conducted an exhaustive survey of models belonging to this type of coordination problem, where they defined then as models seeking to link the production plans of several production plants which are part of a vertically integrated firm, where the output from one plant becomes an input into another plant.

The main objective of such a type of coordination is to achieve near optimal solutions on performance measures as total cost, production lead-time and others. This type of coordination considers the impact of production planning process from one plant to another and demand uncertainties. Effective multi-plants coordination must be able to integrate the issue of lot sizing, nervousness and safety stock into a coherent framework. Models and research considering such a type of coordination can be found in Zipkin (1986); Cohen and Lee (1988); Beek et al. (1985); Kumar et al. (1990) and Carlson (1979).

2.2.2 General Coordination Problem (GCP)

The general coordination problem is defined as coordination between functions in the supply chain, where attempts are made to integrate decisions pertaining to different functions e.g. production and distribution in supply chain or organization (Bhatnagar et al., (1993); Chandra (1994); and Sarmiento and Nagi (1999)).

The literature presents a good categorization of the general coordination problem and classifies it into three main distinguishable categories presenting the integration of decision making pertaining to them. The following are those three categories as mentioned in Bhatnagar et al. (1993); Chandra (1994); sarmiento and Nagi (1999); Min and Zhou (2002):

1. Integrated Supply and Production Planning,
2. Integrated Production and Distribution Planning, and
3. Integrated Inventory and Distribution Planning.

The model of the supply chain and production planning category studies the relationship between the supplier and buyer, and most of the decisions to be made were determined by the optimal order quantities of the vendor, thereby minimizing the total model costs jointly between the vendor and the buyer. Most of the models assume that the vendor faces constant deterministic demand patterns, simplification of the production process, and conflict between purchasing large shipment sizes and the just in time concept. Such models have been studied by Goyal and Gupta (1989); Monahan (1984); Bannerjee (1986) and Rosenblatt and Lee (1985).

The second category treated in literature is the level of integration between production planning and distribution planning. The decision issue here that production planners are concerned with is to determine optimal production/inventory levels for each product in every period of time, so that the total model cost of setup production and inventory holding was minimized. On the other hand, the distribution planners must determine a schedule for distribution of orders to customers so that the total transportation costs are minimized also; when a large inventory buffer exists, these two functions will be treated independently (Bhatnagar et al., 1993).

Models classified under this category were studied by King and Love (1980); Williams (1981); Blumenfeld et al. (1987); Cohen and Lee (1988); Ishii et al. (1998), Chandra and Fisher (1992).

The third category addresses the general coordination between inventory planning and distribution planning phases. This aspect of coordination considers the scenarios where a number of customers have to be supplied from one or more warehouses. The decision problem is one of determining the replenishment policies at the warehouses and the distribution schedule for each customer, so that the total model cost (inventory and distribution) is minimized. A trade-off between reducing inventory cost versus an increase in the transportation cost was conducted.

Models classified under this category were investigated by Federgruen and Zipkin, (1984); Bell (1983); Dror and Ball (1981); Chandra (1990); Burns (1985); Anily and Federguen (1990).

This research work focused on developing, evaluating, and analyzing the **I**ntegration and **C**oordination between **I**nventory and **D**istribution functions that consider the transportation system explicitly, since the main interest is to concentrate on the following points:

1. How have the logistics activities, functions, and aspects been integrated?
2. What are the advantages to be gained and obtained from the integration of the inventory, distribution, and transportation function within the supply chain?
3. What are the effects and the impacts of different replenishment strategies on the supply chain performance measures?

The most recent classification of production and distribution in the supply chain done by Chen (2004), classifies the models of production – distribution problems into five classes based on three different dimensions: a) supply chain planning decision level, b) integration structure, and c) problem parameters of the models. Those classes are as follows:

Class 1: Production –Transportation Problems

Class 2: Joint Lot-sizing and Finished Product Delivery Problems,

Class 3: Joint Raw-Materials Delivery and Lot Sizing Problems,

Class 4: Generalized Tactical Production – Distribution Problems, and

Class 5: Joint Job Processing and Finished Job Delivery Problems

The problem addressed in this thesis belongs to the fourth class of **General Tactical Production–Distribution Problems**, which is more general in structure, and whose parameters are considered e.g. multi-products, multi-location, multi-time period. Such problems deal with dynamic demand over time and seek optimal solutions among all feasible solutions.

Min and Zhou (2002), classify the supply chain modeling into four main models (deterministic, stochastic, hybrid, IT driven models) based on classical guidelines, a hybrid model considers the inventory and simulation models in under deterministic and stochastic models, while the added IT-driven category reflects the current advances in IT for improving the supply chain efficiency such as WMS, TMS, CPFR, MRP, DRP, ERP, GIS models.

An additional taxonomy exists that discusses the integrated multi functional problems such as location/routing, production/distribution, location/inventory, inventory/transportation, and supplier selection/inventory models, for more information see in Min and Zhou (2002). The category of integrated inventory/transportation decisions labeled as "Joint Integrated Transportation and Inventory Problems" (JITIP) is being taken in consideration in this thesis, and a recent contemporary research survey of such problems in the supply chain have been discussed by Schwarz (2004).

The proposed supply chain discussed in this thesis falls under the JITIP category, and is proposing the simulation based heuristics methodology as a solution method of integrating the supply chain through joining the transportation and inventory policies and decisions. "Transportation" involves activities related to the physical movement of goods between different geographic points. "Inventory" is concerned with characteristics of the goods being transported, such as demand, required service level, replenishment policies, etc.

2.3 Generalized Formulation of Integrated Joint Inventory / Transportation Supply Chain Models

The supply chain logistics network in Figure 1.1, involves managing the activities of supplying products from more geographically dispersed sources, to more geographically-dispersed destinations, henceforth called end-demand points, with a fleet of vehicles. Inventory may be held in several supply chain locations. End customers may have deterministic or stochastic demands. Decision-making may be centralized or decentralized. By definition, IJTIP involves two sets of management concerns: those related to transportation policy and those related to inventory policy. Table 2.1 summarizes some selected policies of both functions that could be jointly integrated.

Consider IJTIP formulation proposed by Schwarz (2004) such that *I is* a vector specifying the inventory policies and *T is* a vector specifying the transportation policies under consideration, and *C (I, T)* represents the cost in period *t, t = 1,….,H*, associated with any given joint policy the general formulation can be given as follows:

IJTIP: Minimize $_{\text{w.r.t. I,T}}$ $\left\{ \sum_{t=1,.....H} C_t(I,T) \right\}$ (2.1)

Subject to: $I \in \pi$ (2.2)

$T \in \psi$ (2.3)

Table 2.1 Selected Inventory and Transportation Policies (Schwarz, 2004)

Inventory Policy	Transportation Policy
• Safety stock allocation • Determining replenishments size • Rules for filling customer orders/demands (shipment consolidation) • Allocating vehicle inventory among customers	• Assignment of vehicles to routes and/or customers • Vehicle-capacity constraints • Sequencing of customers on routes • Truck filling degree • Customer delivery time-windows

Focusing on those models consider transportation and inventory as joint policy variables. Various methodologies have been used on the general JTIP, among them integer programming, stochastic programming, and Markov-decision analysis, simulation based heuristics. One of the earliest attempts at solving jointly related functions in production and distribution problem was reported by Folie and Tiffin (1976). In this thesis a simulation based heuristics was developed considering multi–products. The problem deals with determining the distribution of products among the supply chain. The objective is to minimize the overall distribution costs.

A review of some important related analytical models that assist in developing the proposed simulation based heuristics model and the associated examined distribution strategy will be presented in this thesis considering the transportation and inventory policy implemented in each model.

2.3.1 Supply Chain Analytical Based Models

2.3.1.1 Deterministic Analytical Models

Starting with single-product, single depot, multi-retailer deterministic models developed by Anily and Federgruen (1990, 1993) and Anily (1994) were the first discussed models, The objective is to determine a long-term joint transportation-inventory policy that enables all retailers to meet their demands while minimizing system-wide long-run average transportation and inventory costs. Anily and Federgruen (1993) extend the analysis in Anily and Federgruen (1990) to the case in which the depot can hold inventory. A combined routing and replenishment strategy algorithm was proposed similar to Anily and Federgruen (1990), in Chan et al. (1998) which characterizes the asymptotic effectiveness of the class of fixed partition policies and the class of so-called Zero-Inventory Ordering (ZIO) policies, under which a retailer is replenished if and only if its inventory is zero. A similar strategy and policy will be examined in this thesis in chapter 8, where a transshipment points model will be presented

Most recent analytical models with deterministic demand were developed by Gaur and Fisher (2002); examine a periodic-review model of a supermarket chain. Their objective is to determine a weekly delivery schedule that specifies the times when each store should be replenished and the routes for the capacitated vehicles that visit these stores at a minimum transportation cost.

2.3.1.2 Stochastic Analytical Models

Considering stochastic demand types Federgruen and Zipkin (1984) could be considered as a first model dealing with stochastic customer demand. They solve a single-day problem and show how some well-known interchange heuristics for the deterministic VRP can be modified to handle the stochastic demand. In their model, the quantity of product to be delivered to retailers is determined on the basis of the level of its inventory. Then, the retailers are assigned to the vehicles and the routes are determined.

Most recent proposed analytical stochastic models are done by Kleywegt et al. (2002a, 2002b); Adelman (2001); Park et al. (2002); Kleywegt (2002) formulates the IJTIP with direct deliveries as a Markov-decision process and proposes a dynamic-programming approach. The original problem is decomposed into individual retailer sub-problems. Adelman (2001) considers a multi-item inventory-control problem with joint replenishment costs. In this model, a dispatcher periodically monitors inventories for a set of products. The objective is decomposed into a collection of functions separated by item, by deciding first which retailers to visit, then, partitioning these retailers into disjoint subsets. Static allocation is used. Adelman also formulates the problem as a Markov-decision process and studies a price-directed control policy. Rather than considering a myopic policy that minimizes only the costs related to the current replenishment. Park et al. (2002) extend the single-product, single-vehicle, single-depot, N-retailer stochastic-demand model by considering dynamic allocation of vehicle inventory, instead of a static route, for a "symmetric" system (in which all retailers are equidistant from the depot and one another).

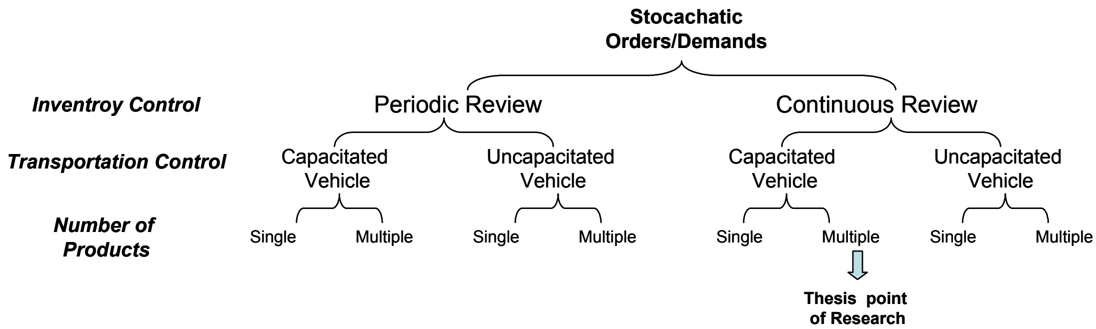


Figure 2.1 Stochastic Transportation-Inventory Research Topics

Other related deterministic and stochastic demand models found in Anily and Federgruen (1993); Herer and Roundy (1997); Viswanathan and Mathur (1997); Bell et al. (1983); Blumenfeld et al. (1985); Chien et al. (1989); Christiansen(1999); Christiansen and Nygreen(1998a,b); and Fumero and Vercellis (1999). Stochastic demand models have been found in Golden et al. (1984); Qu et al. (1999); Cetinkaya and Lee (2000); Kumar et al. (1995); Liu (2003) and Hwarng et al. (2005).

However, regardless of the method used, optimal joint transportation-inventory policies for large-scale problems are NP-hard and difficult to solve considering the mathematical models mentioned in Figure 2.1. Hence, fast heuristics and simulation models are required to guarantee a certain level of solution quality proposed as a solution methodology of these models, the proposed models discussed in this thesis consider the problem of multi-products, capacitated vehicle, continuous review and stochastic demand, more details in Schwarz (2004) and Chen (2004).

2.3.2 Supply Chain Simulation Based Heuristics Models

Despite the great emphasis given in the last decade on the need for companies to smooth their physical boundaries in favor of a more integrated perspective, simulation based heuristics is a method by which a comprehensive integrated supply chain model can be analyzed by considering both its strategic and operational elements.

This method can evaluate the effectiveness of a pre-specified policy before developing new ones. Given that simulation models are well suited for evaluating the dynamic decisions under what-if scenarios, supporting a multi-decisional context and it is easier to imitate the real life problem. Simulation approaches take into account the uncertainty of the system.

Simulation tools are available that can be used to build simulation models with great ease. Several supply chain models were developed such as Swaminathan et al.(1995); Towill et al.(1992); Jain et al.(2001); Mason et al.(2003); Cachon and Fisher(1997, 2000); Terzi and Cavalieri (2004); Gaither and Frazier(2002); Manzini et al.(2005).

Recent surveys done by Terzi and Cavalieri (2004) and Kleijnen (2004) present a comprehensive review of most published simulation models within the supply chain context. Specific simulation models will be presented and discussed such as Swaminathan et al. (1995); they studied the influence of sharing supplier capacity information on the performance of a supply chain using a simulation(s) for comparing different information sharing scenarios after deriving the optimal inventory policy for the manufacturer under stochastic demand. Towill et al. (1992) conducted a simulation study to analyze the effect of system redesign strategies on the performance of a supply chain. They simulated a supply chain with three echelons: factory, distributor, and retailer. The various strategies tested include the effect of integrating information flow throughout the supply chain and removing the distributor echelon.

Cachon and Fisher (1997) developed a novel innovation designed simulation model to improve the efficiency of the inventory management through the supply chain of Campbell's Soup Company. Several ordering policies such as utilizing the electronic data interchange (EDI) between supply chain locations and a vendor managed inventory concept, will be examined in this thesis in chapter 7. Cachon and Fisher (2000) compare a traditional information policy that does not use shared information along with a full information policy that does exploit shared information. They found that supply chain costs are 2.2% lower on average with the full information policy than with the traditional information policy. They conclude that in contrast the value of information sharing with two other benefits of information technology, faster and cheaper order processing, lead to shorter lead times and smaller batch sizes, respectively.

General-purpose discrete event simulation software cannot be directly used for simulating supply chains. The simulation modules provided in the software should be combined or modified to represent the activities typical to supply chains. Bhaskaran (1998) illustrates the magnitude of a supply chain-reengineering project for a blanking and stamping operation at General Motors, using simulation as the primary analytical tool. He describes the level of detail required to understand material and information flows and evaluates different system configurations to identify improvement involving more sophisticated control mechanisms. Swaminathan, Smith and Sadeh (1998) provide a supply chain-modeling framework, which enables rapid development of customized decision support tools for SCM. Jain et al. (2001) developed a high-level supply chain simulation model using a general-purpose simulation tool. Their justification for using general-purpose simulation software instead of a commercially available supply chain simulation tool was that general-purpose simulation software lets the user select the desired level of abstraction.

Recently, contemporary researchers such as Manzini et al. (2005) present a VIS visual interactive simulation approach as a valid way to support design and management decisions in order to achieve the integrated optimization of the supply chain, since most of the literatures do not discuss the difficulties and time required in applying or building the simulation models. They examine five representative real networks which are related to different chains and industrial concerns, a conclusion was made according to the time and cost of developing such simulation models.

Hwarng et al. (2005) developed a simulation model to study the impact and the benefits of coordinating activities and consolidating distribution points in supply chains on the overall performance of a complex supply chain. These study models are relatively complex supply chains and evaluate the impact of simplifying demand and lead time assumptions under various supply chain configurations. Several strategies and aspects were investigated such as the effect of risk pooling and the synchronization of production cycles in a multi-level multi-retailer supply chain under the influence of various parameters such as batch size, delivery frequency and ordering cycle. This study highlights the extent of complicated interaction effects among various factors that exist in a complex supply chain and shows that the intricacy of these effects can be better understood with a simulation model.

Persson (2003) developed a supply chain simulation model in an electronic Swedish Company to investigate four different upstream routes for the supply of mechanical parts for mobile communications manufacturing. The first route concerns traditional invoicing, the second route includes the use of vendor managed inventory, VMI, at the manufacturer's plant. The third route is a special case of VMI. The fourth route concerns components that are sold directly to retailers from the suppliers. The simulation model of the described routes incorporates both the dynamic behavior of the upstream external supply chain and the internal supply of the plant.

Recent and efficient supply chain modeling framework was based on the Supply-Chain Operations Reference (SCOR) model. Several versions have been developed to describe the business activities associated with all the phases of satisfying a customer's demand. The Supply Chain Council developed this model. One of the primary objectives of this model is to provide a standard framework for describing the activities associated with supply chains (Stadtler and Kilger, 2002). The SCOR model divides the business activities into four basic process categories (level 1). These process categories are further divided into process elements (level 2, 3). This provides a good standardized framework for defining the activities of a supply chain. One of the published simulation models built according to the SCOR model offered by Barnett and Miller (2000); and Pundoor (2002) and Pundoor et al. (2004) describe how the SCOR model provides the process structure necessary to understand supply chain systems. The SCOR supply chain-modeling framework utilized in this thesis to construct the proposed conceptual supply chain simulation model will be presented in chapters 3 and 4.

Mason et al. (2003) estimated the total cost benefit that can be achieved by suppliers and warehouses through the increased global visibility provided by an integrated system. They developed a discrete event simulation model of a multi-product supply chain to examine the potential benefits to be gained from global inventory visibility, trailer yard dispatching and sequencing techniques. They suggest for future research in order to quantify operational improvements resulting from the implementation of an integrated system. Potential issues to be considered include the coordination of replenishment when a single vendor supplies multiple SKUs, so that full-truckload trucking can be utilized. When a pull system is implemented, initial order quantities are smaller due to existing safety stock. This may result in less than full-truck load trips. However, assuming demand does not decrease, as soon as the system exhausts the safety stock, the system should reach equilibrium and reverts back to full-truckload trucking.

See more models in Towill et al. (1992); Bagchi et al. (1998); Berry and Naim (1996); Chen and Chen (2005); Petrovic et al. (1998); Petrovic (2001); Schunk (2000); Van der Vorst (2000b);Van der Vorst et al. (2000a);Sindhuchao et al. (2005); Chen and Chen (2005); Nilsson (2006); Díaz and Buxmann (2003); Gaither and Frazier(2002); Chan and Chan(2005).

The work done by Mason et al.(2003), Persson (2003), Manzini et al. (2005), Hwarng et al. (2005) have been taken into consideration in developing the simulation model utilizing the SCOR model discussed in Barnett and Miller(2000), Hermann et al.(2003),Pundoor(2002),Pundoor et al. (2004) proposed in this thesis.

2.4 Supply Chain and Advanced Demand Information Models

Information sharing practices such as vendor-managed inventory (VMI) give manufacturers access to more accurate demand information than ever before, e.g. customer sales data. The value of this type of information sharing has been established in many studies. Such as Gavirneni et al. (1996); Aviv and Federgruen (1998); Cachon and Fisher (2000); Lee et al. (2000); Cheung and Lee (2002); Smaros et al. (2003); Ozer (2003); Cachon (2001).

Several models implemented and examined the effect of the information technology on the supply chain performance measures such as Cachon (2001) who examines three trucks dispatching policies to a model and a retailer who sells multiple products with stochastic demand. The objective function is a challenge to balance transportation, shelf space, and inventory costs, through applying three policies: 1) a minimum quantity continuous review policy, 2) a full service periodic review policy, and 3) a minimum quantity periodic review policy. Cachon and Lariviere (2001), conduct a study of contracts that allow the supply chain to share demand forecasts credibly under either compliance regime. Two ordering contract compliance regimes were considered and investigated.

Lee and Whang (2000) study and define the types of information shared: inventory, sales, demand forecast, order status, and production schedule in the supply chain, and sharing the information in industry was presented also, they discuss three alternative system models of information sharing: the information transfer model, the third party model and the information hub model.

Recent models such as Smaros et al. (2003) and Ozer (2003) built and developed a discrete-event simulation which is used to examine how a manufacturer can combine traditional order data available from non-VMI customers with sales data available from VMI customers in its production and inventory control and what impact this has on the manufacturer's operational efficiency. The simulation model was based on a real-life VMI implementation and uses actual demand and product data. Their key finding was that even for products with stable demand, a partial improvement of demand visibility can improve production and inventory control efficiency, but that the value of visibility greatly depends on the target products' replenishment frequencies and the production planning cycle employed by the manufacturer.

2.5 Summary

Simulation is a useful tool for studying supply chains. Discrete event simulation packages available today are not very suitable for supply chain simulation. The amount of effort needed in building supply chain models can be greatly reduced by reusing components from supply chain component libraries. Generalizing and standardizing supply chain simulation modules to ensure their usage across different kinds of industries. This constraint defines a level of detail for implementing the modules. If the modules are too detailed, they might become specific to a particular industry.

While a great deal of work has been done to investigate the effect of different real life distribution strategies considering multi-product safety stock, multi-location facing uncertainty demand operated with capacitated vehicles in long and short-haul transportation network, not much research is available in the field of such problem types especially when considering real life complex supply chain networks. One difficulty is that supply chains involve many different planning activities conducted by different participants. It is unclear how they build a unified supply chain model that imitates the real life supply chain business process, chapters 3 and 4 describe the procedure of building the proposed conceptual supply chain simulation modeling approach utilizing a UCM and SCOR model which will affect the performance of the entire system.

3.0 Modeling a Conceptual Supply Chain Model Framework

3.1 Introduction

Nowadays, the concept of modeling the supply chain represents an important revolution and new approach to the development and evaluation of the complex supply chain systems.

Supply chain systems are collections of autonomous components that interact or work together to perform tasks that satisfy their end customer goals. Several supply chain-modeling methodologies were proposed such as Petri nets and coloured Petri net (Van Der Vorst et al., 2000b; Van Der Vorst , 2000a), conceptual models (Mason et al., 2003; and Hwarng et al., 2005), supply chain process reference model based on SCOR (Barnett and Miller, 2000; Pundoor,2002; Pundoor et al.,2004) and others see more in chapter 2.

Each of the above methodologies has its strong and weak points, and each includes features which are tailored for a specific application domain. The Use Case Map (UCM) method and applications presented by Abdelaziz et al. (2004) supported by Supply Chain Operations Reference SCOR Ver.6.1 (2004) assists in developing the conceptual supply chain simulation model discussed in this thesis. Both methods are able to capture and describe the most shared elements in the supply chain, such as cooperation and interaction, organizational design, communication, collaboration, and coordination.

The proposed conceptual modeling approach is especially tailored for describing the most important and active supply chain business processes and activities; it provides a systematic approach for generating executable model definitions from a high-level modeling design. This method captures effectively the complexity of the supply chain through depicting the internal supply chain business processes and activities structure, relationships, conversations, and commitments. Each of those processes provide a starting point for developing the details of the supply chain models and implementations to satisfy the thesis objectives and requirements.

3.2 Supply Chain System Objects and Components

A supply chain objects library proposed by Biswas and Narahari (2004) was used and a detailed description and classification of various library objects was discussed in Appendix I and can be classified into two categories:

- Structural objects and
- Policy objects

The structural objects are the physical entities of supply chain networks. The physical structure of the supply chain networks is modelled using these classes. Physically the supply chain network is composed of plants, warehouses, distributors, retailers, suppliers, customers, orders, and vehicles. The policy objects embed business logic, which is used to control the flow of products and information through the network, such as inventory policy, order management policy, demand planning policy, supply planning policy and distribution policy.

The set of structural objects is used in conjunction with the policy objects to build the object models of a supply chain. These models are used to provide customized inputs for various decision problems to be studied.

The policy objects describe the protocols used in procurement, manufacturing, transportation, and distribution of material within the supply chain. For example, a structural object such as "Warehouse" can be composed with a policy object such as "Inventory Policy" to describe different types of warehouse management and replenishment schemes.

Those structural objects integrated with predefined policies will be used to construct the high-level supply chain system utilizing the UCM conceptual visualization aids.

3.3 Designing a High-Level Supply Chain Model

Developing and understanding complex systems is not easy to achieve by traditional systems that concentrate on low level details. The main goal of the use of a high level view is to understand the entire supply chain and its structure without referring to any implementation details. The Use-Case Maps supported by SCOR 6.1 level 1 and 2, which are suitable for high-level visual representations are particularly a starting point for generating more detailed visual descriptions, because of their ability to simplify and successfully depict the design of complex systems and to provide a powerful visual notation for a review and detailed analysis of the design.

The main UCM notation summarized in Table II.1 in Appendix II; this helps to visualize, think about and explain the overall behaviour of a whole supply chain system. It describes scenarios in terms of causal relationships between responsibilities. It also emphasizes the most relevant, interesting and critical functionalities of the system, where the details will be considered according to SCOR 6.1 model.

3.3.1 Generalized Proposed Serial Supply Chain Model Scenarios

In this section I will describe the proposed high-level supply chain structure and objects of a five-echelon serial supply chain system utilizing the UCM and SCOR model and show how the proposed modeling approach is able to capture real supply chain components based activities and different system scenarios in visual views. The following scenarios represent interactions between some important supply chain components and functions. Examples of interactions shown are end customer components with a distribution center, distribution center with central warehouse components, and central warehouse production plants with suppliers. By tracing application scenarios, the high-level model is derived.

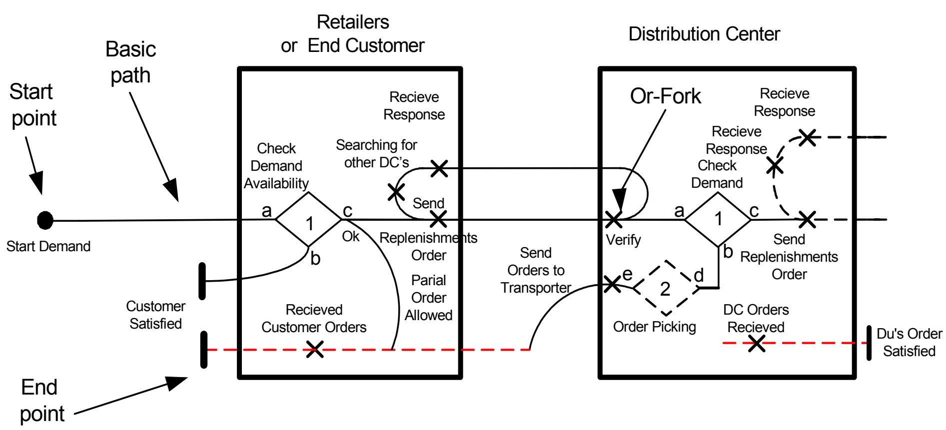
This modeling approach maintains the most important steps such as: 1) Identify scenarios and major components involved in the supply chain. 2) Identify roles for each component. 3) Identify pre-conditions and post-conditions to each scenario. 4) Identify responsibilities and constraints for each component in a scenario. 5) Identify sub scenarios and replace them with stubs.

3.3.1.1 End Customer (Retailers)-Distribution Center Scenarios

The retailers/end customer scenarios describe the flow of material and information between the end demand point and distribution center (bottom-up approach), the customer order pre-condition state is ready for processing (customer made an order, it contains several multi-products). The scenarios starts when the data from the SAP/ERP system is retrieved and the checking of the demand order quantities through product available inventory positions (IP) has been performed, where the inventory positions are represented by the following:

Product Inventory Position (IP) = Available On Hand Inventory (OH) – Demand Quantity (D) + In-Transit Quantity (T)

The scenarios start with the check of the static demand stub, which hides the detailed information of the checking demand request process (see stub 1) in Figure 3.1. The checking demand stub request may result in three post conditions. Such as: satisfy the whole order from the existing inventory, a partial order may be satisfied and the rest will be back ordered or the whole order will be treated as a lost sales order. Therefore, the Check Demand Request stub 1 is represented as a static stub. Figure 3.2 illustrates the plug-ins for the Check Demand Request stub.



<u>Preconditions</u>:

- Customer Order Issued and Received.

<u>Post conditions</u>:

- Order satisfied
- Open orders (backorder)
- Lost Sales Record

Figure 3.1 End customer (Retailers)-Distribution Center Scenario

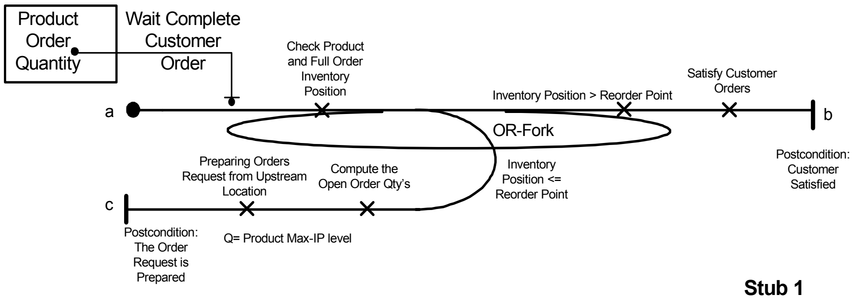


Figure 3.2 Plug-ins for Check Demand Request Stub

After checking demand, the paths lead to the generating of replenishment order from the distribution center components; in the event that the required demand could not be satisfied from the existing on-hand inventory, the distribution center verifies the replenishment order based on a pull principle; then the path leads to an or-fork immediately after the order is verified indicating alternative scenario paths. One path leads to refuse the replenishments order request, e.g. because those ordered products are not stocked in this location (wrong information flow, product inventory allocation strategy). Then the path continues to the result stub to inform the model that the order request will be submitted to another distribution center (error message). These scenarios will be utilized later in case of multi-echelon supply chains. The other path leads to accept the replenishment request and the path proceeds to the distribution center to check product availability (check demand) stub, according to the inventory management control policy. The distribution center checks whether the demand stub has the same outgoing ports b and c.

The outgoing path from port b leads to satisfying the product replenishment order followed by a second important business process based on the SCOR Model called Order Picking Consolidation stub (Levels 3 and 4). Figure 3.3 depicts the main activities and decisions made in the order picking and consolidation stub.

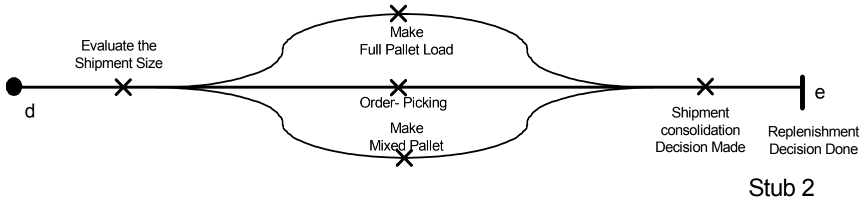


Figure 3.3 Stub 2 Plug-ins for Order Picking and Consolidation Request Stub

There are three plug-ins associated with the Order Picking Consolidation stub. Events and states with consolidating and aggregating the shipment size that forms the final customer shipment loads according to the following rules:

1. Shipping only product full pallet type, and/or
2. Manual Order-picking (eventually Negative Order-Picking Policy),
3. Shipping mixed pallets consisting of several product types.

Then, after the order picking and consolidation process, the shipment order is transferred to shipping and loaded onto trucks to be transported to the demand location through transportation components. Those processes are according to SCOR blocks such as M2.2; M2.4; M2.5; D2.5; D2.6; D2.7; D2.8; D.9 (for more details found in SCOR Ver. 6.1,2004). At this point, the post condition replenishment decision has been satisfied at port e, which leads to the shipment transportation components.

The transportation component starts with a transportation request, which is responsible for searching and preparing the required fleet size to perform the shipment transportation request. The transportation component has the possibility to manage and transport the whole shipment size by using a capacitated fleet size. The path e leads to the Preparation for the Transportation Request stub; three plug-ins are associated with that stub as illustrated in Figure 3.4. Three types of transportation offers are considered; the 3rd party transportation logistics provider (Common carrier), Private carrier, or Mixed carrier.

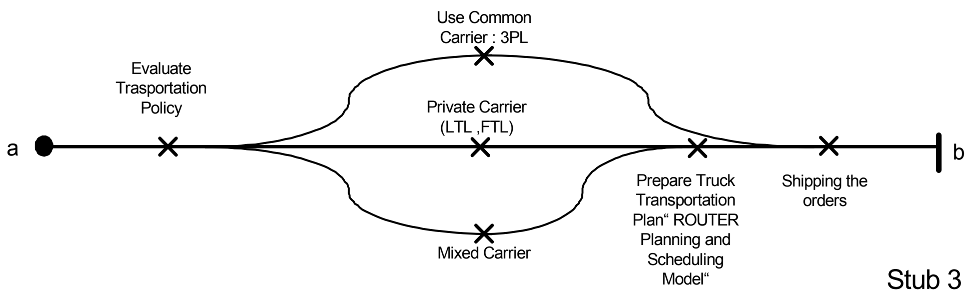


Figure 3.4 Stub 3 Plug-ins for Preparation Transportation Request Stub

Vehicle routing and scheduling were not considered in this model; only one to one shipment trips were modelled. The path leads to completion of the shipment request and satisfies the precondition by the end customer or retailers outlets.

3.3.1.2 Distribution Center-Central Warehouse Scenarios

The DC/CW scenario is similar to the previous end-customer distribution center scenario with little differences in the order-picking stub, which allows direct shipments to end customers without passing through the distribution center. Figure 3.5 illustrates the modified order-picking consolidation stub 2.1. Only product full pallets are transported to distribution centers and mixed pallets in case of direct shipments to customers.

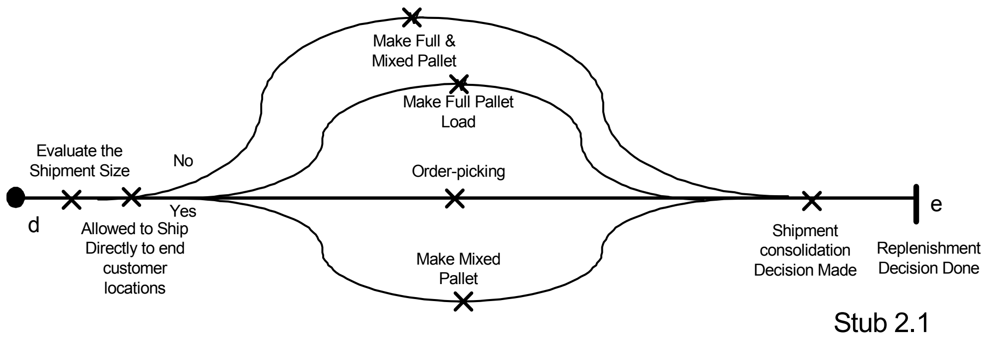
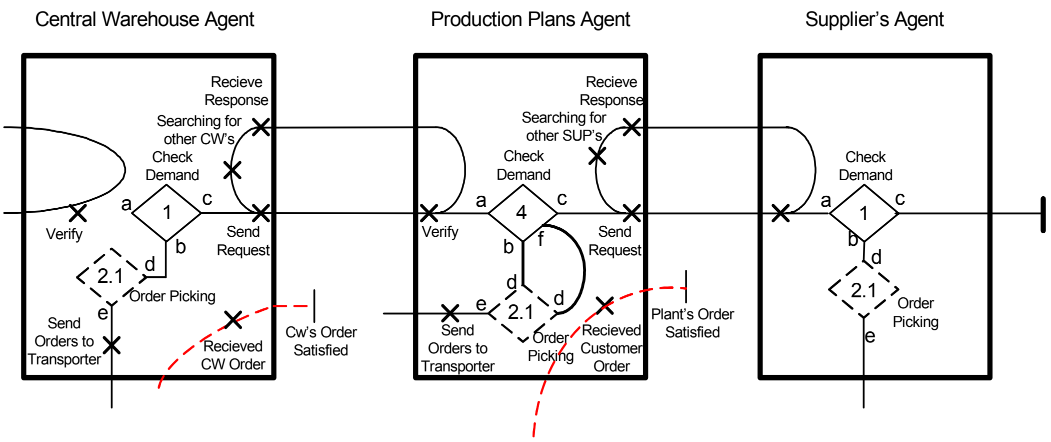


Figure 3.5 Sub 2.1 Plug-ins for Order Picking and Consolidation Request Stub

3.3.1.3 Central Warehouse - Production Plants and Supplier Scenarios

Figure 3.6 shows the proposed basic conceptual scenarios between plant central warehouses, production facility and raw material suppliers, which represent the material management loop in Figure1.2. This loop is designed under the push production principle; such that products are produced in production plants and stocked in plant central warehouses to satisfy downstream demand requirements (distribution center, retailers, and customers). The modelled scenario starts with the new production plan stub 4, which hides the detailed information of the production order request process. The production orders request stub 4 is illustrated in Figure 3.7, and it starts checking the production plan in the next planned period to confirm to the planned demand; the path leads to an or-fork immediately after the IP check responsibility, which results in two possible alternatives based on whether the product order was planned and scheduled and will be shipped or an urgently requested order will be issued and scheduled in the production plan; then the path leads to an extra production planning scenario.

It checks if raw material is available or a new request is issued to suppliers, then it reschedules the production plan according to the new adjustments.



<u>Preconditions</u>:

- Replenishments order issued and received.

<u>Post conditions</u>:

- CW order satisfied
- Open CW orders Issued
- Issuing raw material request
- Adjusting the production plans

Figure 3.6 Central Warehouse-Production Plants and Suppliers Scenarios

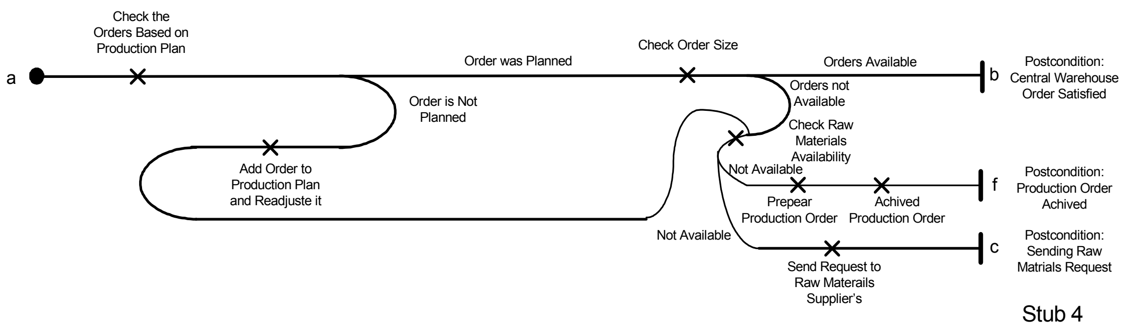


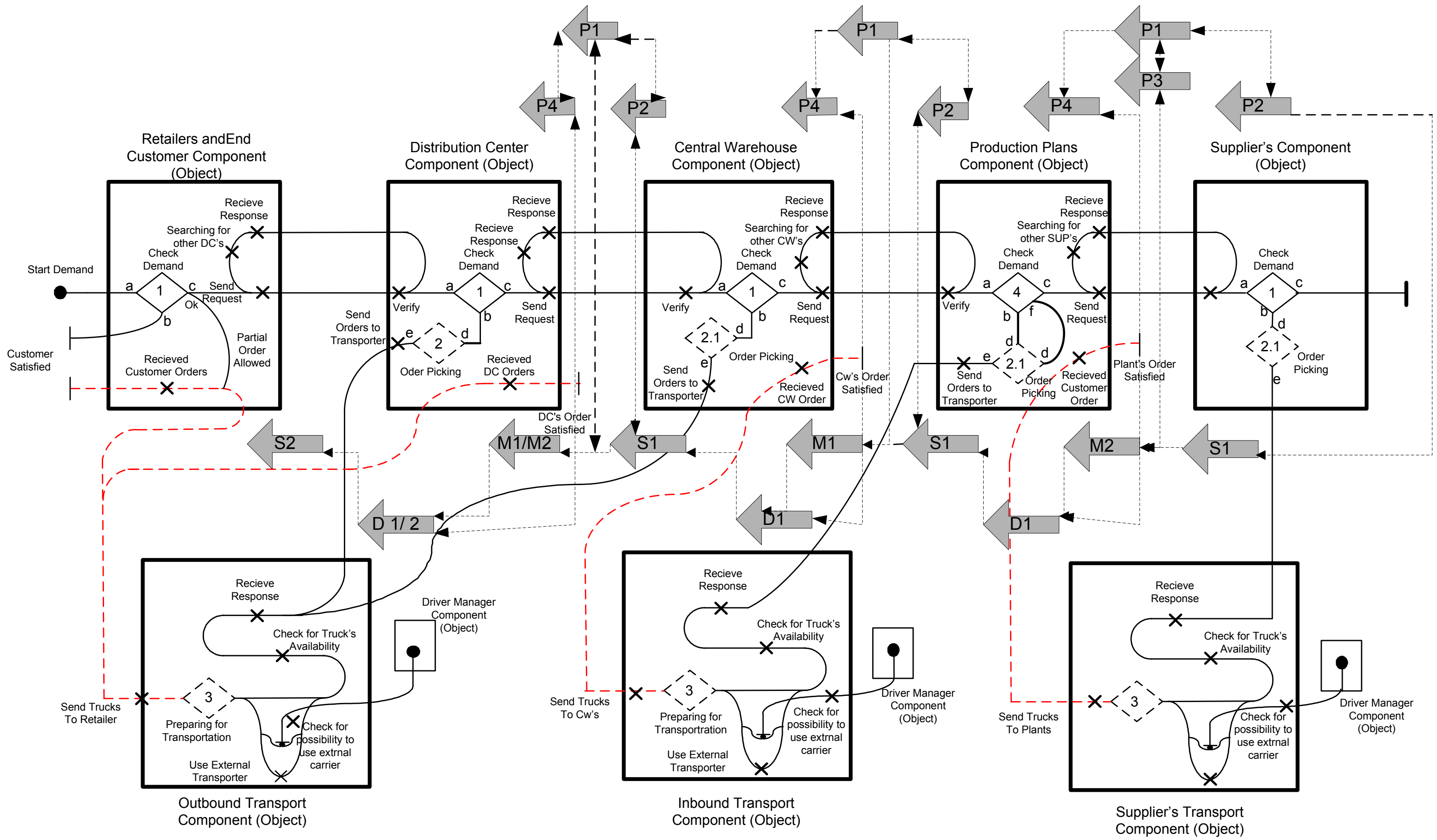
Figure 3.7 Plug-ins for Check Production Plan Stub

A generalized proposed serial supply chain conceptual model is depicted in Figure 3.8 with associated model stubs. Two main types of transport components were considered: Inbound, and Outbound, where outbound presents long-haul and short-haul distribution transportation activities.

The next chapter discusses modeling aspects, which develop and provide more detailed policies that capture the internal details of the supply chain business process, and their relationships are discussed considering the supply chain policies objects and strategies in Table I.1 and Table I.2 in Appendix I. The latter production – supplier scenarios will not be considered and modelled as a black box that can supply the required products without any backorder (infinite supply source).

3.4 Summary and Conclusion

In this chapter, I present the development steps of a prototype serial supply chain model utilizing high-level notation method of Use Case Maps and the SCOR 6.1 supply chain process reference model. The developed prototype model is capable of providing a solution for modeling and constructing a practical supply chain simulation model, which is required to be flexible and to consider system dynamics, utilizing the visualized high-level model that helps us to understand, and define the behaviour of the supply chain components and the possibility of integrating the functions. That was one of the main objectives of this thesis, as mentioned in chapter 1.



Sup's : Raw Materials Supliers
Cw's : Central Warehauses
DC's :Distribution Centers

Information Flow
Materials and Transportion Flow

Figure 3.8 The Generalized Conceptual Serial Supply Chain Scenarios using UCM and SCOR 6.1 Level 2 Modeling Methodology

4.0 Modeling The Operational Supply Chain Level (LDNST Model)

4.1 Introduction

One of the main objectives of this thesis mentioned in chapter 1 was to design and develop a real life supply chain simulation model of a food supply chain firm, which will be used in assisting the logistics supply chain managers in evaluating the distribution supply chain performance measures. Therefore, the contributions of this chapter are discussing some theoretical and practical operational modeling logics that were considered in the developed Logistical Distribution Network Simulation Tool (LDNST) according to the conceptual supply chain framework presented in chapter 3, and detailed operational elements proposed in SCOR 6.1 model levels 3 and 4 (more see Aldarrat et al., 2005; Noche et al., 2004; and Housein et al., 2005).

The main objectives of the developed LDNST were to assist in evaluating alternative inventory allocations policies and coordinated distribution strategies that lead to an integration between transportation and inventory decisions. The LDNST considers the production-distribution section in the supply chain. The developed tools were implemented on a real supply chain case study. The company owns several production plants, central warehouses and distribution centers named as logistic center hubs spread all over Germany, producing and distributing thousands of product types. Considering the complexity of managing such a distribution supply chain, integrated and coordinated distribution strategies needed to be examined and developed such that supply chain performance measures would be optimised; thus, better allocation of the safety stock inventory in logistic center hubs were needed. The LDNST was established to conduct several simulation distribution experiments under different supply chain conditions and distribution strategies. This chapter describes the logic of the detailed modeling aspects of the LDNST supply chain simulation tool, along with its effectiveness in comparing distribution strategies for locating inventory and minimizing total logistics costs within the supply chain levels. The LDNST is built by a discrete event simulation tool (DOSIMIS-3) linked with a supply chain object oriented library programmed by visual C++ developed specifically for this purpose.

4.2 Modeling and Design of Distribution Networks Literature Review

Distribution network design problems have received increasing attention from the research community in recent years because great savings are expected from a better-designed network. Work has been performed at the modeling and solving levels simultaneously (Aldarrat et al., 2005; and Noche et al., 2004). Supply chain network design decisions have a significant impact on performance because they determine the supply chain configurations and set constraints in which inventory, transportation and information can be used either to decrease distribution network costs or increase responsiveness (Chopra and Meindl, 2004; Ballou, 2004a).

Early work on designing distribution networks focused on locating warehouses in relation to customers. The warehouse location problem was the first issue in the distribution network design because it accounts for the transportation costs from the central warehouses to the customers (outbound transportation, direct shipments), but it does not account for the transportation costs between suppliers and the central warehouses (inbound transportation). Accounting for the location of suppliers increases the complexity of the problem and brings it to the class of network design problems.

The simulation based heuristics methodologies were selected as solution methodology utilized in this thesis to quantify how well alternative networks would function through variation in demand and supply. The simulation models assist in answering the following questions:

1. What are the relationships between inventory policies and the resulting safety stock inventory levels, customer service levels, and redeployment of stock?
2. Does the location of inventory storage for different classes of products have an effect on total inventory levels and redeployment of stock?

4.3 Modeling Supply Chain with DOSIMIS-3

DOSIMIS-3 was developed by SDZ GmbH. The DOSIMIS-3 is a discrete event simulator for material flow and logistic aspects, enabling the user to intuitively analyse production and assembly, material flow and transport and other logistic systems.

The first DOSIMIS-3 version was launched in 1984 with new versions released every year, with an intuitive and interactive graphical user interface that is easy to use. Hidden behind the surface, DOSIMIS-3 offers a specific functionality for simulating production and logistic processes. That allows the building of material flow models based on a process-oriented model, an event oriented model or a combination of both.

A specialized supply chain library policy controller was developed considering the supply object library in Appendix I, and real life business processes (such as order-picking and consolidation process), with the help of the conceptual SCOR models, that were integrated with the DOSIMIS-3 tool to construct the Logistical Distribution Network Simulation Tool (LDNST).

So whenever, the developed supply chain library policy controller DLL is called, the supply chain location input data is read. All function and algorithm procedures are written in visual C++ programming language, which takes care of the planning activities proposed by the SCOR6.1 model. The overall proposed integrated LDNST simulation model framework is demonstrated and broken into several main sequential steps and phases. The developed supply chain library policy controller DLL and DOSIMIS-3 tool are linked by a designed interface simulation cockpit as shown in Figures 4.1 and 4.2 (See Aldarrat et al.,2005).

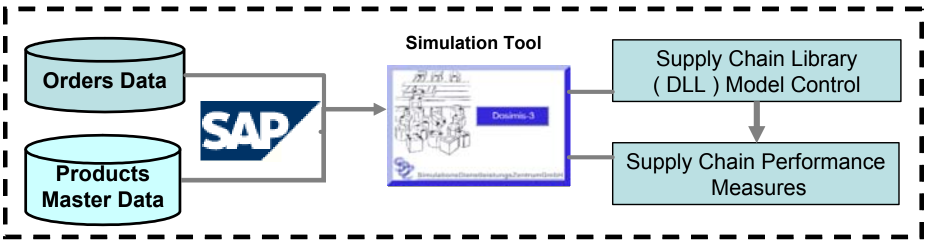


Figure 4.1 Proposed Interaction between DOSIMIS-3 and Supply Chain Library Controller

Each supply chain location has been assigned to a specific controller associated with control policy and input data files. In such a way, LDNST was employed using different sets of input data without affecting the model code. This approach offers more flexibility in implementing more experimental distribution scenarios without the need of reprogramming. The DOSIMIS-3 model is responsible for managing the logic by which the model entities and resources interact dynamically with each other; each group of blocks has a corresponding representation, and these can be combined into a sequential block diagram such as general supply chain representation in Figure 3.7 in chapter 3.

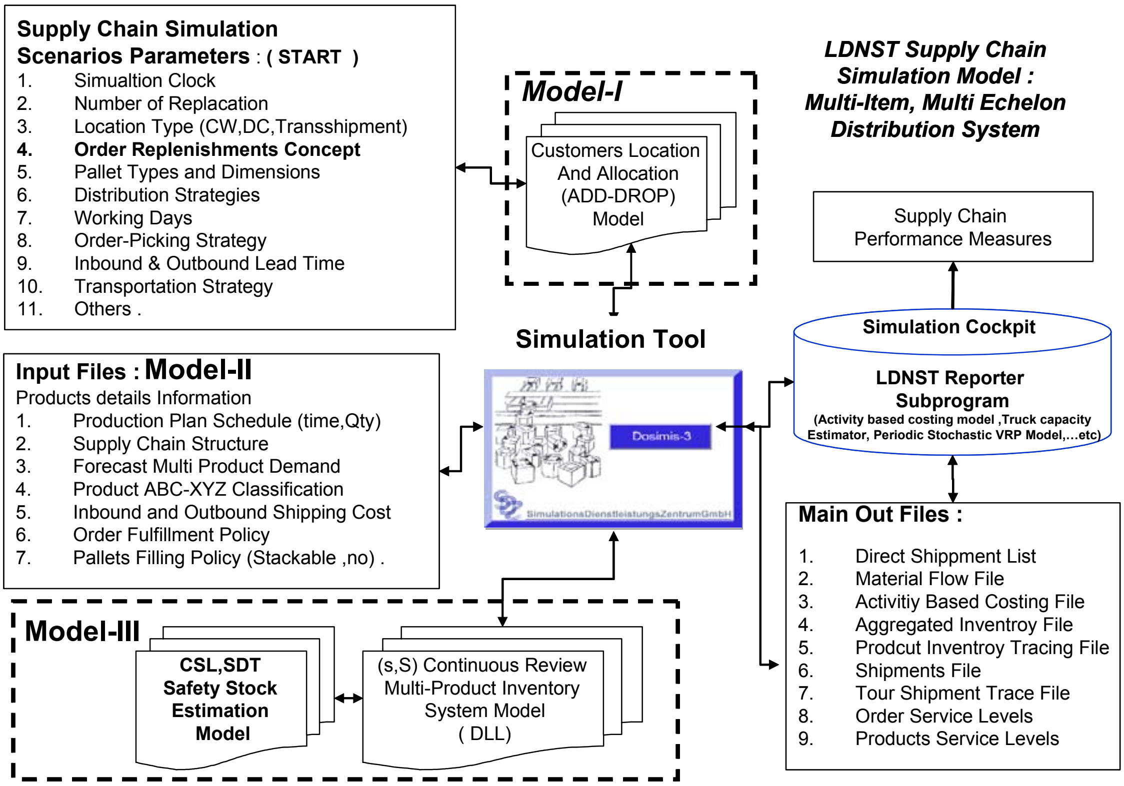
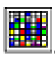


Figure 4.2 The Proposed Integrated LDNST Supply Chain Simulation Framework

Figure 4.3 depicts a screen dump of a simple supply chain consisting of 1 supplier and 5 distribution centers with 10 demand point locations represented by an appropriate abstraction of DOSIMIS-3 module as seen in Figure 4.4. (For more details on other DOSIMIS-3 modules see SDZ, 2005). The developed supply chain library policy controller DLL considers the complex decision algorithms and presents them by the decision table symbol .

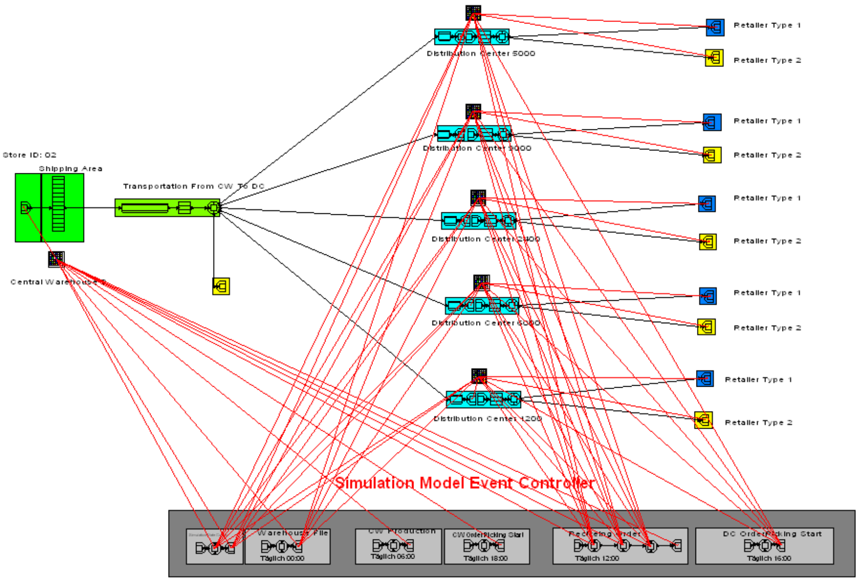


Figure 4.3 Simple Supply Chain DOSIMIS-3 Simulation Model
(Single supply source, 5 Distribution Centers, 10 Customer demand Points)

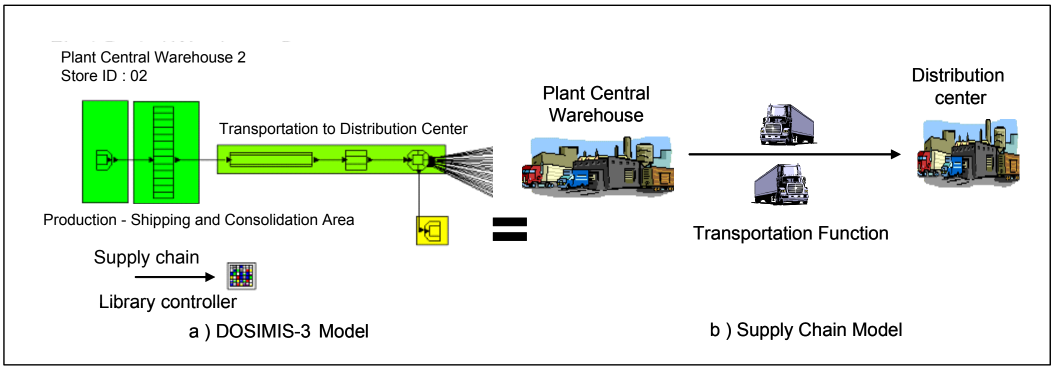


Figure 4.4 A Prototype DOSIMIS-3 Supply Chain Model Representation

4.3.1 The Supply Chain Simulation Model Characteristics

1. Entities represented as examples of the orders, shipments, tours, product types.
2. Attributes are the characteristics of the entities with a specific value that can differ from one to another e.g. orders are assigned to shipment delivery and vice versa.
3. Resources are the things like space in storage area of limited size, truck capacity, etc

4.3.2 The Supply Chain Validation Methodology

One of the most important aspects in the simulation studied is the validation of the model. If the model is not valid, then any conclusions derived from the model will be doubtful some authors like Law and Kelton (2000) described that the validation phase passes though 3 important steps:

1. Verification determines that the simulation model performs as programmed.
2. Validation is concerned with the modeling of the concept in capturing the real system representation.
3. Credibility, the end phase, describes that the owner believes in the simulation model results.

Hoover and Perry (1989) present the following approach to model validation: after the model is developed, it is necessary to observe the system for a period of time before collecting data for all variables and performance measures; then the same previous variables are input into the build simulation model collecting the model performance measures from the model output. The decision on model validation is based on the degree to which the performance means are produced by the model and those means then collected from the real system. Van Der Vorst (2000b) mentions that it is impossible to perform a statistical validation test between the model output and the real system output due to the nature of these data, where the output process of most real systems and simulation are non-stationary, and auto corrected, which means that the distribution of those data changes every time with different values and they are not correlated. Law and Kelton (2000) mentioned that it is most useful to ask whether or not the difference between the system and the model output is considered to affect any conclusions.

4.4 Description of the Developed Supply Chain Simulation Model

In the developed Logistical Distribution Network Simulation Tool (LDNST), the supply chain planner enters or imports data of the supply chain distribution network, and LDNST predicts the performance, operationally and financially, of the proposed network. If the current network is entered in, alternative scenarios can be tried, in order to see how the current operation will function if e.g. demand falls, rises, spikes seasonally, for one product, several products, or entire product classes (See Aldarrat et al., 2005).

LDNST also lets the user try out changes to the existing distribution network configuration, to see what the impact will be. Thus, users can evaluate what the effect would have been on the last scenarios financially if they had implemented make to order (MTO) instead of make to stock (MTS), or if one of the logistic center hubs had been closed, or if inventory had been consolidated on full trucks prior to shipping them (Aldarrat et al., 2005)

The following network specifications were considered in LDNST:

- **Network Structure:**
  - Products - weight, size, sales price,
  - Sites - location, type of site, capacities,
  - Real demand, forecasted or distribution - time and place it occurs, order quantity and required product.
- **Network Policy:**
  - Inventory Policy - where (if at all) inventory is stocked, how often it is counted, when it is reordered, handling, holding inventory costs.
  - Replenishment Policy – how much quantity should be ordered and based on what concept (pull, push, hybrid),
  - Sourcing Policy - where orders for re-supply get handled, and which site supplies which products,
  - Transportation Policy - how products are transported, Less than Truck Load (LTL), Full Truck Load (TL), direct shipments or hybrid and how much shipment costs are affected
- **Raw materials Sourcing and Production:**
  - Raw materials suppliers and production policies are modelled using the black box: simple production lead-time and quantities estimated.

The LDNST supply chain library policy controller DLL main elements will be explained in the next sections.

4.4.1 Developed Supply Chain Library Elements

The supply chain library controller is a collection of system elements; algorithms and processes that together control and manage the system dynamics. The model consists of the basic elements representing all the activities and supply chain business processes that are performed in each location according to the supply chain model in chapter 3, items (materials), inventories, retailers and customers' allocation and shipments in the network. Table 4.1 summarizes the main library control classes within LDNST supply chain simulation framework; in addition, it is discussed how they are organized and how they behave. The current developed library consists mainly of 14-object classes representing various elements and components in the distribution supply chain under study. The sample of the designed UML classes and model details are found in Figure III.1 in Appendix III.

Table 4.1 LDNST Object Library and Control Classes (Aldarrat et al., 2005)

	Class Name	Responsibility
1	ABC and XYZ Products Class	Determines the product class type and family
2	Products Information Class	Products specification and characteristics
3	Order Management Class	Controls orders and flows
4	Truck Capacity Class	Checks the utilized truck capacity -Tours
5	Spedition Type Class	Controls the shipping mode and region
6	Spedition (Shipping Cost) Class	Controls the units shipping costs and tariff
7	Locations and Customers Class	Controls customers' location and allocation
8	Facility Location Type Class	Distinguishes between facility types (plants, central warehouse, distribution center, transshipment point)
9	Inventory Control Management Model Class	A (s,S) continuous multi items multi echelon inventory distribution policy control
10	Transportation Strategy Class	Controls of transportation mode and type (FTL, LTL, direct shipments)
11	Tour Management Model Class	Construction of shipment tour between two points (no routing)
12	Shipping and Warehousing Activities Class	Tracing the shipping and warehousing activities (loading, order-picking, unloading, splitting…)
13	Global Supply Chain Controller	Controls general supply chain variables (e.g. pallet types, volumes, weights, working days and time…)
14	General Simulation Class	Controls simulation events and activities

4.4.2 Selected LDNST Supply Chain Simulation Components

The following were the main supply chain components utilized in the LDNST:

- **Supply Chain Locations**: The model prototype simulates the network of plants, central warehouses, distribution centers, and transshipment points that respond to consumer demand points of finished goods SKUs; suppliers are not considered.
- **Materials and Inventories**: Each plant produces only a specific range of finished goods stocked in central warehouses directly utilizing a push concept; no product is produced in more than one production plant. Several product types could be held in inventories at logistic center hubs (distribution center). Raw materials are not modelled in this system.
- **Transportation Methodology**: Several integrated approaches of modeling transportation shipments were considered. The transportation lead-time is modelled as a delay time associated with moving material from one location to another (dock to dock). This delay time is assumed to be uniformly distributed between 1 to 4 working days.
- **The Packaging Unit Load:** Four forms of unit load were modelled as follows:
    - Form-1 Individual consumer product unit, which represents the smallest unit in the simulation model, customer demands are received in this form e.g. (boxes, bags, bottles, small cartons),
    - Form-2 Cartons which pack several identical consumer product units, and forming a bigger unit load than for an individual consumer,
    - Form-3 Production Product full pallets form, packs several identical one product cartons together in one full standard European pallet with maximum of 2.4 m height indicated in this thesis as Q_{ip}^{FP} ,and
    - Form-4 Mixed pallet forms, packing several different product types together function in desired filling degree (set in this thesis as 90% of the total pallets volume) and desired customer pallet height.

4.4.3 The LDNST Supply Chain Simulation Input Data Mask

A significant amount of historic data from the company's ERP system could be integrated and transferred to the LDNST simulation model through an input data mask, such as product lists, product ABC-XYZ classification. Moreover, the global supply chain system parameters could also be defined.

Figure 4.5 shows both designed supply chain location input data masks linked to the LDNST model divided into 7 input blocks as follows:

1. Location information: number, type and name
2. Product information: products list, products reorder point, products up to level stocking quantities, and customer allocation, ABC-XYZ classification
3. Flow information: production, order flow in terms of customers' demand
4. Cost information: activities location costs and shipping costs
5. Inventory policy: allowed to keep inventory or not allowed
6. Transportation policy: Pull replenishments, SF-PCR-VMI-1, SF-ADI-VMI-2
7. If allowed to have a lateral transshipment between distribution centers
8. The global system parameter reads the dimensions of the mixed pallets and the standard pallet height, pallet packing type, maximum number of pallets that can be stacked above each other, working days on the calendar and finally, whether direct shipments are allowed or not.

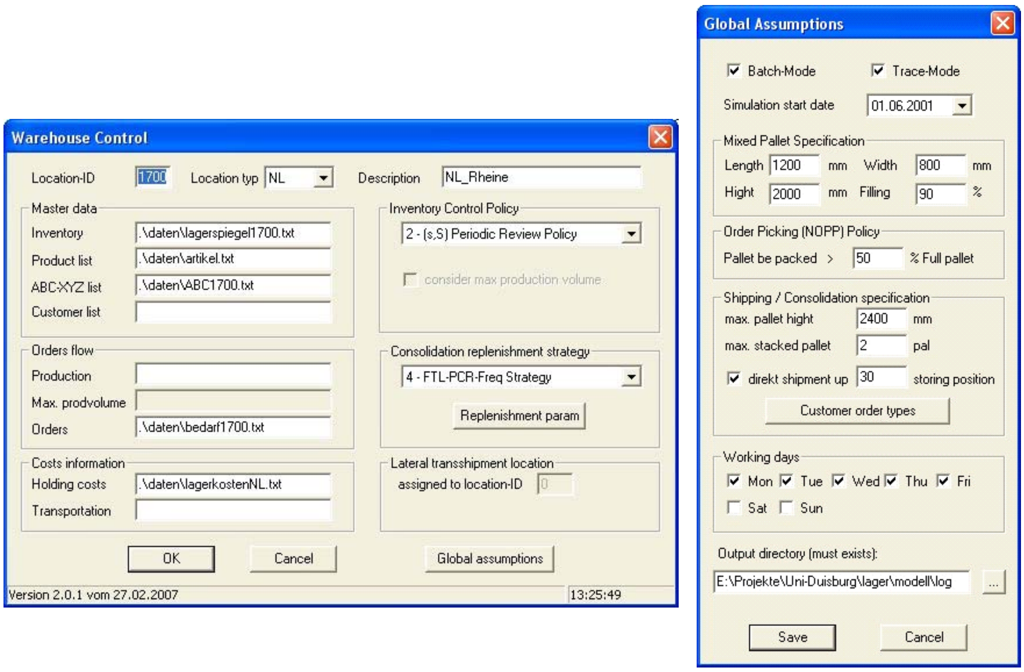


Figure 4.5 LDNST Simulation Model Input Data Parameter Masks
(Aldarrat et al., 2005)

4.4.4 LDNST Supply Chain Product Assortment and Inventory Model

The developed LDNST model invokes a multi independent items inventory model, each product facing stochastic demand and supply conditions. There is no supply –demand link between them, and their supply and demand processes are distinct. Such assumptions are actually used in commercial inventory control programs. Zipkin (2000); Elsayed (1994), and Silver et al. (1998) stated different methodologies for analyzing the behavior of the multi item multi location (such as Aggregate Performance Measure, Inventory–Workload Trade off Curve, Cost Estimation and Optimization, Aggregate Sensitivity Analysis, ABC Analysis, Exchange curves).

LDNST characterizes the multi products performance with the aid of ABC-XYZ analysis which is constructed based on the demand forecasted data for each product type.

4.4.4.1 Designing of Two-Dimensional ABC-XYZ Product Classifications

It is another tactic for coping with a large number of items in a multi location problem. Essentially, it means dividing the items into a few groups. Commonly, three groups are used, labeled A, B and C on the basis of sales volume or number of orders per period, where A class has the highest value of the total supply delivered volume or the most demanded items in the supply chain during the study period or in general based on the decisions made by the management. B items represent medium values and C class is the smallest added value to the supply chain location.

Normally the A class includes only a few items, say 10 %, while the B class is large at 30 % and the C group is the largest at 60 %. Even so, the A class items typically account for the bulk of the total sales (often as much as 80 %), while the C items cover only a small fraction with the B class items somewhere in between (Zipkin, 2000) .

Products that belong to A class should receive the most personalized attention from management with 5 to 10 % of the SKU (Stock Keeping Unit). Usually these items also account for somewhere in the neighborhood of 50 % or more of the total annual Euro movements of the population of the items under consideration. Class B items are of the secondary importance in relation to class A. These items, because of their Euro added value or other considerations, require a moderate but significant amount of attention. The largest numbers of the items fall into this class, usually as mentioned before, about 50% of the total annual Euro usage. Class C are the relatively numerous SKU’s that take up only a minor part of the total Euro inventory investments but incurring a space in the distribution system locations and capacities, which may result in lower Inventory turnover rates (Silver et al., 1998)

Flores and Whybark (1987) recommended using a two dimensional classification where the first was the traditional ABC analysis and the second based on criticality (as cited in Cohen and Ernst, 1988). The XYZ will be utilized as a second multi product classification scheme.

The XYZ analysis classifies the product according to an extra three categories based on the dynamic of their demand consumption rate or coefficients of variation $v(d_p^k)$ (Silver et al., 1998; Kljajic et al. 2004).

The XYZ analysis also divides stock in classes, which differ in their prognosticating bareness. So it is guaranteed that despite the different need processes, the correct supply principles are used. X-Products are those products with homogeneous and constant demand behaviors; Y-products follow trending or seasonal patterns, while Z-products are characterized by irregular or sporadic demand behaviors and difficult to prognosticate. Table 4.2 summarizes suggested multi product families and classes characteristics according to ABC-XYZ classification stated by Alicke (2003). According to Table 4.2 the combination of ABC-XYZ classification clusters the products into nine basic families as (AX, AY, AZ…CZ) categories.

The XYZ analysis classified the products in each supply chain location based on the product coefficients of variation $v(d_p^k)$ (Kljajic et al. 2004; Johannes and Posten 2006) as follows:

$$v(d_p^k) = \frac{\sigma(d_p^k)}{\mu(d_p^k)} \tag{4.1}$$

Such that: Products family X: if $v(d_p^k)$ less than or equal 0.5

Products family Y: if $v(d_p^k)$ between 0.5 and 1.0

Products family Z: if $v(d_p^k)$ greater than 1.0

Table 4.2 Multi Products Classes Characteristics According to ABC-XYZ Classification (Alicke 2003)

<table>
<tr><th>Product Class and Family</th><th>Product Class A
High added value</th><th>Product Class B
Medium added value</th><th>Product Class C
Low added value</th></tr>
<tr><td>Product Class X
Constant demand</td><td colspan="2">JIT (Just In Time), JIS (Just In Sequence), No (low) Safety Stock (SS),High Prediction accuracy</td><td>JIT, JIS, Low SS,Medium Prediction</td></tr>
<tr><td>Product Class Y
Fluctuant Demand</td><td colspan="3" rowspan="2">Safety Stock (SS) depends on: Reliability of the supplier - Fluctuation of the demand - Quality of the product- Low Prediction accuracy</td></tr>
<tr><td>Product Class Z
Sporadic Demand</td></tr>
</table>

4.4.5 Modeling LDNST Independent Inventory Control Management Model

This section discusses practical inventory control models that are often used in conjunction with the developed supply chain simulation model LDNST. The proper application of an independent demand inventory system can mean significant savings. Independent demand inventory systems are based on the premise that the demand or usage of a particular item is independent of the demand or usage of other items (Zipkin, 2000; Elsayed, 1994; Silver et al., 1998).

Inventory types that can be managed with independent demand systems including most finished goods, spare parts and resale inventories. Items whose demand or usage is related to other products such as raw materials, component parts, and work-in-process inventories are often better managed using the dependent demand systems. Independent demand inventory systems were modeled as pull systems; two factors classify independent demand inventory systems as shown in Table 4.3, based on a review mechanism and the type of order quantity. The review mechanism deals with when to check the inventory to see if more stock is required. There are two basic approaches: continuous and periodic review.

The second factor was whether the order quantity is fixed or varies from order to order. Within each of the four classes of models these two factors create, the manager must also be concerned with the determination of the reorder point and the safety stock.

Table 4.3 (S, s) Independent Demand Inventory Systems (Silver et al., 1998)

	Review Frequency	
	Continuous Review	**Periodic Review**
Order Quantity	Fixed Order Quantity	Fixed Order Quantity
	Variable Order Quantity	Variable Order Quantity

The simulation model was designed as **(S_p^k, s_p^k)** multi products continuous review with variable order quantity. **(S_p^k, s_p^k)** continuous review systems are inventory control systems that monitor the level of inventory I_p^k every time an inventory transaction takes place. When the inventory of an item reaches a critical level, called the reorder point s_p^k, a variable replenishment order is placed. These models are often called reorder point models reflecting the order process. Figure 4.6 illustrates the behavior of the theoretical (S_p^k, s_p^k) product (p) inventory system.

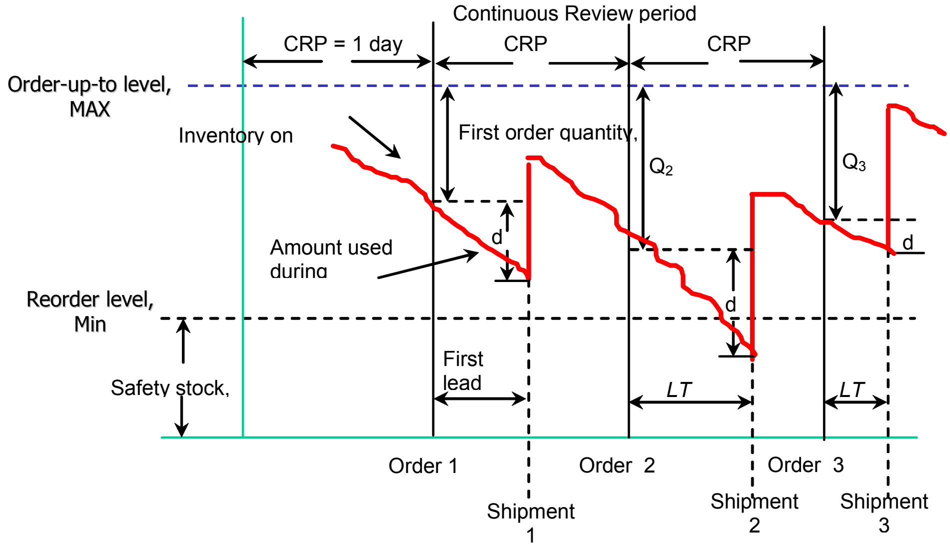


Figure 4.6 Theoretical (S_p^k, s_p^k) of Product (p) Continuous Review Systems with Variable Order Quantity

The proposed (S_p^k, s_p^k) continuous review models are useful in managing the inventory of multi products classified according to ABC or ABC-XYZ classifications. They are relatively easy to use and can be easily automated, such that the model monitors every inventory transaction on a continuous daily basis. This allows the monitoring and controlling of a large number of items relatively easily.

The quantity to be ordered can be established in several ways. One approach is to set the quantity to be ordered based on the amount of shelf space available S_p^k (max) when the $S_p^k = 0$, or, the quantity ordered could be based on the difference between the maximum space available S_p^k and the inventory position I_p^k calculated based on equation 4.2 , then the replenishment order occurs when the product inventory position I_p^k is less than or equal to the product reorder point $I_p^k \leq s_p^k$.

$$I_{pt}^k = I_{p\,t-1}^k - D_{pt}^k - B_{pt}^k + T_{pt}^k \qquad (4.2)$$

The advantage of the variable order quantity model is that special circumstances such as seasonality or large sales can be taken into account when placing orders. Ballou (2004b) classified the estimation of the (S_p^k, s_p^k) pull inventory model parameters considering the safety stock as follows:

- Statistical Reorder Point (CSL s_p^k)
- Stock to demand Reorder Point (STD s_p^k)

These models and methods were the most frequently described in the literature and observed in practice for perpetual demand patterns that are projected in the short run from historical time series.

4.4.5.1 Designing The Statistical s_p^k Using CSL Method

The reorder point safety stock (safety inventory) is designed based on the desired Cycle Service Level (CSL) of decision makers. Cycle Service Level (CSL) is the fraction of replenishment cycles that end with all the customer demand being met (Chopra and Meindl, 2004; Zipkin, 2000). A replenishment cycle is the interval between two successive replenishment deliveries. Therefore, CSL is equal to the probability of not having a stock out in a replenishment cycle, several suggested CSL levels could be investigated such as 99%, 95%, 90%, and 80%. The procedure in Figure 4.7 assists in designing s_p^k based on desired Cycle Service Level.

4.4.5.2 Designing the s_p^k Using STD Method

Unlike the statistical estimation of the s_p^k, Stock-To-Demand is an empirical and practical approach to inventory control whereby a forecast is made at specified intervals based on such factors as convenience, requirements of multiple items in inventory, workload scheduling when orders emanate from multiple inventory locations, and supplier order-size or product lot-size minimums. Then, inventory levels are managed according to desired goals, such as a particular turnover ratio or number of days of inventory. It is usually executed in a manner similar to the periodic review method with the exception that most of the parameters of the method are set based on judgment, experience and goals for inventory. The SDT method procedure is summarized in Figure 4.8.

Estimating statistical s_p^k using Cycle Service Level (CSL):

- CSL= probability (demand during lead time ≤ $\overline{D}_{pt}^k$ + SS $_{iL}$ = s_p^k)
- If demand during lead time is normally distributed with a mean of $\overline{D}_{pt}^k$ and a standard deviation of $\sigma_{pt}^k = \sqrt{L_1} \times \overline{\sigma}_{pt}^k$, so that

$$F(\overline{D}_{pt}^k + SS\ , \overline{D}_{pt}^k, \sigma_{pt}^k) = CSL$$

- By using the definition of the inverse normal, the equation can be derived

$$\overline{D}_{pt}^k \times L_1 + SS = F^{-1}(CSL, \overline{D}_{pt}^k, \sigma_{pt}^k)\text{, and}$$

$$SS = F^{-1}(CSL, \overline{D}_{pt}^k, \sigma_{pt}^k) - D_L$$

- By using the definition of standard normal distribution, its inverse can be modified as $SS = F^{-1}(CSL) \times \sigma_{pt}^k = k_{ss} \times \sigma_{pt}^k$
- The product reorder point calculated by

$$s_p^k = \overline{D}_{pt}^k \times \mathrm{L}_1 + k_{ss} \times \overline{\sigma}_{pt}^k \qquad (4.3)$$

- Finally, the maximum product stocking level S_p^k

$$S_p^k = k_{\max} \times \overline{D}_{pt}^k \qquad (4.4)$$

Figure 4.7 Estimating (S_p^k, s_p^k) Parameter using CSL

Estimating utilizing Stock to Demand concept (STD):

- Estimating the product safety stock

$$SS = k_{ss} \times \overline{D}_{pt}^k$$

- The product reorder point can be calculated by

$$s_p^k = \overline{D}_{pt}^k \times \mathrm{L}_1 + k_{ss} \times \overline{D}_{pt}^k \qquad (4.5)$$

- Finally, the Maximum product stocking level S_p^k

$$S_p^k = k_{\max} \times \overline{D}_{pt}^k \qquad (4.6)$$

Where $k_{\min}$ = min safety stocking factor, $k_{\max}$ = maximum stocking factor

Figure 4.8 Estimating **(** S_p^k, s_p^k **)** Parameter using SDT

The push inventory control consists of a variant of the STD policy. Rather than replenish orders originating at the location where the inventory is held, they originate from a source point such as a plant that serves the stocking points (Ballou, 2004b).

4.4.6 Modeling LDNST Transportation Rates Profiles (SCNT)

Transportation rates are the prices of hiring carriers for their service. Various criteria are used in developing rates under a variety of pricing situations. The most common rate structures are related to volume, distance, and demand (Ballou, 2004a). Two supply chain transportation rates were modeled such as: the unit outbound long-haul shipping and outbound short-haul shipping cost associated with the distribution to customer demand.

The non-linear dependencies of the costs from shipment sizes, and transportation distance; third-party in the supply chain transportation costs adds another dimension of complexity to the problem of the cost modeling and calculations. The transportation cost was modeled as close to reality as possible; however, function in distance and shipment size rates with extra-related rates considering the transportation to fixed defined location in the supply, the following shows an example of transportation shipping cost types of the supply chain network which motivated this thesis and will be presented and optimized later.

4.4.6.1 Modeling Long-Haul Transportation Cost Function

A sophisticated long-haul transportation cost function was considered and developed where the transportation cost offered by the transportation 3^{rd} party was classified into three main categories: 1) specific destination (e.g. logistic center hubs); 2) based on the customer location according to location zip code e.g. direct shipments; 3) special orders delivery (e.g. weight, volume, heights).

Those rates and classes were developed based on shipment quantity discount concept function in the number of transported pallets between the sources and destinations. The cost rates profiles are different from one location to another; an example of supply chain long haul transportation rates is presented and illustrated in Figure 4.9. If the plant central warehouse decides to send shipments less than truck capacity, a higher unit cost per pallet per class will be considered.

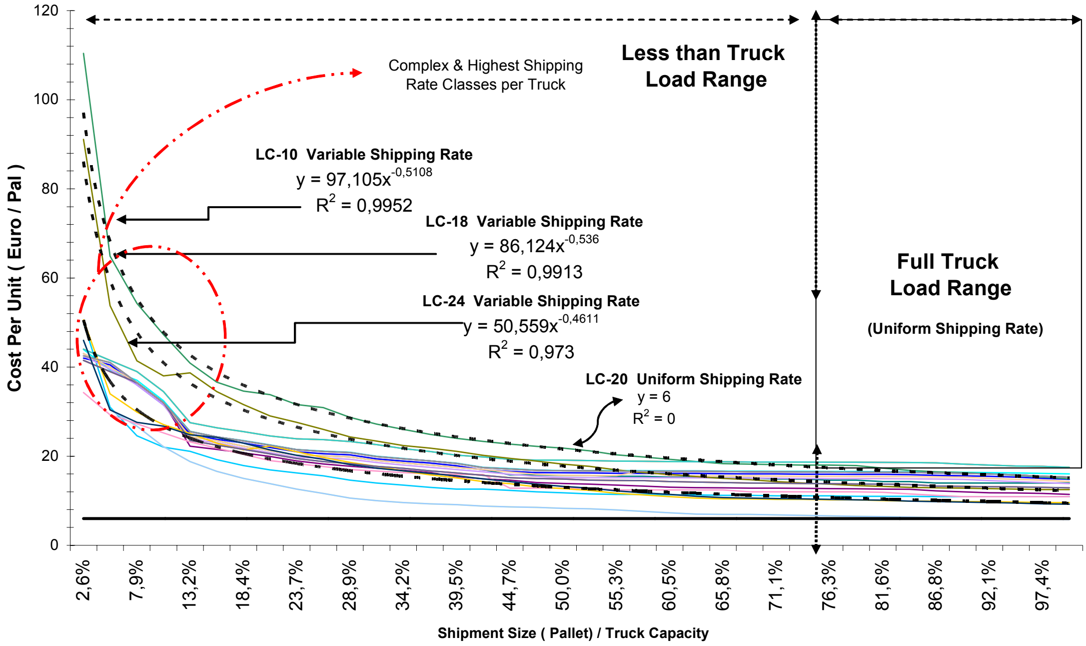


Figure 4.9 Examples of Long-Haul (Distance-Shipments Class) Freight Rates

4.4.6.2 Modeling Short-Haul Transportation Cost Function

The short-haul transportation cost function was modelled and classified into two main classes: 1) distance-related freight rate; 2) special orders delivery (function in shipment weights). In Figure 4.10 this diagram shows an example of the short-haul transportation cost as distance-shipment size related freight rate.

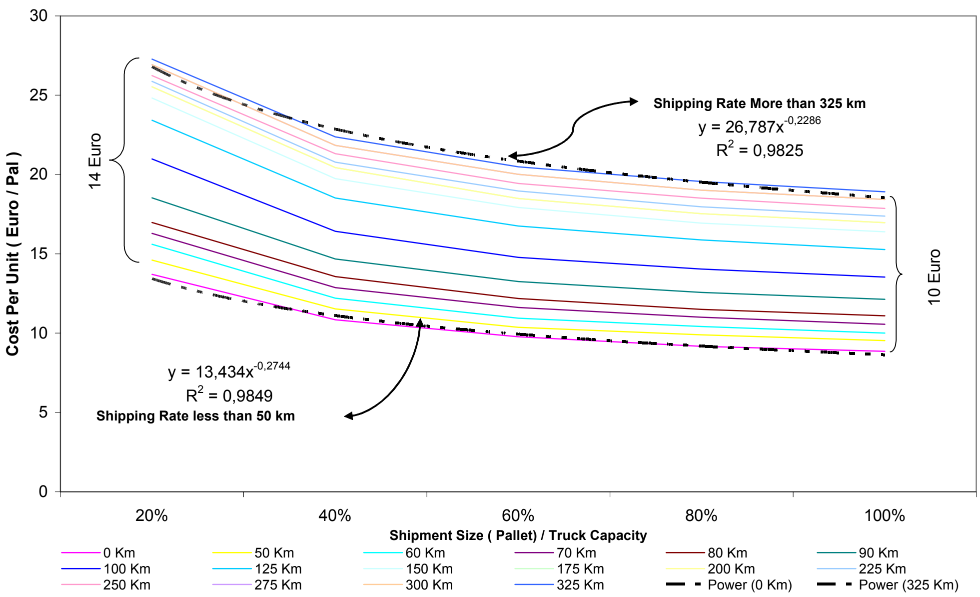


Figure 4.10 An Example of Short-Haul (Distance-Shipments Size Class) Freight Rates

4.4.7 Modeling LDNST Replenishments Orders Cycle Time

The orders were considered as a simulation entity and scheduled to be received on a daily basis. The downstream replenishment orders are received by the upstream supply chain locations, such as the central warehouse at 8:00 clock; the order-picking and delivery preparation processes take 6 hours, such that the shipments to downstream supply chain locations will be ready at 18:00 clock in the plant central warehouses shipping area.

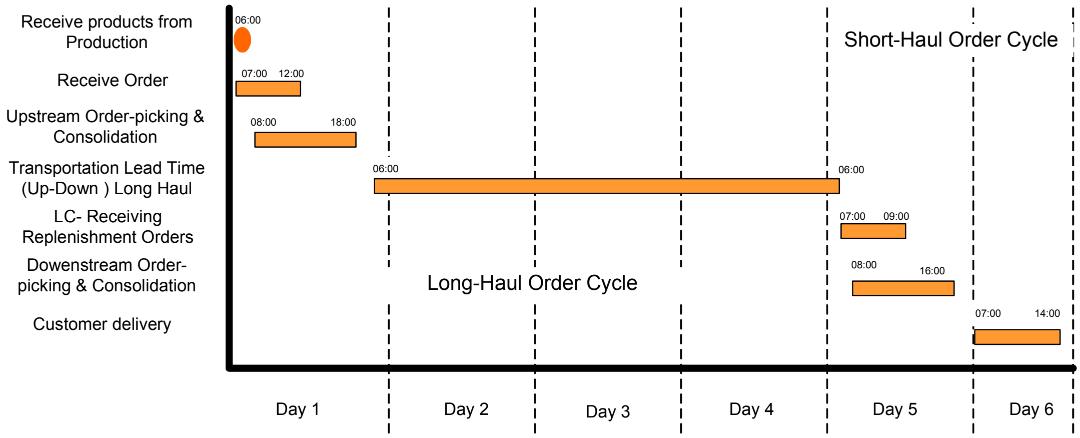


Figure 4.11 Order Activities Cycle Time (in Days)

The customers' orders are scheduled to be delivered in the morning at 6:00 clock only when the whole customer order is satisfied, otherwise a partial shipment order is placed depending on the order fulfillment strategy discussed later.

The maximum replenishments order delay between downstream locations and upstream locations can not exceed more than 5 working days and between downstream and customer locations not more than 1 delivery day as shown in Figure 4.11. Figure 4.12 depicts the modelled order activity delay. Only abstracted main supply chain activities are modeled. The order cycle time considered the weekend period in account.

4.4.8 Modeling Handling and Order-Picking Activities

It is easy to think of the warehouse as being dominated by product storage. There are many activities that occur as part of the process of getting material into and out of the warehouse. Most warehouses engage in the these activities (receiving, pre-packaging, put away, storage, order picking, packaging and or pricing, sorting and/or accumulation, and finally packing ad shipping), (Tompkins and Harmelink,1994).

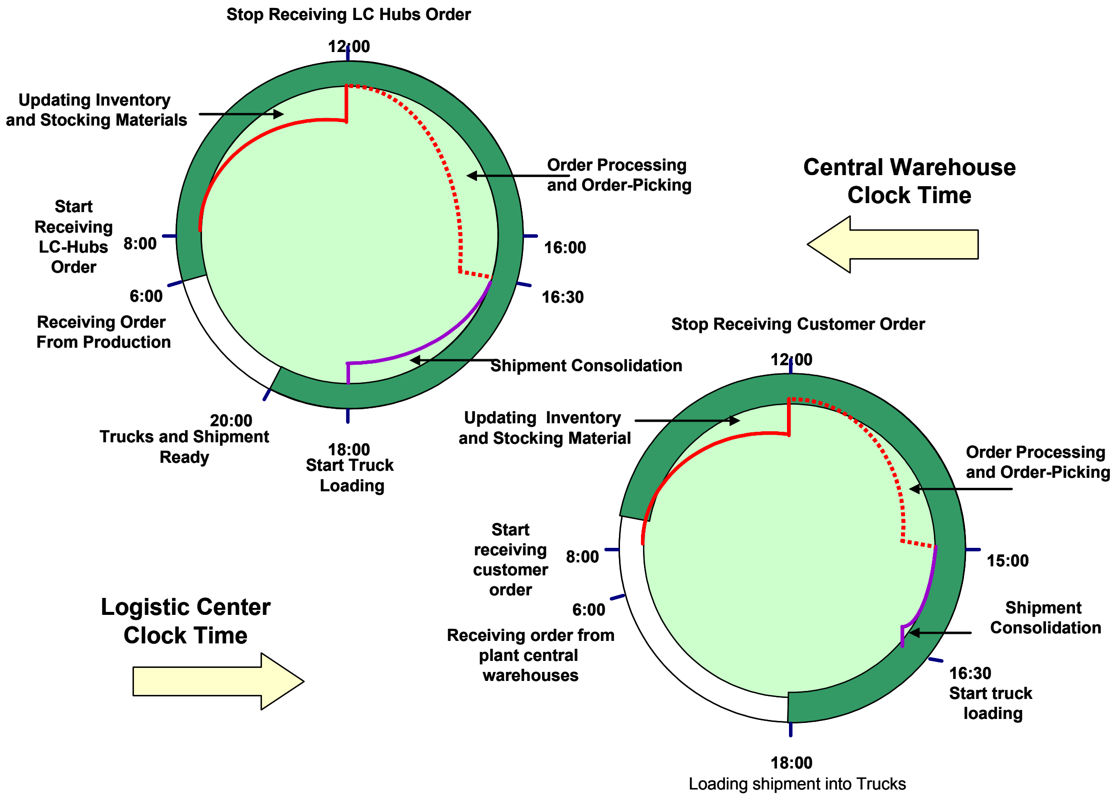


Figure 4.12 Order Activities and Events Schedule Cycle Time

Consider put away activity as the act of placing merchandise in storage. It includes both transportation and placement component, and the order picking activity as the process of removing items from storage to meet specific demand requirements represents the basic service that the warehouse provides for the customer, and is the function around which most warehouse designs are based.

In a real life supply chain customer demand may be met with a desired specific pallet height and quantity Q_{lp}^{FP} that differs in the amount of the production product full pallets Q_{ip}^{FP} . Such a case results in extra order picking activities. A perceptual Negative Order-Picking Policy (NOPP) was modelled in case the customer full pallet less than standard full product pallet $Q_{lp}^{FP} < Q_{ip}^{FP}$ which results in minimizing the number of picked cartons in the warehouse. For example, the proposed negative order-picking strategy mechanism of three customer orders cases is summarized in Table 4.4.

Table 4.4 An Example of Negative Order-Picking (NOPP) Policy

Product		X11111	
Production Full Pallet Quantity		32 Cartons	
Standard Negative Order-picking Condition	NOPP Ratio 50/50 %	up to 16 cartons	Picking to new pallet
		above 16 cartons	Picked down and send same pallet

Case I

Customer Full Pallet Quantity **24 cartons** **(Customer)**

Customer order	Action		
1 Pal	1x 24 cartons	-->	8 cartons picked down
1,5 Pal	1x 24 cartons	-->	8 cartons picked down
	1x 12 cartons	-->	12 cartons picked to new pallet
2 Pal	2x 24 cartons	-->	2x 8 cartons picked down

Case II

Customer Full Pallet Quantity **12 cartons** **(Customer)**

Customer order	Action		
1 Pal	1x 12 cartons	-->	12 cartons to new pallet
1,5 Pal	1x 12 cartons	-->	12 cartons picked to new pallet
	1x 6 cartons	-->	6 cartons picked to new pallet
2 Pal	2x 12 cartons	-->	2x 12 cartons picked to new pallet

Case II

Customer Full Pallet Quantity **32 cartons** **(Customer)**

Customer order	Action		
1 Pal	1x 32 cartons	-->	1 Full Pallet
1,5 Pal	1x 32 cartons	-->	1 Full Pallet
	1x 16 cartons	-->	16 cartons picked to new pallet
1,75 Pal	1x 32 cartons	-->	1 Full Pallet
	1x 24 cartons	-->	8 cartons picked down
2 Pal	2x 32 cartons	-->	2x 1 Full Pallet

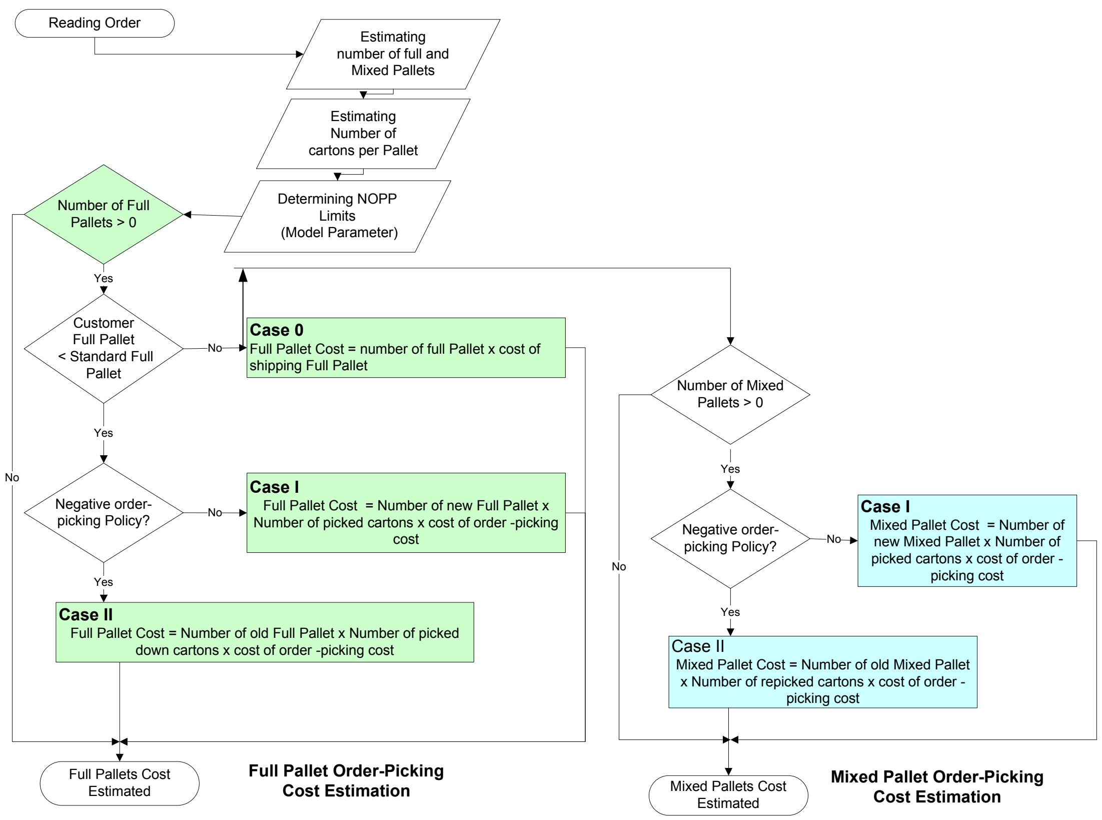


Figure 4.13 Estimating Handling and Order-Picking Cost

Figures 4.13 Shows the main steps in estimating the handling and order picking cost considering the proposed Negative Order Picking Policy – NOPP.

4.4.7 Modeling Pull Shipment Order Consolidation Algorithm

The modelled shipment consolidation was based on findings of Higginson and Bookbinder (1994, 1995), Cetinkay and Lee (2000), Axater (2001), three shipment consolidation policies can be classified as time policy dispatch orders at a scheduling shipping date, quantity policy dispatch orders when a fixed consolidated quantity is reached, and time-quantity policy as mixed policy of time and quantity policies. The first proposed replenishment consolidation policy is modelled based on a pull system (time policy of daily delivery with no temporal consolidation). The detailed pull shipment consolidation heuristic is summarized in the following steps.

4.4.7.1 Proposed Pull Shipment Consolidation Algorithm

Step 1: Generate aggregated forecasted demand quantity of product p in at supply chain location (k).

$$D^{k}_{pt} = \sum_{p=1}^{p}\sum_{l=1}^{l} d^{k}_{plt} \tag{4.7}$$

Step 2: Evaluate the product inventory position of product (p).

$$I^{k}_{pt} = I^{k}_{p\,t-1} - D^{k}_{pt} - B^{k}_{pt} + T^{k}_{pt} \tag{4.8}$$

Step 3: Check the product (p) inventory position against the aggregated product forecasted requirements.

$$\text{if } \begin{cases} I^{k}_{pt} > D^{k}_{pt} & \text{sufficient stock} \\ I^{k}_{pt} \le D^{k}_{pt} & \text{Generate replenishment order} \end{cases}$$

Step 4: If $I^{k}_{pt} \le s^{k}_{p}$ then add product p to pull replenishments order list (Ψ^{k}_{pull}) and replenishment order quantities list (CQ^{jk}_{t}) where:

$$Q^{k}_{pt} = (S^{k}_{p} - I^{k}_{pt}) + B^{k}_{pt} \tag{4.9}$$

and,

$$B^{k}_{pt} = \begin{cases} I^{k}_{pt} - D^{k}_{pt} & \text{if } I^{k}_{pt} \le 0 \\ 0 & \text{Otherwise} \end{cases} \tag{4.10}$$

Step 5: Prepare for shipping and consolidation for each product p type,

$$\text{if} \begin{cases} Q_{pt}^{k} \text{ MOD } \beta\, Q_{p}^{FP} = 0 & \text{Full truck load trips with } Q_{pt}^{k} \\ \text{otherwise} & \text{adjust } Qnew_{pt}^{k} = \beta_{p}^{FP} \quad \text{where } \beta = 1,2,3,.. \end{cases}$$

Step 6: Generate aggregated consolidation list (Ψ_{pull}^{k}), quantity (CQ_{t}^{jk}), and CQ_{t}^{jl}.

$$CQ_{t}^{jk} = \sum_{p=1}^{p} Q_{pt}^{k} + \sum_{p=1}^{p} Qnew_{pt}^{k} \qquad \text{Shipment to Hubs} \qquad (4.11)$$

$$CQ_{t}^{jl} = \sum_{p=1}^{p} Q_{pt}^{k} \qquad \text{Direct Shipments to customer} \qquad (4.12)$$

Step7: Estimate transportation requirements and truck filling degree.

$$\delta = \begin{cases} \dfrac{CQ_{t}^{jk}}{w_{jt}^{k}} & \textit{Shipment to Hubs} \\ \dfrac{CQ_{t}^{jL}}{w_{jt}^{k}} & \textit{Direct Shipment to customer} \end{cases} \qquad \text{Then,} \qquad (4.13)$$

$W_{jt}^{k} = \delta * w_{jt}^{k}$ and, (4.14)

$$\eta\% = \begin{cases} \dfrac{CQ_{t}^{jk}}{W_{jt}^{k}} & \textit{Shipment to Hubs} \\ \dfrac{CQ_{t}^{jl}}{W_{jt}^{l}} & \textit{Direct Shipment to customer} \end{cases} \qquad (4.15)$$

Figure 4.14 summarizes the detailed supply chain order replenishment business processes and activities according to the SCOR model levels 3, 4 based on the above mentioned pull replenishment consolidation heuristics; other integrated consolidation algorithms (VMI-1, VMI-2) will be discussed and presented later in chapter 8.

4.5 Selected and Proposed Supply Chain Performance Measures

The SCOR model classified performance measures in terms of effectiveness and efficiency in accomplishing a given task in relation to how well a goal is met. In the logistics and supply chain context, effectiveness is concerned with the extent to which goals are accomplished and they may include lead-time, stock out probability, and fill rate. Efficiency measures how well the resources are utilized, for which the measures may include inventory costs and operation costs (Mentzer and Konrad, 1991; SCOR Ver 6.1, 2004).

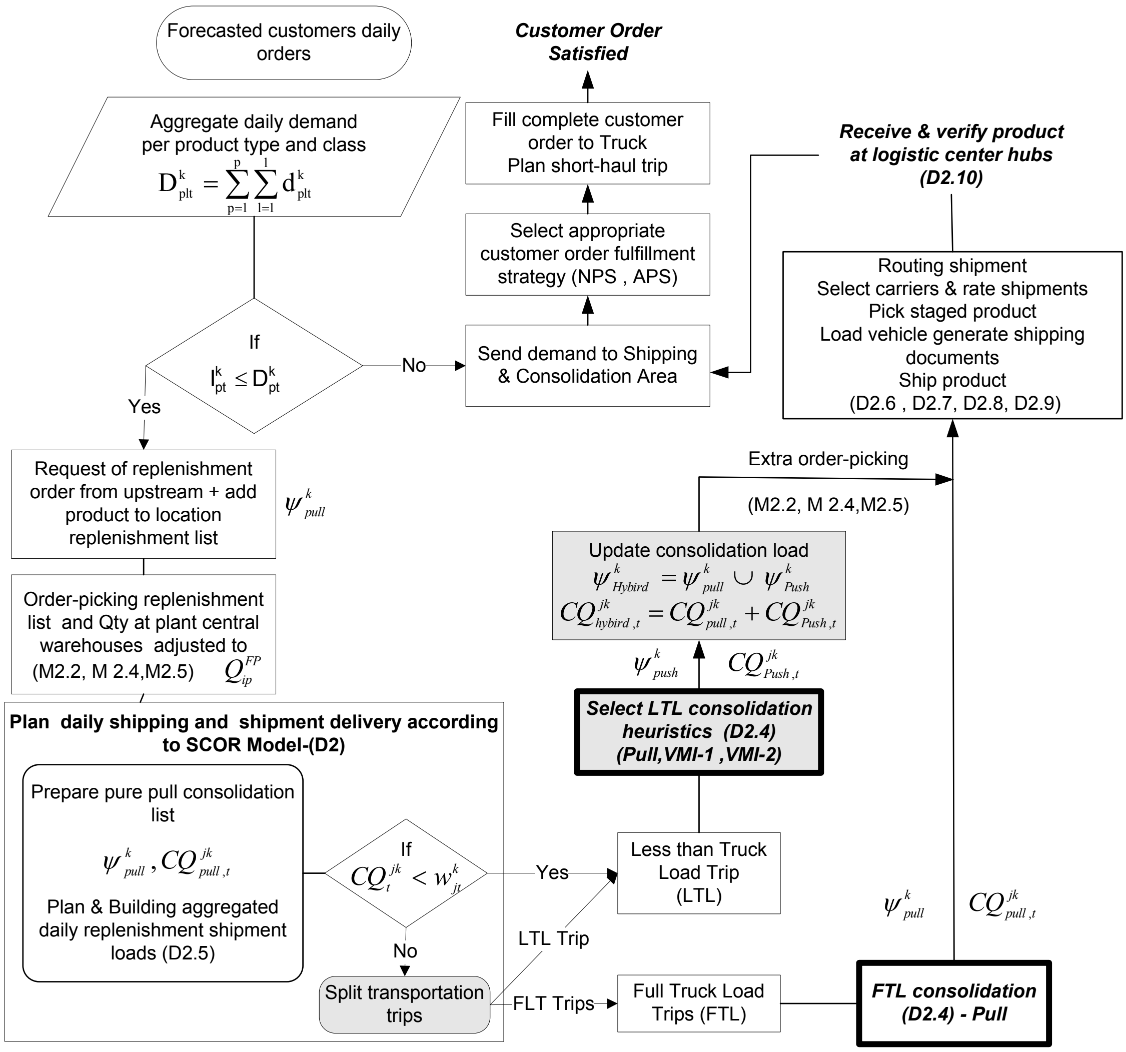


Figure 4.14 Proposed Pull and Hybrid Supply Chain Replenishment Algorithm
Number between () presents an appropriate SCOR model process element ID

Some firms may concentrate on operational efficiency, while others are more concerned with service effectiveness in the supply chain. The differences in the views of performance measures would lead to inconsistency in the performance measures used across supply chain members and consequently sub-optimize supply chain-wide performance (Bechtel and Jayaram, 1997; Caplice and Sheffi, 1995; Gunasekaran et al., 2001).

Among the previous supply chain performance conceptualizations, the SCOR model provides a useful framework that considers the performance requirements of member firms in a supply chain. Table 4.5 provides a useful framework for developing and constructing a corresponding instrument for supply chain performance measurement utilized in the simulation model. Several selected supply chain performance measures have to be distinguished between different simulation scenarios categorized by objectives that are based on i) Cost or profit, ii) Measure of customer responsiveness, iii) Productivity.

Table 4.5 Selected SCOR Performance Measures (SCOR, 2004)

Supply chain process	Measurement criteria	Performance Indicator
Customer facing	Supply chain reliability	• Delivery performance • Order fulfilment performance • Perfect order fulfilment
	Flexibility and responsiveness	• Supply chain response time • Production flexibility
Internal facing	Costs	• Total logistics management costs • Value added productivity • Processing cost
	Assets	• Cash to cash cycle time • Inventory days of supply • Assert turns

4.5.1 Measures Based on Supply Chain Cost

The supply chain cost drivers for each business process and activity discussed in chapters 3, and 4 were formulated as the most important value added activities according to the SCOR Model. The following were the main cost drivers that form the total supply chain cost:

1. Supply Chain Network Transportation Cost (SCNT)=(Inbound Transportation Cost) + (Long-haul outbound transportation cost) + (Short-haul Outbound transportation cost) + (Direct Long-haul transportation cost)

$$\text{SCNT} = \sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} Q_{pijt} * C_{ij} + \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} Q_{pjkt} * C_{jk} + \sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{t=1}^{T} Q_{pklt} * C_{kl} + \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{t=1}^{T} Q_{pjmt} * C_{jm} \tag{4.16}$$

2. Supply Chain Network Inventory Cost (SCN) = (Average ending inventory in logistic center hubs * inventory holding carrying cost per pallet per period). The logistic center hubs average ending inventory is estimated by equation 4.17.

$$I^{k}_{All,t} = \frac{\sum_{k=1}^{k}\sum_{p=1}^{P}\sum_{t=1}^{T} I^{k}_{p,t}}{T} \tag{4.17}$$

$$\text{SCNI}_1 = \sum_{k=1}^{K}\sum_{t=1}^{T} I_{All,t}^{k} * h_t^k \quad (4.18)$$

Sometimes, multi-item inventory models assume different holding cost per each product type, so equation 4.18 will be adjusted to equation 4.19.

$$\text{SCNI}_2 = \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T} I_{p,t}^{k} * h_{p,t}^{k} \quad (4.19)$$

3. Supply Chain Network Ordering Cost (SCNO) = Total number of complete orders * ordering cost

$$\text{SCNO} = \sum_{j=1}^{J}\sum_{t=1}^{T} O_t^j * A_t^j + \sum_{k=1}^{K}\sum_{t=1}^{T} O_t^k * A_t^k \quad (4.20)$$

4. Supply Chain Network Handling Cost (SCNH) = (Full Pallet Handling cost) + (Mixed Pallet Handling cost) + (Order-picking cost)

$$\begin{aligned}\text{SCNH} = \\ &\sum_{j=1}^{J}\sum_{m=1}^{M} MP^{jm} * MPC + \sum_{j=1}^{J}\sum_{m=1}^{M} FP^{jm} * FPC + \sum_{j=1}^{J}\sum_{m=1}^{M} OPK^{j} * OPKC^{\text{j}} \\ &+ \sum_{k=1}^{K}\sum_{l=1}^{L} MP^{kl} * MPC + \sum_{k=1}^{K}\sum_{l=1}^{L} FP^{kl} * FPC + \sum_{k=1}^{K}\sum_{l=1}^{L} OPK^{k} * OPKC^{\text{k}}\end{aligned} \quad (4.21)$$

5. Supply Chain Network Warehousing Cost (SCNW) = (receiving cost) + (Shipping Cost)

$$\begin{aligned}\text{SCNW} = &\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} Q_{pijt} * Inc^{j} + \alpha * \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} Q_{pjkt} * Outc^{k} \\ &+ \beta * \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{m}\sum_{t=1}^{T} Q_{pjmt} * Outc^{k} + \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} Q_{pjkt} * Inc^{k} \\ &+ \sum_{p=1}^{P}\sum_{k=1}^{k}\sum_{l=1}^{L}\sum_{t=1}^{T} Q_{pklt} * Outc^{k}\end{aligned} \quad (4.22)$$

Finally, Total Supply chain Network Cost (TSCN) will be

TSCN = SCNT + SCNI + SCNO + SCNH + SCNW (4.23)

4.5.2 Measures Based on Productivity

1. Total number of shipments trips = summation of total long-haul shipment trips only.
2. Average number of quantities shipped = total quantities demanded / total number of shipments.

3. Inventory Turnover (DBK-1): total simulated location throughput in pallets to location average inventory Level, The *evaluated turnover rate* measures the quality of the inventory management in the warehouse. A monetary evaluation is made of the inventory to calculate this value. The observation of these values provides information about the capital bound in the distribution warehouse. (VDI-4400,2000)

$$\text{DBK - 1} = \frac{\sum_{p=1}^{P}\sum_{k=1}^{k}\sum_{l=1}^{L}\sum_{t=1}^{T} Q_{pklt} * Outc^{k}}{I_{All,t}^{k}} \tag{4.24}$$

4.5.3 Measures Based on Customer Responsiveness.

Four selected qualitative performance measures service levels were estimated, proposed by Silver et al. (1998), Chopra and Meindl (2004), and VDI-4400(2000) as:

4. Supply chain location order-lines/product service level (P1, DLS-1%): defined as the fraction of just in time product orders-lines that are filled from the available inventory without being back ordered in the logistic center hubs.

$$\text{DLS-1\%} = \frac{\text{JIT satisfied product order - lines}}{\text{Total number of simulated prodcut order - lines}} * 100 \tag{4.25}$$

The supply chain product service level (N-DLS-1%) is estimated as:

$$\text{N - DLS-1\%} = \frac{\sum_{i}^{k} DLS - 1}{|\text{K}|} * 100 \tag{4.26}$$

5. Just in time order delivery service level (DLS7%): this measure considers the fraction of the total number of orders submitted completely in just in time without delay to the total number of simulated orders. This measure is useful in a situation where multiple items are considered, and where the customer order may be delayed caused by stocking out of specific order lines. That results in delaying the complete order until the partial order has been submitted.

$$\text{DLS - 7\%} = \frac{\text{Number of complete orders delivered JIT}}{\text{Total number of simulated orders}} * 100 \tag{4.27}$$

The supply chain delivery service level (N-DLS-7%) is estimated as:

$$\text{N - DLS - 7 \%} = \frac{\sum_{i}^{k} DLS - 7}{|\text{K}|} * 100 \tag{4.27}$$

Those supply chain performance measures will be assessed in evaluating and comparing the simulation experiments scenarios and proposed distribution strategies.

4.6 Description of Distribution Supply Chain Network Case Study

A real life complex distribution network belonging to a food supply chain network motivated this thesis and was modelled and analyzed using the developed LDNST tool. In this thesis only the German supply chain will be considered as a thesis case study. Considering the German supply chain, several brands of products and about 3000 SKU's per day (stock keeping unit) are produced about (300) selected products were considered. Produced in 3 plant central warehouses, distributed to 24 regional logistic center hubs to cover a daily demand from approximately 5000 retailers and customer demand points spread over Germany. Figure 4.15 shows the generic German distribution supply chain network and Figure 4.16 shows the locations of supply chain components. The company suffers from several profit-pressures due to the following problem:

1. Higher uncertainty of demand has an effect on extra products safety stock inventory levels, related inventory costs and higher transportation costs,
2. A massive concentration among their customers in the retail sector,
3. Lower just in time delivery service levels, especially big customers (wholesalers),
4. The challenge of the "Europeanization" of the market.

The supply chain initial calibration performance measures were estimated and evaluated by implementing the LDNST model and validated by a supply chain logistics team in the company. That will be considered as the initial reference model (REF); the results will be summarized later as the main interest is to concentrate on the following points which will be discussed in the next chapters in more detail:

1. How have the logistic activities, functions, and aspects been integrated?
2. What are the advantages to be gained and obtained from the integration of the inventory, distribution, and transportation function within the supply chain?

3. What are the effects and the impacts of different replenishments strategies on the supply chain performance measures?

4. Developing and proposing a cooperative and comparative supply chain replenishments strategy through joining the transportation activities and inventory decisions.

The next sections will be concerned with analyses of the case problem input data and performing an initial calibration that fits the LDNST requirements, and this hybrid model will be integrated with the developed and designed simulation model, and heuristics algorithms - based techniques (Aldarrat et al., 2005).

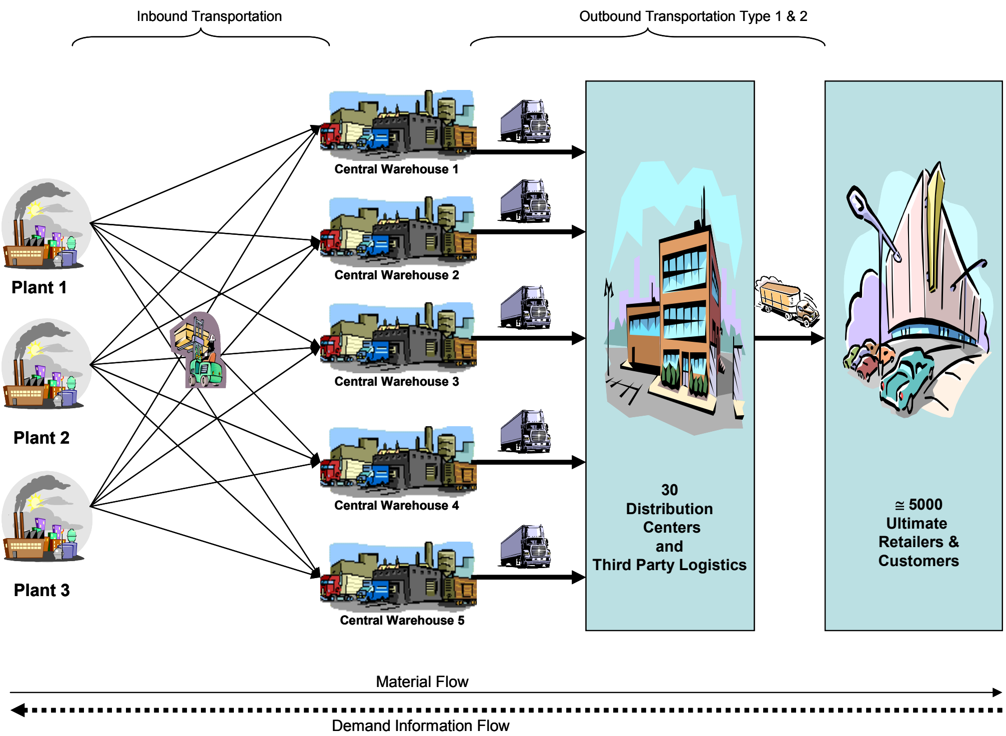
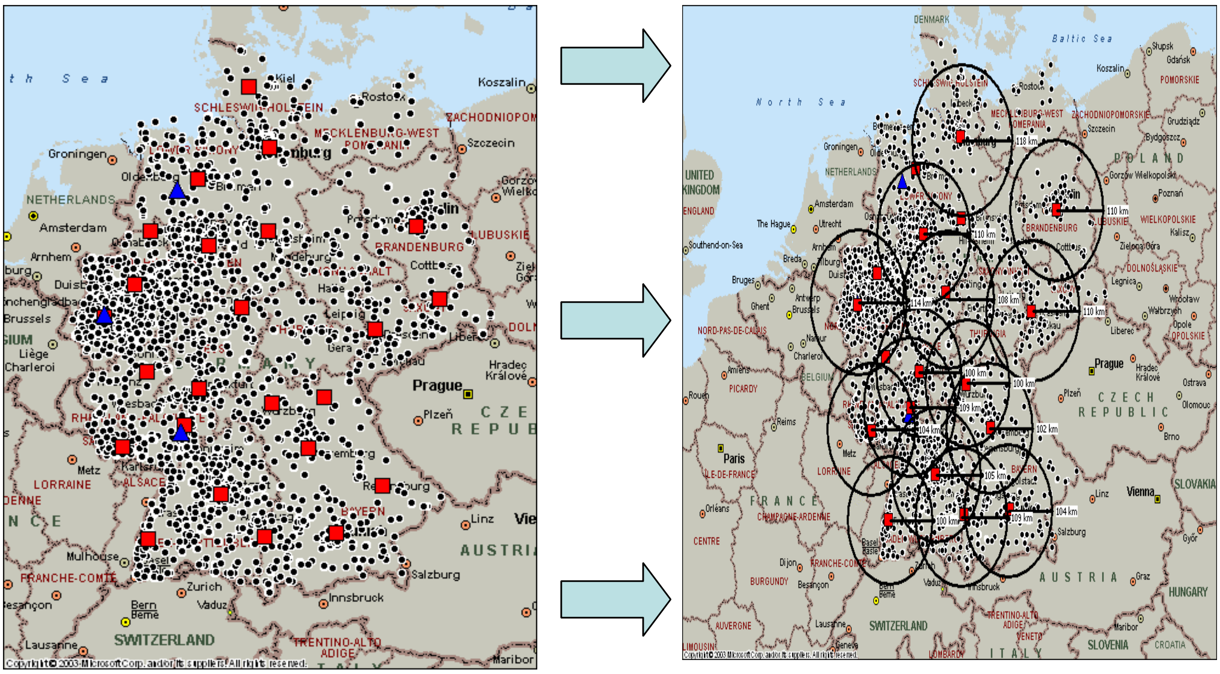


Figure 4.15 Generic German Distribution Supply Chain Network

4.6.1 Supply Chain Customer Location and Allocation (Model I)

Three types of customer orders assigned to the logistic center hubs were classified as follows: type-1 (wholesalers), type-2 (retailers), and type-3 (local demand requirements for supplying other networks and locations. Those two main customer types were allocated first to optimize the location and allocation of the customer's points with the objective of minimizing the total distance travelled and minimizing the short-haul distribution delivery time.

A location-allocation model was performed based on a hybrid ADD/Drop fixed charge location heuristics (Sule, 2001; Daskin, 1995). The distance travelled was estimated with respect to a GPS tool linked to the developed supply chain library DLL model and LDNST input data model according to location zip code, Figure 4.16 illustrates the final graphical allocation of the 19 optimized logistic center hubs with three customers and other 5 logistic center hubs with only type-3 customers orders, with an objective function of minimizing total distance travelled cost and achieving a maximum covering area of 1 day delivery. Figure 4.17 illustrates the optimized final allocation of customer types to logistic center hubs. Considering that logistic center hubs 1, 4,11,16,23 operate as collecting local demand hubs.



Candidate Supply Chain Locations

Allocation of Supply Chain Locations
(Maximum Covering = 95 % within 3 hour)

Plants Central Warehouses | Logistic Center Hubs | End Customers (Wholesalers/Retailers)

Figure 4.16 German Supply Chain Locations and Allocation Model

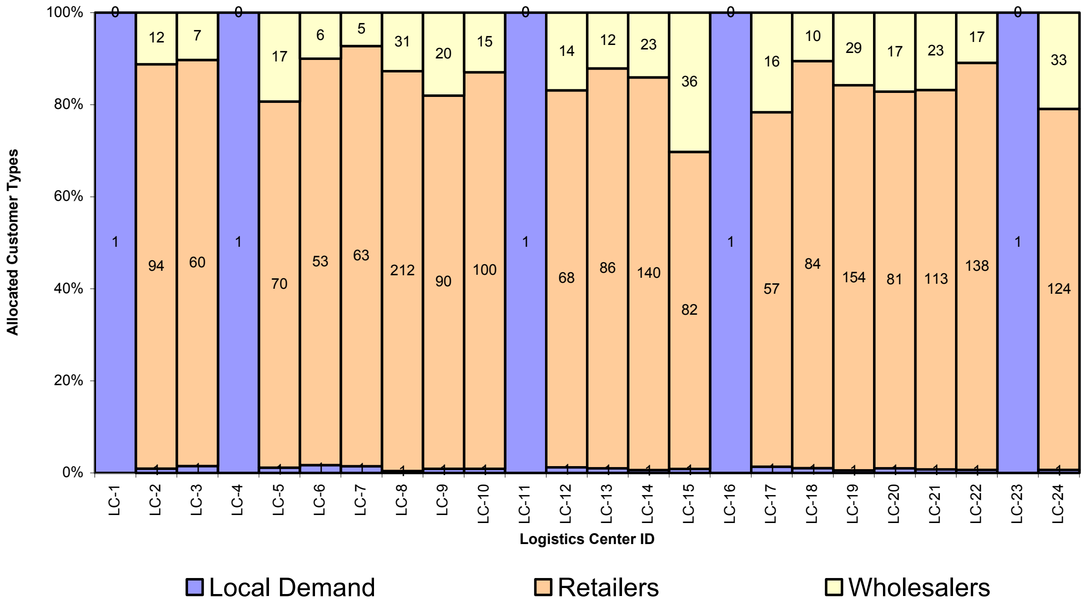


Figure 4.17 Allocation of Customers Orders Type to Logistic Center Hubs

4.6.2 Supply Chain Demand Variability

4.6.2.1 Logistic Center Hubs Demand Variability

The real life supply chain demand data of the 24 logistic center hubs are collected and analyzed, assuming an independent relationship between demand patterns in each logistic center hub. Three types of customers' orders considered by the logistic center hubs were as type-1 wholesaler's demand, type-2 retailer's demand, and type-3 local logistic center hubs demand. Five out of twenty-four logistic center hubs deal with collecting the local demand type-3 only and there are no customer orders; those logistic center hubs are LC-1, LC-4, LC-11, LC-16, and LC-23. As mentioned before, the supply chain model should be capable of capturing the system state at each moment in time in order to calculate system performance measures. Customer orders contain several orderliness each order line represents demand of certain types of products in the smallest unit load form (form-1 see section 4.4.2).

Modeling a supply chain with multi-product types is one of the most complex and important aspects of the recent research direction in supply chain research problems. Most of the available research assumes homogeneous demand patterns. Hwarng (2005) studied the impact of comparing realistic demand distribution against normal demand distribution assumption. This study of Hwarng (2005) shows higher significant backorder levels when the realistic demand was utilized. Which proves that using a different demand distribution realistically represents the demand characteristics and leads to an increase in average backorder and total stock out of as much the demand variability of both are large; when the demand distributions is not too simplified to normal. Such a conclusion assists to utilize the realistic demand distribution instead of simplifying them to normal distribution assumptions.

Analyses of the logistic center hubs demand were performed to estimate the appropriate fitting distribution. The average daily demand requirements at the logistic center hubs are summarized in Table IV.6. The German supply chain demands orders during the period of one fiscal year were provided by the company. The main data set analysis is based on daily sales history of each customer order.

This analysis is crucial in order to determine the appropriate demand distribution at each logistic center hub. The application was determined using distribution fitting software MINTAB 7. The test for goodness-of-fit was conducted to check the fitting of the demand data to the proposed probability distribution. The appropriate theoretical distribution for each logistic center hub and its relative goodness-of-fit are shown in Table IV.1 Appendix IV. Figure IV.1 shows the results of the distribution fitting software MINTAB 7.0 and the normality test of 4 selected logistic center hubs LC-1, LC-8, LC-16, and LC-19.

4.6.2.2 Plant Central Warehouses Demand Variability

The historical sales data and the proportion of the materials to be delivered from the plant central warehouses were also established. Based on the daily sales volume, it was found that about 62% of the demanded materials supplied by the plant central warehouse-3 and 28% of the materials were sent by plant central warehouse-1; only 12 % of the demanded materials were covered by plant central warehouse-2.

The above identified demand distributions and proportional demand volumes were linked to the LDNST simulation model. The realistic demand distribution patterns Figure 4.18 shows the demand variability of plant central warehouses 1, 2, 3 respectively classified according to customer orders types.

The test for goodness-of-fit was conducted to check good distribution fitting to the aggregated demand of plant central warehouse. The appropriate theoretical distribution was found to be the normal distribution in all plant central warehouses.

4.6.3 Calibration Phase Case Study and Simulation Experiments Assumptions

The following are the most important assumptions considered in designing the simulation model:

- Dynamic process environments,
- The orders determine the flow of goods, in all orders, the sources are plant central warehouses and the sinks are the end customers demand type,
- Every plant central warehouse is assigned to all logistic center hubs (multi sourcing condition),
- Every customer demand point is assigned uniquely to one logistic center hub (No lateral transshipment allowed),
- Standard European Pallet (SEP) with maximum of 2.4 m height will be used to move the full pallet product from the warehouses to logistic center hubs with the following dimensions: (Length: 1.2 m * Width: 0.8 m * Height: 2.4 m),
- The mixed pallet of the following dimensions will be used to move the product from the logistic center hubs to retailers and customers: (Length: 1.2 m * Width: 0.8 m * Height: 1.8 m * Percentage of filling space: up 90%),
- Transportation costs based on the direct tour with one destination will be accounted for, with no routing allowed,
- The simulated truck capacity for long and short-haul is (34-38) SEP,
- Transportation lead-time from plant central warehouse to logistic center hub is set to an internal delay of 1-4 days,
- No specific quantity or time temporal shipment consolidation procedure was implemented only the above mentioned daily shipment consolidation algorithm in section 5.2.7 was applied first as a pure pull model,
- It is allowed to stack 2 pallets above each other (if possible) with a maximum height of 2.4 meter (truck consolidation strategy), and
- The distribution supply chain network operated under the pure pull network concept, and the production operates under the push strategy.

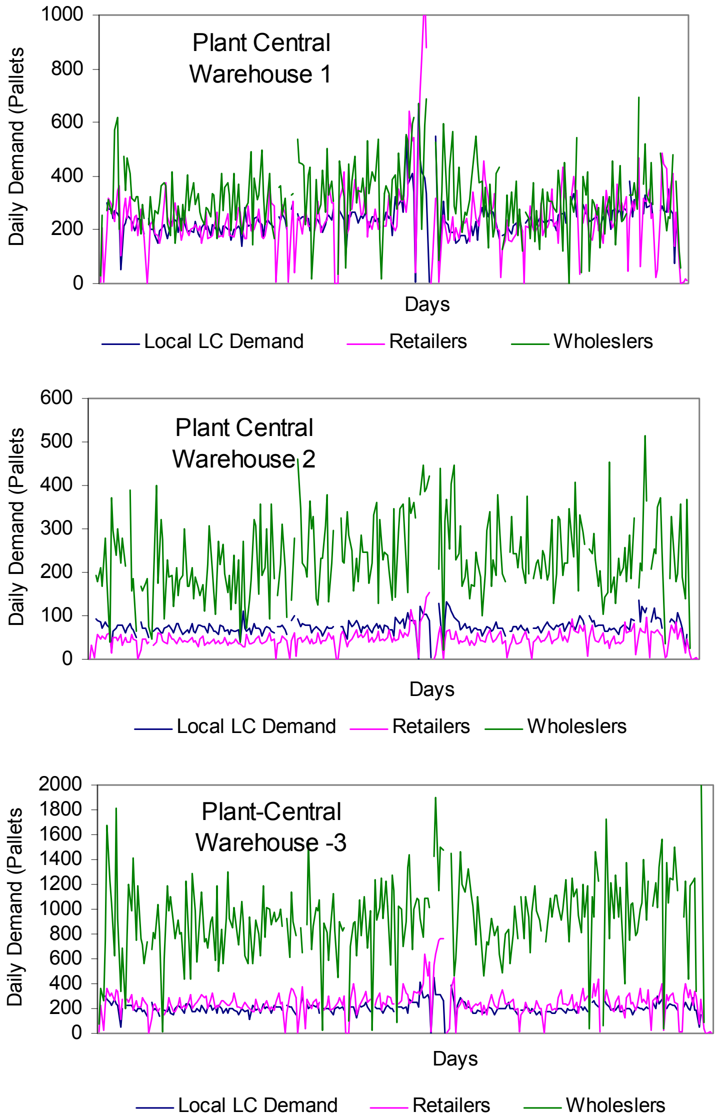


Figure 4.18 Variations of Aggregated Customer Demand Types

4.7 Estimating initial Performance Measures (Reference Model)

As a basis for the simulation study a reference distribution model should be constructed. Two scenarios concerning the order fulfilment strategy were conducted and the best one will be considered later as an initial reference model (0).

The customer orders contain several order-lines, with each order line representing product demand, as described in Figure 4.19. The modelled order fulfilment decision activates when insufficient inventory of a certain product type occurs, which results in choosing one of two decisions; no partial order shipment or partial order shipment allowed.

Location LC-19 Shipment Entity

Shipment_Date	Shipment ID	From	TO	Number of Pallets	Occupied Places	Weight (kg)	Shipping Rate
08-Sep-04	T 2312	LC-19	1	2,75	3	304,81	45,0000 P
08-Sep-04	T 2313	LC-19	2	2,91	3	316,308	19,0000 P
08-Sep-04	T 2314	LC-19	X	12,2	12	274,074	12,0000 P
08-Sep-04	T 2315	LC-19	3	1,24	1,5	143,946	19,0000 P
08-Sep-04	T 2316	LC-19	4	2,32	2,5	269,652	40,0000 P
08-Sep-04	T 2317	LC-19	5	17	8,5	848,16	13,6300 P

Order (X) Entity — Order lines

Order_Date	Order-Nr	Product-ID	Qty	TO	From	Source	Full_Pallet_Qty	Full-Pallet Hight(Cm)	Customer_Type
07-Sep-04	0	Product-1	576	x	LC-19	1	2880	2250	1
07-Sep-04	0	Product-2	6	x	LC-19	3	144	2220	1
07-Sep-04	0	Product-3	144	x	LC-19	1	3168	2020	1
07-Sep-04	0	Product-4	40	x	LC-19	1	640	2390	1
07-Sep-04	0	Product-5	100	x	LC-19	1	640	2390	1
07-Sep-04	0	Product-6	10	x	LC-19	3	640	2190	1

Figure 4.19 Order and Shipment Entity Types Example

Eppen and Schrage (1981) discussed an allocation rule called Fair Share (FS) rationing, where the available inventory is rationed so as to maintain equal stock out probabilities for all end-stock points. De Kok (1990) introduced the consistent Appropriate Share (CAS) rationing rule using cost and service (fill rate) as the criteria that is deemed to be more customer-oriented. Banerjee et al. (2001) presents three order fulfilment policies, namely No Partial Shipments (NPS), Availability-based Partial Shipments (APS) and Dynamic Partial Shipments (DPS) using simulation modelling approach. With the supplier filling the customer orders on a first-come-first-serve basis, they showed that APS and DPS provide considerably superior results in terms of stock-out; than the NPS improved the service levels policy, albeit through increased shipments. The NPS performs better in minimizing the transportation cost. Considering the Banerjee et al. (2001) model, the proposed two order fulfilment policy was modelled as follows:

- No Partial Shipments (NPS)
- Availability – based on partial shipments (APS)

Under the NPS policy, no partial shipments are allowed. If the customer order entity is unsatisfied because some products demand quantities are unavailable, then the entire order is delivered later.

In APS policy the logistic center hubs shipments are based on the adequacy of its available order lines of inventory; the shipment lot is delivered at the scheduled time and the unsatisfied backlog demand will be delivered in the next shipments. This is in marked contrast to the order splitting procedure suggested by De Kok (1994). The purpose of the partial shipment is purely stock out avoidance at the retail level while increasing the short-haul transportation cost rapidly.

Several numerous simulation experiments were conducted to investigate the effect of the order fulfilment policy on the transportation cost. Table 4.6 summarizes the modelled order fulfilments policy based on customer order type.

Table 4.6 Customers Order Type and Order Fulfilment Policies

Wholesalers order Type	NPS
Retailers order Type	NPS
Local Location demand	APS

The simulation results of two initial experiments revealed the following: the first one assumes that no partial shipments were allowed (NPS); the second experiment was conducted under the assumption that availability partial shipments (APS) were implemented as supply chain order fulfilment policy. Table 4.7 summarizes the results of both experiment policies, assuming that the LC inventory control parameters based on the parameters of the benchmark set 6 are discussed later in chapter 7.

Table 4.7 Order Fulfilment Policy Cost Supply Chain Performance Measures

Cost Description	**Model**	**NP Policy**	**APS Policy**
Activity Based Costing Model	Order Cost	113.432 €	137.488 €
	P-CW Outgoing Cost	540.635 €	540.635 €
	LC-Hubs Outgoing Cost	726.627 €	745.327 €
	LC-Hubs Incoming Goods	533.025 €	533.025 €
	Handling Cost (Order-picking)	913.557 €	914.711 €
Transportation Cost	Long-Haul Transportation	6.236.329 €	6.236.329 €
	Short-Haul Transportation	6.465.542 €	6.892.611 €
Inventory Model	Inventory Cost	2.160.756 €	2.146.248 €
Supply Chain Service Level	N-DLS1%)	97,98%	98,98%
	N-DLS7 %	79,02%	80,28%
Total Supply Chain Model Cost		17.689.903 €	18.146.374 €

From Table 4.7, we can see that a major reduction of 2.5% in the total supply chain cost is achieved when the NPS order fulfilments policy is utilized. The highest reduction part of ordering cost were achieved when the orders under NPS policy will wait until the entire customer order lines are available. This shows the effect on reducing the short-haul transportation cost with a percentage of 6.20 % compared with the policy of APS.

The second simulated experiment was implementing the NOPP policy discussed in section 4.4.8, considering the NPS policy that shows the effect of the NOPP policy in reducing the order-picking cost as summarized in Table 4.8.

Table 4.8 Effect of NOPP Policy on Handling Cost

Models	**With NOPP**	**Without NOPP**
Order-Picking Cost	848,243 Euro	1,000,000 Euro

Table 4.8 shows that applying the NOPP policy reduces the handling cost (order-picking cost) more than 15 –17 %. The NOPP policy with 50/50 ratios will be utilized in further experiments. Those achieved performance measures will be considered as main reference supply chain performance measures in further simulation and distribution strategies.

5.0 Distribution Supply Chain Simulation-Optimization Methodology

5.1 Introduction

This chapter discusses the methodology and the procedures made to construct and evaluate several distribution supply chain scenarios and configurations utilizing the developed simulation model described in chapters 3 and 4.

First, we consider all the empirical results that were obtained from chapter 4 (calibration phase) to be thesis reference model considered as supply chain performance measures for further evaluations. Well-known distribution strategies proposed in the literatures considering practical implementation to the supply chain have been simulated. The developed simulation studies and experiments were run on a Pentium IV computer CPU 3.2 GHz. Several distribution strategies have been evaluated and the proposed optimization scenarios are presented later in chapters 6, 7, and 8.

The main proposed supply chain distribution scenario covered in this thesis can be summarized as follows:

1. Pure and Hybrid Hub and Spoke Distribution Network,
2. Safety Stock Inventory Allocation Strategy,
3. Integrated Inventory and Long-Haul Transportation Consolidation Shipments, and
4. Transshipment Points Concept.

5.2 Evaluation of Simulation Results Approach.

The proposed evaluation simulation experiments methodology illustrated in Figure 5.1 depicts the general procedure of evaluating proposed distribution strategy.

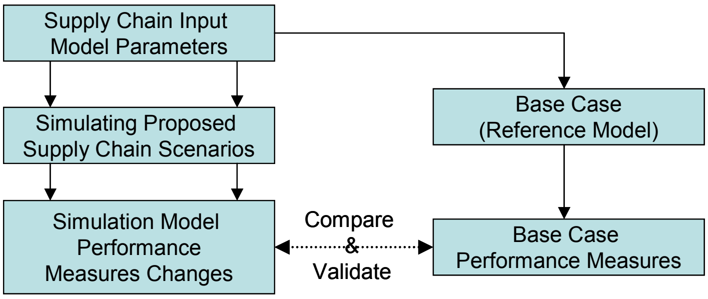


Figure 5.1 General Evaluations Procedure

The evaluation process is conducted in 3 main phases (1, 2, and 3) and performed sequentially as shown in Figure 5.2.

5.1.1 Phase 0 and I (Calibration Phase)

The Phase 0 and I seeks to allocate and optimize the location and allocation of the logistic center hubs to customers with the objective of minimizing the total distance travelled and minimize the delivery time, so the customers' orders may be received within a 1 day order cycle, with an appropriate order fulfilment strategy and order picking policy, this phase is implemented in chapter 4.0

5.1.2 Phase II

Phase II searches to optimize the performance of the whole supply chain network through evaluating and simulating the previously proposed distribution strategy in section 5.1. A special focus in this phase was made to minimize the long-haul supply chain transportation cost between the plant central warehouses and the logistic center hubs, where the major sharing of those costs in the total supply chain cost occurs. The short-haul was modelled to estimate the upper bound limit (no routing decisions were made).

The highest long-haul transportation costs will occur when the replenishment trips between the plant central warehouses and logistic center hubs are made by less than truckload trips. Several safety stock allocation distribution strategies will be examined and proposed in this phase in terms of minimizing the less than truck load trips by implementing and proposing advanced coordinated and integrated replenishment strategies.

Those proposed advanced coordinated and integrated replenishment strategies seek the possibility of increasing the replenishment truck filling degree within the objective of minimizing the long-haul transportation costs, supply chain total supply chain cost, and improving the logistic center’s performance measures.

Two proposed advanced coordinated and integrated replenishment strategies and shipment consolidation heuristics will be presented and evaluated in chapter 7 named as SF-PCR-VMI1 and SF-ADI-VMI2. Several nominated supply chain network strategies will be examined, considering that all the transportation activities made in phase II were based on the assumption of a one to one trip without implementing vehicle routing (no milk run concept).

5.1.3 Phase III

In phase III advanced supply chain configurations will be proposed and examined such as transshipment points and a special sub-transshipment points supply chain network, considering the optimized shipment consolidation heuristics recommended above in phase II. Figure 5.2 shows the generalized proposed simulation based heuristics methodology, and Figure V.1 in Appendix V summarizes some of the main selected simulation experiments and strategies which will be discussed in detail in chapters 6, 7 and 8.

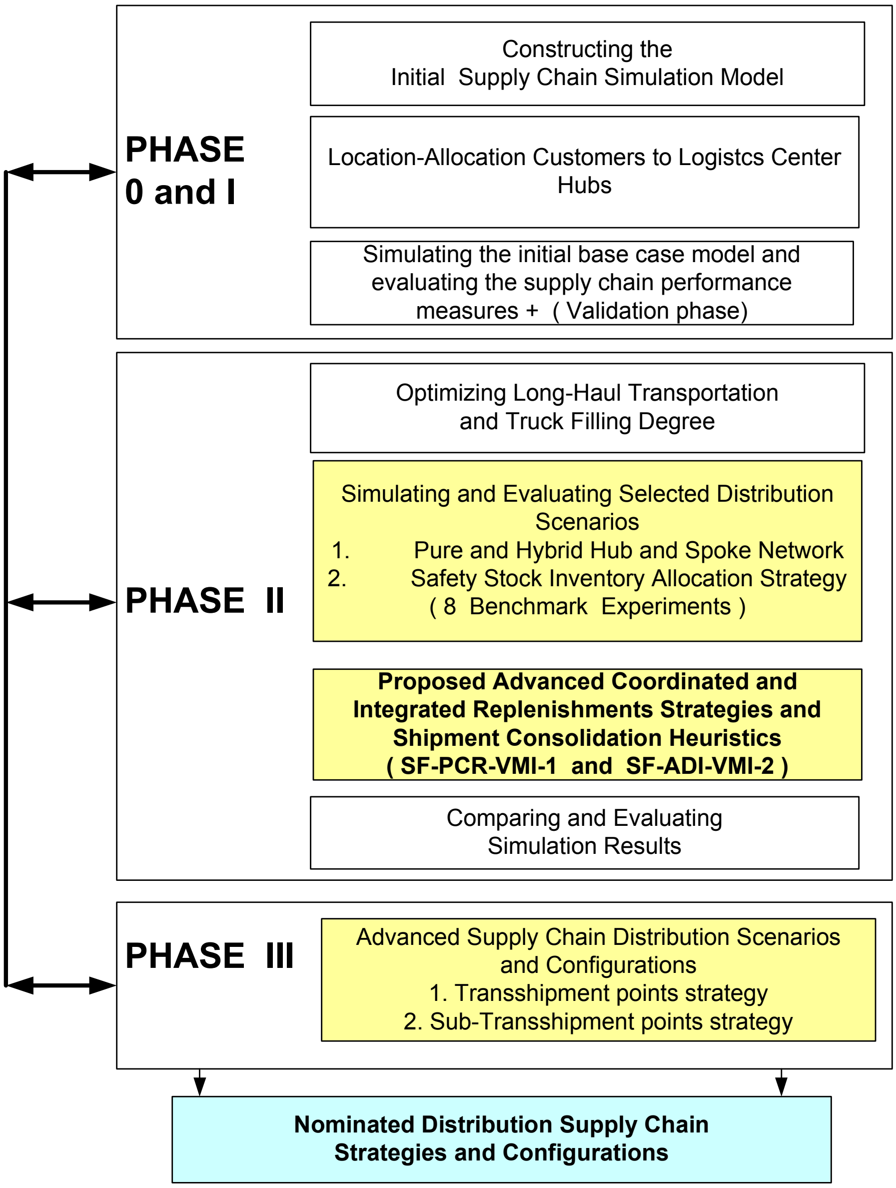


Figure 5.2 The Proposed Thesis Simulation Based Heuristic Optimization Methodology.

6.0 **Modeling** Pure and Hybrid Supply Chain with Direct Shipments

6.1 Introduction

This chapter explains, and analyzes the settings of first simulation experiments. Those experiments carried out a total of two main distribution strategies which will be examined and analyzed according to the distribution supply chain network presented in chapter 4.0

Those two experiments analyzed the impacts and the effects of applying the direct shipments from the plant central warehouses to the end customer terminal points without going through the regional logistic center hubs.

Finally, all the simulation results are summarized and final conclusions are reported at the end of this chapter.

6.2 Hybrid Hubs Networks with Direct Shipments Strategy

Logistics planning involves decisions on the flow of physical goods from locations they are available to where they are demanded. The increasing trend of using logistics providers (LSP's) has enabled the information of hub-and-spoke networks in the physical goods industry. Goods from different origins are consolidated at hubs, and shipped to destinations. The benefit is the economies of scale as a result of consolidation. Hub-and-spoke networks have been classified into two types:

1. Pure Hub-and-spoke network, and
2. Hybrid Hub-and-spoke network.

In a pure hub-and-spoke network, direct deliveries are not considered. Therefore, all goods have to flow through the hubs (Aykin, 1995; Das et al., 1996; Chong et al. 2006 and Watts, 2000). In hybrid hub-and-spoke networks goods can flow in either direction. Such that direct shipments strategy means shipping the customer demand directly from the plant central warehouses to end customers' stores without going through distribution center hubs or any intermediate points.

As mentioned in chapter 5 the first phase in the decomposition methodology can be implemented by satisfying some customer daily demands from the plant central warehouses directly instead of sending them through the logistic center hubs only when economies of scale justification are presented.

6.2.1 Direct Shipments Simulated Scenarios

The following scenarios and models are described below:

Model Nr. 1: (Pure Hub Network, no direct shipments) in this model customer daily demand is submitted from logistic center hubs and no direct shipments are allowed.

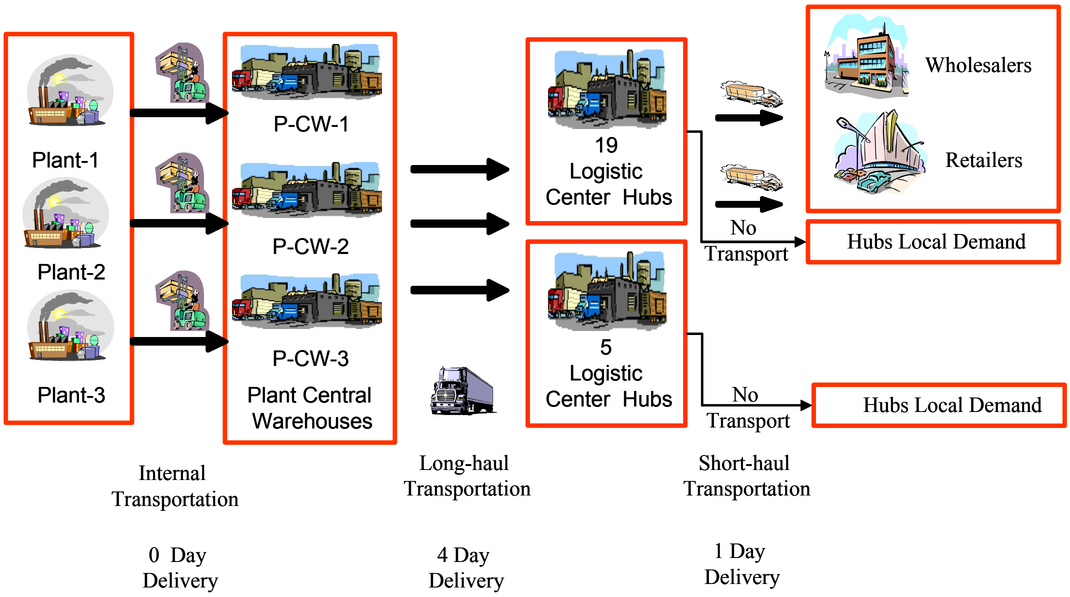
Model Nr. 2: (Hybrid Hub Network, with direct shipments) Customer daily demand may be supplied directly from plant central warehouses only when the daily demands are relatively equal to full truckload.

6.2.2 The Logistic Center Hubs Inventory Control Model

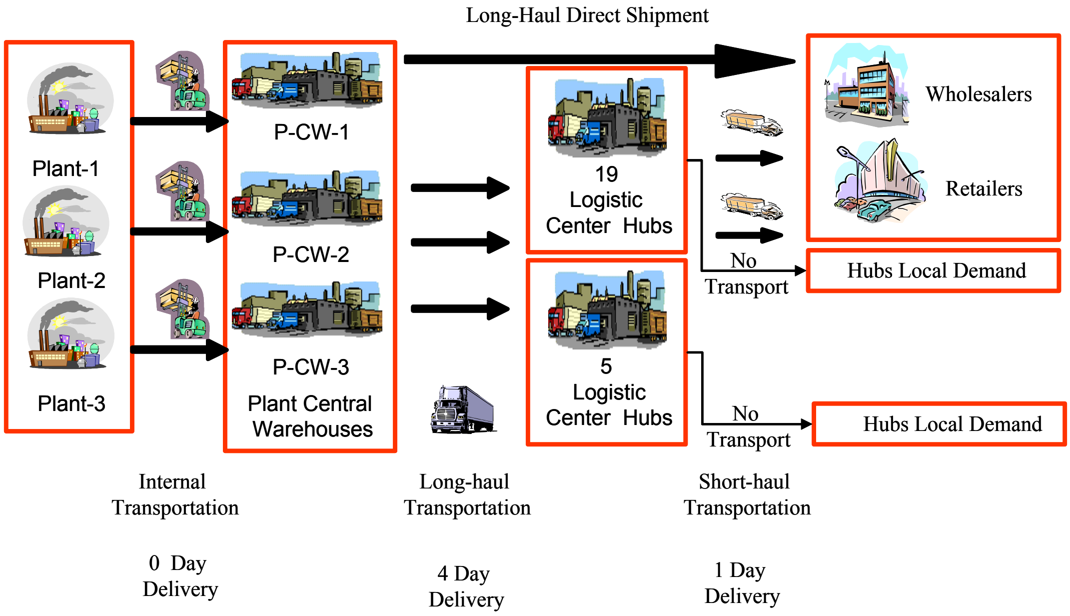
The inventory controlling policy and parameters were designed based on the inventory parameters of benchmark set 6 that will be presented in chapter 7, and the logistic center hubs are using the (s,S) continuous review inventory control policy.

6.2.3 Simulated Model Figures

The problem investigated is classified into two different supply chain models as shown in Figure 6.1 below as a pure against hybrid hub-and spoke network structure. The system consists of three of supply, multiple customers' types (wholesalers, retailers, local hub demand), and twenty four different hub locations.



(a) Model (1)



(b) Model (2)

Figure 6.1 The Simulated Model Scenarios a) Pure Hub-and-Spoke Network
b) Hybrid Hub-and-Spoke Network

6.2.4 Proposed Direct Shipments Algorithm

Feige et al.(1999) and Bramal and Simchi-Levi (1997) show that the worst-case ratio of the cost of direct shipments to lower bound on the optimal cost is no more than 1,061 whenever the customer economic lot exceeds 71% of the vehicle capacity; that is, whenever the shipment lot size $CQ_{pull,t} \geq \frac{w_{jt}^{m}}{\sqrt{2}}$ for all i $\in$N.

Where: CQ_i Economical Order Quantities to be shipped

w_{jt}^{m} Vehicle capacity between j and m at period t

The modelled transportation cost as in chapter 4 shows high shipping costs per pallets transported when less-than-truckload (LTL) is used. Having direct shipments from several plant central warehouses to customer locations will involve multiple shipments to the customer locations. This will cause the company to lose the benefits of shipments consolidation (full truck load) in the long-haul transportation at the logistic center hubs; this is one of the direct shipments disadvantages.

Step 1: Set simulation day = 1

Step 2: Allowed to have direct shipments to end customer, if yes, go to step 3 otherwise step 7

Step 3: Select customer type (wholesalers, retailers, both)

Step 4: Evaluate customer average daily order size (demand) $CQ_{pull,t}^{jm}$

Step 5: if $CQ_{pull,t}^{jm} \geq \%\eta \times w_{jt}^{m} \geq \frac{w_{jt}^{m}}{\sqrt{2}}$ then establish a direct shipments trip

Otherwise step 6.

Step 6: Estimate fleet size and transportation cost

Step 7: Customer order will be served through the allocated logistic center hub

Step 8: Set simulation day = simulation day + 1

Step 9: Repeat Step 1 to 7 until simulation day = simulation period

Figure 6.2 Full Truck Load Direct Shipments Pseudo Heuristic (RDSH)

So that sourcing from the three plant central warehouses directly to the customer are only recommended when the customer's daily demand at least equals to $\frac{w_{jt}^{m}}{\sqrt{2}}$ to have a full truckload trip. The direct shipments algorithm procedure is summarized in Figure 6.2.

Figures 6.3 and 6.4 present the concept and the performance of the proposed algorithm in terms of the types of daily routes performed and the number of vehicles used, and non-dominated solutions. The following illustrates the aim of the pure hub's strategy by looking at a brief example of 3 day orders and four customers A, B, C, and D; in Figure 6.4 the main long-haul route present the transportation between the plant central warehouse and the logistic center hub and then the demand pallets distributed to the customers as a short-haul route.

Figure 6.3 shows that the number of customers per day is stochastic and changed from day to day and the daily demands are also stochastically changed, (e.g. customer C has no order in the day 2 and customer A has no order on the day 3). If we assume that the average demand of the customer C on the day = 1 was more than $\frac{w_{jt}^{m}}{\sqrt{2}}$ direct shipments will be efficient from the plant central warehouse and it will reach the customer location within a one day delivery period, as illustrated in Figure 6.4 where the hybrid hubs network can be utilized.

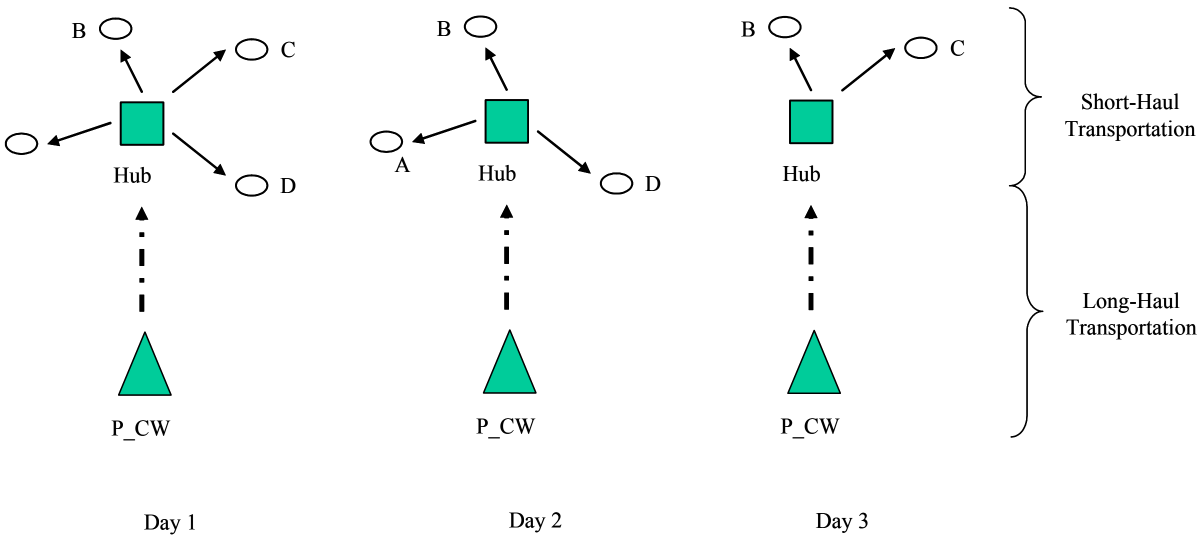


Figure 6.3 Shipment Routing in a Pure Network

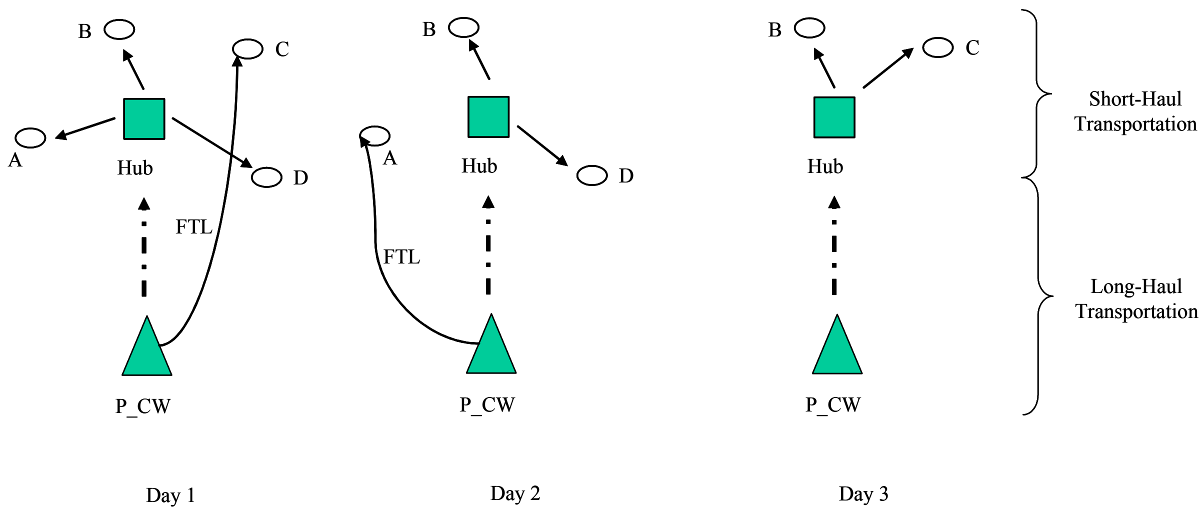


Figure 6.4 Shipments Routing in a Hybrid Network

In day = 2 the customer C has no demand, while the customer A is having demand more than full truck load; in this case the demand will be submitted directly from the plant central warehouse, unlike the day before where it was supplied from the logistic center hub.

The percentage of the daily customer demand to the full truck capacity has been investigated and Figure 6.5 shows the testing of several $\eta\%$ percentages starting from whole customer daily demand supplied from the plant central warehouses where no logistic center hubs are used (worst case scenario), and increasing $\eta\%$ by 15 % step. The $\eta\%$ has been set to 75 % of the truck capacity which means if the customer daily demand is more than 75% of the truck capacity, it will be served directly from the plant central warehouse.

Figure 6.5 shows an increasing trend in short-haul transportation cost, when the percentage value of $\eta\%$ increases, where the long-haul transportation cost is decreased. Increasing the value of $\eta\%$ means the possibility of delivering more full truckloads. The strange behaviours of increasing the short-haul transportation cost have been investigated through the simulation and the main reasons were found as:

- Allowing direct shipments from the plant central warehouses up 1 pallet order (means all customer orders will be supplied from plant central warehouses); consider only the long-haul transportation cost.

- Increasing the $\eta\%$ value by 15%, most of the daily customers' demand satisfy this condition, so a very small percentage of customers orders are not been delivered; from the logistic center hubs.

- Increasing the percentage of $\eta\%$ results more in reducing the probability of having customer daily demand meeting the condition of full truckload, the supply chain coordinator is expected to enforce supply based on customer demand from the logistic center hubs.

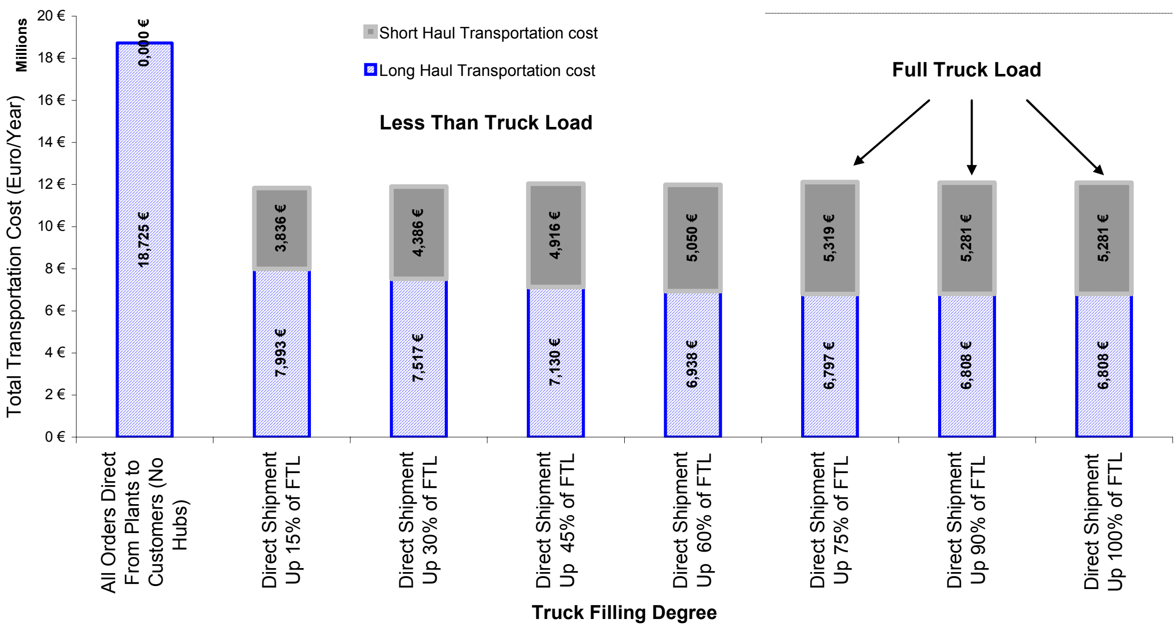


Figure 6.5 Effect of $\eta\%$ on The Total Transportation Cost
(Long-Haul, Short-Haul, and Total Network Transportation Cost) Hybrid Mode

6.3 Simulation Results and Analysis

6.3.1 The Effect on the Supply Chain Transportation Cost

In terms of the supply chain transportation cost, Figure 6.6 illustrates how significant reduction occurs to the total supply chain transportation cost with a magnitude of - 4.6%. There is also a reduction in short-haul transportation cost of about 17%, increasing the long-haul by 9%; reasons will be discussed in the following sections.

6.3.1.1 The Effect on Long-Haul Transportation

Table 6.1 shows the difference between pure and hybrid models in terms of long-haul transposition cost and the percentage of the FTL (Full Truck Load) and LTL (Less than Truck Load) in both models.

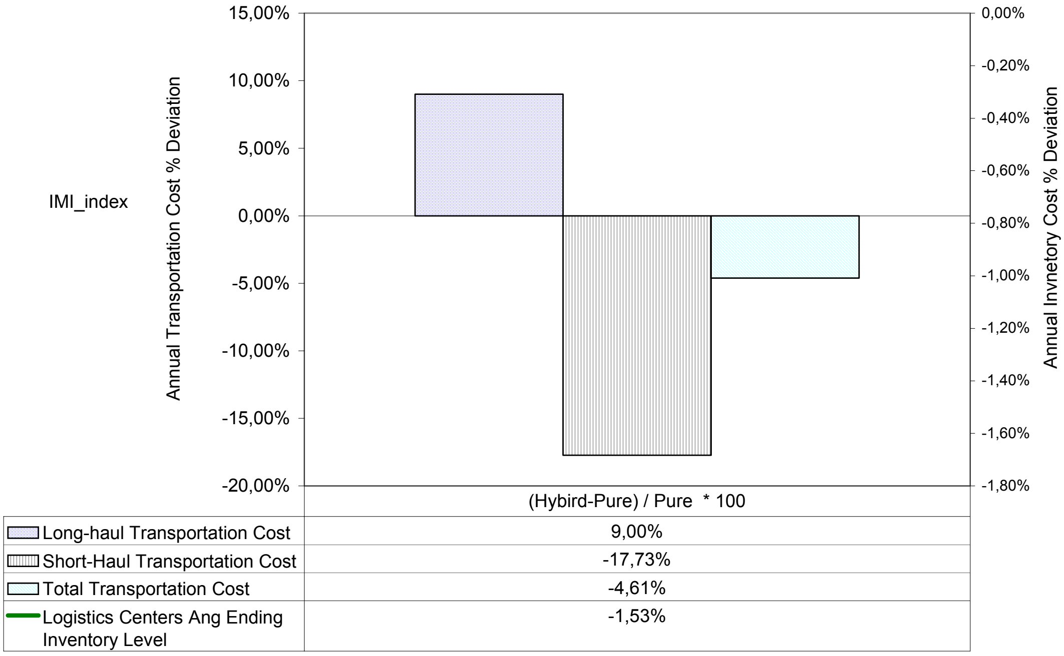


Figure 6.6 The Effect of Direct Shipments Strategy on Supply Chain Total Transportation Cost and Logistic Center Hubs Inventory Cost

Table 6.1 The Effect of The Direct Shipments Strategy on Truck Trip Types

Model Description			Pure Hubs (No Direct Shipments) Model-1			Hybrid Hubs (Direct Shipments) Model-2		
Sourcing Location			Plant-CW-1	Plant-CW-2	Plant-CW-3	Plant-CW-1	Plant-CW-2	Plant-CW-3
Long Haul	Direct Shipments To Customers	% FTL-D				84%	99%	91%
		% LTL-D				16%	1%	9%
		% Cost				15%	20%	34%
	Shipments To Logistic Center Hub	% FTL-LC	40%	18%	53%	35%	11%	40%
		% LTL-LC	60%	82%	47%	65%	89%	60%
		% Cost	100%	100%	100%	85%	80%	66%
	Total Long Haul Transportation Cost		1.907.121 €	1.174.198 €	3.155.011 €	2.037.742 €	1.248.756 €	3.510.998 €
Short Haul	Shipments from Logistic Center Hubs to Customers		*6.465.542 €*			*5.319.111 €*		
Total Transportation Cost (Euro/Year)			*12.701.872 €*			*12.116.607 €*		
% Difference in Long Haul						6,85%	6,35%	11,28%
% Difference in Short Haul						-17,73%		

Figure 6.6 shows a reduction in terms of total transportation supply chain cost by -4%; the following main two reasons caused the effect of increasing the long-haul transportation cost in the hybrid hubs network: *1) Decreasing the number of long-haul* trips. 2) Increasing the trip length in long-haul.

The model hybrid hubs network shows a reduction in the number of trips made between the plant central warehouses and the logistic center hubs where a part of customer daily demand has been satisfied directly as illustrated in Table 6.1, the models percentage deviations measures by (IMI-index%) are calculated as:

$$IMI - index = \frac{\text{Hybrid Hub Network Tours - } Pure \text{ Hub Network Tours}}{Pure \text{ Hub Network Tours}} \times 100$$

The effect of the direct shipments have a significant reduction on the replenishment trips to some of the logistic center hubs from specific central warehouse plants as in the case of plant central warehouse 3, most trips to logistic center hubs have been made as less truck load types, which will be more expensive in terms of the transportation cost per transported pallet, this results in increasing the long-haul transportations costs.

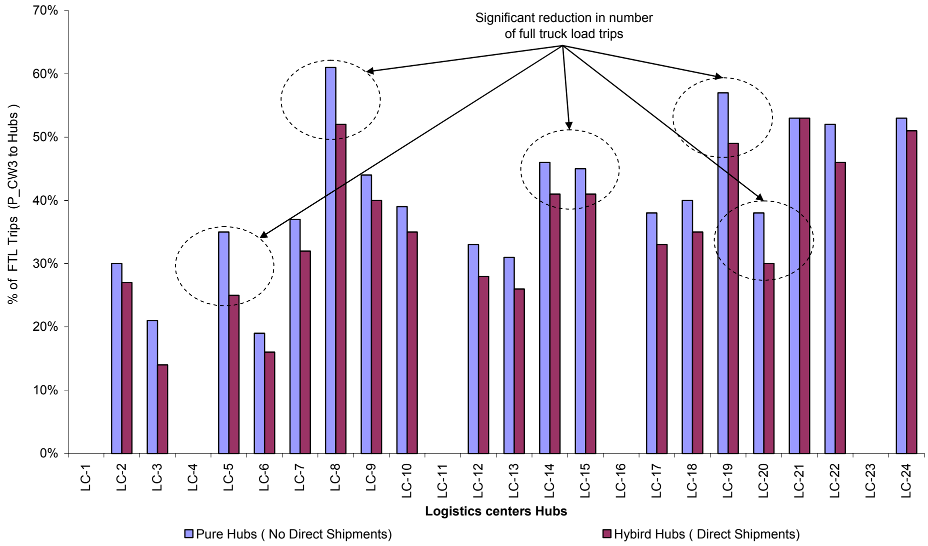


Figure 6.7 The Effect of the Hybrid Hubs with Direct Shipments on FTL Trips
e.g. P_CW3 to Hubs (Circles means big sources of increasing the long-haul transportation)

Figure 6.7 shows the reduction of the trip types in terms of the full truckload trips before applying the direct shipments strategy, the second reason for increasing the long-haul is caused by increasing the trip length in long-haul. Simulation results show that shipment trips were made from the plant central warehouses to customer demand points and logistic center hubs. This findings show an increase of the daily trips' distance travelled in case of hybrid hubs network by more +10 %, on average in long-haul transportation as illustrated in Figures 6.8 and 6.9. This also explains the effect of increasing the long-haul transportation cost, where the transportation cost tariff per unit load transported has been changed to another transportation class based with longer distance travel.

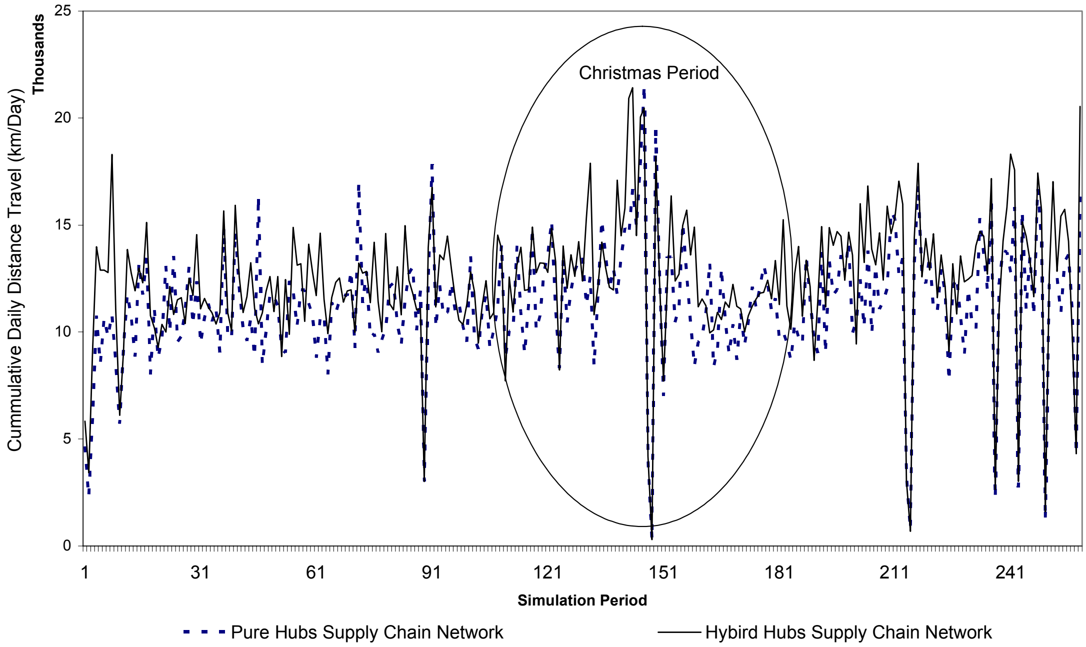


Figure 6.8 Simulated P_CW 3 Total Daily Distance Travelled at ($\eta\%$ = 75 %)

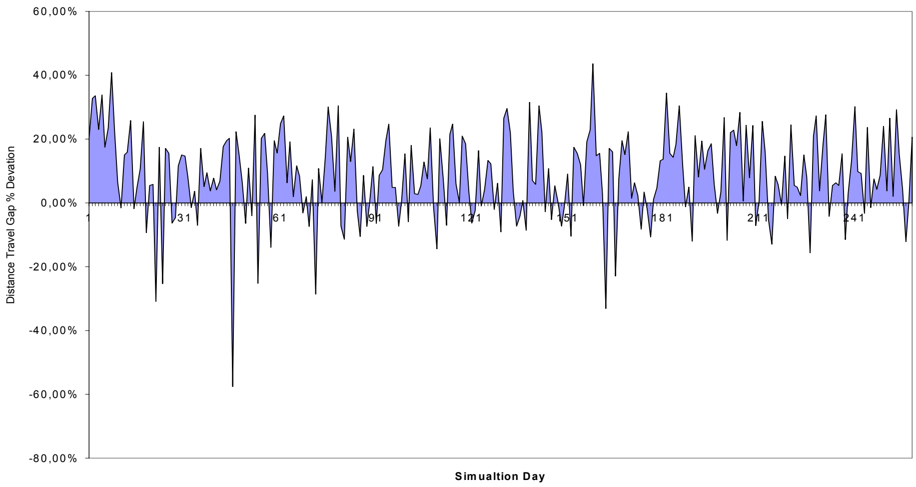


Figure 6.9 Gap % of Hybrid and Pure Hubs Network in terms of The Total Daily Distance Travelled (e.g. P-CW 3, $\eta\%$ = 75 %)

6.3.1.2 The Effect on Short-Haul Transportation

Figure 6.10 illustrates and explains the savings achieved in the short-haul transportation cost through direct shipments that shows an example of customer (105) which served in this period from the plant central warehouse 1 as direct shipments instead of being supplied from the hub 8. That achieves a savings in the total transportation cost of 86 Euros when the customer is supplied directly. The orders from the other sources may be less than the truckload constraints submitted after consolidation from logistic center hub 8.

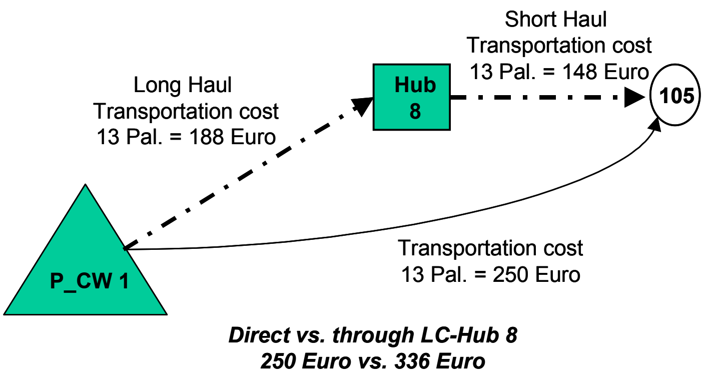


Figure 6.10 Transportation Cost Justification in Hybrid Hubs Network (P_CW3)

6.3.2 The Effect on Distribution of Orders and Materials Flow

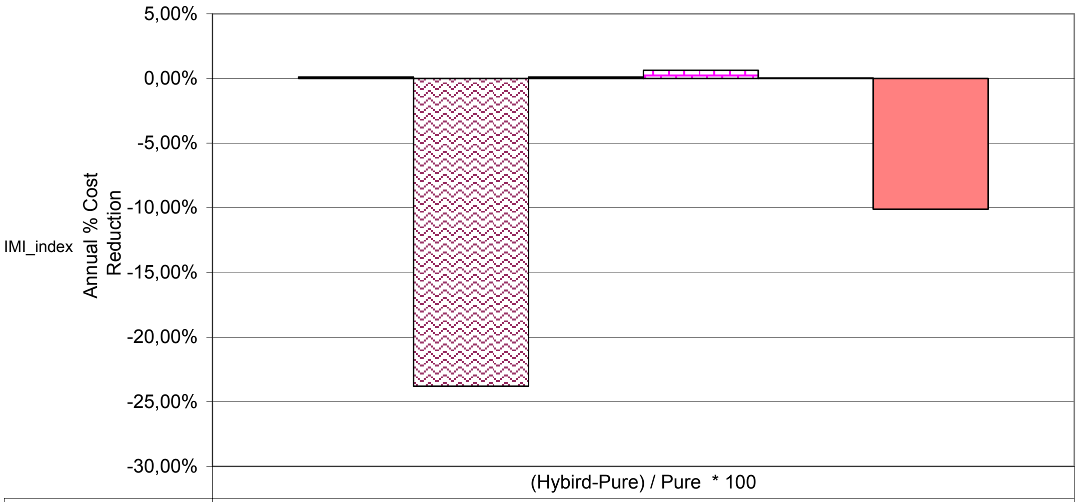
A new demand distribution plan of the material flow after direct shipments was generated. In a pure hubs network the customer's total demand (100 %) is supplied only from the allocated logistic center hubs. Table 6.2 summarizes the simulated redistribution of the supply chain annual demand flow under the hybrid hubs network, that shows effect also in the total number of products stocked after direct shipments are allowed (see Table IV.2).

Table 6.1 New simulated annual demand distribution plan of hybrid hubs network

Sourcing Location	% of Demand satisfied Directly from Plant Central Warehouses	% of Demand satisfied through Logistic Center Hubs
Plant-CW-1	19%	81%
Plant-CW-2	29%	71%
Plant-CW-3	38%	62%

6.3.3 The Effect of Direct Shipments on Supply Chain Activities Cost

The other effect can be seen more clearly in Figure 6.11 in reduction in the total outgoing cost by – 10% and -24% in total incoming cost in the whole supply chain.



	(Hybird-Pure) / Pure * 100
Full Pallet Cost	0,12%
Incoming Goods cost	-23,79%
Mixed Pallet Cost	0,12%
Order Cost	0,64%
OrderPicking cost	0,05%
Outgoing Cost	-10,10%

Figure 6.11 The effect of direct shipments on the Supply Chain Activity Cost

The biggest difference in reduction in incoming goods cost (24%) resulted by receiving small shipment sizes in hybrid strategy, compared to the consolidated shipment in the pure hubs network. The second reason for reducing the outgoing refereed is to decrease the number of short-haul trips in logistic center hubs where some portion of the network daily demand has been submitted directly from the plant central warehouses. The handling cost shows neglected effect, based on the assumption that both handling cost in plant central warehouses and logistic center hubs are equal.

6.3.4 The Effect of Direct Shipments on Inventory Supply Chain Costs

Figure 6.12 shows the effect of applying the hybrid hubs network on the average ending inventory levels. This causes an unexpected reduction in most of the average ending inventory levels in most logistic center hubs under the hybrid hubs networks, except hub 22 which shows a small increase of 1 %.

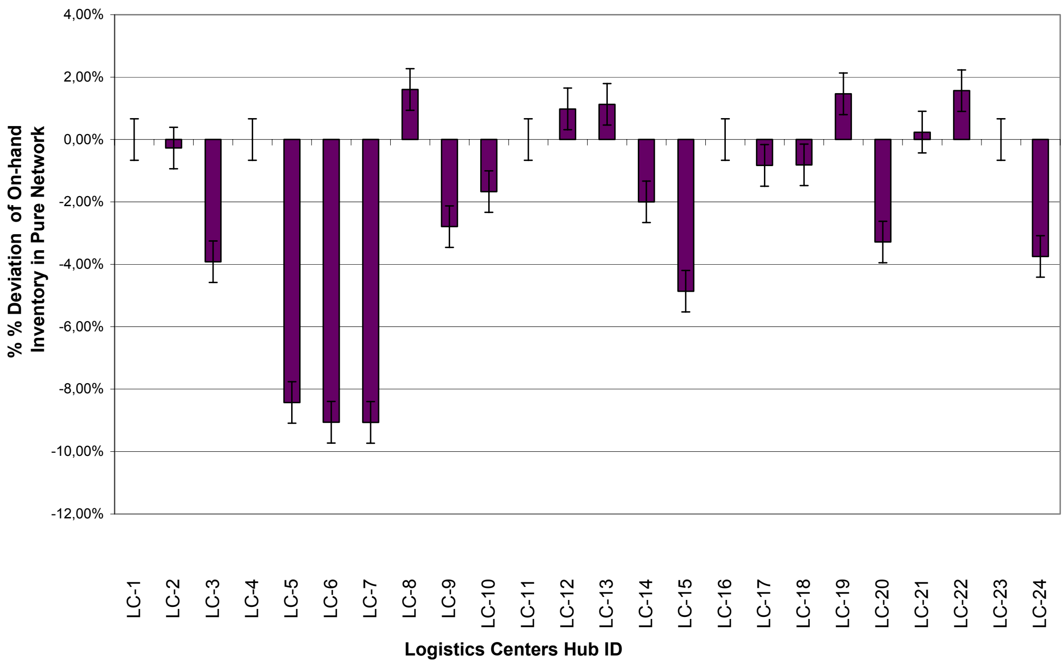


Figure 6.12 The Effect of Direct Shipments on Average Ending Inventory of Logistic Center Hubs

The reduction of the inventory levels ranges from 1% to 8 % at the hybrid concept. This unexpected reduction was investigated and justified. The simulation results of both models show that the percentage difference of replenishment trips to hubs in the hybrid network is reduced, which was also expected. The explanation of such phenomena could be justified by the difference of the shipment size made under both model networks. Hub Nr.7 has been selected for a closer study of the reasons of decreasing inventory levels in the hybrid and increasing the level in pure networks.

Figure 6.13 illustrates tracing the on hand inventory levels in the hub Nr. 7; the simulation results shows large replenishment shipments in the pure hubs network model compared to the hybrid. The inventory consumption rate is higher in the pure model, due to consolidation of total demand of each product type. The chance of product replenishment is higher than in the hybrid, as shown in Figure 6.13.

The daily aggregated demand in pure network causes higher and faster consumption rates of products inventory in logistic center hubs, unlike in the hybrid networks where the customers' demand could be satisfied directly from plant central warehouses. Thus, justifying the increase of number and size of replenishments in the pure model, also results in build-up ending inventory higher than the hybrid model. Figure 6.14 shows the effect of the hybrid hubs network on the aggregated replenishment sizes.

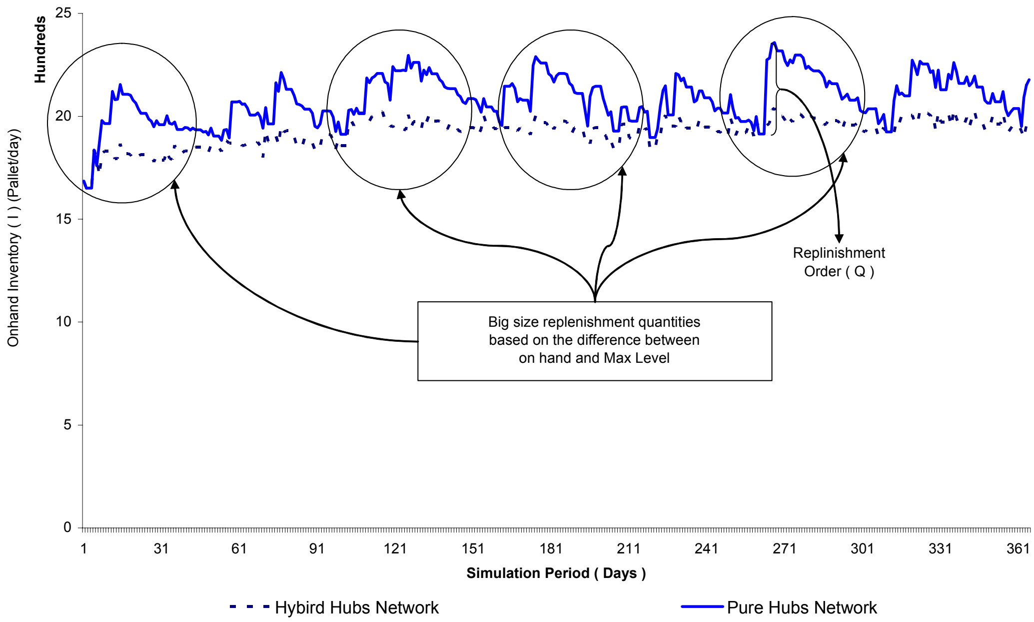


Figure 6.13 Simulated Daily On Hand Inventory in Hub Nr. 7

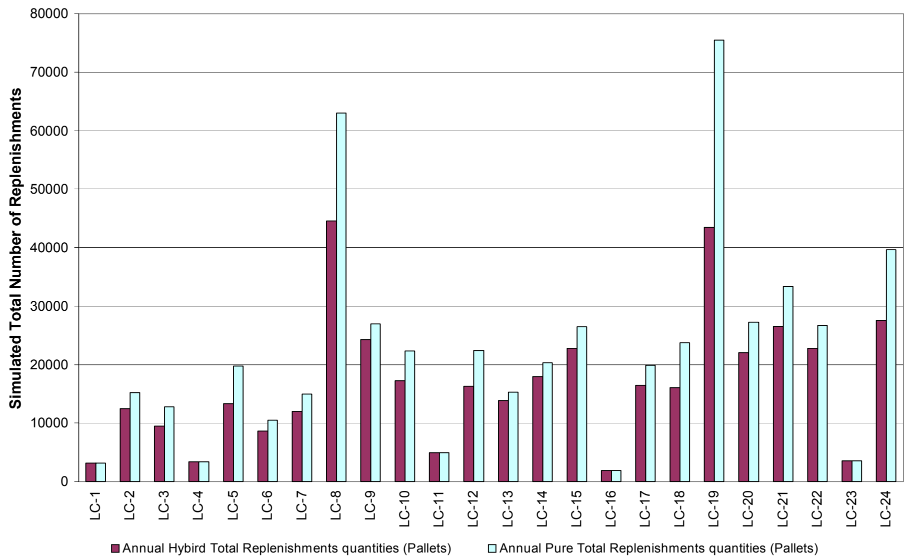


Figure 6.14 Simulated Total Replenishments Quantities of Both Models

A product that belongs to (AZ) family has been selected to study the effect of replenishment size in pure and hybrid hubs network. Figure 6.15 justifies the reasons for having higher average ending inventory as in pure network.

A replenishments sized Q2 in pure model was higher than Q1 made in hybrid model, such reasons caused by extra residual stock resulted by the new redistribution plan in Table 6.2, lowering the consumption rates of inventory. A new redesigning of the product reorder levels and safety stock should take place based on the adjusted new consumption rates.

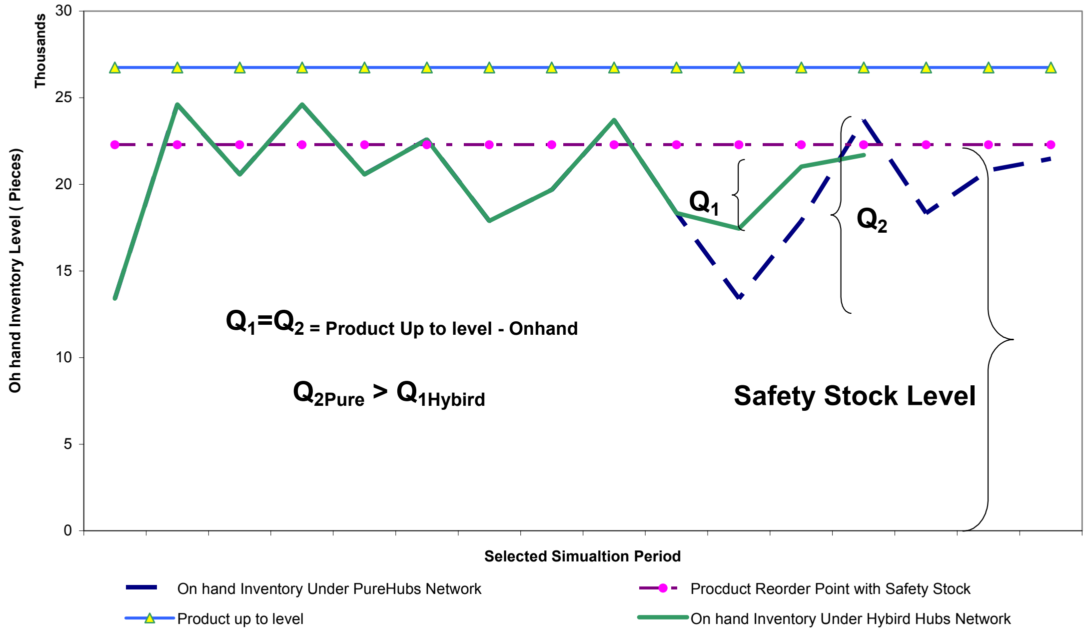


Figure 6.15 On Hand Inventory Level and Replenished Product Quantities of AZ product under both Models

Table 6.2 Total Supply Chain Direct Shipments Model Costs

Cost Description		Pure Hubs Netwrok	Hybrid Hubs Network
Model Activity Costs		2.827.276 €	2.535.865 €
Transportation Cost	Long-Haul Transportation Cost	6.236.329 €	6.797.495 €
	Short-Haul Transportation Cost	6.465.542 €	5.319.111 €
Logistic Centers Inventory Cost		2.160.756 €	2.127.636 €
Supply Chain Service Level	N- DLS1%	97,98%	98,10%
	N- DLS7%	79,02%	79,58%
Total Supply Chain Model Cost		17.689.903 €	16.780.107 €
Cost Saving %		**-5,14%**	

The total supply chain cost in hybrid hubs with direct shipments strategy model shows a significant improvement and reduction in terms of total system cost by 5 %. The network service level is higher than before due to the higher availability of products safety stock level in each logistic center hubs after conducting the direct shipments of big customer demand summarized in Table 6.3.

6.4 Results of Analysis and Conclusions of Direct Shipments Model

- Several other scenarios have been investigated with different $\eta\%$ values ranging from 0 to 100 %. Step 15 %, which results in perfect and significant savings can be achieved when $\eta\%$ is above 75 % of the truck capacity (full truck load).
- No significant effect appears in the performance of the logistic center hubs LC-1, LC-4 LC-11, LC-16, and LC-23, where they are responsible for collecting local demand only and have no customer assignment. And it should be noted that this accumulated local daily demand redistribution to other supply chains is out of the scope of this thesis.

This chapter concludes after testing these two distribution network scenario models that the following actions should be conducted:

1. Considering the hybrid model as the best scenario at this stage; it shows a reduction in terms of total simulated supply chain cost as shown in Table 6.3.
2. Applying the hybrid direct shipments strategy concept to the supply chain case study results in a redistributing of the total supply chain demand as seen in Table 6.2. Big customers demand such as wholesalers will be supplied directly from the plant central warehouses and other customer types supplied through the logistic center hubs with a percentage of 81%, 71%, and 62% from the total annual supply chain demand respectively.
3. More distribution strategies should be investigated and developed to improve the customer service levels assigned to hubs, reducing inventory cost, the possibility of achieving more savings in total supply chain costing model.
4. The simulation results summarized in Table 6.1, applying the hybrid direct shipments strategy show an increase in the long-haul (outbound) transportation cost with a percentage of 6%, 6%, and 11% respectively.
5. There is a decrease in the number of full truck load trips made between plant central warehouses to logistic center hubs, such bad indicator show a possibility of examining and developing more efficient scenarios and distribution strategies in improving the supply chain and reducing the transportation cost.

6. The simulation results show that in the total supply chain costs the transportation cost (long-haul and short-haul) represent 70 % of the total supply chain, while the inventory holding cost accounts for about 14% of the total supply chain cost.

The main advantages achieved by applying this strategy are:

- A Hybrid hubs network avoids the expenses of operating some big customer demands (e.g. wholesalers) from the logistic center hubs when the daily customers' orders of a full truck load were demanded.
- The biggest advantage of hybrid hubs network with direct shipments is the ability to use centralized inventories at the plant central warehouses. They can aggregate demand and provide a high level of product availability with lower levels of inventory than individual logistic center hubs in supply chain network under study. It is recommended to allocate those special big customers product types in upstream locations where direct shipments were allowed.
- A Hybrid hubs network also offers the plant central warehouse the opportunity to further lower inventories by postponing customization until after the customer order has been placed.
- A good information infrastructure is designed and offered so that the logistic center can provide product availability information to the customer even though the inventory is located at the plant central warehouses. The customer may not have visibility into order processing at the plant central warehouses, even though the order is placed with the logistic center. A Hybrid hubs network will generally require significant investment in the information infrastructure.
- Big customers order response time tend to be smaller in general in hybrid hubs network, due to proposed direct shipments and EDI concept. This is used because the orders are received directly without considering the designed long-haul order delay modelled in chapter 4.
- Order visibility is very important in the context of plant central warehouses storage because two stages in the supply chain are involved in every customer order. Order tracking, however, becomes harder to implement in a situation of direct shipments because it requires complete integration of information systems for both the retailer as well as the plant central warehouses.

This type of distribution strategy also has a number of important disadvantages:

- Risk pooling effects will be neglected or reduced because a part of the daily aggregated demand will be satisfied directly, that increases the variations in the average daily demand in each of the logistic center hubs.
- Increasing the long-haul transportation costs between the logistic center hubs and the plant central warehouses caused an increase in the number of LTL trips.
- Outbound (long-haul) transportation costs will be high with direct shipments due to increasing distance to the end consumer.

6.5 Further Experiments and Extended Studies

The next sections and studies will concern optimization of the supply chain by evaluating and studying the effect of the redesign, integration, and coordination of different safety stock inventory management strategies on the supply chain. Here in this chapter seen clearly the effect of the replenishments quantities on the transportation costs and the supply chain inventory costs based on the new demand redistribution plan.

Also this study shows that most logistic center hubs hold too much higher safety stock levels. The future experiments and sections will focus more on readjusting and reducing the inventory levels in the whole supply chain network without affecting the desired service levels and minimizing the total supply chain cost through establishing eight safety stock allocation plans.

7.0 Benchmark Simulation Experiments and Analysis of Results

7.1 Introduction

This chapter presents, and analyzes the designed simulation benchmark experiments conducted in this thesis. Eight selected safety stock inventory and allocation decisions were examined and analyzed. Benchmark experiment parameters are designed upon the discussion and suggestions agreed by supply chain coordinator in the firm. Supply chain performance measures are discussed in section 4.4 and have been estimated; averages and standard deviations for the various performance measures were also calculated. From these results, the values for a 90% confidence interval on all the simulation experiments and scenarios are achieved.

Section 7.2 presents the first benchmark experiment group concerning investigation of the effect of safety stock inventory decisions on the supply chain performance measures under fixed pull transportation strategy, where a total of six experiments were conducted and divided into two sub experiments. A summary of the performance measures exists and is summarized; the second benchmark experiment presents two examined product class allocation schemas named Spatial Postponement presented in section 7.3. Finally, general summarized recommendations and conclusions are made in section 7.4.

7.2 Evaluating The Effect of Multi-Products Independent Demand Supply Chain Safety Stock Strategy

The proper application of an independent demand inventory system can mean significant savings. Independent demand inventory systems are based on the premise that the demand or usage of a particular item is independent of the demand or usage of other items Silver et al., (1998).

This thesis works a pull system which authorizes the plant central warehouses of finished goods to replace products, as they are demanded in downstream logistic center hubs. The independent demand inventory models answer the question of when to place the replenishment order and how much to order at one time. The (s,S) continuous review model is utilized as mentioned in chapter 4 as an inventory controlling policy.

Simchi-Levi et al. (2003) based on inventory report reduction 2000, summarized some important points of managing and optimizing independent demand inventory models such as utilizing periodic inventory review, tight lead time and safety stock, Introduce or enhance cycle counting practice, and ABC approach. The next section will consider six designed benchmark experiment sets considering the evaluation of the effect of the safety stock decision on the supply chain performance measures.

Efficient and effective management of safety stock inventory throughout the supply chain significantly improves the ultimate service provided to the customer. Although the supply chain's overall performance depends on the sites' joint performance, in real life each supply chain site is managed by fairly autonomous management teams, each with its own objectives and mission. For simplification purposes (s,S) generalized inventory management parameters are assumed.

7.2.1 Designed Group-1 Benchmark Experiment Sets

This section describes, and presents the six main benchmark experiment sets designed and conducted utilizing the developed supply chain simulation model presented in chapter 4 divided into two sub experiment sets that evaluate different comparative and proposed distribution strategies mentioned in section 7.2. The first examined distribution strategy, as mentioned in section 7.1, was focusing on studying and evaluating the effect and the impact of safety stock inventory decisions on the supply chain performance measures, considering the classification presented by Ballou (2004b). The first sub group set was based on the statistical estimation of the reorder point using the product cycle service level (CSL), and the second sub group experiment set according to the stock to demand concept (STD).

Sub experiment set 1, accounts for the statistical design of the reorder point at no safety stock, 80% CSL, and 95% CSL; while sub experiment set 2 contains 3 estimated parameters according to the STD concept no safety stock exists, regular class safety stock, variable class safety stock.

The second sub group experiment set presents an empirical estimation of the inventory reorder parameters (s,S) values reflecting the supply chain coordinator policy depending on the product class type. The maximum S level considers the physical warehouse stocking capacity for each product type class, and the product demand research suggests the S level of products class A equal to 10 days of average daily demand as maximum inventory allowed, products class B equal to 10 days of average daily demand as maximum inventory allowed. Finally, product class C requires a maximum of 15 days of average daily demand as maximum inventory allowed.

7.2.2 Group-1 Benchmark Experiment Sets Simulated Scenarios

According to the suggested network configuration in chapter 6, a Hybrid Hub Network, with direct shipments model will be considered as a base supply chain network configuration. The benchmark experiments set are simulated under the following network configuration and assumption:

- Hybrid Hub with direct shipments supply chain network
- Initial Logistic centers inventory levels were set equal to product reorder point
- Logistic center hubs implementing a (s,S) order up to level continuous review inventory control policy
- L1= 4 days order lead-time between plant central warehouses and logistic center hubs see Figure 6.1a
- L2= 1 day customer order delivery lead time see Figure 6.1b
- Logistic center hubs holding inventory of all product classes
- Pull Supply chain replenishments order type

The summarized simulation model input parameters used in designing the six-benchmark experiment set are presented in Table 7.1.

Table 7.1 Group-1 Benchmark Experiments Set Simulation Input Parameters

Benchmark Experiments Set	Plant-central Warehouses	Logistic center Hubs	Customers	Network Configuration	Replenishment type	Reorder Point Estimation Method	s Level Safety Stock Factor (k_{ss})			Product up to Level (K_{max})		
							Product Class / Family					
							A	B	C	A	B	C
B-Exp-Set-1	3	24 (19 LC Hubs+ 5 CLC Hubs)	3000	Hybrid with direct shipments supply chain network	Pull supply chain section (4.4.7)	Statistical ROP	CSL= 0 %			10	10	15
B-Exp-Set-2							CSL= 80 %			10	10	15
B-Exp-Set-3							CSL= 95 %			10	10	15
B-Exp-Set-4						SDT ROP	0	0	0	10	10	15
B-Exp-Set-5							1	1	1	10	10	15
B-Exp-Set-6							0	2	6	10	10	15

As is shown in Table 7.1, the first three benchmark experiment sets consider the statistical method of estimating the safety stock according to the CSL method mentioned in section 4.4.5.1, and the next three benchmark experiments utilizing stock to demand concept (STD).

Considering the product demand uncertainty and variability phenomena, the first group summarized the parameters of three experiment sets using the statistical methodology in estimating and designing the reorder point in each product classes based on cycle service level (CSL) three different safety stock factors k_{SS} were considered (0%, 80%, 95%) see in Chopra and Meindl (2004).

Those three different k_{SS}= $p_u \geq (k)$ probability (unit normal variable) takes on a value of k or larger was set as 0, 0.842, 1.644 based on Silver et al. (1998), see Equations 4.3.

The difference between the experiments under the SDT group was in different estimated values of k_{SS} in each product class, where no safety stock was considered in the B-Exp-Set-4 only the average daily consumption rate during the lead-time period was considered such that the k_{SS} value set equal to 0, in the second B-Exp-Set-5 that considers a 1 day safety stock factor to all product type classes.

Silver et al. (1998) stated that a large U.S. based international consulting firm estimates that 80-90 % of its clients use equal to the time supply; the drawback of that model is that it fails to take into account the differences in the uncertainty of forecasting from item to item group. The policy variable is the common number of time periods of supply. In other words, all items in a certain group have different safety stock factors than the other classes; the designed B-Exp-Set-6 discusses the concept of variable safety stock.

The other reason in designing the B-Exp-Set-6 is to study the effect of different shipment sizes of each product type and the amount of the allocated safety stock in the logistic center hubs to the transportation cost and service levels. Considering that a higher shipment size of products class A and B with lower safety stock will maximize the truck utilization and holding relatively higher safety stock k_{SS} of product class C will minimize the chances of stocking out and delaying the whole orders.

As was mentioned before in section 4.7, the designed supply chain simulation model considers the NPS order fulfilment strategy in satisfying the end customer final demand (Retailers, Wholesaler). However, the unavailability of the slow mover low demanded product will increase the chances of having bad N-DLS1 % and N-DLS7 % performance measures.

Considering B-Exp-Set-6 experiment, the nominal shipment sizes of the different product classes could be as 6 D_{At}^{k}, 4 D_{Bt}^{k}, and 5 D_{Ct}^{k} where $D_{At}^{k} \geq D_{Bt}^{k} \geq D_{Ct}^{k}$ according to the ABC analysis. The product class reorder point was estimated according to the equation 4.5.

The maximum stocking level S_{p}^{k} for each product class was designed according to the equations 4.2 and 4.4, where $\mathbf{k_{max}}$ was estimated according to physical product inventory consideration and capacity provided by the supply chain logistics manager in the considered supply chain network. A uniform fixed $\mathbf{k_{max}}$ was assumed to have simplified the simulation model and eliminates the effect of estimating the S_{p}^{k}. Where the mathematical models are not able to estimate. Silver et al.(1998) suggested values $\mathbf{k_{max}}$ estimated according to average logistic center hubs inventory capabilities as provided by the supply chain coordinator. The deviation between experiments is expressed as % improvement deviation index (IMI_{Base}^{EXP-ID}) of total supply chain costs, N-DLS-1%, and N-DLS7% (Z^{Exp}) to the base case (Z^{Base}) in which:

$$IMI_{Base}^{EXP-ID} = \frac{Z^{\mathrm{Exp}} - Z^{\mathrm{Base}}}{Z^{\mathrm{Base}}} \times 100 \qquad (7.1)$$

7.2.3 Group-1 Benchmark Experiments Simulation Results and Analysis

The developed simulation model simulated for one fiscal year, considering the above benchmark experiment sets appears in section 7.2.2 and Table 7.1. The simulation will examine which of the above benchmarks are capable of superior performance in terms of supply chain network performance measures; a suitable warm-up period in order for the model to achieve a steady state was considered.

An analysis of the simulation results considering the activity based costing model mentioned in chapter 4. Table 7.2 summarizes the simulated activity based costing results of the above six benchmark experiment sets. The shaded cells represent the minimum cost according to the associated activity. The supply chain network performance measures results are summarized in Table 7.3, and Figure 7.2.

Table 7.2 Benchmark Experiments Group-1 Activity Based Costing Results

Benchmark Experiment Models		Supply chain Network Activity Based Costing Measures					
		Ordering	***Handling***	***Warehousing***	***Long-Haul Transp.***	***Short-Haul Transp.***	***Inventory***
Statistical ROP	**B-Exp-Set-1**	116.649 €	**911.611 €**	1.516.393 €	6.641.439 €	**5.180.528 €**	**351.504 €**
	B-Exp-Set-2	115.754 €	911.930 €	1.515.191 €	6.644.747 €	5.197.139 €	382.068 €
	B-Exp-Set-3	**115.162 €**	912.197 €	1.514.016 €	6.644.250 €	5.208.221 €	413.532 €
STD ROP	**B-Exp-Set-4**	116.649 €	**911.611 €**	1.516.393 €	6.641.439 €	**5.180.528 €**	**351.504 €**
	B-Exp-Set-5	115.856 €	911.904 €	1.515.123 €	6.647.521 €	5.196.266 €	378.720 €
	B-Exp-Set-6	115.400 €	912.070 €	**1.513.153 €**	**6.635.226 €**	5.197.451 €	429.624 €
Objective Function Min(costs),Max(DLS)		115.162 €	911.611 €	1.513.153 €	6.635.226 €	5.180.528 €	351.504 €
Benchmark Exp Set ID		3	1 &4	6	6	1 & 4	1

Table 7.3 Benchmark Experiments Group-1 Supply Chain Network Performance Measures

Benchmark Experiment Models		Supply chain Network Performance Measures			IMI %		
		TSCN	***N-DLS-1 %***	***N-DLS-7%***	***Cost***	***N-DLS-1***	***N-DLS-7***
Statistical ROP	**B-Exp-Set-1**	**14.718.124 €**	93,99%	52,76%	**0,00%**	**0,00%**	**0,00%**
	B-Exp-Set-2	14.766.829 €	95,71%	61,79%	**0,33%**	**1,83%**	**17,11%**
	B-Exp-Set-3	14.807.378 €	**96,66%**	**67,93%**	**0,61%**	**2,84%**	**28,76%**
STD ROP	**B-Exp-Set-4**	**14.718.124 €**	93,99%	52,76%	**0,00%**	**0,00%**	**0,00%**
	B-Exp-Set-5	14.765.390 €	95,71%	61,63%	**0,32%**	**1,83%**	**16,81%**
	B-Exp-Set-6	14.802.924 €	95,87%	61,95%	**0,58%**	**1,99%**	**17,43%**
Objective Function		14.718.124 €	67,93%	96,66%			
Benchmark Exp Set ID		1 & 4	3	3			

In Table 7.3 the percentage of IMI_{Base}^{ExpID} with respect to B-Exp-set-1 no safety stock was considered. According to Table 7.2, the transportation cost (long-haul, short-haul) accounts for more than 44%, and 35% respectively and in total about 80%, while the other 20% represents the inventory, order-picking, and warehousing costs. Table 7.3 shows that the multi objective function could not be satisfied, where the experiment set (1, 4) achieved the minimum supply chain total cost, but relatively low service levels in both N-DLS1%, N-DLS7% compared to sets (2,3,5,and 6).

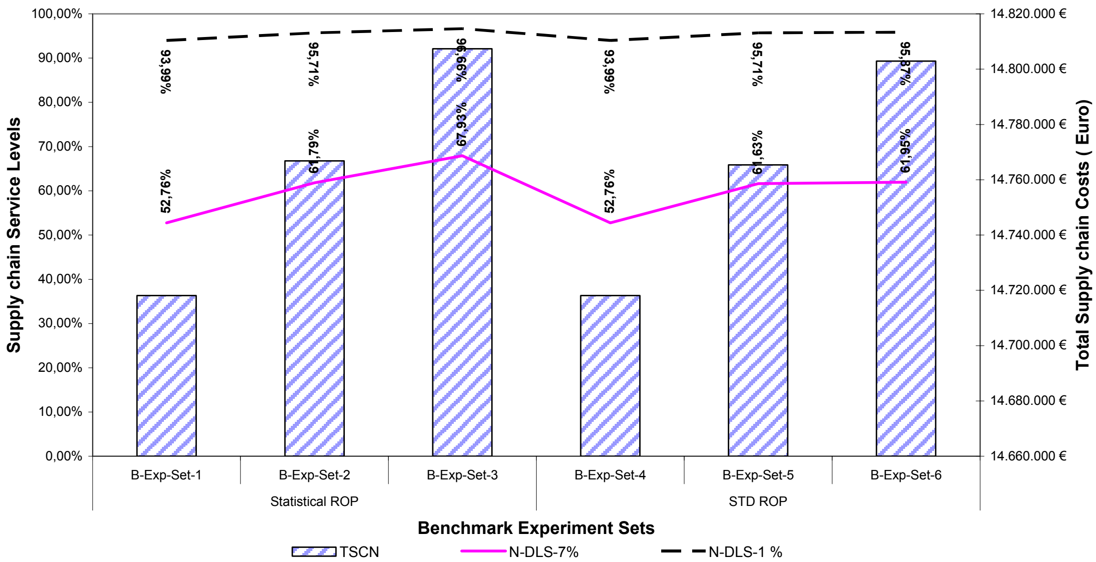


Figure 7.1 Benchmark Experiments Group-1 Supply chain Network Performance Measures

The above results illustrated the effect of holding higher safety stock according to the experiment set which utilized the statistical concept of estimating the product reorder point. As shown in Table 7.3 and Figure7.2, experiments B-Exp-set-3 and B-Exp-set-6 where extra safety stock exist, performed better than the others with respect to the supply chain service levels where more than 60% of the customer orders will be submitted from the existing inventory at just in time basis, and the remaining 40% will be delivered in the next working days until the replenishment orders are received.

Considering B-Exp-set-3 and B-Exp-set-6, both experiments hold relatively higher designed safety stock than other experiments, where B-Exp-set-3 has achieved high supply chain service levels while it has also minimized the inventory cost by 3.7% compared to inventory cost of B-Exp-set-6, demand uncertainty is taken into account, while B-Exp-set-6 has achieved better than B-Exp-set-3 in terms of minimizing the long-haul transportation cost which represents more than 40 % of the total supply chain cost.

It was clear that experiments utilizing the statistical estimation of the reorder point performed better than those by stock to demand (STD). Since they consider the randomness and the uncertainties of products average daily demand, where most of the logistic center hubs face non-stationary demand according as mentioned before, the SDT methodology will be utilized later on the other experiment conducted in this thesis which is based on the request of the supply chain coordinator, due to the practical reason of estimating the k_{ss} values in each product class. The experiments utilizing the statistical estimation of product reorder point will be discussed and analyzed through the sensitivity analysis for the proposed future experiments in chapter 8.

The minimization of the long-haul transportation cost has been achieved when the strategy of variable safety stock K_{SS} was implemented which proves the effect of the shipment sizes on the transportation cost, this effect can be seen in the results of the B-Exp-set-6, where the nominal shipment sizes of the different product classes could be expressed as 6 D_{At}^{k}, 4 D_{At}^{k}, 5 D_{At}^{k}.

The effect of holding more safety stock K_{SS} shows a positive correlation effect to both N-DLS1%, and N-DLS7%. More product availability though extra K_{SS} has accelerated and increased the customer orders delivery index N-DLS-7% by 17%, 28%, 16%, and 17%, an improvement to product service level N-DLS-1% with 2% achieved when higher safety stock was utilized, with no such significant improvement to total supply chain costs since most of the benchmark sets were designed to improve the customer service levels N-DLS-1%, N-DLS-7%.

Detailed simulation results of average ending inventory and service levels of supply chain logistic center are found in Table VI.1, and Table VI.3 Appendix VI, which shows the effect of a multi product safety stock strategy. Benchmark sets B-Exp-set1 and B-Exp-set4 are redundant experiments, where both experiment consider the regular stock during the lead time demand with no safety stock factor k_{ss} = 0, furthermore, B-Exp-set4 will be considered instead of B-Exp-set1.

Most of the $I_{All,t}^{k}$ values considering the statistical method of estimating the safety stock level perform better than those designed according to the stock to demand in most of supply chain locations. The reason was the ability of CSL method in considering the stochastic demands behaviour in the logistic center hubs according to the previous ABC-XYZ analysis in Chapter 4.

Table 7.5 shows that not all the $I^{k}_{All,t}$ values estimated by the CLS cause a minimizing of the average daily inventory level LC-8, LC-9 and LC-19. They show higher $I^{k}_{All,t}$ values compared to those estimated by the SDT models in B-Exp-set5, and B-Exp-set6. Through the investigation and by analyzing the detailed simulation results, the previous logistic center hubs are having a higher supply chain demand percentage 12%, 6%, 15% respectively (see Table IV.3) and stocking more than 134,114,112 demand product type (see Table IV.4). The main effect of such reduction refers to the amount of holding a relatively reasonable variable safety stock of CY, and CZ products in B-Exp-set 6 higher rather than B-Exp-set3, B-Exp-set4 (see Table IV.4).

This finding support and prove derived conclusion of no safety stock required for products classified as AX and AY, products family AZ will depend on the ability of the forecasting technique, the variable safety stock were utilized only to product families that follow the BX, BY, BZ, CX, CY and CZ where estimation of variable k_{ss} is required for smaller safety stock to B class, higher than those belonging to C class, (Alicke, 2003).

The results of simulation models utilizing the CSL perform relatively better than the SDT sets in the logistic center LC-19, LC-24 where higher demand uncertainty exists and higher stocking product types of class CX, CY, and CZ (see Tables IV.1 and IV.3).

The effectiveness and effect of the estimated k_{ss} parameters proposed in B-Exp-set6 can be seen in other logistic center hubs facing and holding AX where higher and fast mover products as in LC-12, LC-13, and LC-21 with a relatively stationary demand pattern CV^{k}_{D}. A higher DLS-1% and DLS-7% of 95%, and 60% across all the supply chain locations were achieved without holding too much product safety stock of this product class. Tables IV.3 summarize the archived DLS-1% and DLS-7% of each logistic center hub.

7.2.4 Group-1 Benchmark Experiment Summary and Conclusion

From the above results, the models utilizing the CSL in estimating the safety stock amount perform better than those in SDT according to both DLS-1%, and N-DLS-7%, while the capability of variable safety stock presented in B-Exp-set-6 is also able to achieve reasonable N-DLS-1%, and N-DLS-7% CLS of more than 95% and 60% respectively.

Considering the supply chain activity based costing results in Table 7.3, the minimum long-haul transportation cost has been achieved in B-Exp-set-6 (product class variable safety stock concept) with relatively small $IMI^{Base-B-ID}$ to B-Exp-set-3 (fixed 95% CSL). The reason for such a finding refers to the impact of the variable shipment size of 6 D^k_{At}, 4 D^k_{Bt}, 5 D^k_{Ct} where $D^k_{At} \geq D^k_{Bt} \geq D^k_{Ct}$ utilized in estimating the B-Exp-set-6 inventory parameters.

The strategy of holding variable safety stock amounts according to ABC-XYZ products classification was recommended in the supply chain, such that no safety stock may be required to product families belongs to AX and AY more frequent fast mover products, and an appropriate variable safety stock to other product families such as AZ, BX, BY, BZ, CX, CY, and CZ as was implemented in B-Exp-set-6.

Lower handling and short-haul transportation costs in experiments B-Exp-set-1, B-Exp-set-2, B-Exp-set-4, B-Exp-set-5 justify the positive correlation relationship to N-DLS7 %, as shown in Table 7.3, which means that when no or little appropriate product safety stock level in the logistic center exists, the number of distribution trips to thee customer within the simulation period will be reduced and cause delays in customer orders.

Lower warehousing costs in experiment B-Exp-set-6 are justified by the reduction of the number of replenishment trips between plant central warehouses and logistic center hubs and total shipment quantities ($\alpha * \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} Q_{pjkt} * Outc^k$) as in equation 4.7. This also supports the previous conclusion of effect of the variable shipment sizes in minimizing long-haul transportation costs in B-Exp-set-6. Table VI.3 shows that, the logistic center with higher demand uncertainty measure CV^k_D presents lower DLS-7% compared to the others, even when higher product safety stock levels were considered as in B-Exp-set 4 and 6. Thus, needs for more integration and coordination supply chain functions are essential.

The non-stationary supply chain multi-product demand faced by the logistic center hubs, complicate the estimation of the safety stock k_{ss} levels for each product types. As mentioned in Zipkin (2000), and Silver et al. (1998) that the mathematical optimizing and estimating of the s^k_p, and S^k_p in (s, S) multi-product continues review inventory model implemented in this thesis will not be considered. The B-Exp-set 6 results will be considered as the thesis reference model (Ref-M) best distribution strategy it will be compared with a further designed experiment and simulated scenarios and an improvement index (IMI^{EXP-ID}_{Base}) will be calculated.

7.2.5 Supply Chain Reference Model (Ref-M)

The B-exp-set-6 is considered to be the base case model and is used to evaluate and compare further supply chain performance measures. After the model validation, the following extra detail results were discussed.

7.2.5.1 Estimating Lower Bound Transportation Costs of Reference Model

The lower bound transportation cost was estimated when eliminating the effect of the unit freight discount rate per shipment size offered by the transportation 3rd party logistic as mentioned in section 4.5.5, where all the long-haul and short-haul unit transportation costs were considered as a minimum fixed unit transportation cost. Table 7.4 summarizes the % deviation to simulated lower transportation costs for both long and short-haul transportation.

Table 7.4 % Deviation of B-Exp-Set-6 Transportation Cost to Simulated Lower Bound Fixed Transportation Cost Model

Location ID	**P-CW-1**	**P-CW-2**	**P-CW-3**	**LC-1**	**LC-2**	**LC-3**	**LC-4**	**LC-5**	**LC-6**
Simulated Transportation Cost (Base case)	2.009.345 €	1.218.391 €	3.407.490 €	0 €	177.668 €	122.298 €	0 €	186.301 €	91.064 €
Simulated Lower Bound Transportation Cost	1.938.119 €	920.642 €	3.136.324 €	0 €	83.426 €	58.910 €	0 €	93.173 €	38.857 €
Gap to base %	**-3,54%**	**-24,44%**	**-7,96%**	0,00%	-53,04%	-51,83%	0,00%	-49,99%	-57,33%
Location ID	**LC-7**	**LC-8**	**LC-9**	**LC-10**	**LC-11**	**LC-12**	**LC-13**	**LC-14**	**LC-15**
Simulated Transportation Cost (Base case)	161.454 €	693.799 €	300.246 €	253.974 €	0 €	205.250 €	155.828 €	288.906 €	262.306 €
Simulated Lower Bound Transportation Cost	75.565 €	347.710 €	166.882 €	132.920 €	0 €	104.822 €	76.387 €	149.758 €	141.639 €
Gap to base %	-53,20%	-49,88%	-44,42%	-47,66%	0,00%	-48,93%	-50,98%	-48,16%	-46,00%
Location ID	**LC-16**	**LC-17**	**LC-18**	**LC-19**	**LC-20**	**LC-21**	**LC-22**	**LC-23**	**LC-24**
Simulated Transportation Cost (Base case)	0 €	161.916 €	207.772 €	550.586 €	286.349 €	298.252 €	390.833 €	0 €	402.649 €
Simulated Lower Bound Transportation Cost	0 €	84.549 €	96.616 €	308.390 €	151.365 €	144.253 €	199.332 €	0 €	218.577 €
Gap to base %	0,00%	-47,78%	-53,50%	-43,99%	-47,14%	-51,63%	-49,00%	0,00%	-45,72%

As a reminder, no vehicle routing decision was modelled, that justify the biggest deviation % shown in lower bound in short-haul trips that are made by LTL trips. Milk-run routing strategies were recommended to minimize the costs through construct of full truckload trips.

Those simulated short-haul transportation costs in Table 7.4 will be considered as upper bound short-haul transportation cost of pair to pair trips (worst case). Table 7.4 shows indicators on the opportunity for minimizing the long-haul transportation cost through utilizing the concept of full truckload that may be resulting in more cost saving.

The next section summarizes the simulation investigations and results of long-haul truck filling degree.

7.2.5.2 Reference Model Long-Haul Truck Filling Degree

The simulated frequency of the long-haul trips between plant central warehouses and logistic center hubs is estimated and the simulated truck filling degree of the long-haul transportation is summarized in Figure 7.2. Table 7.5 shows the simulated average truck filling degree for transports between the plant central warehouses and the logistic center hubs; all the shaded areas indicate the full truck load trips.

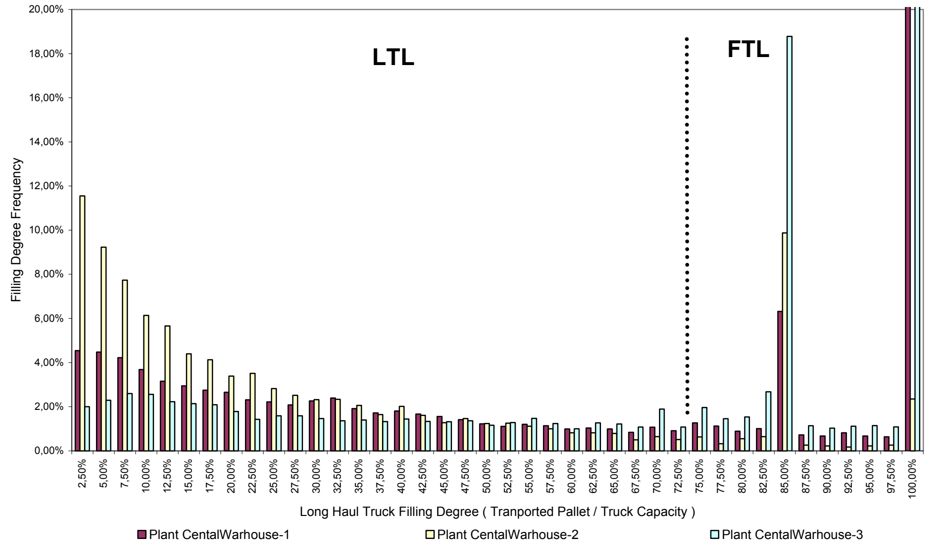


Figure 7.2 Reference Model Long-Haul Truck Filling Degree $\eta\%$

Table 7.5 Ref-Model Average Long-Haul Truck Filling Degree $E(\eta\%)$

LC-HUB/CW_Plants	P-CW-1	P-CW-2	P-CW-3
LC-1	15,00%	6,50%	15,75%
LC-2	39,75%	12,00%	57,50%
LC-3	36,00%	11,50%	44,25%
LC-4	18,75%	6,00%	12,25%
LC-5	45,00%	17,00%	54,75%
LC-6	25,25%	14,50%	43,75%
LC-7	24,75%	17,50%	59,25%
LC-8	**82,75%**	46,75%	**75,00%**
LC-9	65,00%	34,75%	68,25%
LC-10	47,50%	22,75%	64,75%
LC-11	32,25%	9,25%	14,50%
LC-12	54,50%	23,00%	57,00%
LC-13	38,50%	32,75%	56,50%
LC-14	32,50%	32,50%	69,25%
LC-15	50,75%	52,50%	69,25%
LC-16	5,50%	4,50%	11,75%
LC-17	51,00%	22,75%	62,00%
LC-18	42,25%	22,00%	63,50%
LC-19	**82,00%**	56,00%	**73,00%**
LC-20	68,75%	18,75%	62,75%
LC-21	58,00%	30,25%	**75,25%**
LC-22	51,25%	25,25%	**73,25%**
LC-23	14,50%	8,00%	17,50%
LC-24	63,00%	43,25%	**72,75%**
$E(\eta\%)$	**43,52%**	**23,75%**	**53,07%**
$\sigma(\eta\%)$	20,60%	14,79%	21,98%
$cv(\eta\%)$	0,47	0,62	0,41

As a reminder the volume of daily customer demand is satisfied directly from the plant central warehouse as discussed in chapter 6. Table 7.5 and Figure 7.2 show that most of the long-haul transportation trips are made in less truck load, e.g. the replenishment trips made from the plant central warehouse 2 almost are less than 50 % of the truck utilization (see Table 7.5). More investigation and designed modes are required to optimize and integrate the supply chain.

7.2.5.3 Tracing Reference Model Average Ending Inventory Levels

It was assumed in chapter 4 that the plant central warehouses have enough stocking inventory and they are able to submit logistic center replenishments without considering backorder (infinite supply sourcing assumption). This assumption was made where the plant central warehouses are responsible for supplying other supply chain networks so as (e.g., other supplying requirements .etc) to optimize the inventory system in plant central warehouses, which was not considered in future analysis. And the plant central warehouses will be treated as an infinite sourcing of material supply with designed product fill rate equal to 100% and with no back order allowed. The simulated average daily safety stock stored in the logistic center hubs of the reference model is summarized in Table IV.5. Figure 7.3 illustrates an example of the $I^{8}_{All,t}$ average ending inventory level of LC-hub 8.

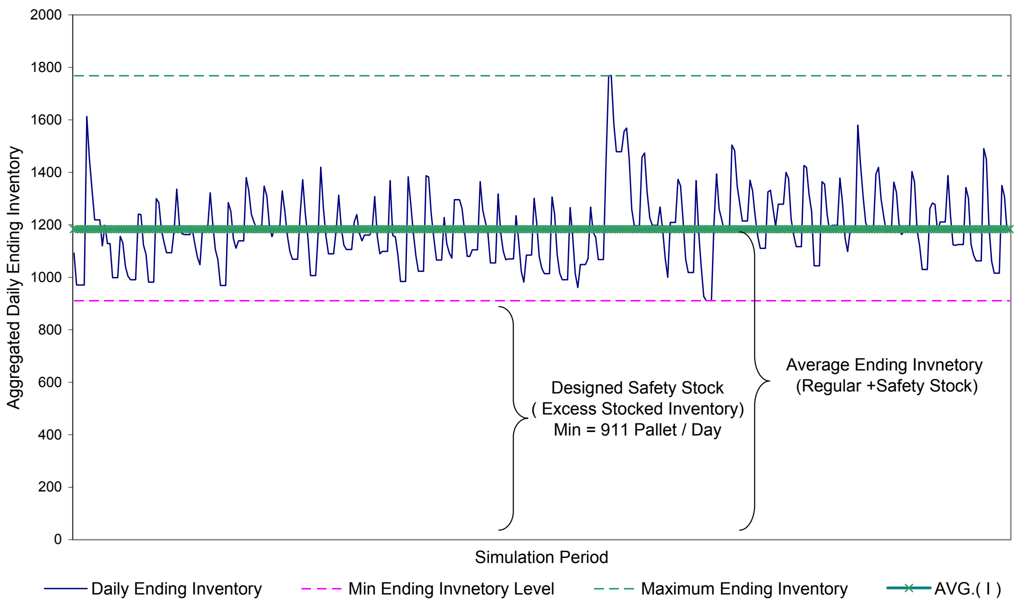


Figure 7.3 Simulated $I^{k}_{All,t}$ Daily Ending Inventory in LC-HUB 8

Several distribution strategies will be examined later against the reference model and several supply chain restructuring alternatives will be also investigated. The next section presents and summarizes the results of two extra benchmark experiment sets, examined and compared with the reference model results.

The newly designed benchmark distribution scenarios are utilized based on the concept of spatial postponement also known as product inventory allocation strategy. More detailed information found in Chopra and Meindl (2004) and Nozick et al. (2000, 2001). The product inventory allocation strategy is classified as one of the strategies applied in industry to minimize the effect of having a big safety stock in the supply chain.

7.3 The Spatial Product Class Postponement (Inventory Allocation Strategy)

Ballou (2004a) defined the postponement principle as the time of shipment and the location of final products processed in the distribution of the product; this process should be delayed until a customer order is received. The idea is to avoid shipping goods in anticipation of when demand will occur (time postponement) and to avoid creating the form of the final product in anticipation of that form (form postponement).

The spatial product class postponement strategy proposed in this section is implemented to avoid holding slow moving product or a specific products class family on the downstream supply chain location, and keeping them on the upstream location until a customer order is received as in time postponement. (Nozick , 2001 ; Nozick et al. , 2001 and Hawrng et al., 2005)

The supply chain studied in this thesis, the sourcing variety of products from several sourcing locations needs to be addressed, specifically, how to match supply chain performance measures and demand effectively. Unfortunately it is not clear how many units and which products need to be stocked and allocated.

A Ship To Order (STO) concept is introduced in this section and investigated. This concept IS similar to the Make To Order (MTO) concept with a little difference in adjustment of the shipment size. This is a widely used strategy nowadays, especially in industries where high demand uncertainty exists.

7.3.1 Description of the New Designed Benchmark Experiment Sets

The newly designed benchmark experiments are designed under the same assumptions made in section 7.2.2, with modified logistic center inventory parameters. The generalized simulation model input parameters of those two benchmark experiments are presented in Table 7.6.

Table 7.6 Main Benchmark Experiments Simulation Model Input Parameters

Benchmark Experiments Set	Plant-central Warehouses	Logistic center Hubs	Customers	Network Configuration	Replenishments type	Reorder Point Estimation Method	s Level Safety Stock Factor (k_{ss})			Product up to Level (K_{max})		
							Product Class / Family					
							A	B	C	A	B	C
B-Exp-Set-7	Same as Table 7.1					SDT ROP	0	2	STO	10	10	Pull
B-Exp-Set-8							1	STO	STO	10	Pull	Pull

The main difference between those two benchmarks is that in B-Exp-set7 the logistic center hubs are holding inventory of two product classes and product class C is allocated in the plant central warehouse and replenished according to ship to order (STO) concept. While in B-Exp-set8, the logistic center hubs holding inventory of one product class (Class A) and the products class B and C are allocated in the plant central warehouses and are replenished according to ship to order.

7.3.1.1 The Ship To Order Concept (STO)

The concept of ship to order is similar to the concept of make to order (MTO), both are based on actual demand; the difference of the STO to MTO concept proposed in this thesis was in adjustment of the product shipment size to largest integral production full pallets quantities Q_{ip}^{FP} , and the product replenishment decision is made only when the minimum inventory position equal to zero I_p^k= o. The maximum stocking capacity S_p^k was set to one full pallet. A residual stock will be generated if the demand less than products full pallets size Q_{ip}^{FP} .

The simulated model designed to investigate the network is illustrated in Figure 7.4.

7.3.2 Group-2 Benchmark Experiment Simulation Results and Analysis

The newly developed benchmark experiments have been simulated again for one fiscal year, with activity based costing model results summarized in Table 7.7, and the supply chain network performance measure results summarized in Table 7.8.

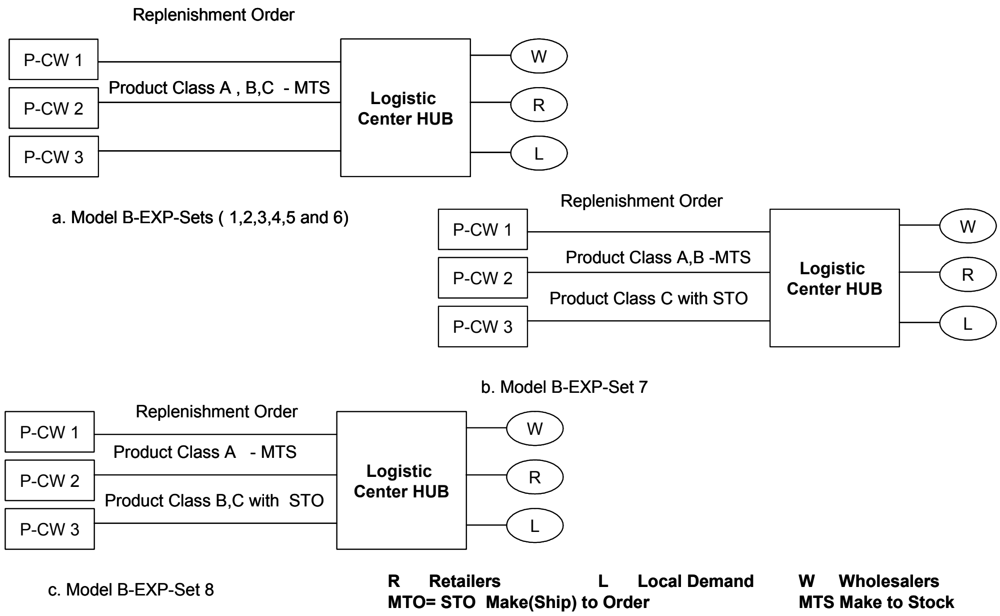


Figure 7.4 Spatial Products Classes Postponement Model with STO Strategy

Table 7.7 Benchmark Experiments 7and 8 Activity Based Costing Results

Benchmark Experiment Models	Supply chain Network Activity Based Costing Measures					
	Ordering	***Handling***	***Warehousing***	***Long-Haul Transp.***	***Short-Haul Transp.***	***Inventory***
B-Exp-Set-7 (Class C STO)	**121.142 €**	908.535 €	1.508.795 €	**6.628.186 €**	**5.139.779 €**	272.160 €
B-Exp-Set-8 (Classes B&C STO)	121.948 €	**907.338 €**	**1.508.044 €**	6.629.421 €	5.141.290 €	**239.472 €**
Objective Function Min(costs),Max(DLS)	121.142 €	907.338 €	1.508.044 €	6.628.186 €	5.139.779 €	239.472 €
Benchmark Exp Set ID	7	8	7	7	7	8

Table 7.8 Benchmark Experiments 7 and 8 Supply Chain Network Performance Measures

Benchmark Experiment Models	Supply chain Network Performance Measures		
	TSCN	***N-DLS-1 %***	***N-DLS-7 %***
B-Exp-Set-7 (Class C STO)	14.578.597 €	**86,04%**	**24,69%**
B-Exp-Set-8 (Classes B&C STO)	**14.547.513 €**	67,93%	14,20%
Objective Function Min(costs),Max(DLS)	14.547.513 €	86,04%	24,69%
Benchmark Exp Set ID	8	7	7

Analyzing the above simulation results, compared with base case results shows that the product class reallocation strategy in upstream supply chain locations increased the ordering cost in both benchmark experiment sets by about 4.98 % and 5.67 % respectively. The increasing of the ordering costs are caused by implementing the STO policy that generates smaller more frequent orders every time. The product classes such as A or B follow the make to stock concept (MTS) will be replenished when they reach the products reorder point.

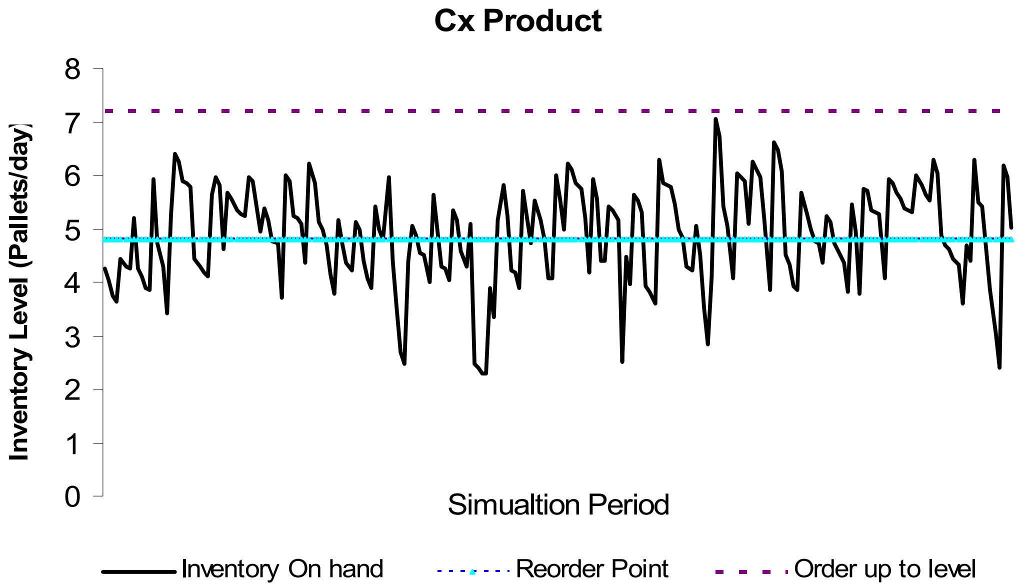
In the STO strategy, no safety stock was assigned; only regular cycle inventory exists, and product replenishment orders will be made when the product on hand inventory is equal to zero or less (backorder) s_p^k = 0 SKU's. This practice justified the reduction of the inventory cost by more than 36% and 44% with respect to reference model inventory costs. The second reason can be accounted for by generating frequent smaller shipment sizes of those reallocated product classes.

The examined benchmark experiments with ship to order (STO) strategy, show a relatively small but significant reduction to supply chain activities costs and long-haul transportation costs due to smaller replenishments quantities than in the reference model were made.

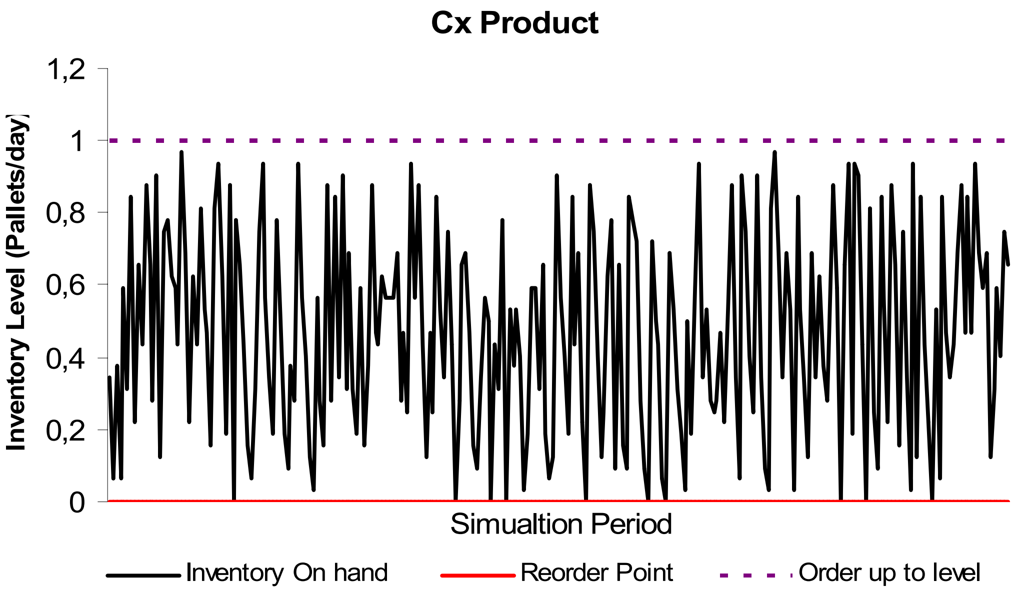
The logistic center inventory model operated utilizing the ship to order (STO) strategy shows special effect, when the demanded product quantity is less than the production full pallet $D_p^k \leq Q_{ip}^{FP}$; then a replenishment order of shipment size one was made to the plant central warehouses.

This concept produced an extra residual stock inventory for those products operated as STO strategy to be considered similar and variable product safety stock, Figure 7.5, illustrates the simulated I_{Cx}^{19} of a selected CX product type in the logistic center hub 19 without STO strategy and with STO strategy in experiment B-Exp-set-7.

As mentioned in Chopra and Meindl, (2004) and Nozick et al. (2000, 2001) the product delay differentiation strategy minimizes the inventory cost through achieving less safety stock. Table VI.2, depicts the reduction of both cycle and safety stock. Total reduction in supply chain safety stock was achieved by simulating for both benchmark experiment sets according to reference model B-Exp-set-6 by more than -49.73%, and -64.65% respectively.



a) Without STO Strategy



(b) With STO Strategy

Figure 7.5 Effect of the STO Strategy on Relocated Product Class CX.

There was a negative influence on short-haul – transportation cost, product DLS-1% service level, and a significant negative impact on delivery lateness service level DLS-7%. When implementing spatial postponement with (STO) concepts, that both service levels were positively correlated with short-haul transportation cost. Backordering the demand by at least 4 days until the shipments arrives caused such an effect. The effect of implementing the NPS strategy is the second reason for such a reduction; since no order can be delivered until all the order lines in the order are satisfied.

A reduction of -1.5% and -1.7% in total supply chain cost of both benchmark experiments sets was achieved when spatial postponement with (STO) concept was implemented.

The safety stock allocation strategy discussed in experiments set 7 and 8 could be a perfect and an appropriate distribution strategy, when minimizing the supply chain costs have a higher priority than delivery service level. The inventory cost was reduced by 36%, and 44% respectively in these two experiments compared by experiments B-Exp-Set 6.

Both Experiment sets 7 and 8 performed better when the inventory carrying cost in the logistic center hubs was relatively higher than the penalty cost. It was recommended to stock slow mover products in supply chain upstream locations, and stocking only the fast mover products closer to end customer demand points.

A Trade-off between the total supply chain costs and supply chain service level should be made according to the supply chain decision marker point of view.

7.2.3 Group-2 Benchmark Experiments 7 and 8 Summary and Conclusion

To conclude, the simulated scenarios demonstrate the potential of the spatial postponement with STO strategy in minimizing the inventory holding cost with a relative reduction in the long-haul transportation cost, while negative supply chain service levels were achieved. The effectiveness of spatial postponement with STO strategy could be utilized efficiently if we are able to reduce the order cycle time (lead time).

7.4 Benchmark Experiments Summary and Conclusion

The previous benchmark simulation experiments models and findings show several points that may improve and optimize the distribution process in the studied supply chain such as:

- Lower long-haul truck filling degree since the supply chain operated as a pure pull supply chain demand driven concept, which increases the long-haul transportation cost where most of the trucks are less than truck load.
- The inventory control parameters hold different levels of multi product safety stock.

For example, multi-product with stochastic demand greatly complicated the decision problem in coordinated control context. Several questions should be answered according to Silver et al. (1998) such as.

1. How often do we review the status of the item?
2. When do we reorder the group of items (joint replenishment problem)?
3. How much do we order?
4. How do we allocate the total order among the individual items?

More coordination and integration distribution strategies should be investigated and examined, so improvement to supply chain performance measures may be achieved. Cooperation and coordination across multiple parties within the supply chain and across functions is required. The best solution could be obtained by using global information and centralized control because the decisions are made with visibility to the entire system using information for all location (Silver et al.1998).

Benefits can be gained from sharing information across supply chain locations. Vendor Managed Inventory (VMI) with integrated Distribution Requirements Planning (DRP) will provide the appropriate strategy that may lead to improving the supply chain performance measures (Silver et al., 1998; Chachon and Fisher,2000; Ozer, 2003;Chen,2001;Karaesmen et al. 2004 and Ozer et al. ,2003).

The next chapter presents two proposed VMI models supported with two developed long-haul consolidation heuristics (PCR-VMI-1, ADI-VMI-2), utilized to improve the distribution supply chain performance measures, and integrating FTL and LTL transportaion trips to achieve shipping cost savings with an initiative focused on long-haul transportation activities and logistic center hubs inventory jointly due to higher sharing of both costs to total supply chain.

8.0 Proposed Integrated Long-Haul Consolidation Heuristics Simulation Experiments

8.1 Introduction

This chapter introduces and analyzes two main proposed integrated long-haul consolidation heuristics utilizing the vendor managed inventory distribution concept; the developed and designed heuristics are integrated into the developed simulation model presented in chapter 4, and are investigated, compared, and examined against the simulation benchmark experiments summarized in chapter 7. Supply chain performance measures discussed thus far have been estimated.

Section 8.2 presents an introduction and related literature review of vendor-managed inventory and the effect of the information management decisions on the supply chain performance measures. Section 8.3 introduces the differences between the two proposed integrated long-haul consolidation vendor managed heuristics as functions of information and materials flow. The detailed models formulation and the simulation parameters and results of the two developed long-haul consolidation models named as (SF-PCR-VMI1) and (SF-ADI-VMI-2) are presented in sections 8.4 and 8.5 respectively, simulation model sensitivity analysis will be found in section 8.6., two proposed advanced supply chain network configuration presented and simulated in section 8.7. Finally, general summarized recommendations and conclusions are made in section 8.8.

8.2 Introduction to Vendor Managed Inventory Concept

In many industries, vendor managed inventory re-supply (VMI) has become a popular strategy for integrating the inventory, transportation and distribution functions, resulting in reducing inventory holding and/or distribution costs. Silver et al. (1998) and Ballou (2004a) mentioned that probabilistic demand raises several new issues and creates extreme modeling complexities in a multi-echelon supply chain. Two useful dimensions of information and supply chain control strategies were to distinguish and classify as local versus global information and centralized versus decentralized control as shown in Table 8.1.

Table 8.1 Different Types of Information Management (Silver et al., 1998)

	Centralized Control	**Decentralized Control**
Global Information	Vendor managed Inventory Global planning systems	Base stock control Distribution Requirements Planning
Local Information	Make no sense	Basic inventory control

Local information implies that each location in the supply chain sees demand only in the form of orders that arrive from the locations it directly supplies. Also it has a visibility of only its own inventory status.

The global information implies that the decision maker has visibility of the demand, costs and inventory status of all supply chain parties' locations (Silver et al. 1998). Centralized control implies that attempts are made jointly to optimize the entire system usually based on individual or a group of functions. Centralized control is often identified with push systems because a central decision maker pushes stock to the supply chain downstream locations. Decentralized control implies that decisions are made independently by separating locations; decentralization is often identified with a pull system because independent decisions make pull stock from their suppliers (Pyke and Cohen, 1990).

The most appropriate and best solutions are obtained by using global and centralized control because the decisions are made with visibility to the entire system using information for all locations. Cachon and Fisher (1997), show that when the retailer is flush with inventory, its demand information provides little value for suppliers because the retailer has no short term need for an additional batch. The retailers' demand information is most valuable when the retailer's inventory approaches a level that should trigger the supplier to order additional inventory. But this is also precisely when the retailer is likely to submit an order. Hence, just as the retailers demand information becomes most valuable to the supplier, the retailer is likely to submit an order, thereby conveying the necessary information without explicitly sharing demand data.

Vendor Managed Inventory popularly known as VMI is gaining great momentum in retail business processes. Efficient supply chain management requires the rapid and accurate transfer of information throughout a supply system. Vendor Managed Inventory (VMI) is designed to facilitate that transfer and to provide major cost saving benefits to both suppliers and retailers customers. Vendor Managed Inventory is a continuous replenishment program that uses the exchange of information between the retailer and the supplier to allow the supplier to manage and replenish merchandise at the store or warehouse level (Silver et al., 1998; Cachon and Fisher, 1997; Aviv and Federgruen,1998,Gandhi, 2003).

VMI is a backward replenishment model where the supplier does the demand creation and demand fulfilments. In this thesis, the designed pull simulation model in chapter 4 assumes that the logistic center hubs manage their own inventory levels and decide how much to fulfil and when according to the continuous (s, S) inventory model with a local information control. Two newly developed VMI heuristics models were proposed and integrated to the original simulation model, and a global information control was conducted.

The VMI process is a combination of e-commerce, software and people. The e-commerce layer is the mechanism through which companies communicate the data. VMI is not tied to a specific communication protocol. VMI data can be communicated via EDI, XML, FTP or any other reliable communication method. More on Silver et al.(1998); Kuk et al. (2004).

The main difference between those proposed VMI models were in deciding which product families should be pushed ahead to logistic center hubs to form full truck load trips. Those extra pushed products modify the supply chain network from a pure pull supply chain to a hybrid supply chain network.

8.3 Development of Extended Hybrid Vendor Managed Inventory Simulation Models

It is important to examine the potential benefits to be gained from implementing the vendor managed inventory concept on the supply chain between logistic center hubs and plant central warehouses. Two new supply chain long-haul consolidation heuristics were developed considering the VMI concept, in order to analyze the potential supply chain performance measure advantages realized by VMI. The proposed models were developed and can be described as follows:

1 Ship all full vendor managed inventory scenarios without inventory visibility supported by Products Clustering Replenishment (PCR) strategy referred to later as **SF-PCR-VMI1**.

2 Ship full when possible vendor managed inventory scenarios with inventory visibility supported by Advanced Demand Information replenishment (ADI) strategy known as **SF-ADI-VMI-2**.

Both proposed models were tested, evaluated and compared with previously benchmarked experiments described in chapter 7. In the replenishment order fulfilment process using the VMI concept, typically the activities of forecasting and creating the replenishment orders are performed at plant central warehouses (centralized decision with global information control).

In SF-PCR-VMI-1 the candidate extra pushed product types and sizes are prepared based on the Products Clustering Replenishment (PCR) strategy which will be discussed in detail in section 8.4. where those extra products are shipped without considering the product inventory level in the logistic center hubs. In SF-ADI-VMI-2 an Electronic Data Interchange model (EDI) is an integral part of the VMI process and plays a vital role in the process of data communication. In VMI-2 models the logistic center hubs send the daily aggregated forecasted demand and the inventory position to the plant central warehouse via EDI model, then the plant central warehouses prepare and consolidate the normal shipment sizes with extra product types need in the next periods to form a full truck load trip.

In both VMI models, the plant central warehouses prepare the shipment list before shipping the products to the logistic center hubs. The logistic center hubs update the inventory position levels of those candidates pushed products. Figures 8.1 and 8.10 illustrate the flow of order fulfilment and information flow of both VMI models (Gandhi, 2003).

It is necessary to analyze and investigate which of those VMI models performs better in optimizing the supply chain performance measures. The next sections will discuss and present the model's formulation and the analysis of the simulation results of both VMI models. A general summary and conclusion will also be presented along with a sensitivity analysis which will be conducted in section 8.6 to present and measure the developed supply chain model robustness.

8.4 Ship Full-Vendor Managed Inventory Model with Products Clustering Replenishment Strategy (SF-PCR-VMI-1)

8.4.1 Introduction to SF-PCR-VMI-1 Distribution Methodology

The proposed SF-PCR-VMI-1 strategy in this section represents the first proposed and developed long-haul consolidation strategy called **Ship ALL FULL strategy.** That works by loading the unused truck space with extra (pushed) products to fill the unoccupied places and generating full truck load trips. Those pushed product types are generated according to the proposed Products Clustering Replenishment algorithm (PCR) which will be presented in section 8.4.2.

Determining an optimized replenishment strategy in multi-product environments may be difficult to obtain. Thus, the proposed consolidation heuristic adopted by filling the trucks with both normal replenishment shipment sizes with specific product types determined by the PCS algorithm.

The following example explains the mechanism of the SF-PCR-VMI-1 proposed strategy. Assume that the daily aggregate replenishment shipment size of a certain supply chain location was 36 pallets, and the carrier is capable of transporting 60 pallets per trip. Therefore, forming a full truckload trip requires the pushing of additional 24 pallets forward to the supply chain location.

The proposed PCA was adopted, where the extra consolidated products will be clustered to different product family groups according to the selected family clustering criteria.

8.4.2 The Proposed Products Clustering Replenishments (PCR) Heuristic

The proposed PCR replenishment algorithm is stochastic in nature, with truck capacity constraints. Several items are shipped at the same time and there is no joint replenishment algorithm applied yet.

The combination of the ABC and XYZ analysis forms a starting point for the proposed PCR algorithm, where the candidate pushed products were selected according to their ABC-XYZ classification. Table IV.4 summarizes the number of candidate product types classified into nine main family groups and clusters named as AX, AY, AZ and CZ product family clusters with respect to their stocking locations. An example of implementing the PCA algorithm in two logistic center hubs considering three products clustering criteria is illustrated in Table 8.2.

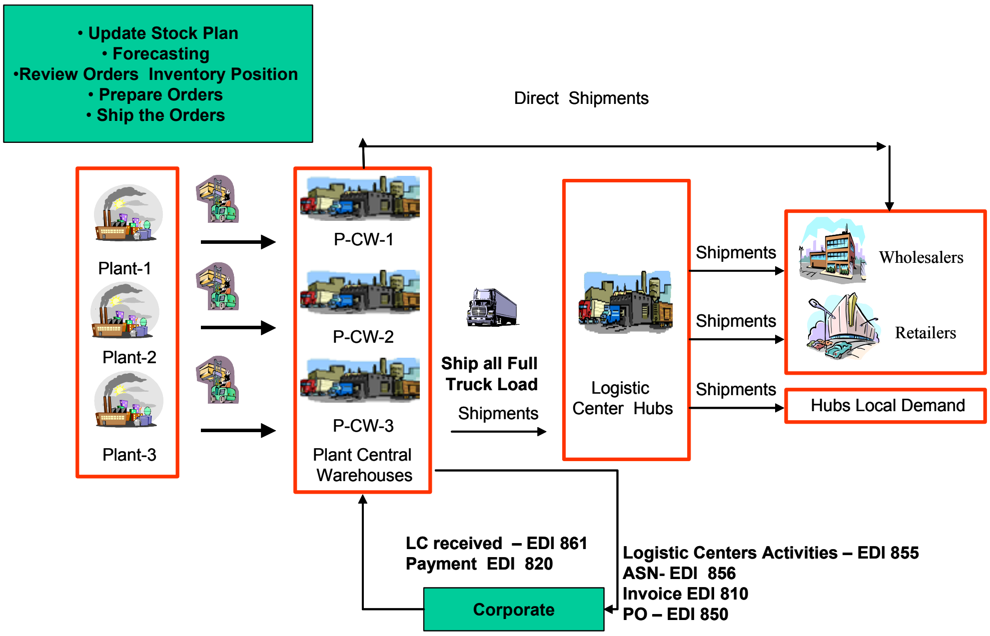


Figure 8.1 The Proposed SF-PCR-VMI-1 Materials and Information Flow

The product families CY and CZ will not be considered in this study due to non-stability of demand and therefore can not be predicted with any certainty, unlike the family CX where the demand volume is relatively small but the demand pattern is stable and can be predicted.

Table 8.2 An Example of Implementing the PCR Algorithm to LC-8 and LC-19

PCA Criteria (Cluster families)	Cluster family description	Number of candidate Products P^k_{PCR}	
		LC-8	LC-19
AX	High Fast Moving Products (HFMP)	7	8
AXAYBXBY	High and Medium Fast and Medium Moving Products (HMFMP)	37	31
AXBXCX	Only Fast Move Products (FMP)	26	26
CYCZ	Low and Medium Slow Moving Products (LMSMP)	88	71

8.4.3 Formulating The SF-PCR-VMI-1 Heuristic Model

Considering the developed supply chain simulation model in chapter 4, and the integrated pull consolidation strategy presented in Figure 4.10. The SF-PCR-VMI-1 strategy adds new steps that are integrated with the old pull strategy as shown in Figure 8.2 utilizing the PCR algorithm.

Step 6: Generate aggregated consolidation list (ψ^{k}_{pull}), quantity (CQ^{jk}_{t}), and CQ^{jl}_{t}.

$$CQ^{jk}_{t} = \sum_{p=1}^{p} Q^{k}_{pt} + \sum_{p=1}^{p} Qnew^{k}_{pt}$$ Shipment to Hubs

$$CQ^{jl}_{t} = \sum_{p=1}^{p} Q^{k}_{pt}$$ Direct Shipments to Customer

Step 6.1 Select case
$$\begin{cases} case-1 & CQ^{jk}_{t} < w^{k}_{jt} \quad \text{LTL Trip} \\ case-2 & CQ^{jk}_{t} > w^{k}_{jt} \quad \text{FTL \& LTL Trips} \\ case-3 & CQ^{jk}_{t} = w^{k}_{jt} \quad \text{FTL Trip} \end{cases}$$

Step 6.2 Select Only LTL Trips of case 1 and 2. Case 3 same as section 4.4.7.1

Step 6.3 Estimate the unused truck capacity such that:

$$w_{LTL\,jt}^{k} = w^{k}_{jt} - CQ^{jk}_{t}$$

Step 6.4 Generate aggregated pushed consolidation list (ψ^{k}_{push}), and insert product quantity ($Q\_Push^{k}_{pt}$) according to above PCR algorithm

where:

$$\psi^{k}_{push} = \{1,2,3.......P^{k}_{PCR}\}$$

$Q\_Push^{k}_{pt} = Q^{FP}_{lp}$: Such that $Q\_Push^{k}_{pt}$ = 1 in all ψ^{k}_{push} list

$$CQ^{jk}_{Push,t} = \sum_{1}^{P^{k}_{PCR}} Q\_Push^{k}_{pt}$$ Repeat until $w_{LTL\,jt}^{k} = 0$

Step 6.5 Estimate the new hybrid replenishments consolidation list ψ^{k}_{Hybird} and hybrid replenishment shipment size where:

$$\psi^{k}_{Hybird} = \psi^{k}_{pull} \cup \psi^{k}_{Push}$$ and

$$CQ^{jk}_{hybird,t} = CQ^{jk}_{pull,t} + CQ^{jk}_{Push,t}$$

Figure 8.2 SF-PCR-VMI-1 Long-Haul Consolidation Heuristic Model Formulation

The main difference can be seen in steps 6.1 to 6.5 where additional products are consolidated and pushed ahead to logistic center hubs based on the PCR algorithm. According to Higginson and Bookbinder (1994, 1995) and Chen (2005b), the proposed shipment consolidation heuristic above classified under the quantity based consolidation concept.

8.4.4 Selected Base Products Specification and Characteristics

The effect of the proposed strategies on the reference model and benchmark experiments was considered, namely to test the impact of the proposed heuristics on the supply chain performance measures.

Five products have been selected from different product families to evaluate the different impacts of the proposed heuristics on specific product performance measures such as average on hand ending inventory level. Figures 8.3 display the demand patterns of the selected products in LC-19 that apparently experiences consumer for compassion. Table 8.3 characterizes the selected product demand parameters and the fitted product cluster families in three selected logistic center hubs.

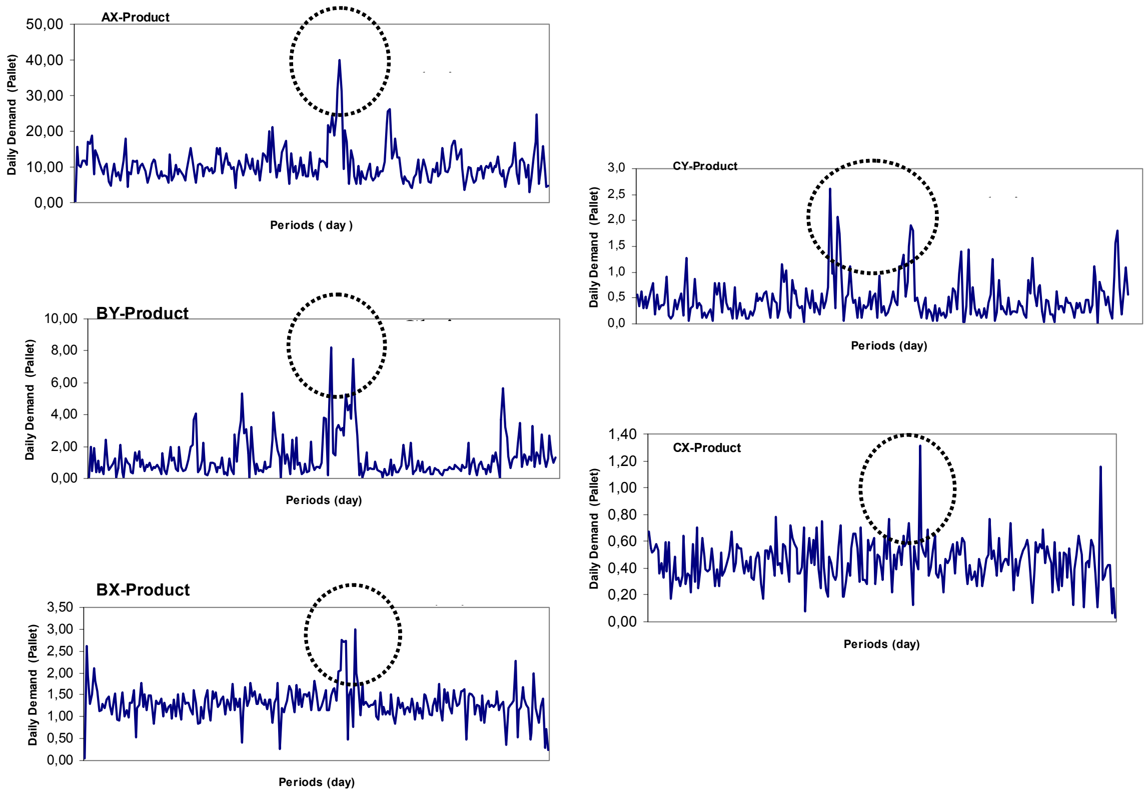


Figure 8.3 Five Selected PCF Products Demand Variability Patterns in LC-19

Table 8.3 Selected Product Types and Specification

Product ID	Logistic center Hub-5			Logistic center Hub-19			Logistic center Hub-8			Q_{lp}^{FP} units/full pallet
	E(D)*	$v(d_p^k)$	PCF	E(D)*	$v(d_p^k)$	PCF	E(D)*	$v(d_p^k)$	PCF	
1	1.3	0.69	AY	10.6	0.46	AX	9.3	0.54	AY	640
2	1.6	0.93	AY	1.3	1.0	BY	2.7	0.85	AY	144
3	0.4	0.5	AX	1.3	0.30	BX	1.4	0.35	BX	640
4	1.0	0.8	AY	0.5	0.8	CY	1.4	0.5	BY	640
5	0.3	0.33	BX	0.4	0.5	CX	0.4	0.5	CY	640

*in pallet/day PCF: Product Cluster Family

8.4.5 Description of the Simulated Scenarios with SF-PCR-VMI-1 Heuristic

Eight main simulation scenarios were investigated, according to a different product clustering replenishment algorithm as summarized in Table 8.4. Only 19 logistic center hubs are considered to implement the SF-PCR-VMI-1, and the hubs LC-1, LC-4, LC-11, LC-16, and LC-23 are replenished according to the algorithm in section 4.6.

The eight different experiment sets were designed and integrated into the simulation model presented in chapter 4. Those experiments are different in terms of implementation of the PCR algorithm as shown in Table 8.4. In experiment one only those higher fast moving products of the AX family are selected to be pushed and to fill the unused truck capacity in ranking ascending order. The other eight experiments vary in the number of candidate products and families.

Table 8.4 Simulated Scenarios with SF-PCR-VMI-1 Heuristic Input Parameters

Scenarios ID	Number of Logistic Center Hubs	Benchmark Experiment Reference Model	ψ_{Hybird}^{k} Replenishment List	
			ψ_{pull}^{k}	ψ_{push}^{k} with PCR Algorithm
1	19 LC Hubs with ψ_{Hybird}^{k} + 5 LC Hubs with ψ_{pull}^{k}	**B-Exp-set 6**	Pure Pull Replenishment Algorithm	AX
2				AXAY
3				AXAYBX
4				AXAYBXBY
5				AXBX
6				AXBXCX
7				AY
8				AYBY

The proposed scenario models are compared to performance measures of the benchmark experiment results set 6 mentioned in Chapter 7.

8.4.6 Simulation Results and Analysis of Models with SF-PCR-VMI-1 Heuristic

8.4.6.1 Effect of SF-PCR-VMI-1 on The Total Supply Chain Costs and Service Levels.

Simulating the model for one fiscal year, the supply chain activity based costing model and the total supply chain performance measures are summarized in Tables 8.5, and 8.6 respectively.

Table 8.5 Simulated Supply Chain Activity Based Costing Models
with SF-PCR-VMI-1 Heuristic

Benchmark Experiment Models		Supply Chain Network Activity Based Costing Measures					
		Ordering	**Handling**	**Warehousing**	**Long-Haul Transp.**	**Short-Haul Transp.**	**Inventory**
Hybird Models	AX	115.241 €	912.161 €	2.060.961 €	9.305.123 €	5.201.548 €	5.333.004 €
	AXAY	114.841 €	912.456 €	2.017.864 €	9.012.361 €	5.219.409 €	4.984.884 €
	AXAYBX	114.801 €	912.583 €	1.970.772 €	8.710.307 €	5.221.259 €	4.525.308 €
	AXAYBXBY	**114.485 €**	912.623 €	1.918.873 €	8.353.628 €	5.223.452 €	4.032.036 €
	AXBX	115.171 €	912.170 €	2.047.697 €	9.187.605 €	5.203.163 €	5.186.808 €
	AXBXCX	115.152 €	912.170 €	2.058.124 €	9.139.813 €	5.203.672 €	5.270.112 €
	AY	115.052 €	912.447 €	2.055.399 €	9.268.819 €	5.215.763 €	5.324.040 €
	AYBY	114.855 €	912.447 €	2.054.631 €	9.175.467 €	5.217.166 €	5.294.736 €
Pure	Base	115.400 €	**912.070 €**	**1.513.153 €**	**6.635.226 €**	**5.197.451 €**	**429.624 €**
Objective Function		114.485 €	912.070 €	1.513.153 €	6.635.226 €	5.197.451 €	429.624 €
Exp Set ID		AXAYBXBY	Base	Base	Base	Base	Base

Table 8.6 Supply Chain Network Performance Measures
with SF-PCR-VMI-1 Heuristic

Benchmark Experiment Models		Supply Chain Network Performance Measures			IMI %		
		TSCN	***N-DLS-1***	***N-DLS-7***	***Cost***	***N-DLS-1***	***N-DLS-7***
Hybird Models	AX	22.928.038 €	96,45%	64,88%	**54,89%**	**0,60%**	**4,73%**
	AXAY	22.261.815 €	97,50%	71,85%	**50,39%**	**1,70%**	**15,98%**
	AXAYBX	21.455.030 €	97,59%	72,53%	**44,94%**	**1,79%**	**17,08%**
	AXAYBXBY	20.555.097 €	**97,87%**	**74,97%**	**38,86%**	**2,09%**	**21,02%**
	AXBX	22.652.614 €	96,60%	65,63%	**53,03%**	**0,76%**	**5,94%**
	AXBXCX	22.699.043 €	96,61%	65,78%	**53,34%**	**0,77%**	**6,18%**
	AY	22.891.520 €	97,00%	67,98%	**54,64%**	**1,18%**	**9,73%**
	AYBY	22.769.302 €	97,27%	69,63%	**53,82%**	**1,46%**	**12,40%**
Pure	Base	**14.802.924 €**	95,87%	61,95%			
Objective Function		14.802.924 €	97,87%	74,97%			
Benchmark Exp Set ID		Base	AXAYBXBY	AXAYBXBY			

The effect of the proposed SF-PCR-VMI-1 Model without inventory visibility on the supply chain performance measures compared to benchmark experiments set 6 results and the improvement index deviations IMI_{Base}^{ExpID} are calculated and summarized in Table 8.6.

The proposed design simulation experiments were simulated for one fiscal year. Analysis simulation results are shown in Table 8.5 which summarized the simulated activity based costing results of the above nine hybrid simulation models with different PCR, where shaded cells indicate the minimal activity cost category. Table 8.6 depicts the whole supply chain network performance measure and the simulation models improvement index against the result of the B-Exp-Set-6. Table 8.6 shows hybrid experiments that consider a higher variety of product types and families such as in the case of PCR= AXAYBXBY which performs better in minimizing the supply chain cost and maximizing the service levels than the experiment with only one type of the product family where PCR=AX the only fast moving product. The above observation and behavior was justified by pushing a variety of products downstream, instead of pushing only one product type family.

As we can see from Table 8.6, under this examined scenario with AXAYBXBY more than 75% of the end customer orders were prepared for delivery and consolidation just at the time the order was received. This was an improvement of more than 20 % higher than in the case of B-Exp-set6 without changing the inventory control parameters of the other experiments. The other experiments also show relative improvements in terms of DLS-1% and DLS-7% where a significant positive impact was seen in improving the DLS-7% index (faster delivery to customers).

The proposed VMI-1 shows relatively small improvements as illustrated in Table 8.6 concerning the DLS-1% with a maximum improvement of 2% when the Ψ^{k}_{push} includes the AXAYBXBY family, where DLS-1% is designed to measure the product availability in the supply chain location considering the safety stock. The achieved improvements were gained through the increasing availability of those products in the Ψ^{k}_{push} by means of a generated extra residual stock.

Tables 8.5 and 8.6 show significant increase in total supply chain costs in the nine experiments with an average range of 50%. It is a result by an increased shipment size of hybrid replenishment quantities caused by $\Psi^{k}_{Hybird} = \Psi^{k}_{pull} \cup \Psi^{k}_{Push}$ and $CQ^{jk}_{hybird,t} = CQ^{jk}_{pull,t} + CQ^{jk}_{Push,t}$ as mentioned in the proposed replenishment algorithm in Figure 8.2.

The mechanism of the SF-PCR-VMI-1 is explained through the following presented example: suppose that the unused truck capacity of an established route between plant central warehouses and logistic center hub number 8 was $w^{k}_{LTL\,jt} = 9$ pallet places to have a full truck load trip. Assuming that PCR criteria considered only the AX product family, according to Table 8.2, that the number of AX products in LC-8 is 7 products; then the ψ^{k}_{Push} consolidation list will be $\psi^{8}_{Push} = \begin{Bmatrix} AX, AX, AX, AX, AX, AX, AX, AX, AX \\ 1\ \ ,2\ \ ,3\ \ ,4,\ \ 5,\ \ 6,\ \ 7,\ \ 1,\ \ 2 \end{Bmatrix}$ where the products 1 and 2 have been loaded two times in this case, while in the case of the compounded family list of PCR=AXAY the candidate number of products is 7+11=18 product types; the pushed consolidation list is $\psi^{8}_{Push} = \begin{Bmatrix} AX, AX, AX, AX, AX, AX, AX, AY, AY \\ 1,\ \ 2,\ \ 3,\ \ 4,\ \ 5,\ \ 6,\ \ 7,\ \ 1,\ \ 2 \end{Bmatrix}$,

as it was shown in Figure 8.2, the number of products types in ψ^{8}_{Push} randomly loaded according to the ranking list and unused truck capacity such as :

$$\psi^{8}_{Push}(w_{LTL\,jt}^{\ k})$$

Such a relationship led to an improvement in the supply chain service levels with higher total supply chain costs; the complexity of determining the appropriate pushing product family strategy utilizing the proposed PCR algorithm in uncertainty multi-product demand patterns complicated the long-haul replenishment decisions, most product types classified were B and C Class with an average daily demand is $E(D^{k}_{p}) \le 1.5\,Q^{FP}_{p}$.

Experiments with PCR=AX and PCR=AY show a lower improvement index among the others when the reason refers to the considered number of candidate product types in both experiments according to Table IV.4 that AX products represent only a smaller percentage of the total product types, and the AY family accounts for middle percentage of the total product types. The improvements were also achieved and justified even when K_{ss} =0 whereby no safety stock was considered.

It can be recognized that models considering more product families improve the supply chain service levels and minimize the total supply chain costs. This is the case with the PCR=AXAYBXBY experiments which lower supply chain costs. Considering compounded product types and families in the ψ^{k}_{Push} as in the experiment where PCR= AXAY improve the supply chain service levels by more than 15%, while considering individual product family type such as in the experiment with PCR=AX or PCR=AY individually improves the supply chain service levels only by 4% and 9 % respectively.

Table VI.5 and Table VI.6 show relatively little significant reduction in ordering costs (less than 1%) caused by a reduction in the replenishment order times of those pushed product families, because the pushed products have not reached the reorder point level s_p^k yet. This early replenishment generates a residual stock effect mentioned by Silver et al. (1998).

An increase in the outgoing costs of the plant central warehouses ranges from 35-45% in all tested scenarios, the simulated scenarios show that lower outgoing costs occur when the candidate Ψ_{push}^k list to the logistic center hubs was bigger such as in the case of PCR=AXAYBXBY simulated scenarios where under this tested experiment a higher number of candidate product types was capable of being pushed forward to downstream locations.

There was an increase in the long-haul transportation cost by 25-35%. In all simulated scenarios, this effect is justified by increasing the outgoing costs as mentioned previously and that all the transportation trips were made in full truckload trips between those 19 logistic center hubs and the 3 plant central warehouses.

Increases in the incoming pallet costs in the logistic center hubs ranged from 50%-64%, approximately double the quantities when the SF-PCR-VMI-1 strategy was implemented resulted also from higher $CQ_{hybird,t}^{jk}$. Investigating and justifying the causes of those effects on the supply chain performance measures could be summarized thus:

1- Pushing extra product types in the Ψ_{push}^k list according to the defined PCR algorithm result, forming full truckload trips with 100% truck capacity utilization.
2- Higher uncertainty of daily consumption rate of some product types and families clustered into Ψ_{push}^k list according to the PCR algorithm was less than 1 pallet per day, resulting in the build-up of a huge and accumulating ending inventory of such product types.

Considering the latter effect, Figure 8.4 shows the simulated average daily ending inventory levels of the supply chain locations with building up a huge inventory levels when implementing the SF-PCR-VMI-1 strategy.

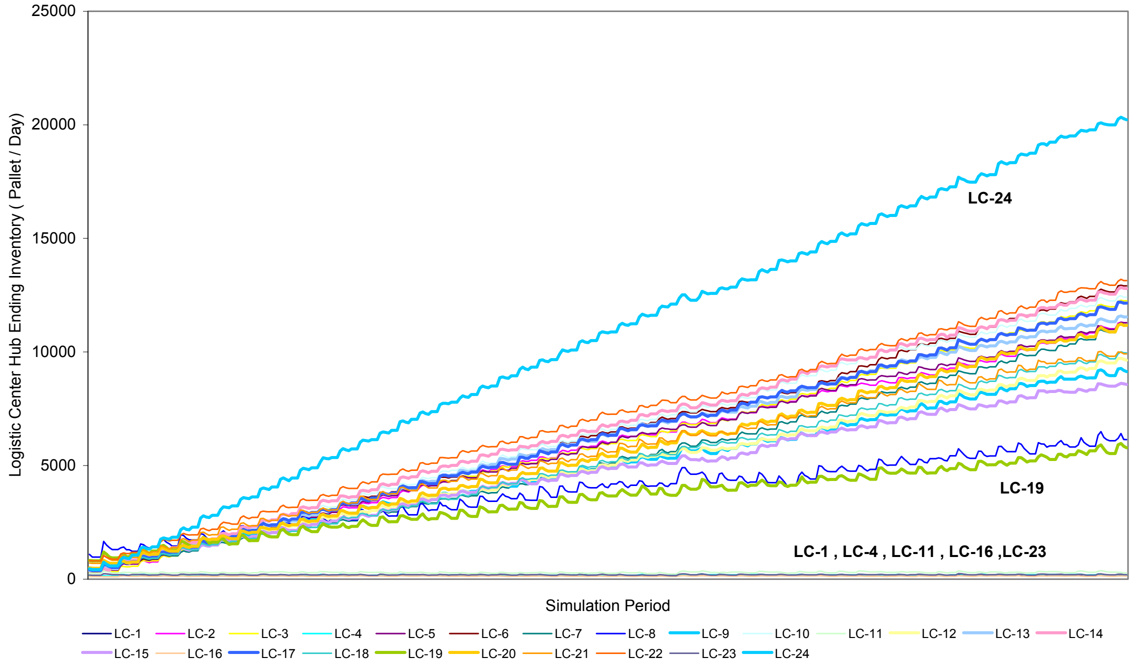


Figure 8.4 Average Daily Ending Inventory Based on SF-PCR-VMI-1 Model (PCR=AXAYBXY family)

Figure 8.5 shows the simulated $\mathrm{I}^{k}_{p,t}$ of the five products in the benchmark experiment set 6 which is considered as the reference model experiment with different ending inventory levels. Considering the SF-PCR-VMI-1 with PCR= AXAYBXBY experiment the effect of the build-up inventory in logistic center hubs appeared in Figure 8.4 could be justified through Figures 8.6, and 8.7. Those figures show the effect of the SF-PCR-VMI-1 strategy on the product inventory level $\mathrm{I}^{k}_{p,t}$ and the amount of generated residual stock of the five selected product types belonging to different product families in logistic center hubs LC-19 and LC-8.

Figures 8.6, and 8.7 illustrate the behaviour of the product ending inventory in LC-19 of the five selected product types before implementing the heuristic according to B-Exp-set6 and after implementing the SF-PCR-VMI-1 heuristic with the PCR=AXAYBXBY family. Figure 8.7 shows that products with higher consumption rates included in the Ψ^{k}_{push} from time to time have triggered replenishments before reaching their desired reorder points. This caused an excess stock; an account must be taken of this excess residual stock because it produces more safety stock above and beyond the usual product reorder point, as we can see in more details in Figures 8.8 and 8.9 that the estimated daily demand of the product AX is E(D)=10.6 pallet/day >>> Q_{lp}^{FP} full pallet while in the case of BX,BY product types the estimated E(D)=1.3 pallets/day $\approx Q_{lp}^{FP}$, considering the higher uncertainty and non stationary nature of product demand measured by coefficient of variation $cv = \sigma(D) / E(D)$ ranged from 0.5 to more than 1.0, so that a higher building of excess residual stock inventory of those product types occurred when :

$$\begin{cases} \mathrm{E_p}(D_p^k) \leq \mathrm{Q_p^{FP}} & \text{Huge excess product inventoy} \\ otherwise & \text{Little excess product inventoy} \end{cases}$$

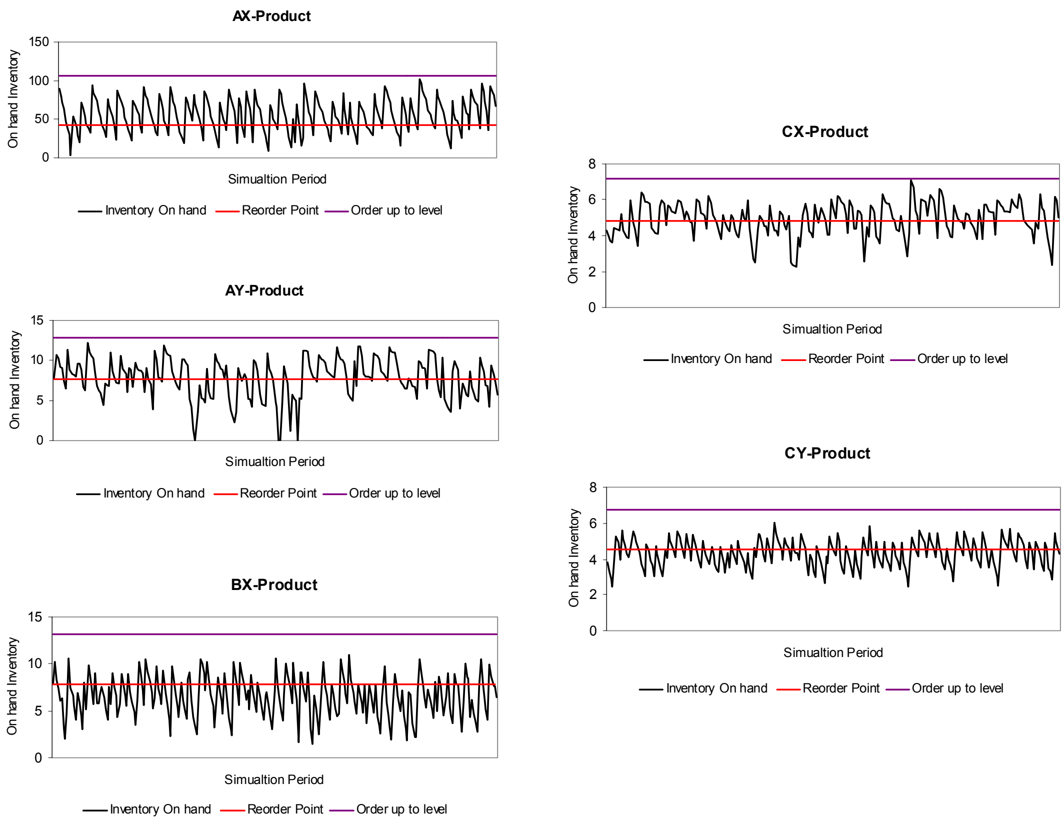


Figure 8.5 B-Exp-set-6 Simulated $I_{p,t}^k$ of Selected Products Types in LC-19

Table 8.7 summarizes the simulated average ending inventory of the five products in each logistic center hub with and without implementing the hybrid models.

Table 8.7 Simulated $I^k_{p,t}$ of Selected Products Types With and Without SF-PCR-VMI1

Model	Location	Product 1		Product 2		Product 3		Product 4		Product 5	
		$I^k_{p,t}$	$\sigma(I^k_{p,t})$	$I^k_{p,t}$	$\sigma(I^k_{p,t})$	$I^k_{p,t}$	$\sigma(I^k_{p,t})$	$I^k_{p,t}$	$\sigma(I^k_{p,t})$	$I^k_{p,t}$	$\sigma(I^k_{p,t})$
Pure Pull (B-EXP-set-6)	LC-19	55	21	8	3	7	2,1	5	0,92	4	0,8
	LC-8	51	18	16	5	6	2	7	2	3	1,4
Hybrid Model with PCR=AXAYBXBY	LC-19	68	19	132	58	48	16	5	0,7	5	0,62
	LC-8	53	14	18	6	11	3	14	3	4	2
% of Excess Inventory	**LC-19**	**24%**		**1550%**		**585%**		**0%**		**25%**	
	LC-8	**4%**		**13%**		**84%**		**100%**		**33%**	

Figures 8.6, 8.7 and Table 8.7 explain the reason for the development of such huge residual stock levels in all selected logistic center hubs when implementing the SF-PCR-VMI-1 heuristic integrated with a hybrid simulation model.

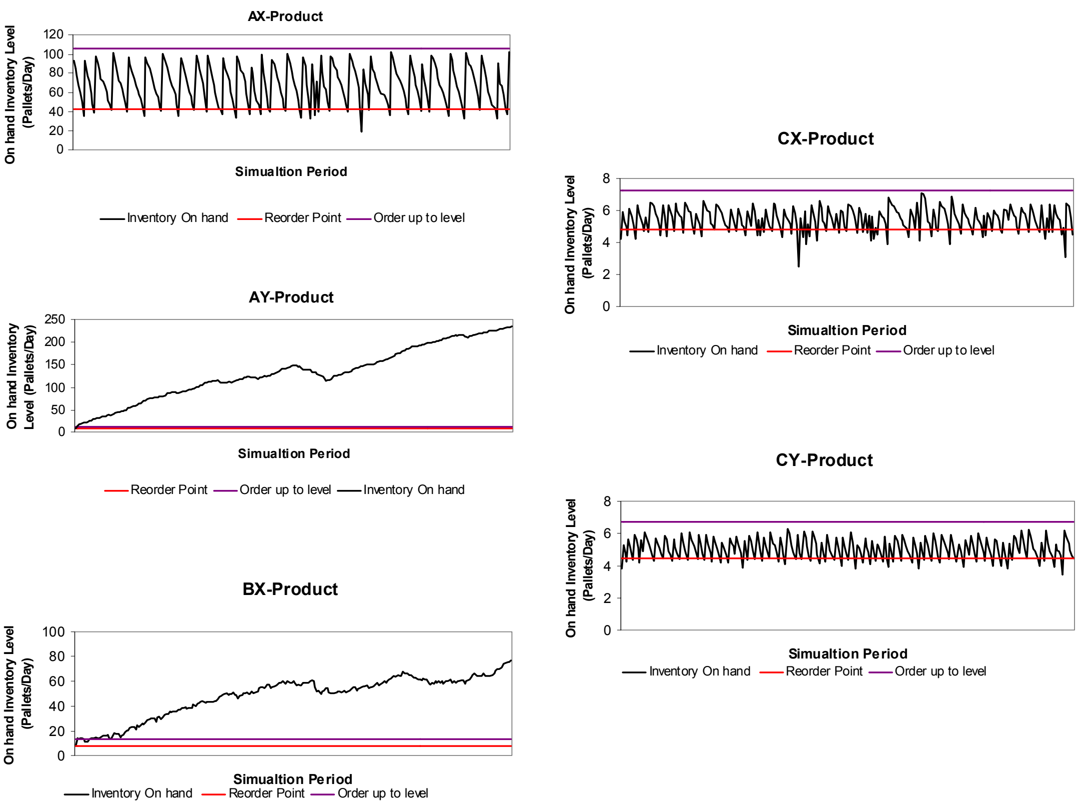


Figure 8.6 Simulated $I^k_{p,t}$ with SF-PCR-VMI-1 at PCR=AXAYBXBY in LC-19

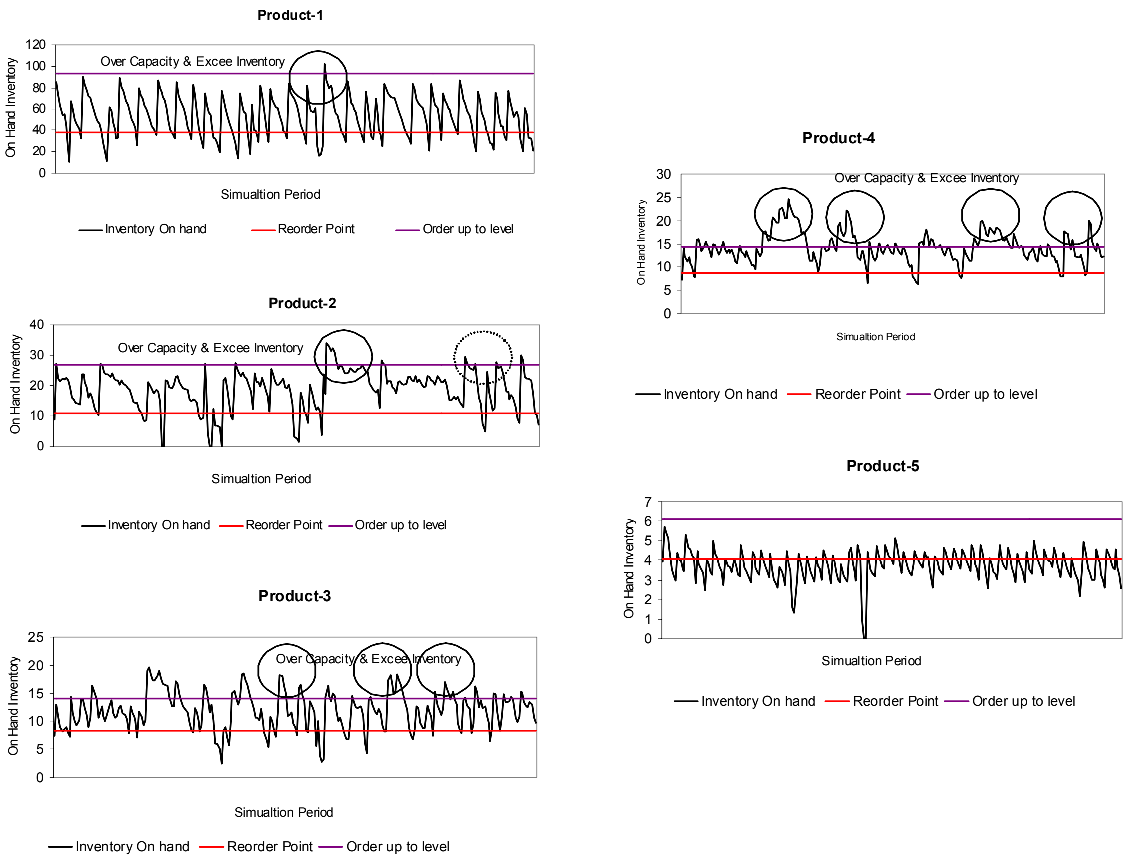


Figure 8.7 Simulated $I_{p,t}^{k}$ with SF-PCR-VMI-1 at PCR=AXAYBXBY in LC-8

Table 8.7 shows also other effects of implementing the joint replenishment SF-PCR-VMI-1 heuristic integrated with hybrid models. Even some product like product 4 and 5 in LC-19 belonging to C class develop small residual stock in comparison to the B-EXP-set-6; even through this product class was not in the ψ_{Push}^{k} list with the PCR=AXAYBXBY family.

The reason is due to the higher availability of the other highly demanded product families that increase the consumption rate of slow moving products inventory position $\mathrm{I}_{p,t}^{k}$ and also the effect of NPS order fulfilments strategy implemented in Chapter 4. Where the customer's orders are not allowed to be split and send only complete.

Figures 8.8 and 8.9 show a comparison between the inventory levels of the AX and CX products in LC-19 before and after implementing the proposed SF-PCR-VMI1 heuristics.

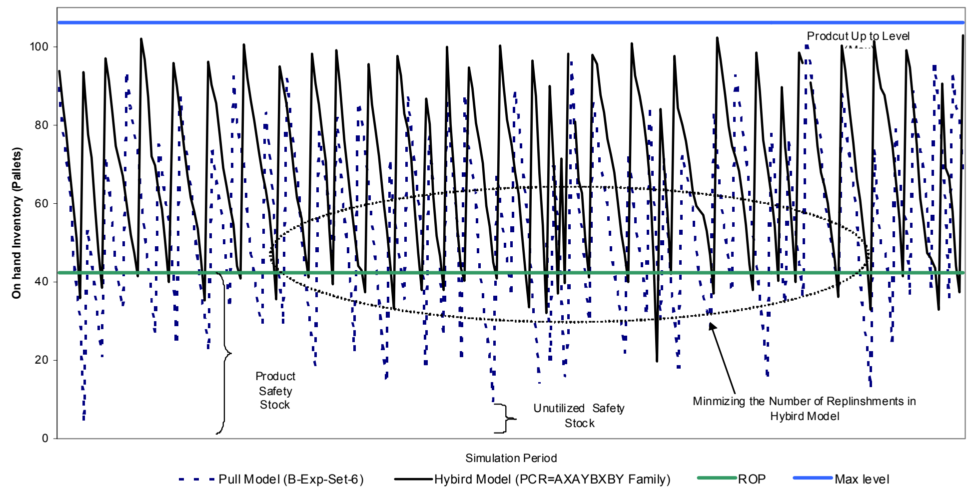


Figure 8.8 Simulated $I_{p,t}^{k}$ of AX Product of Hybrid Model at PCR=AXAYBXBY in LC-HUB 19

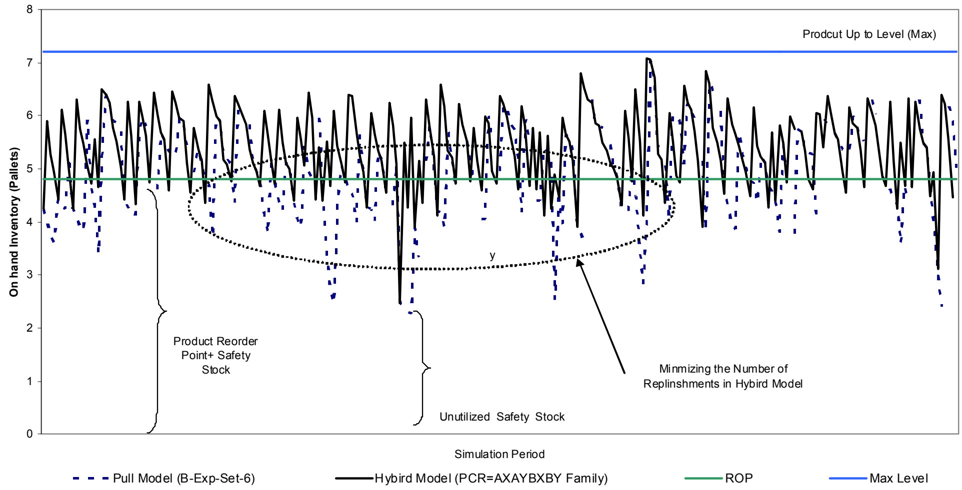


Figure 8.9 Simulated $I_{p,t}^{k}$ of CX Product of Hybrid Model at PCR=AXAYBXBY in LC-HUB 19

8.4.7 Summary and Conclusion of SF-PCR-VMI-1 Models

In the hybrid experiments with a different PCR list, the availability of specific product types was increased and considering the NPS policy, a higher DLS-7 and DLS-1 % will be achieved.

The integrated PCR with LTL trips show a negative impact on total supply chain cost and a positive impact of improving the supply chain service levels.

The SF-PCR-VMI-1 model performs perfectly, in case that the supply chain service levels had a higher priority than supply chain costs; in some supply chain networks where the availability of certain types of products are essential, the SF-PCR-VMI-1 is recommended to be utilized. In this thesis considering the multi-criteria objective functions presented in chapter 4, the SF-PCR-VMI-1 caused a higher supply chain cost in all benchmark experiments developed in chapter 7. No further consideration will be made regarding the SF-PCR-VMI-1 heuristic for the following reasons:

- It is building a huge multi-product huge excess residual stock inventory level in all the 19 logistic center hubs, that exceeds the stocking capacity levels of the logistic center hubs more than the physical product capacity, caused by earlier replenishments and differences between the product consumption rates E(D) and product full pallets replenishments shipment size Q_{lp}^{FP} of each product type.
- The complexity of establishing practical criteria for joining product types and families in ψ_{Push}^{k} list.
- Incurring and increasing the daily shipment sizes between the plant central warehouses and logistic center hubs by full truck load trips without considering the visibility of the logistic center hubs products inventory position causes an increase in the total supply chain cost with relative improvement in service levels.

The above mentioned advantages and disadvantages of the SF-PCR-VMI-1 justify for more research work and adjustments to be fully integrated into the transportation and the inventory functions without building a huge excess inventory with the possibility of adjusting the product inventory residual stock. Therefore, it is recommended to utilize the full truckload trips whenever possible.

This enhances the development and improvement of other long-haul replenishment strategies that utilize the full truckload trips concept without causing huge excess inventory levels (minimizing the residual stock) generated by the joint integrated replenishment between the transportation and inventory function. Unlike the SF-PCR-VMI-1 heuristic the newly modified long-haul replenishment should consider the visibility of pushed product inventory positions in downstream locations (logistic center hubs). This model will be discussed in detail in section 8.3.

Several distribution strategies were investigated to improve the performance of the supply chain. One of the new trends in the area of supply chain research is to implement the concept of integrating the information transfer between supply chain parties though the EDI, XML, and other forecasting tools. The advanced demand information concept will be presented in the next section as a new integrated product clustering replenishment policy.

8.5 Ship Full-Vendor Managed Inventory Model with Advanced Demand Information Replenishment Strategy

8.5.1 Introduction to SF-ADI-VMI-2 Distribution Methodology

Advanced demand information is obtained as the customer places orders in advance of further demand requirements. In this thesis the advanced demand information concerns those aggregated individual product demand requirements ordered from the logistic center hubs to satisfy end customer demand needs.

The supply chain performance may be improved by satisfying the customer demand in just in time as we have seen in case of SF-PCR -VMI-1 which pushed replenishment products to accelerate and improve both delivery performance measure DLS-7% and product fill rate DLS-1%. One of the drawbacks that occurs by applying the last SF-PCR -VMI-1 model was the building of huge residual stock ending inventory levels of specific types of products according to the PCR clustering criteria. This problem could be resolved by implementing the advanced demand information concept supported with inventory visibility control and stocking them according to their forecasted needs in downstream locations with appropriate shipment sizes. Therefore, the speed of delivery may increase and improve without building higher inventory levels of specific product types.

Thus, under this proposed distribution strategy with ADI scenarios, the end customer demand and logistic center hub replenishment shipment sizes for any further periods (n) will be progressively revealed. (n) is the period defined as the maximum allowed information horizon period.

This section explains how to achieve benefits gained through applying the ADI concept. The individual aggregated product demand (D^k_{pt}) seen during any period (t) at logistic center hubs (k) is given by the vector list as $D^k_{ptn} = \{D^k_{pt}, D^k_{pt+1}, \ldots\ldots, D^k_{pt+n})$ where D^k_{pt+s} represents forecasted demand requirements during the period (t+s) for further period s at logistic center k where $s \leq n$ are less than the maximum allowed information horizon offered by the location.

The maximum allowed information horizon period depends on the forecasting model implemented in the supply chain locations. In this thesis the maximum allowed information horizon period n = 5 days (1 week in advance) where $n \le L_1 + 1$ or $n \le L_1 + L_2$. As mentioned previously, the supply chain replenishments decisions are centralized and based on global system-wide information control similar to Cachon (2001), Chen (2001), and Zipkin (2000).

Figures 8.10 illustrate the flow of order fulfilment and information flow of SF-ADI-VMI model.

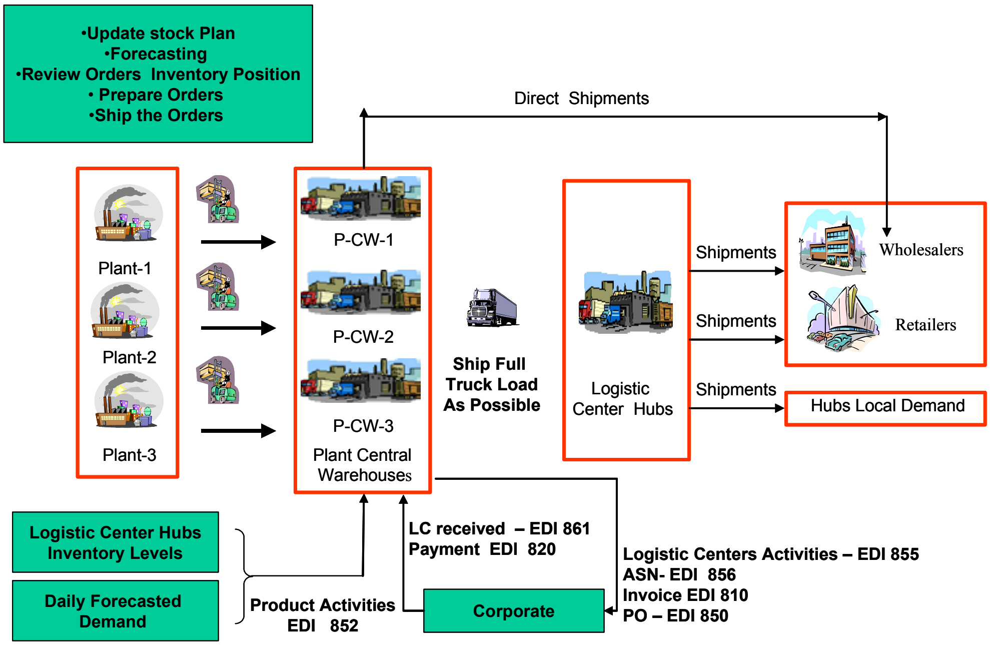


Figure 8.10 The Proposed SF-ADI-VMI-2 Materials and Information Flow

Ozer (2003) stated that the advantage of implementing the ADI is the possibility of minimizing or eliminating the uncertainty in the supply chain location, considering the case of customers placing their aggregated demand order of (n) days in advance, such that $n > L_1 + L_2$. In this case, the logistic centers do not need to carry any regular or safety stock inventory, as the logistic center operates as a cross docking point instead of traditional logistic center hubs with inventory capability. Ozer (2003) neglected to take into consideration the effect of the truck capacity being incapacitated. The proposed ADI concept in this thesis takes into consideration the effect of unused truck capacity.

The main objective of the SF-ADI-VMI-2 model was to integrate the ADI concept with the transportation function considering the logistic center inventory visibility so all the long-haul replenishment trips were made as full a truck load when possible.

8.5.2 The Proposed ADI Replenishments Algorithm (ADI)

The state of the product availability with ADI is given by modifying the product inventory position $I^{k}_{new\,pt}$ in each logistic center hub by considering the aggregated demand requirements of each product type in the next (n) period, instead of daily demand as in the case of benchmark experiment models (pull simulation model).

$$I^{k}_{pt} = I^{k}_{p\,t-1} + T^{k}_{pt} - D^{k}_{pt} - B^{k}_{pt} \quad (8.1)$$

$$I^{k}_{new,pt} = I^{k}_{new,p\,t-1} + T^{k}_{pt} - \sum_{t}^{t+n} D^{k}_{p\,t} - B^{k}_{pt} \quad (8.2)$$

The proposed (SF-ADI-VMI-2) presents the second newly developed long-haul consolidation strategy which is to ship full truck load trip in the long-haul with PCR based on the product advanced demand information and product inventory position.

The proposed consolidation mechanism is different from the previously mentioned SF-PCR-VMI-1 heuristic. In this strategy determining the extra consolidation load list ψ^{k}_{Push} of the pushed products to fit the remaining empty truck places is based on the product forecasting consumption rate. The demand forecast is known only during a predefined further freezing period called frozen information horizon period (n). See more in (Cachon and Fisher, 2000; Ozer, 2003; Chen, 2001; Karaesmen et al. 2004, Lee et al. 2000 and Ozer et al. 2003)

Such strategy increases the possibility of having full truckload trips controlled by the product availability and the consumption rate together.

The following example explains the mechanism of implementing the SF-ADI-VMI-2 strategy. Assume that the daily aggregate replenishment demand of a certain supply chain location can be accommodated in 36 pallets, where the full truck carries 60 pallets, thereby, forming a full truckload trip requiring 24 extra pallets to be pushed downstream. In the proposed replenishment strategy, if the inventory position of allocated products push list in the next predefined further freezing period say n=2 days will be above the reorder points; therefore, no pushed action will be undertaken, but in case the inventory position reaches the trigger point, extra pushed pallets will be shipped in advance.

In this policy, trucks which leave the plant central warehouses may be fully loaded with the normal pulled demand and extra pushed products based on the inventory visibility properties, constructing both $\psi^{k}_{Hybird} = \psi^{k}_{pull} \cup \psi^{k}_{Push}$ list and $CQ^{jk}_{hybird,t} = CQ^{jk}_{pull,t} + CQ^{jk}_{Push,t}$ consolidation qualities. The extra consolidated items have been assigned and clustered into one advanced pushed products list ranked based on the (first in first served) concept ψ^{k}_{Push}, taking into consideration different pushed quantities.

The consolidation list is based on the forecasted needed demand $CQ^{jk}_{Push,t}$ only, unlike the pushed quantity is 1 production full pallet each time the product is pushed forward. As was mentioned in Ozer (2003) and Ozer,et al. (2004), establishing an optimal distribution policy even in the absence of the ADI can computationally be introduced.

8.5.3 Formulating SF-ADI-VMI-2 Heuristic Model

Consider the developed supply chain simulation model in chapter 4, and the integrated SF-ADI-VMI-2 heuristic new controlling steps. Figure 8.11 summarizes the proposed long-haul consolidation heuristic utilizing the ADI policy. The main difference can be seen in steps 6.1 to 6.8.

The replenishment decision occurs when the product inventory position (I^{k}_{pt}) reaches the reorder point level (s^{k}_{p}) at period (t) under the pull policy. While under the proposed ADI policy, additional further demand qualities are required to cover the demand of the next (n) period where the (s) period represents the time in between the (t) and (t+n) periods such that $s \in \{t,.......,t+n\}$. The (n) value was set to be $n \leq 5$ in this thesis (one week in advance), the aggregated product demand requirements faced by the logistic center hubs at time (t) to meet the demand of the next (n) period are a vector of $D^{k}_{p,t+n} \in \{D^{k}_{p,t},...D^{k}_{p,t+s}....,D^{k}_{p,t+n}\}$ where (n) is defined as the length of the predefined information horizon period such that $D^{k}_{p,t+s} \leq D^{k}_{p,t+n}$ represent the accepted advanced demand that may fit in the remaining truck capacity indicated by $w^{k}_{LTL\,jt}$.

Step 6: Generate aggregated consolidation list (ψ^{k}_{pull}), quantity (CQ_t^{jk}), and CQ_t^{jl}

$$CQ_t^{jk} = \sum_{p=1}^{p} Q_{pt}^{k} + \sum_{p=1}^{p} Qnew_{pt}^{k} \qquad \text{Shipment to Hubs}$$

$$CQ_t^{jl} = \sum_{p=1}^{p} Q_{pt}^{k} \qquad \text{Direct Shipments to customer}$$

Step 6.1 Select case
$$\begin{cases} case-1 & CQ_t^{jk} < w_{jt}^{k} \quad \text{LTL Trip} \\ case-2 & CQ_t^{jk} > w_{jt}^{k} \quad \text{FTL \& LTL Trips} \\ case-3 & CQ_t^{jk} = w_{jt}^{k} \quad \text{FTL Trip} \end{cases}$$

Step 6.2 Select Only LTL Trips of case 1 and 2. Case 3 same as section 4.4.7.1

Step 6.3 Estimate the unused truck capacity such that:

$$w_{LTL\,jt}^{\;k} = w_{jt}^{k} - CQ_t^{jk}$$

Step 6.4 Define the maximum allowed information horizon period (n)

Step 6.5 Estimate and establish the aggregated product demand vector according to the next n periods $D_{p,t+n}^{k} \in \{D_{p,t}^{k}, \ldots D_{p,t+s}^{k}, \ldots, D_{p,t+n}^{k}\}$

Step 6.6 Estimate product modified inventory position $I_{p,t}^{k}new$ at time t where :

$$I_{pt}^{k}new = I_{p\,t-1}^{k} + T_{pt}^{k} - \sum_{t}^{t+n} D_{p\,t}^{k} - B_{pt}^{k}$$

Step 6.7 Generate the aggregated pushed consolidation list (ψ^{k}_{push}), and pushed product quantity (CQ_t^{jk}) according ADI Concept

when : $I_{pt}^{k}new \le s_p^{k}$ add product p to ψ^{k}_{push} list

Such that $Q\_Push_{pt}^{k} = S_p^{k} - I_{pt}^{k}new$

$$CQ_{Push,t}^{jk} = \sum_{1}^{P_{PCR}^{k}} Q\_Push_{pt}^{k}$$

Step 6.8 Estimate the new hybrid replenishment consolidation list ψ^{k}_{Hybird} and hybrid replenishment shipment size where : $\psi^{k}_{Hybird} = \psi^{k}_{pull} \cup \psi^{k}_{Push}$ and $CQ_{hybird,t}^{jk} = CQ_{pull,t}^{jk} + CQ_{Push,t}^{jk}$

Figure 8.11 SF-ADI-VMI-2 Long-Haul Consolidation Heuristic Model Formulation

8.5.4 Description of the Simulated Scenarios with SF-ADI-VMI-2 Heuristic

Five different simulation scenarios were investigated considering five values of (n) information planning horizon period summarized in the Table 8.8. The proposed long-haul consolidation replenishment heuristic will be adopted and implemented to whole supply chain logistic center hubs including the five collective logistic center hubs LC-1, LC-4, LC-11, LC-16, and LC-23, unlike the previously proposed SF-PCR-VMI-1 where those logistic center hubs were excluded from implementation as mentioned previously.

Table 8.8 Simulated Scenarios with SF-ADI-VMI-2 Heuristic input parameters

Scenarios ID	Number of Logistic center hubs	Benchmark experiment Reference Model	ψ^{k}_{Hybird} Replenishment List	
			ψ^{k}_{pull}	ψ^{k}_{push} with PCR algorithm
1	24 LC Hubs with ψ^{k}_{Hybird}	**B-Exp-set6**	Pure Pull Replenishment Algorithm	ADI= n = 1 Day
2				ADI= n = 2 Day
3				ADI= n = 3 Day
4				ADI= n = 4 Day
5				ADI= n = 5 Day

8.5.5 Simulation Results and Analysis of Models With SF-ADI-VMI-2 Heuristic

8.5.5.1 Effect of SF-ADI-VMI-2 on Total Supply Chain Costs and Service Levels

Simulating the model again one year, the proposed SF-ADI-VMI-2 heuristic integrated with hybrid model enables to characterize the supply chain performance measures according to the activity based costing model and the total supply chain performance measures. Tables 8.9, and 8.10 summarize the supply chain activity costs, total simulated supply chain cost and service levels of the five newly designed hybrid models respectively.

Table 8.9 Simulated Supply Chain Activity Based Costing Models with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Activity Based Costing Measures					
		Ordering	***Handling***	***Warehousing***	***Long-Haul Transp.***	***Short-Haul Transp.***	***Inventory***
Hybird Models VMI-2	ADI=1	115.116 €	912.544 €	1.513.679 €	6.544.303 €	**5.196.202 €**	428.652 €
	ADI=2	114.587 €	912.727 €	1.514.122 €	6.518.095 €	5.207.605 €	426.204 €
	ADI=3	113.802 €	913.027 €	1.514.462 €	6.494.432 €	5.255.712 €	**426.168 €**
	ADI=4	113.018 €	913.835 €	1.515.656 €	6.461.298 €	5.290.938 €	427.860 €
	ADI=5	**112.913 €**	914.054 €	1.515.806 €	**6.401.224 €**	5.296.779 €	437.760 €
Pure	Base	115.400 €	**912.070 €**	**1.513.153 €**	6.635.226 €	5.197.451 €	429.624 €
Objective Function		112.913 €	912.070 €	1.513.153 €	6.401.224 €	5.196.202 €	426.168 €
Exp Set ID		ADI=5	Base	Base	ADI=5	ADI=1	ADI=3

The effect of the proposed SF-ADI-VMI-2 Model with inventory visibility to the supply chain performance measures is compared to benchmark experiments set 6 results as seen from the improvement index deviations IMI^{ExpID}_{Base} in Table 8.10.

Table 8.10 Supply chain Network Performance Measures
with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Performance Measures			IMI %		
		TSCN	***N-DLS-1***	***N-DLS-7***	***Cost***	***N-DLS-1***	***N-DLS-7***
Hybird Models VMI-2	ADI=1	14.710.496 €	95,98%	63,07%	**-0,62%**	**0,11%**	**1,81%**
	ADI=2	14.693.340 €	96,48%	68,40%	**-0,74%**	**0,64%**	**10,41%**
	ADI=3	14.717.603 €	97,17%	75,23%	**-0,58%**	**1,36%**	**21,44%**
	ADI=4	14.722.605 €	98,82%	88,35%	**-0,54%**	**3,08%**	**42,62%**
	ADI=5	**14.678.536 €**	**99,04%**	**90,65%**	**-0,84%**	**3,31%**	**46,33%**
Pure	Base	14.802.924 €	95,87%	61,95%			
Objective Function		14.678.536 €	99,04%	90,65%			
Benchmark Exp Set ID		Base	ADI=5	ADI=5			

Reporting the differences and the improvements deviation percentage gap in the transportation, inventory, and service levels with respect to B-EXP-set6 were made. Figure 8.12 illustrates that the models with the implemented ADI replenishment strategy optimized the whole supply chain performance measures in minimizing the total supply chain activity costs and maximizing the service levels presented by supply chain products fill rate N-DLS-1% and supply chain order delivery service levels N-DLS-7%.

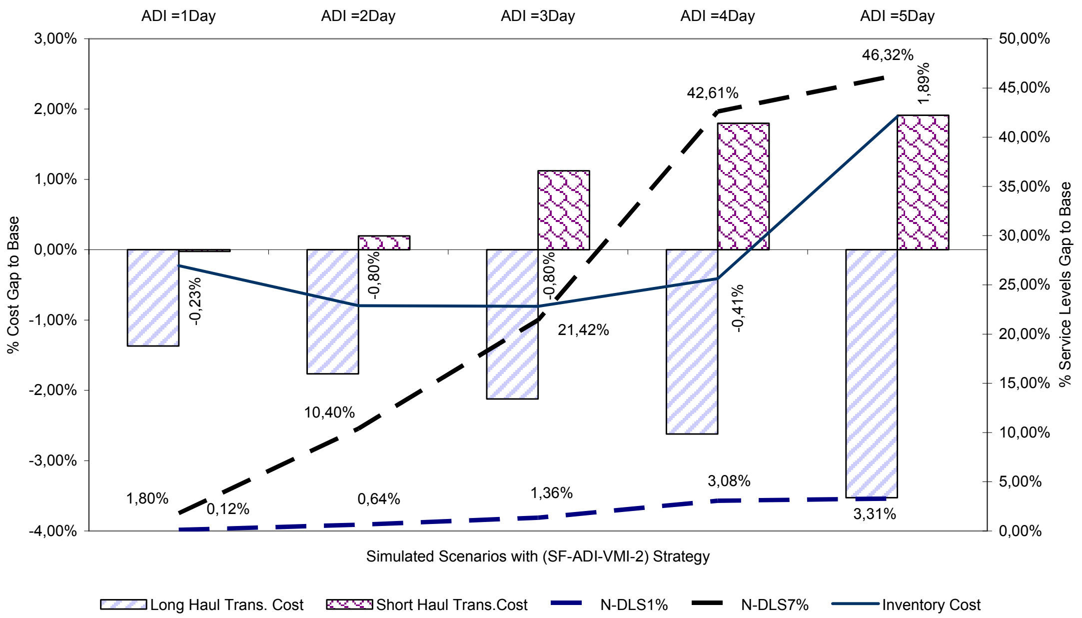


Figure 8.12 The Effect of SF-ADI-VMI-2 on Supply Chain Transportation, Inventory and Service Levels

Table VI.7 shows no such significant effect of implementing the SF-ADI-VMI-2 strategy in increasing the total supply chain cost with an average gap % less than 1 %. While significant improvements in supply service levels in all examined information horizon periods (ADI=1, 2, 3, 4, 5) were recognized, the improvements deviation percentage gap of the supply chain service levels N-DLS1% and N-DLS-7% were more than 3% and 45% respectively with ADI=n=5 days.

Ozer (2003), however, mentioned that the supply chain maintains a lower inventory cost (nearly zero inventories) as customers place orders earlier than (L1+L2) in advance with unlimited truck capacity.

The selected ADI=n=5 day experiment is selected to show the effect of the ADI strategy when the information horizon period is greater than the replenishment lead time L1+L2. As mentioned in Ozer (2003), implementing the ADI brings with it the possibility of minimizing or eliminating the uncertainty in the supply chain location, such as when the customers place their aggregated demand orders of n days in advance, such that $n > L_1 + L_2$. In this case, the logistic centers do not need to carry any regular or safety stock inventory and the generated residual stock occurs by earlier replenishment of some pushed product types which will be operated as variable safety stock.

The above example could be true in the case that the long-haul transportation activities are performed with incapacitated fleet assumption. This means it has the ability to transport any quantities at any time.

In this thesis the proposed designed SF-ADI-VMI-2 model discussed in section 8.5.3 conducts the integration and coordination of the transportation function represented, especially the consolidation of long-haul shipment sizes with integrating the ADI concept to form a full truck load trip without violating the product's inventory limits.

It is expected an increase in the forecast error terms of the used real demand distribution with larger location demand coefficient of variation $cv = \frac{\sigma(D)}{E(D)}$, when utilizing demand information in advance.

The ADI replenishment strategy produces lower average supply chain inventory levels and related inventory costs as shown Figure 8.13; at the same time minimizes the long-haul transportation costs within all the examined information horizon periods (n). The saving in long-haul transportation cost ranges from -1% to 3 % as illustrated in Table VI.7.

The improvement index in Table 8.10 shows the effectiveness and the efficiency of the proposed integrated hybrid models with the SF-ADI-VMI-2 replenishment strategy designed and developed to integrate the long-haul consolidation (transportation decision), jointly with capacitated fleet and considering the logistic center inventory levels (inventory decision).

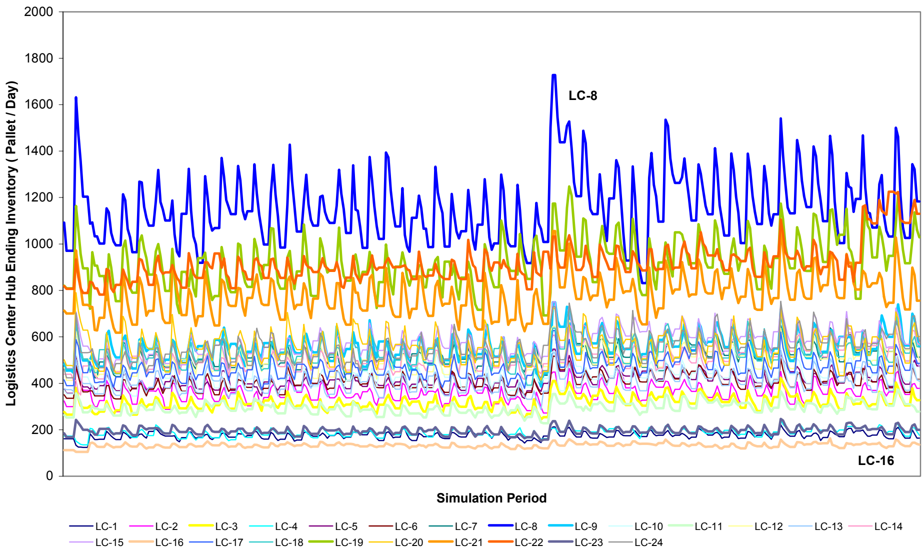


Figure 8.13 Simulated Logistic Center Hubs Average Daily Ending Inventory with SF-ADI-VMI-2 Algorithm

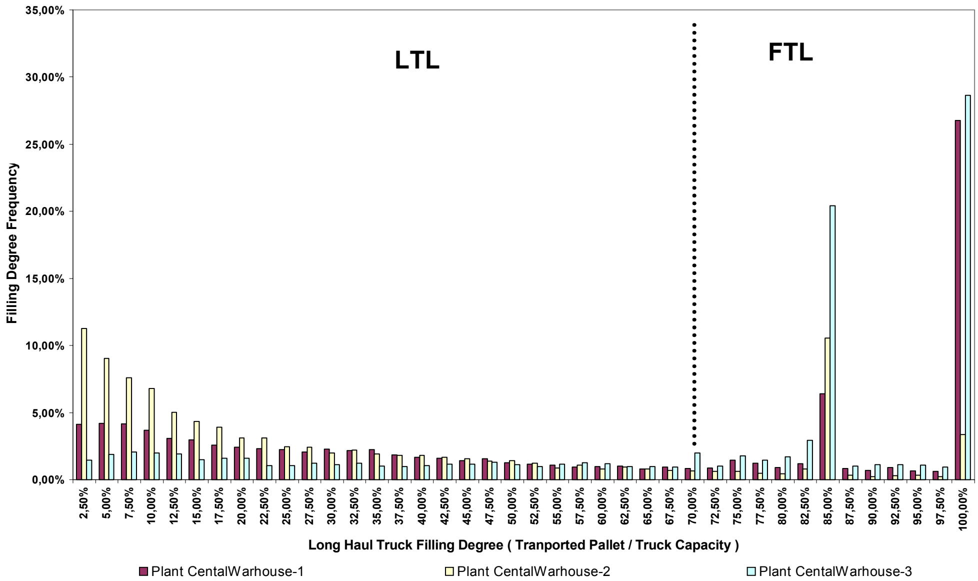


Figure 8.14 Long-Haul Truck Filling Degree with SF-ADI-VMI-2 at ADI=2 days

The reduction of the supply chain inventory cost by achieving higher availability of the product quantities in logistic centers hubs.

The improved the supply chain service levels when the ADI models were implemented could be justified by the higher utilization of the relative availability of the residual stock generated by the earlier replenishments of some products in the logistic center hubs before reaching their reorder point, as was mentioned in section 8.4.6.

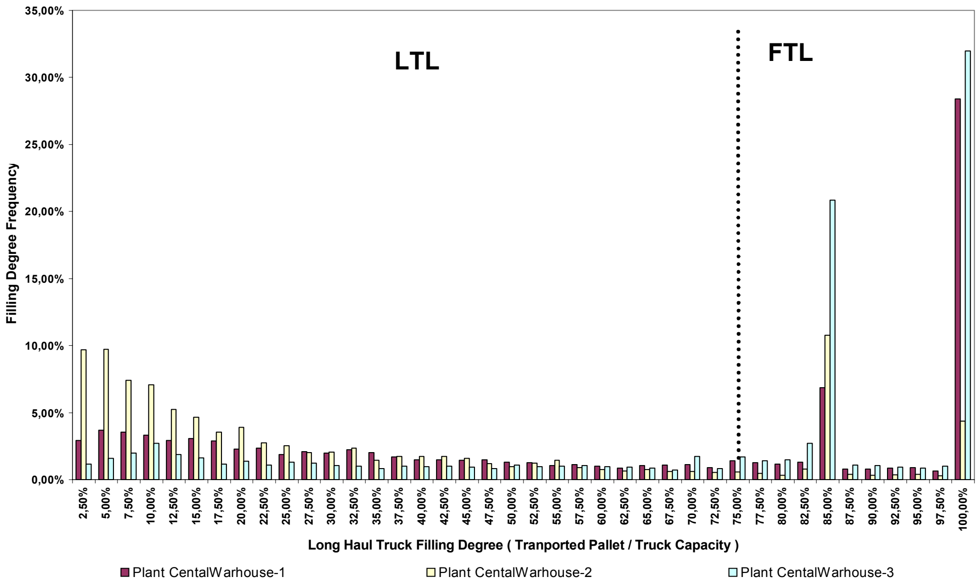


Figure 8.15 Long-Haul Truck Filling Degree with SF-ADI-VMI-2 at ADI = 4 days

Figures 8.14, 8.15 show the improvements in the truck filling degree with SF-ADI-VMI-2 at two ADI values 2 and 4 days, more detailed averages are presented in Table VI.9.

The simulated generated residual stock levels caused by the SF-ADI-VMI-2 models on the $\mathrm{I}_{p,t}^{k}$ of the five selected products types in logistic center hubs LC-19 and LC-8 at ADI=2 days and ADI=4 days, are summarized in Table 8.11 which shows that the SF-ADI-VMI-2 model minimizes the amount of the average ending inventory and the amount of the generated residual stock caused by the proposed joint replenishments strategy with ADI according to the newly modified product inventory position $I_{pt}^{k}new = I_{p\,t-1}^{k} + T_{pt}^{k} - \sum_{t}^{t+n} D_{p\,t}^{k} - B_{pt}^{k}$, considering the forecasted consumption demand during the next (t+n) period $\sum_{t}^{t+n} D_{p\,t}^{k}$. That results in minimizing the time between replenishments and the number of replenishments of each product type replenished earlier than expected as in B-Exp-set-6 whereby each product is replenished independently when the $I_{pt}^{k} \le s_{p}^{k}$.

Table 8.11 Simulated $\mathrm{I}_{p,t}^{k}$ of Five Products Types With and Without SF-ADI-VMI2

Model	Location	Product 1		Product 2		Product 3		Product 4		Product 5	
		$\mathrm{I}_{p,t}^{k}$	$\sigma(\mathrm{I}_{p,t}^{k})$	$\mathrm{I}_{p,t}^{k}$	$\sigma(\mathrm{I}_{p,t}^{k})$	$\mathrm{I}_{p,t}^{k}$	$\sigma(\mathrm{I}_{p,t}^{k})$	$\mathrm{I}_{p,t}^{k}$	$\sigma(\mathrm{I}_{p,t}^{k})$	$\mathrm{I}_{p,t}^{k}$	$\sigma(\mathrm{I}_{p,t}^{k})$
Pure Pull (B-EXP-set-6)	LC-19	55	21	8	3	7	2,1	5	0,92	4	0,8
	LC-8	51	18	16	5	6	2	7	2	3	1,4
Hybrid Model with ADI= 2 Day	LC-19	54	21	7,6	2	5,9	2,3	4,7	0,95	4,2	0,73
	LC-8	44	19,4	13,5	5,9	6,3	2,5	7,7	2,2	3,7	0,63
Hybrid Model with ADI= 4 Day	LC-19	52	21	7,4	2,3	5,7	2,4	4,6	1	4,2	0,7
	LC-8	43	20	13	6	6	3	7,4	2,3	3,6	0,7
% of Excess Inventory	**LC-19**	-2%		-5%		-16%		-6%		5%	
	LC-8	-14%		-15%		5%		-10%		23%	
% of Excess Inventory	**LC-19**	-6%		-8%		-19%		-8%		5%	
	LC-8	-16%		-19%		0%		6%		20%	

Figures 8.16, 8.17 and Table 8.11 show the effect of the SF-ADI-VMI-2 with ADI=2 and ADI= 4 days and the impact of the generated amount of the excess stocks in logistic center hubs (residual stock) caused by earlier order replenishments generated by the ADI policy.

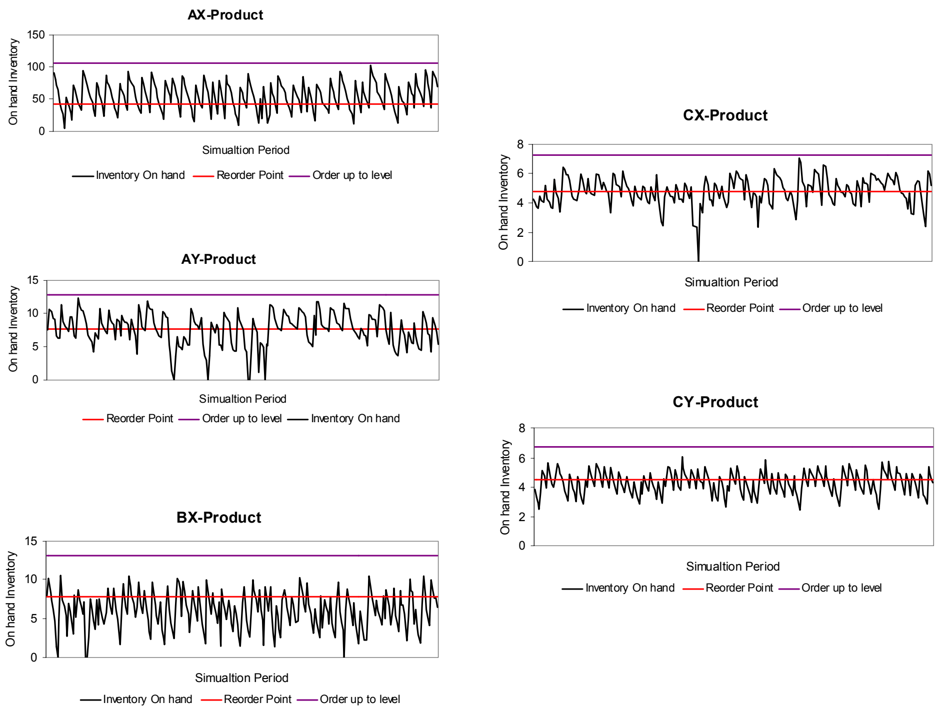


Figure 8.16 Simulated $I_{p,t}^{k}$ with SF-ADI-VMI-2 at ADI= n= 2 Days in LC-19

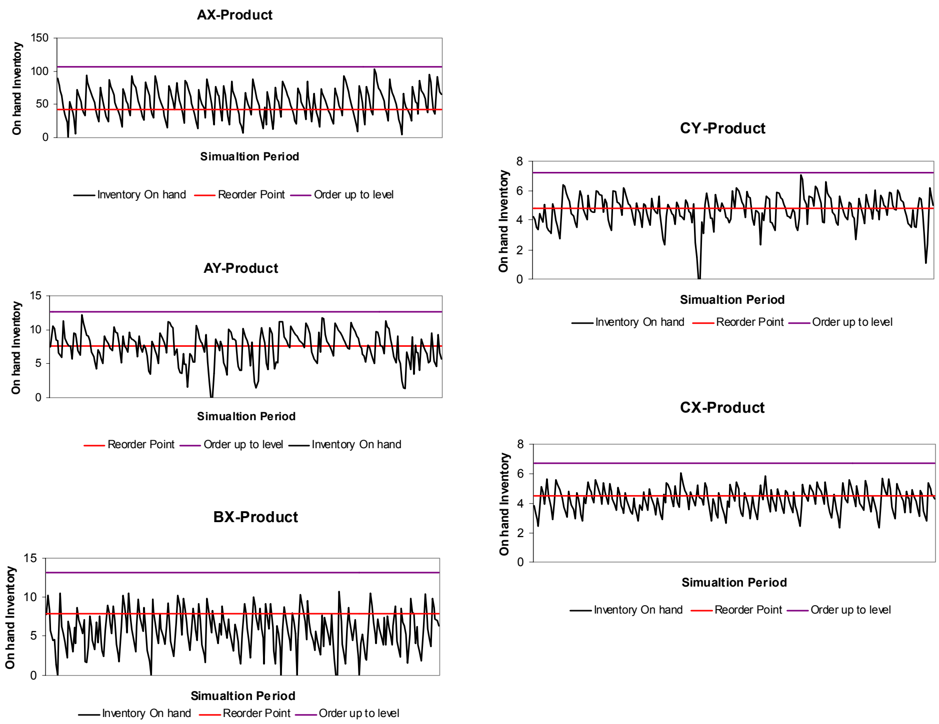


Figure 8.17 Simulated $I_{p,t}^{k}$ with SF-ADI-VMI-2 at ADI= n= 4 Days in LC-19

Table 8.11 also shows that most of the highly demanded products of A and B classes, as in the case of products 1, 2, and 3 gains a reduction of the ending inventory level at the examined two ADI values 2 and 4 days, while an extra excess residual stock occurs for products 4, and 5 belonging to C class.

The reason for such an effect is justified by the low consumption demand rate of those product types and having higher safety stock levels $k_{ss}(class\ \mathrm{C}) = 6$. This gives reason to recommend the reduction of the associated safety stock of those C products, when the ADI policy is utilized to avoid building higher residual stock of such slow moving product family. This is shown in Figures 8.18 of CX products with ADI=2 and ADI=4 days.

The implementation of the joint replenishment SF-ADI-VMI-2 heuristic integrated with hybrid simulation models complicates the predication of the contents of ψ_{Push}^{k} list, where the filling process is done stochastically without fixed pushed product types and as a family as in the SF-PCR-VMI-1 heuristic. Only the products that violate the modified inventory positions will be replenished earlier.

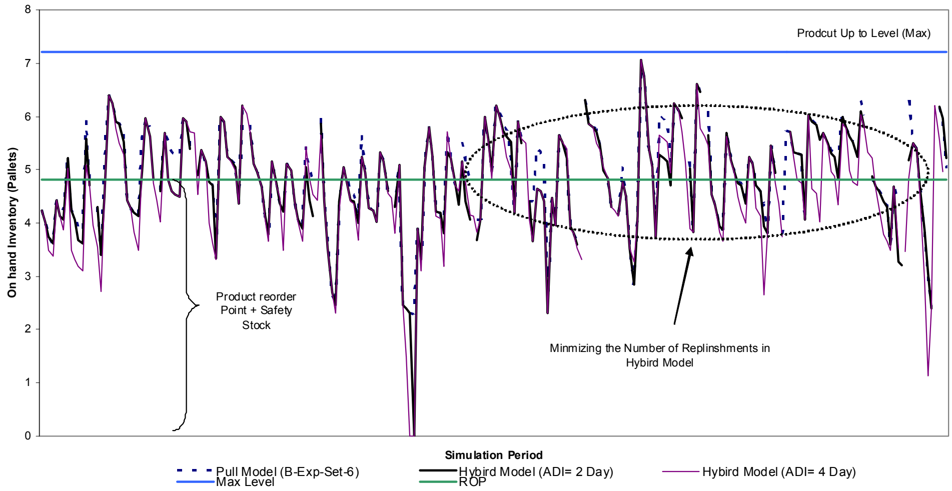


Figure 8.18 SF-ADI-VMI-2 Simulated $I_{p,t}^{k}$ of CX product

The proposed SF-ADI-VMI-2 concept provides improved visibility across the supply-chain pipeline, thereby helping the supply chain decision maker to improve the distribution planning process, reduce inventory, improve inventory turnover and improve stock availability. With information available at a more detailed level, it allows the producer to be more customer-specific in planning.

8.6 Sensitivity Analysis of SF-ADI-VMI-2 Replenishment Strategy

8.6.1 Simulation Results of Sensitivity Analysis Experiments

The previously encouraging simulation results obtained in section 8.5 consider and show the effect of the SF-ADI-VMI-2 to the B-Exp-Set-6 only. Several new hybrid simulation experiments integrated with the SF-ADI-VMI-2 heuristic were established considering the previously designed benchmark experiments representing different safety stock allocation inventory control schemes presented and discussed in detail in chapter 7. The simulation results of two selected advanced demand information horizon periods of ADI=2 days and ADI=5 days, conducted to benchmark experiments 4, 5, 6, 7 and 8 respectively, are summarized in Tables 8.12 and 8.13. The first three benchmark experiments varied in the value of the $k_{ss}(class\ A)$; $k_{ss}(class\ \mathrm{B})$ and $k_{ss}(class\ \mathrm{C})$ values, while the benchmark experiments numbers 7, and 8 examined the concept of the product inventory allocation strategy.

Table 8.12 Simulated Supply Chain Activity Based Costs of Benchmarks Experiments 4, 5,6,7,8 with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Activity Based Costing Measures					
		Ordering	***Handling***	***Warehousing***	***ng-Haul Trans***	***hort-Haul Trans***	***Inventory***
No Safety Stock	**B4 - ADI=2**	115.395 €	912.515 €	1.517.581 €	6.496.923 €	5.192.831 €	346.896 €
	B4 - ADI=5	113.478 €	913.579 €	1.519.011 €	6.281.606 €	5.273.509 €	359.028 €
Uniform Safety Stock	**B5 - ADI=2**	114.858 €	912.863 €	1.516.411 €	6.521.308 €	5.213.209 €	374.832 €
	B5 - ADI=5	113.097 €	914.343 €	1.518.702 €	6.401.461 €	5.299.828 €	385.992 €
Variable Safety Stock	**B6 - ADI=2**	114.606 €	913.036 €	1.515.714 €	6.526.804 €	5.216.550 €	394.992 €
	B6 - ADI=5	**112.890 €**	914.192 €	1.517.683 €	6.436.122 €	5.306.093 €	407.664 €
Class C Spatial Pots+STO	**B7 - ADI=2**	117.177 €	911.407 €	1.510.793 €	6.445.409 €	5.154.400 €	256.932 €
	B7 - ADI=5	114.357 €	912.928 €	1.513.350 €	6.304.050 €	5.251.709 €	273.564 €
Class B and C Spatial Postp	**B8 - ADI=2**	118.984 €	**909.483 €**	**1.508.900 €**	6.269.485 €	**5.109.307 €**	**235.836 €**
	B8 - ADI=5	116.290 €	911.399 €	1.511.755 €	**6.076.680 €**	5.206.279 €	258.696 €
Reference Model (B-Exp-Set-6)		**115.400 €**	**912.070 €**	**1.513.153 €**	**6.635.226 €**	**5.197.451 €**	**429.624 €**
Objective Function Min(costs),Max(DLS)		112.890 €	909.483 €	1.508.900 €	6.076.680 €	5.109.307 €	235.836 €
Benchmark Exp Set ID		B6 - ADI=5	B8 - ADI=2	B8 - ADI=2	B8 - ADI=5	B8 - ADI=2	B8 - ADI=2

Table 8.13 Simulated Supply Chain Performance Measures of Benchmarks Experiments 4, 5,6,7,8 with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Performance Measures			IMI %		
		TSCN	***Simulated N-DLS-1%***	***Simulated N-DLS-7%***	***Cost***	***N-DLS-1***	***N-DLS-7***
No Safety Stock	**B4 - ADI=2**	14.582.141 €	94,99%	61,26%	-1,49%	-0,91%	-1,12%
	B4 - ADI=5	14.460.211 €	98,32%	85,49%	**-2,32%**	**2,56%**	**37,99%**
Uniform Safety Stock	**B5 - ADI=2**	14.653.481 €	96,50%	68,98%	**-1,01%**	**0,66%**	**11,34%**
	B5 - ADI=5	14.633.423 €	99,00%	90,84%	**-1,15%**	**3,27%**	**46,63%**
Variable Safety Stock	**B6 - ADI=2**	14.681.702 €	96,97%	71,96%	**-0,82%**	**1,15%**	**16,15%**
	B6 - ADI=5	14.694.644 €	**99,16%**	**92,32%**	**-0,73%**	**3,44%**	**49,01%**
Class C Spatial Pots+STO	**B7 - ADI=2**	14.396.118 €	91,82%	47,09%	-2,75%	-4,22%	-23,99%
	B7 - ADI=5	14.369.958 €	97,43%	79,85%	**-2,92%**	**1,63%**	**28,89%**
Class B and C Spatial Postp+STO	**B8 - ADI=2**	14.151.995 €	80,13%	28,06%	-4,40%	-16,41%	-54,70%
	B8 - ADI=5	**14.081.099 €**	92,15%	58,15%	-4,88%	-3,88%	-6,14%
Refrence Model	**(B-Exp-Set-6)**	**14.802.924 €**	**95,87%**	**61,95%**			
Objective Function Min(costs),Max(DLS)		14.081.099 €	99,16%	92,32%			
Benchmark Exp Set ID		B8 - ADI=5	B6 - ADI=5	B6 - ADI=5			

Considering the complexity of optimizing a multi-criteria objective function, the following target supply chain objectives were defined to distinguish the differences between supply chain alternatives and performance measures (based on empirical values):

- Total supply chain cost: if $IMI_1^{ExpID} \leq \pm 1\%$ no significant effect considered.
- Desired supply chain product fill rate service level $N - DLS1\% \geq 90\%$
- Desired supply chain order delivery service level $N - DLS7\% \geq 80\%$

Tables 8.12, 8.13 and Figure 8.19 show that all the benchmark experiments supply chain performance measures were improved compared to the benchmark experiment set 6 results without ADI (base case model) indicated by IMI% values.

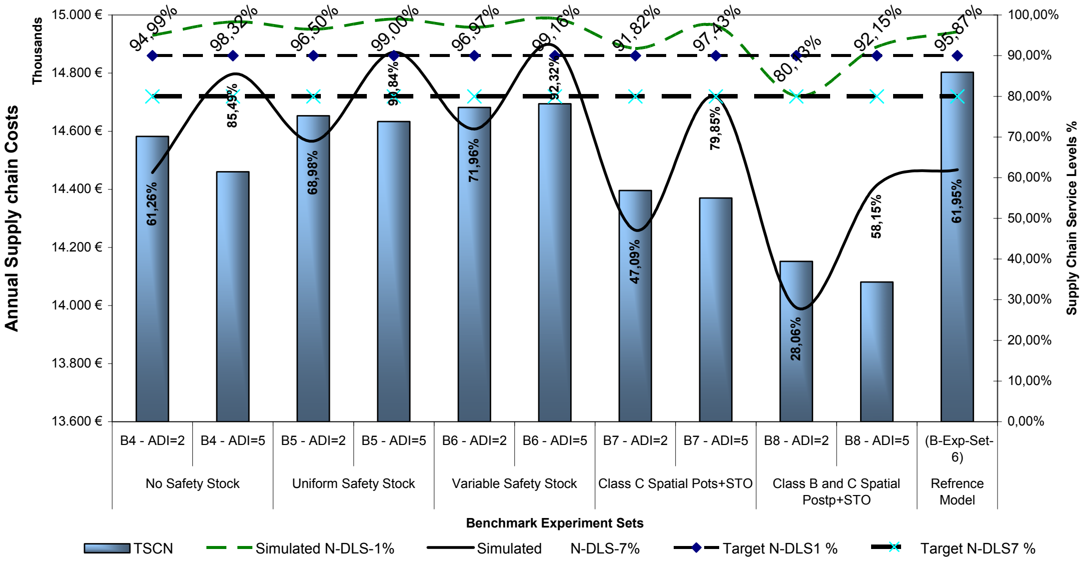


Figure 8.19 Supply Chain Performance Measures of Integrated Benchmark Experiments 4, 5,6,7,8 with SF-ADI-VMI-2 Heuristic

Generally, supply chain performance measures show a major reduction of total supply chain costs which vary from -1,5% to -4,5 % in case of the product allocation inventory policy. The proposed model improves the supply chain performance even when there is no safety stock considered as in benchmark experiments set 4 that reduces the supply chain cost by -1.5%, -2,3 % at ADI=2 and 4 days respectively. Both supply chain service levels N-DLS-7% and N-DLS-1% were improved by 37% and 2 % respectively without redesigning the safety stock amounts.

The above results prove that the SF-ADI-VMI2 heuristic performs fairly well for logistic center hubs allocating low safety stock amounts, even when they are having highly uncertain demand; this makes the proposed SF-ADI-VMI2 operate as a semi substitute for safety stock inventory, as will be explained in the next section.

8.6.2 The Proposed SF-ADI-VMI-2 Heuristic as Semi Substitute Safety Stock

Supply chain benchmark experiments that incorporate advanced demand information carry fewer inventories and are subject to lower holding costs and penalty costs than otherwise equivalent benchmark experiments as shown in Table 8.13.

Table 8.14 summarizes the IMI % index according to the benchmark experiments set 4 with no safety stock considered. The simulated supply chain performance measures were compared with and without implementing the hybrid simulation models that integrated with SF-ADI-VMI-2 heuristics.

Table 8.14 The Summarized IMI % of Pure and Hybrid Simulation Models Integrated with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models			Supply Chain Network Performance Measures			IMI %		
			TSCN	N-DLS-7	N-DLS-1	TSCN	N-DLS-7	N-DLS-1
No Safety Stock	Pure Pull Models	B4	14.718.124 €	52,76%	93,99%	0,00%	0,00%	0,00%
Uniform Safety Stock		B5	14.765.390 €	61,63%	95,71%	0,32%	16,81%	1,83%
Variable Safety Stock		B6	14.802.924 €	61,95%	95,87%	0,58%	17,43%	2,00%
Class C Spatial Pots+STO		B7	14.578.597 €	24,69%	86,04%	-0,95%	-53,20%	-8,46%
Class B and C Spatial Postp+STO		B8	14.547.513 €	14,20%	67,93%	-1,16%	-73,09%	-27,73%
No Safety Stock	Hybrid Model VMI-2	B4 - ADI=2	14.582.141 €	61,26%	94,99%	**-0,92%**	**16,12%**	**1,07%**
		B4 - ADI=5	14.460.211 €	85,49%	98,32%	**-1,75%**	**62,04%**	**4,60%**
Uniform Safety Stock		B5 - ADI=2	14.653.481 €	68,98%	96,50%	**-0,44%**	**30,74%**	**2,67%**
		B5 - ADI=5	14.633.423 €	90,84%	99,00%	**-0,58%**	**72,18%**	**5,33%**
Variable Safety Stock		B6 - ADI=2	14.681.702 €	71,96%	96,97%	**-0,25%**	**36,40%**	**3,17%**
		B6 - ADI=5	14.694.644 €	92,32%	99,16%	**-0,16%**	**74,97%**	**5,50%**
Class C Spatial Pots+STO		B7 - ADI=2	14.396.118 €	47,09%	91,82%	-2,19%	-10,74%	-2,31%
		B7 - ADI=5	14.369.958 €	79,85%	97,43%	-2,37%	51,35%	3,66%
Class B and C Spatial Postp+STO		B8 - ADI=2	14.151.995 €	28,06%	80,13%	-3,85%	-46,81%	-14,74%
		B8 - ADI=5	14.081.099 €	58,15%	92,15%	-4,33%	10,22%	-1,96%

It shows a redundant improvement in all the simulated benchmark experiments, better than those conducted by the pure pull supply chain with a maximum improvement of more than 75% in N-DLS-7% that results in deliveries of more than 90 % of the customer's orders just on time, and more than 99% supply chain product availability service level N-DLS-1% at ADI= 5 days. The above achieved service levels were realized without any significant additional cost less than -1% of the total supply chain cost.

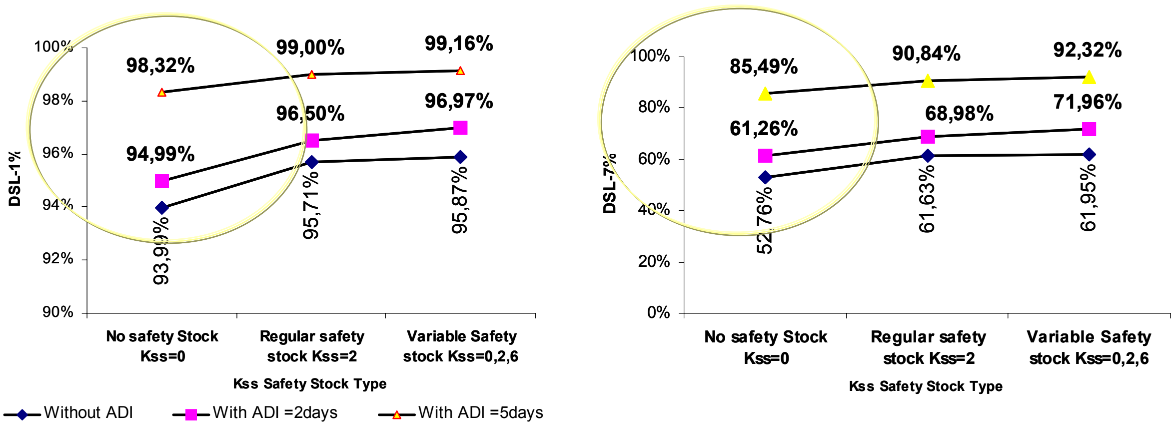


Figure 8.20 The N-DLS-1 and N-DLS-7 % Improvements with SF-ADI-VMI-2 Heuristic Using Different Safety Stock Models

The simulated results show the power of the proposed integrated SF-ADI-VMI-2 heuristic in improving the supply chain performance measure without incurring additional safety stock as done in many situations, which made the integrated SF-ADI-VMI-2 model operate as a semi-substitute method of having fixed safety stock amount in multi-product (s,S) continuous review of inventory systems.

Table 8.15 and Figure 8.20 show the impact of implementing the ADI as a semi-substitute safety stock against fixed safety stock. Three cases were considered; case 1 with no fixed safety stock, case 2 with a fixed regular safety stock factor, and case 3 with fixed variable safety stock factors on the supply chain performance measures.

A more complicated situation was found when those multi-product families had a higher uncertainty and unstable demand patterns, as in the studied supply chain network presented in chapter 4, the proposed SF-ADI-VMI-2 heuristic presents an optimized solution for reducing fluctuation in replenishment shipment sizes through controlling the excess residual stock amounts of those earlier jointly replenished products.

Table 8.15 Impact of ADI Models at Different Safety Stock Allocations Schemes

Performance Measures	Simulated Total Supply chain costs % Gap to B-Exp-Set 4		
Models	Without ADI	With ADI =2 days	With ADI =5 days
No safety Stock	0.00%	-0.92%	-1.75%
Regular safety stock	0.32%	-0.44%	-0.25%
Variable Safety stock	0.58%	-0.58%	-0.16%

8.6.3 Summary and Conclusion of Proposed Heuristics

In the previous sections, two long-haul replenishment consolidation heuristics named full truckload integrated with PCR and full truckload integrated with advanced demand information strategies were presented and discussed.

It was recognized that the supply chain performance measure improvement index IMI% achieved significant and redundant improvement when SF-PCR-VMI-1 and SF-ADI-VMI-2 were implemented with respect to supply chain service levels DLS-1% and DLS-7 %, while SF-ADI-VMI-2 performed better in optimizing the multi-criteria supply chain objective function (Total supply chain costs, DLS-1% and DLS-7 %).

In some cases the proposed SF-ADI-VMI-2 improved the supply chain service levels without incurring additional supply chain costs with cost deviation less than -1%.

The second advantage to be gained by implementing the proposed SF-ADI-VMI-2 heuristics is to end up with lower inventory levels and inventory related costs; in this sense, the proposed SF-ADI-VMI-2 operates as a semi-substitute of higher product safety stocks among the supply chain locations.

8.7 Advanced Supply Chain Simulation Models and Experiments

8.7.1 Introduction to Advanced Supply Chain Simulation Models

Two proposed supply chain configurations and models were developed and modeled. The first model discusses the concept of the transshipment point's logistic center hubs, as one of the well-known distribution supply chain network structures. In this model all the regional logistic centers hubs operate as ***transshipment points*** with a modified (s, S) inventory control. This concept was tested and investigated considering the previously proposed SF-ADI-VMI-2 heuristics. Supply chain performance measures were estimated and summarized ,see more in (Langevin, et al. 2005;Aptekinoglu, at al. 2005;Apte, et al. 2000 and Gudehus 2000).

The second proposed supply chain network configuration named as ***SUB-Transshipment points*** is presented and discussed in Section 8.8.3. Five logistic center hubs LC-1, LC-4, LC-11, LC-16, and LC-23 will be reallocated to 5 of 19 main regional logistic center hubs (RLCH), in terms of minimizing the long-haul transportation costs. The simulation results and analysis are summarized at the end.

8.7.2 Designing Advanced Supply Chain Simulation (Transshipment Points) TP Simulation Models

Unlike the traditional distribution centers each product was stored in all logistic centers and the only replenishment quantities lot sizes were ordered according to the (s,S) continuous review inventory model are based on the Make To Stock (MTS) concept. This study presents another type of traditional distribution center operated as a cross docking or transshipment point distribution center based on the Make To Order (MTO) concept.

The difference between transshipment points with cross docking function and transshipment points with inventory allowed are illustrated in Figure 8.21, which distinguishes between them. In the transshipment points with inventory control the logistic center hubs receive only full pallets from production or plant central warehouses and break them into several order picking lists; this assumption is valid if the sorting and order picking cost is cheaper in logistic centers than in plant warehouses as assumed in chapter 4. It is analyzed on the basis that the replenishment orders from upstream were received in full product pallet type Q_{pt}^{FP} with maximum 2.4 m height, and sorting and order picking processes were conducted in the transshipment points.

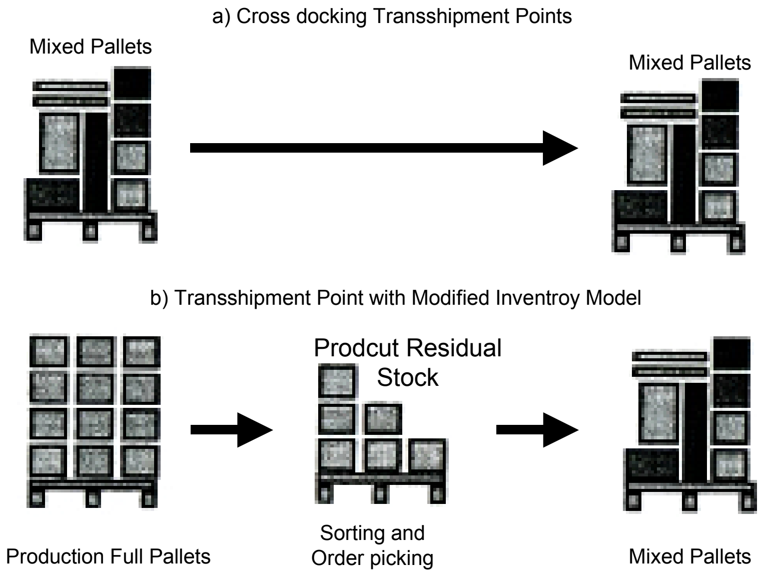


Figure 8.21 Difference Between Cross Docking Transshipment Points and Transshipment Points with Inventory Model (Gudehus,2000)

Reconfiguring the simulation models presented in chapter 4 to fit the transshipment points concept was required also to redesign the (s, S) continuous review inventory model that will be discussed later. Considering the STO policy examined in chapter 7 lower supply chain service levels have been relatively improved when the SF-ADI-VMI-2 heuristics were implemented, caused by the power of the proposed SF-ADI-VMI-2 heuristics in providing extra variable safety stock of those pushed products loaded randomly in the Ψ_{push}^{k} list when the modified product inventory position was less than the total expected demand requirements during the next (t+n) period.

8.7.2.1 The Modified (s, S) Inventory Model Parameters

Simchi-Levi et al. (2003) and Zipkin (2000) mentioned based on the recent survey on inventory reduction report, the products and inventory managers were asked to identify effective inventory reduction strategies. One of the important recommendation points in this survey was to tighten the order lead time and minimize the safety stock factor; this allows the company to make sure inventory is kept at the appropriate level as such an inventory control process allows the supply chain to be identified.

Redesigning the order cycle time presented in section 4.6.9, the long-haul replenishment orders were scheduled to be sent on a daily basis directly. Unlike the models presented in last chapters the adjusted order lead time (L_1+L_2) was set to 2 working days the as shown in Figure 8.22.

The designed inventory levels have been adjusted according to the equation 4.1 and 4.2 of estimating the (s^k_{pt}, S^k_{pt}) using SDT method. Under this study the estimated values of both s^k_{pt} and S^k_{pt} were reset as follows:

$$\text{Logistic center Hubs Stocking Inventory parameters} \begin{cases} s^k_{pt} = 0 \\ S^k_{pt} = Q^{FP}_{pt} \end{cases}$$

The above parameters are valid in case that L_1=1 day and L_2=1 day, and the designed nominal replenishments shipment size is equal to $Q^{FP}_{pt} + B^k_{pt-1}$ that includes the back order quantity of replenished product types in the shipment size and the replenishments decision will be made only when the $I^k_{pt} = 0$, or $I^k_{pt} new = 0$. The latter case when models utilize the proposed hybrid SF-ADI-VMI-2 replenishment strategy. Information and product flows for this in-transit transshipment network are shown in Figure 8.22.

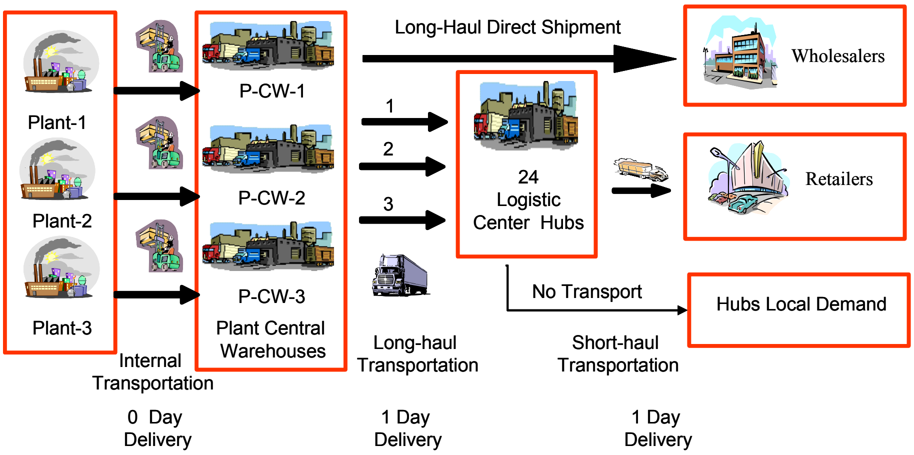


Figure 8.22 In-Transit Merge and Transshipment Supply Chain Network

As previously concluded, the ability to aggregate inventories and postpone product customization is a significant advantage of this type of distribution network. This approach will have the greatest benefits for products with high value whose higher demand uncertainty is hard to forecast.

8.7.2.2 Description of The Simulated Scenarios of Transshipment Points

Five main simulation scenarios were investigated. The first simulated scenario assumes that all the supply chain logistic center hubs operate as pull transshipment points without implementing the proposed SF-ADI-VMI-2 heuristic; this experiment will be considered as the new base reference model. The other four simulated experiments integrate the pure transshipment point supply chain network with the SF-ADI-VMI-2 heuristic at different examined ADI values. The designed simulation scenario parameters were summarized in Table 8.16.

Table 8.16 Simulated Scenarios of Transshipment Supply Chain Network Input Parameters

Scenarios ID	Number of Logistic center hubs	Inventory Model	ψ^{k}_{Hybird} Replenishment List	
			ψ^{k}_{pull}	ψ^{k}_{push} with PCR algorithm
1	24 LC Hubs with ψ^{k}_{pull} or ψ^{k}_{Hybird}	$\begin{cases} s^{k}_{pt} = 0 \\ S^{k}_{pt} = Q^{FP}_{pt} \end{cases}$	Pure Pull Replenishment	None
2				ADI= n = 1 Day
3				ADI= n = 2 Day
4				ADI= n = 3 Day
5				ADI= n = 4 Day

The above proposed scenarios are simulated and supply chain performance measures are summarized in the next section.

8.7.2.3 Simulation Results and Analysis of TP Models with SF-ADI-VMI-2 Heuristic

Simulating the model again for one fiscal year, the supply chain activity based costing model and the total supply chain performance measures are summarized in Table 8.17, Table 8.18 and Figure8.23 respectively.

Table 8.17 Simulated Supply Chain Activity Based Costing of TP Models with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Activity Based Costing Measures					
		Ordering	***Handling***	***Warehousing***	***Long-Haul Transp.***	***Short-Haul Transp.***	***Inventory***
Pure	P-TP	117.595 €	**911.960 €**	1.511.452 €	6.616.520 €	5.337.637 €	**91.440 €**
Hybird Models VMI-2	TP+ADI=1	116.996 €	912.204 €	**1.511.428 €**	6.045.648 €	5.298.345 €	101.700 €
	TP+ADI=2	116.744 €	912.579 €	1.512.161 €	5.915.976 €	5.299.428 €	119.808 €
	TP+ADI=3	116.703 €	913.229 €	1.513.027 €	5.861.578 €	5.306.830 €	141.480 €
	TP+ADI=4	116.678 €	913.459 €	1.513.388 €	**5.830.000 €**	5.309.369 €	163.620 €
Pure	B-Exp-Set6	**115.400 €**	912.070 €	1.513.153 €	6.635.226 €	**5.197.451 €**	429.624 €
Objective Function		115.400 €	911.960 €	1.511.428 €	5.830.000 €	5.197.451 €	91.440 €
Exp Set ID		B-Exp-Set6	P-TP	TP+ADI=1	TP+ADI=4	B-Exp-Set6	P-TP

Table 8.18 Transshipment Points Supply Chain Network Performance Measures with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Performance Measures			IMI%		
		TSCN	***N-DLS-1***	***N-DLS-7***	***Cost***	***N-DLS-1***	***N-DLS-7***
Pure	P-TP	14.586.604 €	55,37%	15,45%	**0,00%**	**0,00%**	**0,00%**
Hybird Models VMI-2	TP+ADI=1	13.986.321 €	73,91%	25,23%	**-4,12%**	**33,50%**	**63,27%**
	TP+ADI=2	13.876.696 €	78,86%	29,30%	**-4,87%**	**42,43%**	**89,64%**
	TP+ADI=3	13.852.847 €	81,02%	31,43%	**-5,03%**	**46,33%**	**103,40%**
	TP+ADI=4	**13.846.514 €**	82,10%	32,70%	**-5,07%**	**48,28%**	**111,65%**
Objective Function		13.846.514 €	82,10%	32,70%			
Benchmark Exp Set ID		TP+ADI=4	TP+ADI=4	TP+ADI=4			

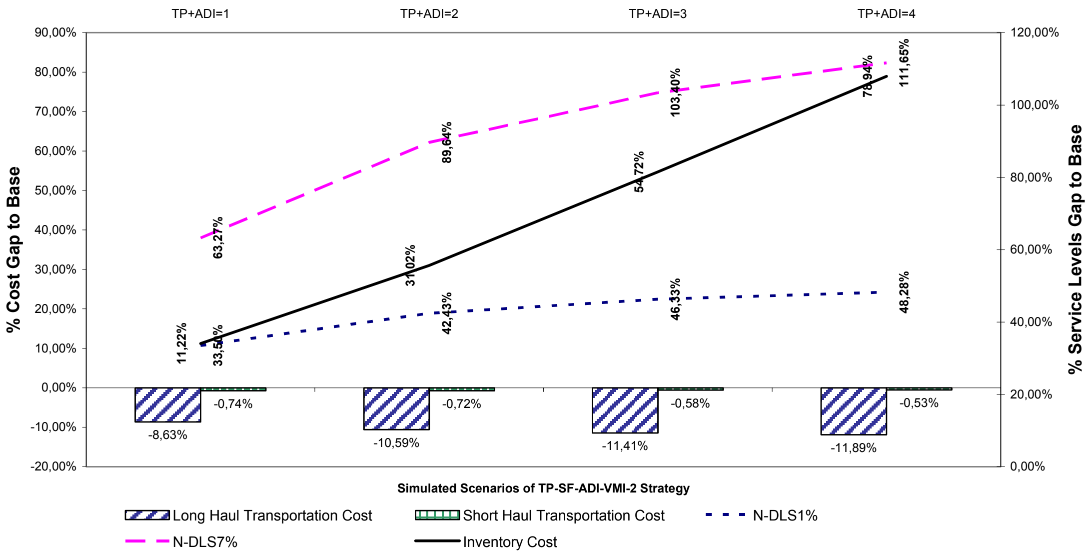


Figure 8.23 The Effect of TP Models with SF-ADI-VMI-2 on The Supply Chain Transportation, Inventory, and Service Levels

The improvement index deviations IMI_{Base}^{ExpID} % is estimated based to pure transshipment point's network detailed results found in Table VI.1.

8.7.2.4 Summary and Conclusion of Simulation Results of TP Models

In most cases, transportation costs are lower than for traditional distribution centers due to the higher small frequent shipments that take place at the carrier hub prior to delivery to the customer, and also because of the reduced number of deliveries and restrictions based on demand concept, unlike before on the (s,S) inventory management system needs. Fewer deliveries save transportation costs and simplify receiving.

Facility and processing costs for the plants and the logistic center hubs as seen in previous models will be higher. The party performing the in-transit merge has higher facility costs because of the required merge capability. Receiving costs by the customer are lower because a single delivery is received.

A very sophisticated information infrastructure is needed to allow the transshipment points to work well. Besides information, operations at the logistic centers, plant central warehouses and the carrier must be coordinated by good ADI tools. The investment in information infrastructure will be higher than for the last modeled strategies.

Just in time order response index N-DLS-7%, and product variety and availability index N-DLS-1% are lower than the previous models with traditional distribution centers. Order response times may be marginally lower because of the need to wait a L_1 period until the product replenishments arrive. It can be seen, that it has improved to more than 30% of the orders delivered on the same day with the ADI=4 days consolidation strategy. Customer experience is likely to be lower than the previous model's in chapter 7 due to the product unavailability at the time of request, and function on the remaining product results in stock at the transshipment points detail results found in Table VI.2.

The main advantage of the proposed and examined transshipment points models is the somewhat lower long-haul transportation which influences the cost by more than -13% resulted by achieving a higher truck filling degree as shown in Figure 8.24 with the pure TP model, and the integrated SF-ADI-VMI2 TP model in Figure 8.25 details found in Table VI.3.

The resulted increasing inventory holding cost in integrated models of more than 70% compared with pure TP shows the effect of the generated residual stock of earlier replenishments as it was discussed before. Figures 8.26 and 8.27 show the effect of the integrated SF-ADI-VMI2 on the inventory levels of the five selected product types in LC-19

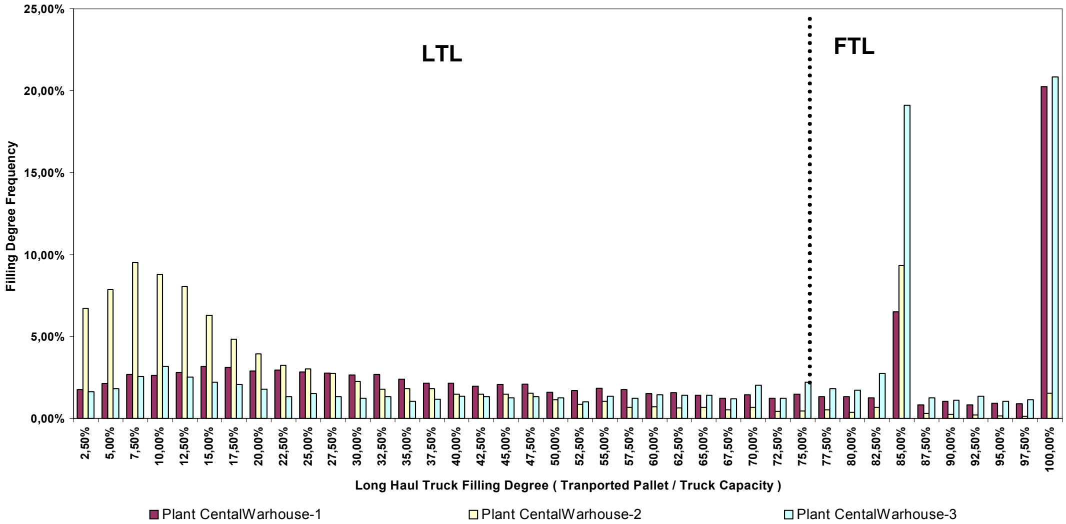


Figure 8.24 Long-Haul Truck Filling Degree of Pure TP without SF-ADI-VMI-2 heuristic

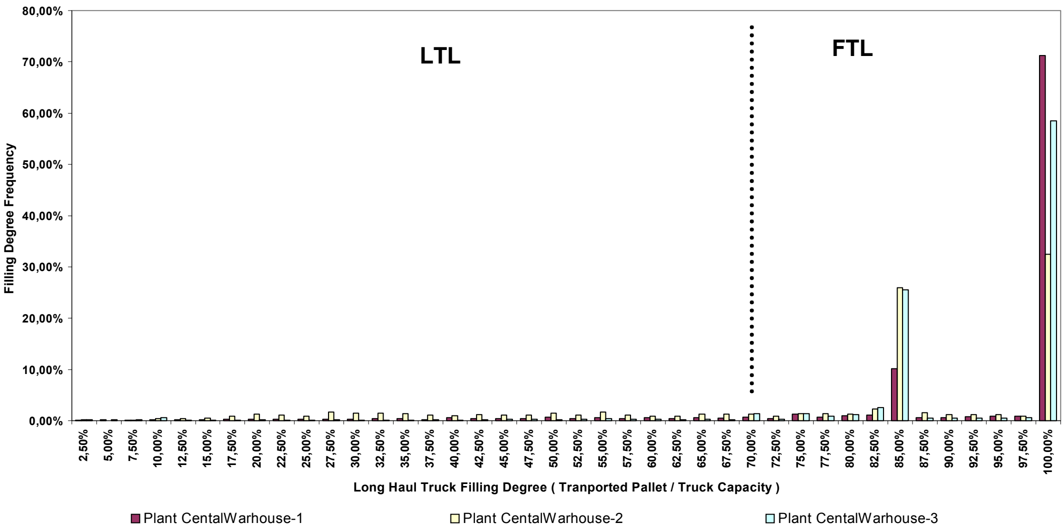


Figure 8.25 Long-Haul Truck Filling Degree of TP Models with SF-ADI-VMI-2 at ADI= 2 or 4 day

Given its performance characteristics, plants warehouses storage with logistic centers as transshipment points are best suited for low to medium with uncertain demand patterns, such as the supply chain case study presented in Chapter 4, where some product average daily demand was relatively low.

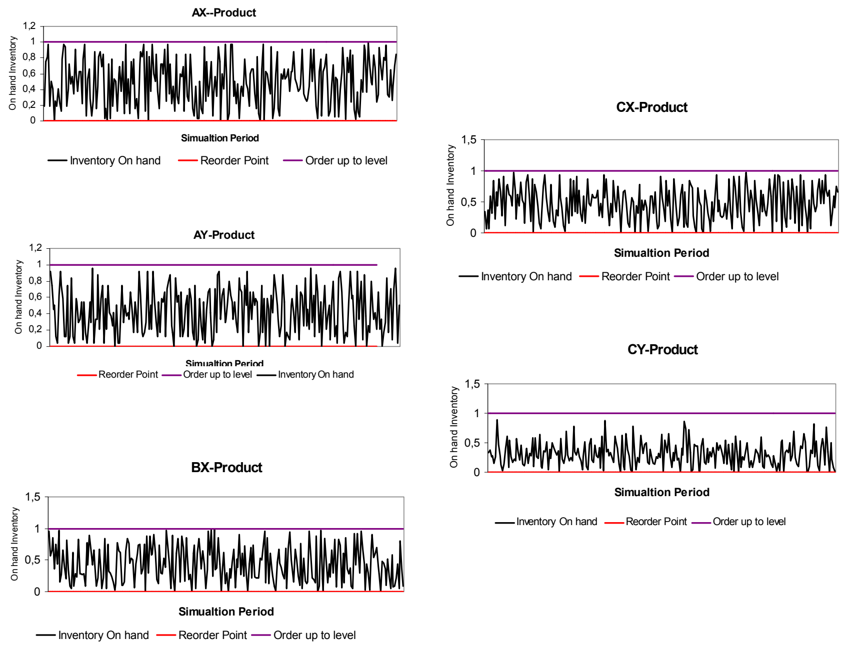


Figure 8.26 Simulated $I_{p,t}^{k}$ Daily Ending Inventory of Pure-TP Model in LC-19

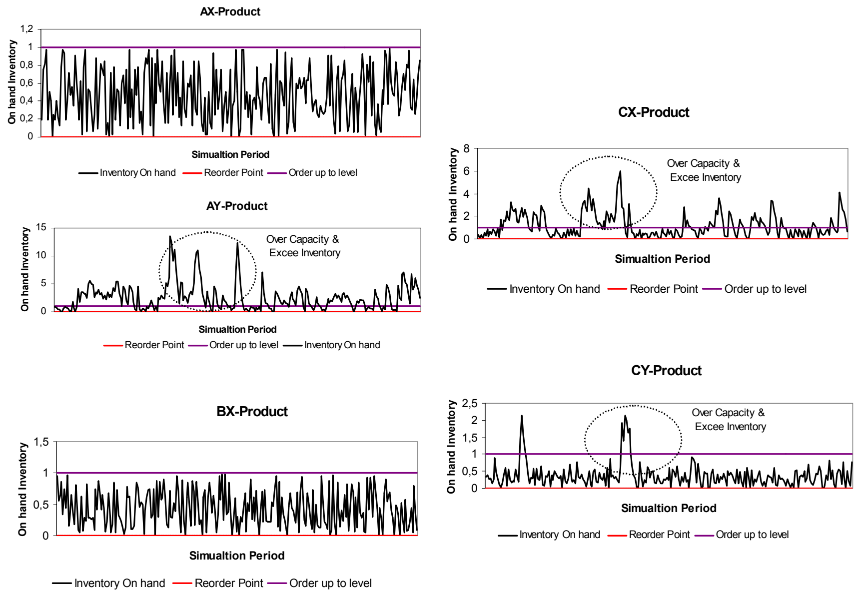


Figure 8.27 Simulated $I_{p,t}^{k}$ Daily Ending Inventory of TP Integrated with SF-ADI-VMI-2 at ADI=4 Days Model in LC-19

8.7.3 Designing Advanced Sub-Transshipment Point Supply Chain Models

8.7.3.1 Introduction To Sub-Transshipment Point Supply Chain Models

Inventory risk pooling or lateral transshipment in inventory distribution systems is an effective means of improving customer service and reducing total system costs. The objective of this study is to investigate the effect of the previously proposed SF-ADI-VMI-2 heuristics on the performance of a **Sub-Transshipment Point** supply chain.

The analysis concentrates on the case of five outlets (stocking locations), which capture most of the characteristics and trade off of multi-location systems with complete pooling. In addition to determining order-up-to quantities for the stocking locations, the decision maker must also specify the details of the transshipment policy. Simulation with a wide choice of model parameters leads to some very interesting and practically useful conclusions, including the following: (a) the benefits of risk pooling through transshipment are substantial and increase with the number of pooled locations; (b) the type of transshipment policy in case of shortages does not affect significantly the system's performance; and (c) it is preferable to form “balanced” pooling groups, consisting of locations that face similar demand. (d) The effect of considering the warehouse and handling cost in defining the appropriate distribution supply network configurations and strategies. Information and product flows for this in-transit transshipment network are as shown in Figure 8.28.

The effectiveness of the proposed SF-ADI-VMI-2 heuristics in estimating the aggregate product demand requirements in downstream supply chain locations will appear in improving the service levels and minimizing the average ending inventory in the 19 main logistic center hubs responsible for the demands of the five sub logistic center hubs LC-1, LC-4, LC-11, LC-16, and LC-23. The effect of the risk pooling and the ability of SF-ADI-VMI-2 heuristics in minimizing the demand uncertainty in main logistic center hubs could be investigated.

Risk pooling straretgy defined as aggregated the independant risks to make the aggregate more certain (Kumar,et al.1995;Hwarng,et al.2005). The inventory risk pooling and minimizing the long-haul transportation links and costs are the significant advantage of this type of distribution network. This model may show a negative significance effect to handling and shipping costs being much higher than for sharing of transportation costs in the total supply chain cost. Extra handling and order picking costs were required for the shipment of the five selected sub-logistic centers hubs, as we will see in simulation results summarized in the next sections.

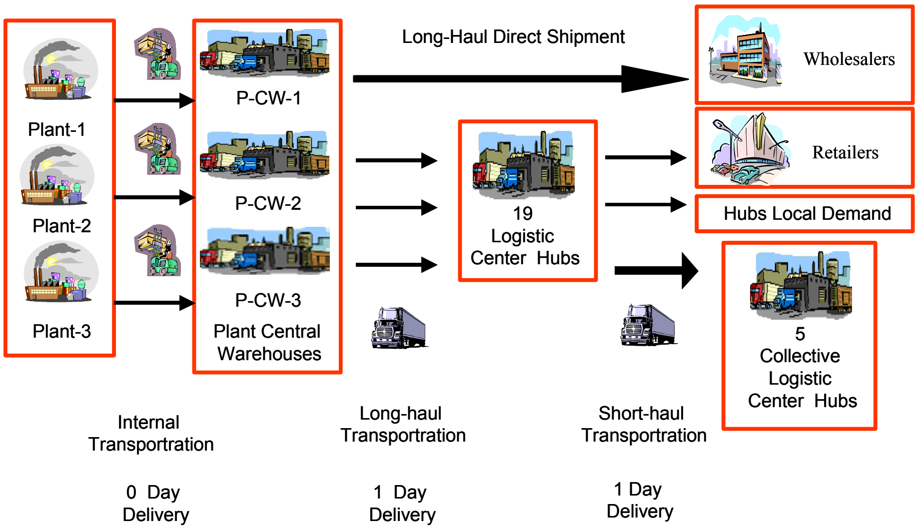


Figure 8.28 Sub-In-Transit Merge and Transshipments Supply Chain Network

8.7.3.2 Description of the Simulated Scenarios of Sub TP

Only one new proposed and examined supply chain network illustrated in Figure 8.28 was simulated and compared to the previously developed simulation scenarios presented in section 8.4.5, they were considered pure transshipment points with or without being integrated into the SF-ADI-VMI-2 heuristics.

The designed simulation scenarios parameters are summarized in Table 8.19. The allocation of the five sub logistic center hubs was based on minimizing the total weighted distance travelled between the main logistic center and the allocated sub logistic center as shown in Table 8.20.

Table 8.19 Simulated Scenarios of Transshipment Supply Chain Network with Sub TP Points Input Parameters

Scenarios ID	Number of Logistic center hubs	Inventory Model	ψ^{k}_{Hybird} Replenishment List	
			ψ^{k}_{pull}	ψ^{k}_{push} with PCR algorithm
1	19 TP SF-ADI-VMI-2 with 5 SUB TP	$\begin{cases} s^{k}_{pt} = 0 \\ S^{k}_{pt} = Q^{FP}_{pt} \end{cases}$	Pure Pull Replenishment	ADI= n = 4 Days ADI= n = 4 Day s
2	24 TP SF-ADI-VMI-2			None
3	24 Pure TP			

Table 8.20 Allocation of The Sub-TP To Main Transshipment Points
(Lateral Transshipments Policy)

Allocated Sub-TP	Main Transshipment Hubs
LC – Hub 1	LC – Hub 17
LC – Hub 4	LC – Hub 24
LC - Hub11	LC – Hub 20
LC - Hub16	LC – Hub 14
LC – Hub 23	LC – Hub 6

The above proposed scenarios are simulated and supply chain performance measures are summarized in the next section.

8.7.3.3 Simulation Results and Analysis of SUB-TP Models with SF-ADI-VMI-2 Heuristic

Simulating the model again for one fiscal year, the supply chain activity based costing model and the total supply chain performance measures are summarized in Table 8.21 and Table 8.22 respectively which will be considered later in the evaluation of the nominated distribution scenarios discussed in the next section.

Table 8.21 Simulated Supply Chain Activity Based Costing of Sub-TP Model with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply Chain Network Activity Based Costing Measures					
		Ordering	***Handling***	***Warehousing***	***Long-Haul Transp.***	***Short-Haul Transp.***	***Inventory***
19 Transhipment points	**19 TP-SF-ADI=4-VMI-2 with 5 SUB TP**	119.458 €	958.697 €	1.545.346 €	**5.764.432 €**	5.499.216 €	180.360 €
24 Transhipment points	**24 TP-SF-ADI=4-VMI-2**	116.678 €	913.459 €	1.513.388 €	5.830.000 €	5.309.369 €	163.620 €
	24 Pure-TP	**117.595 €**	**911.960 €**	**1.511.452 €**	6.616.520 €	**5.337.637 €**	**91.440 €**
Objective Function Min(costs),Max(DLS)		116.678 €	911.960 €	1.511.452 €	5.764.432 €	5.309.369 €	91.440 €
Benchmark Exp Set ID		24 Pure-TP	24 Pure-TP	24 Pure-TP	19 TP-SF-ADI=4-VMI-2 with 5 SUB TP	24 Pure-TP	24 Pure-TP

The improvement index deviations IMI_{Base}^{ExpID} % is estimated based to the 24-pure transshipment point's network experiments results details found in Table VI.4.

Table 8.22 Supply Chain Network Performance Measures
of sub-TP Model with SF-ADI-VMI-2 Heuristic

Benchmark Experiment Models		Supply chain Network Performance Measures			IMI%		
		TSCN	***N-DLS-1%***	***N-DLS-7%***	***TSCN***	***N-DLS-1%***	***N-DLS-7%***
19 Transhipment points	**19 TP-SF-ADI=4-VMI-2 with 5 SUB TP**	14.067.509 €	78,91%	22,93%	-3,56%	42,51%	48,42%
24 Transhipment points	**24 TP-SF-ADI=4-VMI-2**	**13.846.514 €**	**82,10%**	**32,70%**	-5,07%	48,28%	111,65%
	24 Pure-TP	14.586.604 €	55,37%	15,45%			
Objective Function Min(costs),Max(DLS)		13.846.514 €	82,10%	32,70%			
Benchmark Exp Set ID		24 TP-SF-ADI=4-VMI-2					

8.8 Evaluation Nominated Supply Chain Distribution Strategy Models

8.8.1 Quantitative Evaluation of nominated supply chain distribution strategy Models

To develop an efficient and optimized unique supply chain distribution strategy, is one of the most complex and maybe even impossible tasks that face logistics managers, several factors effect and complicate having a unique optimized distribution strategy of a real supply chain distribution network.

The supply chain distribution network, which motivated this thesis, was developed and implemented with different integrated replenishment strategies lead to improving the supply chain performance measures as presented in chapters 4, 6, 7 and 8.

Several and many simulation experiments were conducted and presented: four supply chain distribution networks and configurations (pure hub and spoke, hybrid hub and spoke with direct shipments, transshipment points, sub-transshipment points) were also constructed and three proposed shipment consolidation heuristics (pull replenishments strategy, SF-PCR-VMI-1, SF-ADI-VMI-2) were also developed and integrated into the developed simulation model in chapter 4.

The simulation results of those designed and investigated distribution scenarios were discussed in detail in chapters 4, 6, 7, and 8. Only 38 candidate's distribution strategies are selected and summarized in Figure 8.29 and Table 8.23.

Consider the distribution supply chain network in model 1 as a reference model representing hub and spoke supply chain network without direct shipments between the plant central warehouses and final big customer's demand points. Improvements indexes were estimated to evaluate the percentage improvements deviation to the reference model and to achieve the supply chain targets service levels below.

- Total supply chain cost: if $IMI_1^{ExpID} > \pm 1\%$ significant effect exists
- Target supply chain product fill rate service level $N - DLS1\% \geq 90\%$
- Target supply chain order delivery service level $N - DLS7\% \geq 80\%$

Shaded cells in Table 8.23 show those distribution strategies and supply chain networks that meet the target service levels of both N-DLS-1% and N-DLS-7 %.

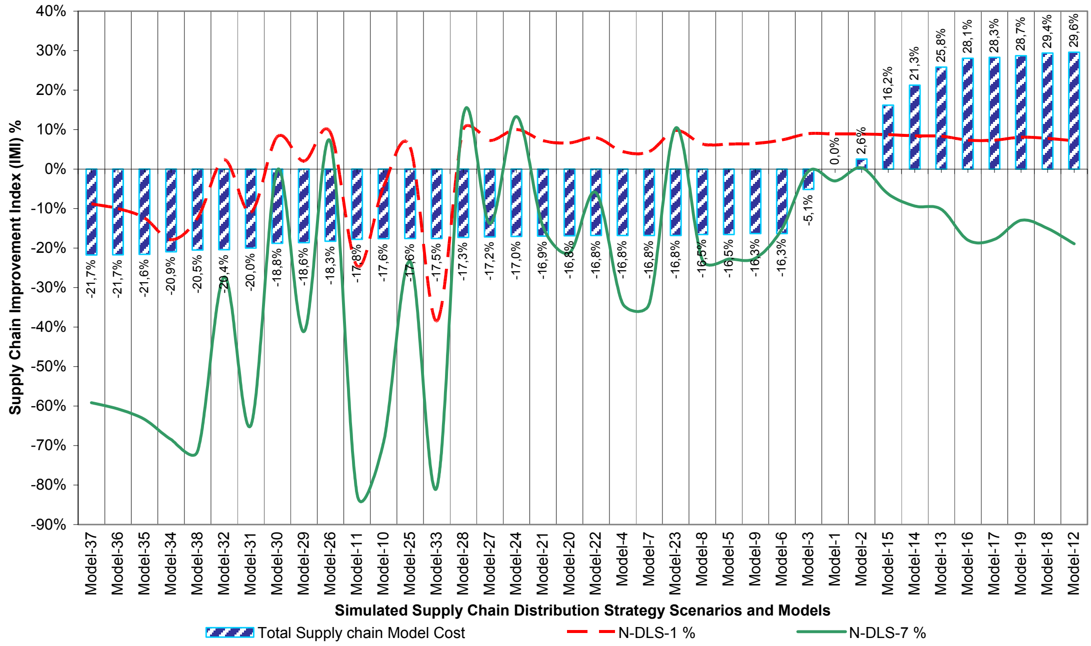


Figure 8.29 Investigated Supply Chain Distribution Variants IMI% Index

The comparison will be made based on the above mentioned supply chain performance measure targets. Only six supply chain distribution variants were selected to be discussed in detail and compared to the reference supply chain network (hub and spoke network without direct shipments, Model-1) modeled in chapter 6. The following is the description of the selected supply chain distribution variants.

Variant 1 : Hybrid hub and spoke network with direct shipments utilizing the pull consolidation replenishments strategy

Variant 2 :	Hybrid hub and spoke network with direct shipments utilizing the SF-PCR-VMI-1 consolidation replenishments strategy with the PCR=AYAYBXBY family
Variant 3 :	Hybrid hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=4 days holding variable safety stock
Variant 4 :	Hybrid hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=5 days holding variable safety stock K_{ss} factor
Variant 5 :	Hybrid hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=5 days holding regular safety stock K_{ss} factor
Variant 6 :	Hybrid hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=5 days holding No safety stock
Variant 7 :	Hybrid hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=5 days holding variable safety stock K_{ss} factor of A and B product class only

Figure 8.29 shows the supply chain performance measures of all the above seven proposed and candidate supply chain distribution strategies as presented in chapters 6,7,and 8.

The potential improvements of those examined distribution scenerios show that higher cost reduction was achieved in variant 6 and 7 of more than -18,26% and 18,77% in costs equals to 3,229,692 Euro/year, 3,229,692 Euro/year, respectively with an order delivery service level N-DLS-7% of 85.45% , 79.85% of just in time delivery and product fill rate N-DLS-1% more than 98 %.

Back to the distribution concept of the variants 6 and 7. It was found that both models holding no product safety stock in the case of variant 6 and only safety stock inventory of A and B product classes was allowed to keep in variant 7 (product inventory allocation strategy).

The common sharing between those two examined distribution strategies was the implementation of the proposed integrated SF-ADI-VMI-2 heuristic that proves the capability of those integrated models to obtain significant results rather than those models that hold safety stock levels to improve the supply chain performance measures. The reason for such service level improvements and reductions in total supply chain costs result through the good interaction between the transportation function of generating full truck load trips when possible with extra pushed demanded products of further demand periods as was mentioned in the SF-ADI-VMI-2 heuristic.

Table 8.23 Summarized Supply Chain Performance Measures of
38 Different Distribution Strategies

Simulation Experiments Designed Parameters & Distribution Strategies							**Target Supply Chain service Levels**		**90%**	**80%**	IMI-Index %		
EXP ID	Transportation	Inventory	Order Property	Safety Stock Type	VMI Heuristics	Model Description	Reference Model	Total Supply Chain Cost	N-DLS-1 %	N-DLS-7 %	Total Supply Chain Cost	N-DLS-1 %	N-DLS-7 %
Model-1	Pull					Pure Network + NPS & negative order picking Property +	Base 0	17.689.903 €	**97,98%**	77,62%	0,00%	8,87%	-2,98%
Model-2	Pull	SDT ROP		Variable Safety Stock		Pure Network + APS & negative order-picking Property +	Base 0	18.146.374 €	**97,98%**	**80,28%**	2,58%	8,87%	0,35%
Model-3	Pull		MTS		None	Hybrid Hub & Spoke Network with Direct Shipments	Base 0	16.780.107 €	**98,10%**	79,58%	-5,14%	9,00%	-0,53%
Model-4	Pull			No Safety Stock		B-Exp-Set-1	B1	14.718.124 €	**93,99%**	52,76%	-16,80%	4,44%	-34,05%
Model-5	Pull	CSL ROP		80 % CSL		B-Exp-Set-2	B2	14.766.829 €	**95,71%**	61,79%	-16,52%	6,35%	-22,77%
Model-6	Pull			95 %CSL		B-Exp-Set-3	B3	14.807.378 €	**96,66%**	67,93%	-16,29%	7,40%	-15,08%
Model-7	Pull			No Safety Stock		B-Exp-Set-4	B4	14.718.124 €	**93,99%**	52,76%	-16,80%	4,44%	-34,05%
Model-8	Pull	STD ROP		Fixed Safety Stock		B-Exp-Set-5	B5	14.765.390 €	**95,71%**	61,63%	-16,53%	6,35%	-22,97%
Model-9	Pull					B-Exp-Set-6	B6	14.802.924 €	**95,87%**	61,95%	-16,32%	6,52%	-22,56%
Model-10	Pull	SDT ROP	STO	Variable Safety Stock		B-Exp-Set-7	B6	14.578.597 €	86,04%	24,69%	-17,59%	-4,40%	-69,14%
Model-11	Pull		STO			B-Exp-Set-8	B7	14.547.513 €	67,93%	14,20%	-17,76%	-24,53%	-82,25%
Model-12	Hybrid				VMI-1	AX	B6	22.928.038 €	**96,45%**	64,88%	29,61%	7,17%	-18,90%
Model-13	Hybrid				VMI-1	AXAY	B6	22.261.815 €	**97,50%**	71,85%	25,84%	8,33%	-10,18%
Model-14	Hybrid				VMI-1	AXAYBX	B6	21.455.030 €	**97,59%**	72,53%	21,28%	8,43%	-9,34%
Model-15	Hybrid				VMI-1	AXAYBXBY	B6	20.555.097 €	**97,87%**	74,97%	16,20%	8,75%	-6,29%
Model-16	Hybrid				VMI-1	AXBX	B6	22.652.614 €	**96,60%**	65,63%	28,05%	7,33%	-17,96%
Model-17	Hybrid			Variable Safety Stock	VMI-1	AXBXCX	B6	22.699.043 €	**96,61%**	65,78%	28,32%	7,35%	-17,78%
Model-18	Hybrid	SDT ROP	MTS		VMI-1	AY	B6	22.891.520 €	**97,00%**	67,98%	29,40%	7,78%	-15,02%
Model-19	Hybrid				VMI-1	AYBY	B6	22.769.302 €	**97,27%**	69,63%	28,71%	8,07%	-12,96%
Model-20	Hybrid				VMI-2	ADI =1Day	B6	14.710.496 €	**95,98%**	63,07%	-16,84%	6,65%	-21,16%
Model-21	Hybrid				VMI-2	ADI =2Day	B6	14.693.340 €	**96,48%**	68,40%	-16,94%	7,20%	-14,51%
Model-22	Hybrid				VMI-2	ADI =3Day	B6	14.717.603 €	**97,17%**	75,23%	-16,80%	7,96%	-5,97%
Model-23	Hybrid				VMI-2	ADI =4Day	B6	14.722.605 €	**98,82%**	**88,35%**	-16,77%	9,80%	10,44%
Model-24	Hybrid				VMI-2	ADI =5Day	B6	14.678.536 €	**99,04%**	**90,65%**	-17,02%	10,04%	13,31%
Model-25	Hybrid						B4-ADI=2day	14.582.141 €	**94,99%**	61,26%	-17,57%	5,54%	-23,43%
Model-26	Hybrid		MTS				B4-ADI=5day	14.460.211 €	**98,32%**	**85,49%**	-18,26%	9,24%	6,86%
Model-27	Hybrid						B5-ADI=2day	14.653.481 €	**96,50%**	68,98%	-17,16%	7,22%	-13,78%
Model-28	Hybrid			Mixed Safety Stock	VMI-2	ADI Models	B5-ADI=5day	14.633.423 €	**99,00%**	**90,84%**	-17,28%	10,00%	13,55%
Model-29	Hybrid						B7-ADI=2day	14.396.118 €	**91,82%**	47,09%	-18,62%	2,02%	-41,14%
Model-30	Hybrid		STO				B7-ADI=5day	14.369.958 €	**97,43%**	79,85%	-18,77%	8,26%	-0,19%
Model-31	Hybrid						B8-ADI=2day	14.151.995 €	80,13%	28,06%	-20,00%	-10,97%	-64,93%
Model-32	Hybrid						B8-ADI=5day	14.081.099 €	**92,15%**	58,15%	-20,40%	2,39%	-27,31%
Model-33	Pull		STO		None	P-TP	Pure TP	14.586.604 €	55,37%	15,45%	-17,54%	-38,48%	-80,69%
Model-34	Hybrid				VMI-2	TP+ADI=1	TP	13.986.321 €	73,91%	25,23%	-20,94%	-17,88%	-68,47%
Model-35	Hybrid				VMI-2	TP+ADI=2	TP	13.876.696 €	78,86%	29,30%	-21,56%	-12,38%	-63,38%
Model-36	Hybrid			Residual Stock	VMI-2	TP+ADI=3	TP	13.852.847 €	81,02%	31,43%	-21,69%	-9,98%	-60,72%
Model-37	Hybrid				VMI-2	TP+ADI=4	TP	13.846.514 €	82,10%	32,70%	-21,73%	-8,78%	-59,13%
Model-38	Hybrid				VMI-2	19 LCH-Hybrid_ADI=2_CLCH DC	TP	14.067.509 €	78,91%	22,93%	-20,48%	-12,32%	-71,34%
Supply chain Objective Min (cost) Max (N-DLS-1% , N-DLS-7 %								13.846.514 €	99%	91%			

The generated residual stock of earlier product replenishments works as non-fixed safety stock, unlike those models which utilized daily fixed amounts of safety stock. Such a proposed model could be highly recommended in a multi-product supply chain where joint replenishment of products with other supply chain functions were required and are essential to minimize specifically the inventory and transportation costs.

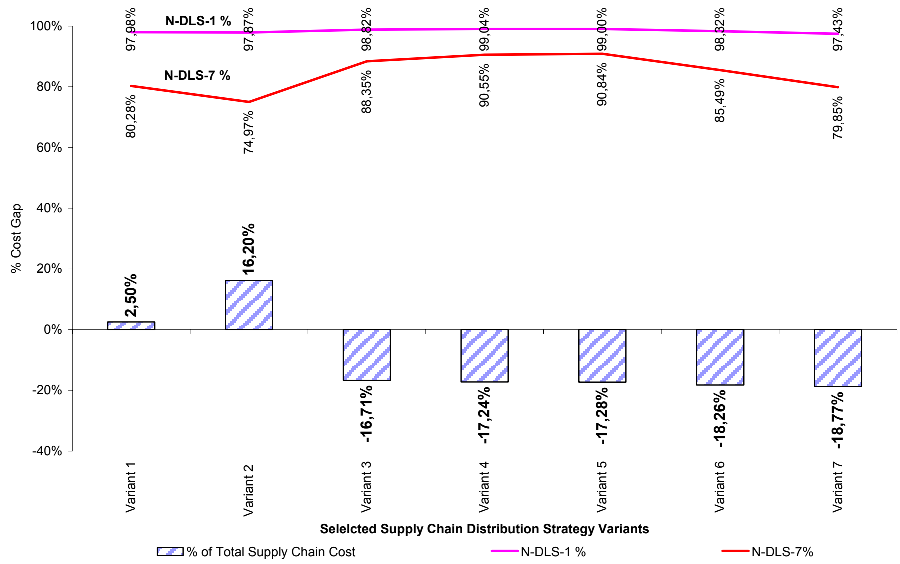


Figure 8.30 IMI% Index of Seven Candidate Supply Chain Distribution Variants

The designed integrated supply chain model holds any amount of daily safety stock as in the case of variants 3, 4, and 5 which achieve higher service levels above the targets with an additional cost as illustrated in Figure 8.30.

An appropriate estimation of the ADI or (n) information horizon period lower bound could be as follows:

$$LB(ADI,n)=\begin{cases}\geq L_1+L_2 & \text{No Safety Stock designed}\\ \geq L_1+L_2-1 & \text{Lower Safety Stock designed}\end{cases}$$

In case a higher safety stock was designed, the performance of the SF-ADI-VMI-2 heuristic, shows a relative small improvement in service level N-DLS-1% and N-DLS-7% with an additional inventory holding cost caused by the generated residual stock amounts. Such a variant is not applicable when the inventory holding costs in downstream locations were higher than in upstream supply chain locations.

Proposed supply chain network structures and configurations were developed and investigated when the order cycles time (L2) were reduced from 4 days to 1 day. In such models the supply chain targets service levels will not be considered as first priority as before and the cost improvement index were important, the redesigned and proposed integrated transshipment points models with SF-ADI-VMI-2 could be an efficient and effective supply chain distribution strategy. Three extra new supply chain networks were presented such as (pure transshipment points, transshipment points integrated with SF-

ADI-VMI2, and Sub transshipment points integrated with SF-ADI-VMI2) with modified (s^k_{pt}, S^k_{pt}) inventory models as mentioned before.

Variant 8 :	Hybrid Transshipment hub and spoke network with direct shipments utilizing the pull consolidation replenishments strategy
Variant 9 :	Hybrid Transshipment hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=4 days
Variant 10 :	Hybrid Sub-Transshipment hub and spoke network with direct shipments utilizing the SF-ADI-VMI-2 consolidation replenishments strategy with ADI=4 days

Figure 8.31 shows the supply chain performance measures of all the above three examined supply chain distribution strategies where the N-DLS-1 %,N-DLS-7% (JIT) reflects the amount of products and orders that satisfied deliveries from the existing product residual stock cased by the SF-ADI-VMI-2.

The potential improvements of those examined distribution scenerios show that higher cost reduction is achieved in variant 9 and 10 of more than -21 % in cost equals to 3,836,939 Euro/year with an just in time order delivery service level N-DLS-7% of 30% in the first day, and 70% the second day and product fill rate N-DLS-1% more than 80%.

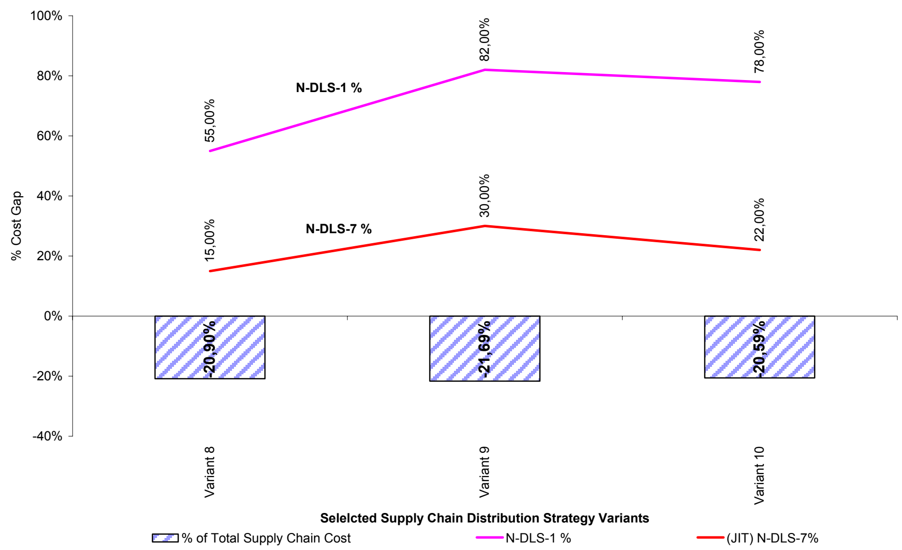


Figure 8.31 IMI% Indexes of Transshipment Points Supply Chain Distribution Variants

Such improvements prove the power of the proposed integrated interaction between the transportation function of generating full truck load trips and the products residual inventory levels. Even in variant 10 additional higher handling and short-haul transportation costs were required to submit the demand of the five Sub-transshipment points. The savings achieved in long-haul transportation costs were higher than those additional handling costs.

8.8.2 Qualitative Evaluation of Nominated Supply Chain Distribution Strategy Models

A supply chain network designer needs to consider network characteristics and requirements when deciding on the appropriate delivery and distribution variety network. The varieties considered earlier have different strengths and weaknesses. In Table 8.24, the various delivery and distribution networks are ranked relative to each other along different selected performance dimensions. A ranking of 1 indicates the best performance along a given dimension and the relative performance worsens, as the ranking gets higher.

The above examined distribution strategies and variants show that most of the proposed simulation models based SF-ADI-VMI-2 heuristics could be considered as an optimized supply chain distribution strategy.

Table 8.24 Comparative Performances of Proposed Distribution Network Designs

Factors	**Proposed Distribution Network Design Variant**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Response Time	2	2	2	1	1	2	2	4	4	4
Product Variety	1	1	1	1	1	1	3	4	4	4
Product Availability	3	2	2	1	1	1	3	4	3	3
Order Visibility	5	4	1	1	1	1	1	4	1	1
Inventory Holding Cost	4	6	4	4	3	2	2	2	1	1
Transportation Cost	4	6	1	1	1	1	2	2	1	1
Facility and Handling	3	5	2	2	2	2	3	2	2	2
Information Cost	2	2	4	4	4	4	4	4	4	4
SUM	24	28	17	15	14	14	20	26	20	20

An evaluation and comparison of those different distribution strategies reveals that all of them were focusing on integrating the long-haul transportation functions considering the product inventory levels in the logistic center hubs two level supply chain for the following reason:

- Utilizing the full truck load concept in the long-haul transportation may improve the marginally discounted transportation cost per pallet in the long-haul transportation activity considering the interaction between the transportation and the inventory.

All the above mentioned variations focus on increased the long-haul truck filling degree to perform full truck load trips, and minimizing the inventory, warehousing and transportation costs. Therefore, the simulated lower bound transportation cost gap % of some selected models, as summarized in Table 8.25, show lower chances of future improvements the supply chain cost through the proposed long-haul consolidation concept (SF-ADI-VMI-2).

Table 8.25 Simulated Lower Bound Transportation Cost of Selected Distribution Strategies

Location	Transporation Type	Proposed Hybird Models				Transhipment Points		
		B-EXP-Set6_ADI=2	**Diff %**	B-EXP-Set6_ADI=4	**Diff %**	B-EXP-TP	B-EXP-TP_ADI=4	Diff %
		Transportation Cost	**(Proposed-SimLB)/LB * 100**	Transportation Cost	**(Proposed-SimLB)/LB * 100**	Transportation Cost	Transportation Cost	**(Proposed-SimLB)/LB * 100**
P-CW-1	*Long-Haul*	1.999.588 €	**3,17%**	1.970.498 €	**1,67%**	1.917.166 €	1.723.117 €	**-10,12%**
P-CW-2		1.190.917 €	**29,36%**	1.182.587 €	**28,45%**	916.994 €	953.416 €	**3,97%**
P-CW-3		3.327.590 €	**6,10%**	3.308.213 €	**5,48%**	3.125.495 €	3.153.467 €	**0,89%**

In Table 8.25 the simulated lower bound transportation costs show significant chances of future reduction in the supply chain logisitcs on the short-haul transportation costs which could be improved through the following suggestions.

The presented and constructed simulation model and integrated heuristics neglects to optimize the short-haul activities; therefore, the following are some recommandation points that may result in further reduction or improvement in the short-haul filling degree.

1. Reorginazing the number of the logisitc centers and the final customers location and allocation models
2. Increasing the possibility of more direct shipments
3. Constructing dynamic short vehicle routing model that constructs daily full truck load trips.
4. Determine the minimal customer order shipment size.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This research work was motivated by a real life industrial project optimizing the performance of a food distribution supply chain network in Germany through the simulation based heuristics techniques, in order to develop an integrated and coordinated distribution supply chain strategy that integrates the transportation and the inventory decisions to achieve an optimized performance measure. This research focuses on the following points: building supply chain simulation models, integrating the transportation and inventory decisions in the supply chain, and improving the supply chain performance measures. The conclusions of the work can be elaborated according to the following details.

1. Simulation is a useful tool for studying the dynamics of supply chains. Discrete event simulation packages available today are not very suitable for supply chain simulation. The amount of effort needed to build supply chain models can be greatly reduced by reusing components from supply chain component libraries as it was concluded in chapters 1 and 2.
2. Satisfying the supply chain multi-criteria objective function and improving the performance measures could be investigated and optimized by conducting

simulation models through (what if) scenarios unlike in analytical models. Where hybrid integration between simulation and analytical models (heuristics) is concerned, it is imperative to employ both analytical and simulation-based techniques in order to achieve better supply chain performance measures.

3. Simulation is a very useful tool for predicting supply chain performance. However because there are few standard simulation elements that accurately represent the activities in a supply chain, and, since distribution network design problems as a part of the system supply chain have received increasing attention from the research community in recent years because great savings are expected from a better designed logistical network, work has been performed at the modeling and solving levels simultaneously.

4. The developed Logistical Distribution Network Simulation Tool (LDNST) model based on the conceptual methodology presented in chapter 2 utilizing the UCM and SCOR model concept are capable of providing a practical solution for modeling and constructing a real life supply chain simulation model, which is required to be flexible and to consider system dynamics. Utilizing this visualized high-level model helps to understand, define the behaviour of the supply chain components as concluded in chapters 3, and 4.

5. Effective design of the supply chain is nowadays recognized as a key determinant of competitiveness and success for most manufacturing organizations. While many quantitative models have been constructed to provide decision support for the management of materials in different supply chain subsystems, the most pressing challenge to the SCM community is to develop efficient modeling and analyzing techniques for supply chain integration and coordination problems so as to gain a full understanding of the characteristics, performance and trade-offs involved. These problems remain difficult to analyze and optimize globally.

6. This dissertation work focuses on evaluating and modeling several representative supply chain distribution strategies that lead to an integrated supply chain design. Each of these examined distribution strategy endeavours has sought to combine simulation models presenting the power of information technology and the analytical heuristics model in novel ways in order to create an even more efficient and practical distribution supply chain network.

7. The combination of proposed simulation models and the base case model are utilized to present several best supply chain scenarios and configurations, when the

presented simulation model is used to study the impact of the different distribution strategies on the supply chain performance measures.

8. It is important to recognize that the hybrid hub and spoke network model with direct shipments was the best scenario in the solution phase 1 and that it shows a reduction in terms of total supply chain cost, and increases the delivery service levels when the truck is shipped directly, if the order size is up $w_{jt}^{m}/\sqrt{2}$ of the truck's capacity. Note also that the hybrid hub network avoids the expenses involved in operating some of the large customers' demands, where the daily customers' orders of a full truck load will be transported from the plant central warehouses directly according to the results of chapter 6.

9. A good information infrastructure is designed and offered so that the logistic center can provide product availability information to the customer even though the inventory is located at the plant central warehouses. The customer should, but may not have visibility into order processing at the plant central warehouses even though the order is placed with the logistic center. The hybrid hub network will generally require significant investment in the information infrastructure.

10. In chapter 7 it was observed that the potential of the spatial postponement with (STO) strategy minimized the inventory holding cost with a relative reduction in the long-haul transportation cost, while negative supply chain service levels were achieved. Note that the effectiveness of spatial postponement with (STO) strategy could be utilized efficiently if it is possible to reduce the order cycle time less than the simulated cycle time (4 days in Long-haul, and 1 day processing the order in the logistic center hubs) as was presented in chapter 8 with transshipment points network.

11. A lower long-haul truck filling degree occurs, when the supply chain is operated as a pure pull supply chain demand driven concept, that strategy increases the long-haul transportation cost where most of the trucks are less than truck load, which has been improved by the benefits of sharing information across the supply chain locations, and implementing the vendor managed inventory (VMI) with integrated replenishment which may represent an appropriate strategy leading to improvement in supply chain performance measures.

12. The long-haul consolidation heuristics named ship full truck load integrated with product clustering replenishments vendor managed inventory named as SF-PCR-

VMI-1 shows and reflects one of the real life used distribution strategies without considering the effect of such policy on the supply chain performance measures as discussed in chapter 8.0.

13. It was recognized that the supply chain performance measure improvements index IMI% is redundantly improved when SF-PCR-VMI-1 and SF-ADI-VMI-2 were implemented with respect to supply chain service levels (DLS-1% and DLS-7 %), while SF-ADI-VMI-2 performs better in optimizing the multi-criteria supply chain objective function (Total supply chain costs, DLS-1% and DLS-7 %). In some cases the proposed SF-ADI-VMI-2 improved the supply chain service levels without incurring additional supply chain costs.

14. The second advantage gained by implementing the proposed SF-ADI-VMI-2 heuristics resulted in lower inventory levels and inventory related costs; in this sense, the proposed SF-ADI-VMI-2 is relatively operative as a semi-substitute of holding high products safety stock among the supply chain locations.

15. In most cases, transportation costs are lower than those of traditional distribution centers when the logistic centers operate with transshipment point strategies, caused by higher small frequent shipments which take place at the carrier hub prior to delivery to the customer and also reduce the number of deliveries and restrict them according to make to order concept (MTO), unlike before, where they are based on the concept of make to stock (MTS).

16. The main advantage of the proposed and examined transshipment points models is the somewhat lower long-haul transportation cost by more than -13% and the inventory holding by more than 70%, while reducing the customer and supply chain service levels. The major disadvantage is the additional physical effort required during the transshipment process itself. Given its performance characteristics, the plant central warehouses linked with logistic center hubs operated as transshipment points are best suited for low and medium uncertain demand patterns, as in the studied supply chain case study where the product average daily demand was relatively low. Transshipment or in-transit merge points are best implemented if there are no more than four or five sourcing locations and each customer order has products from multiple locations.

17. Models with a transshipment points, partly performing as in-transit merge points have higher facility costs because of the required merge capability. Receiving costs for the customer are lower because a single delivery is received.

18. A very sophisticated information infrastructure is needed to allow the transshipment points to work well. Besides information, operations at the logistic centers, plant central warehouses and the carriers must be coordinated by a reliable demand forecasting tool. The investment in information infrastructure will be higher than for the previous model's strategies.

19. In transshipment points network the just in time order response index N-DLS-7%, and product variety and availability index N-DLS-1% are lower than in the last models with traditional distribution center network. In those models order response times marginally are lower because of the need to wait for the lead time (L_1) period until the product demanded replenishments arrive. It has been improved to more than 30% of the order which will be delivered on the same day with ADI=4 days with the consolidation strategy. Customer experience is likely to be lower than the previous models in chapter 7 due to product unavailability at the time of request and the orders will be satisfied from the temporally generated residual stock.

20. The potential improvements of those examined distribution sceneries show that higher cost reduction is achieved in models designed with lower safety stock requirements of more than -18, 26% and 18, 77% in cost equal to 3,229,692 Euro/year, 3,229,692 Euro/year with an order delivery service level N-DLS-7% of 85.45%, 79.85% of just in time delivery and product fill rate N-DLS-1% more than 98%. With regard to those models, it was found that both hold no product safety stock, completely in the case of variant 6 and partially in variant 7 that hold inventory of A and B products only (product inventory allocation strategy).

The commonality between those two examined distribution strategies was the implementation of a proposed integrated SF-ADI-VMI-2 heuristic that proves the capability of those integrated models to obtain a significant result rather than those models which hold higher safety stock levels to improve the supply chain performance measures.

An efficient interaction between the transportation function such generating full truck load trips when possible as was mentioned in the SF-ADI-VMI-2 heuristic performs as a better distribution strategy than pure pull models. In the SF-ADI-VMI-2 heuristic, the generated residual stock of earlier product replenishments works as non-fixed variable safety stock unlike those models, which utilized the fixed amount of safety stock every day. Such a proposed model could be highly recommended in a multi-product supply chain where joint replenishment of products with other supply chain functions is required and essential to minimize specifically the inventory and transportation costs.

21. Through an examination of several distribution strategies and variants, it is evident that most of the proposed simulations are based on the SF-ADI-VMI-2 heuristic methodology models, and could be considered as an optimized supply chain distribution strategy implementing direct shipments.

9.2 Research Contributions

The main objectives of this research were to develop an integrated and competitive distribution supply chain simulation model, which helps and supports logistics designers and planners to evaluate the performance of different distribution strategies to the supply chain. These objectives are realized through the following contributions.

1. Presenting and discussing several practical designs, and controls of the supply chain; however, it is a complex and difficult process to analyze the performance of the supply chain and to determine the appropriate controls and distribution strategy mechanisms.
2. Modeling a real life food supply chain network optimization project motivated this thesis and led to the construction of several integrated distribution strategies to improve the supply chain performance measures. Such a problem motivates the researchers to investigate and construct unified classification of the related problems and solutions models, which may face the supply chain decision maker.
3. The recent lines of research for further supply chain modeling efforts should be focused on those techniques related to general / inter-functional integration (e.g. Production - Distribution, Production - Sourcing, Location - Inventory, Inventory Transportation) considering the controlling and exploring of multi-echelon, multi-period, multi product aspects, as was concluded by MIN and Zhou,(2002); Sarmiento and Nagi (1999); Chan (2004). This thesis considers the integration of inventory and transportation decisions.
4. The complexity and difficulty of modeling real life logistics business processes and obtaining the optimized solutions has encouraged researchers to construct supply chain simulation models that need to evaluate the dynamic decisions rules for

many functions in the supply chain. A (LDNST) real supply chain simulation model was developed, validated and implemented.

5. The integrated production distribution (IPD) with stochastic demand models deserves more research work, as most of the existing researchers consider deterministic models where the demand for products is known in advance (Chen 2004). The developed LDNST tool considers both stochastic real forecasted demand and generated fitted demand distribution.

6. Identification and assessment the effects of several practical cooperative distribution strategies on supply chain performance measures were presented and; several distribution strategies were examined and evaluated under different supply chain configurations.

7. An efficient integrated transportation inventory strategy that incorporates a replenishment policy for the outgoing materials for the performance analysis and optimization of an integrated supply network with a (s,S) inventory control at all sites was developed. This dissertation extends the previous work done on the pull supply network model with control and service requirements. Instead of a pull stock policy, a hybrid stock policy and lot-sizing problems are considered.

8. Six multi-product safety stock allocation strategies were investigated and the effect on the supply chain performance measures were explained and realized.

9. The effect of implementing a pull, and hybrid pull-push replenishment strategy on the supply chain performance measures was examined, considering several products safety stock allocation strategies and supply chain configurations.

10. Developing novel cooperative supply chain replenishments heuristics algorithms that utilize the development trends in the information technology field, such as implementing Advanced Demand Information (ADI) or Early Order Commitment (EOC) policy at downstream and upstream locations and estimating the cost saving effect seem to be an interesting option.

11. Integrating the developed simulation models with an appropriate data exchange interface to be linked with the SAP system is necessary for an efficient operation.

9.3 Recommendations for Future Research

In order to build an integrated supply chain model for a real-life supply chain, several extensions are needed. Of course, there is always room for additional contributions. Below are some of the recommendations for future extensions.

1. Optimizing the short-haul transportation costs by implementing a dynamic vehicle routing model while taking into consideration several criteria such as customer time windows, maximum distance traveled, special deliveries. An initial dynamic VRP model has been developed but it is out of the scope of this thesis.
2. Implementing a periodic review inventory control strategy instead of the continuous review control has been modeled in this thesis.
3. Multi-product joint replenishment concepts that minimize the transportation costs need to be investigated as well as the amount of the residual stock generated from the earlier replenishment.
4. Other shipment consolidation strategies such as a quantity-time based policy instead of the proposed long-haul quantity shipments consolidation (SF-PCR-VMI-1) and (SF-ADI-VMI-2) also need to be investigated.
5. Further investigation is required in integrating the location, inventory and routing decisions.
6. The developed supply chain simulation model requires internationalization and standardization in order to consider several supply chain controlling aspects and strategies.

It is expected that the future recommendations will enhance the usefulness of this research and will result in the development of a fully integrated supply chain simulation based optimization model.

Appendices

Appendix I: Supply Chain Objects Library

Table I.1 Main Supply Chain Structural Objects and Entities (Biswas and Narahari,2004)

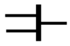
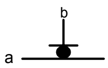
1	End Customer	A customer can be either an internal customer or an external customer. The internal customers are the various entities of the network like the plants and the distributors. The external customers are the consumers of the products (finished or semi-finished) of the supply chain. The customer class may also contain information on the desired service level and priority of the customer.
2	Customer Order	An order contains the name and the quantities of the desired products, the name of the customer, and the name of the entity to which the order is placed. An order can belong to any of the following categories: external customer order, warehouse order, manufacturing order, late-customization order and supplier order. External customer orders are generated either from forecasts (demand planning policies) or by the customer objects in a deterministic manner.
3	Plant	A plant manufactures or assembles finished or semi finished products from raw materials and/or sub-assemblies. A plant may have its associated raw material warehouse, in-process inventory warehouse and finished goods warehouse.
4	Supplier	A supplier provides a plant with raw materials or sub-assemblies. A supplier could be a manufacturing plant or a late-customization center or a full-fledged supply chain.
5	Retailer	An external customer generally buys the products from the retailer. A retailer has an associated stocking warehouse, where the inventories of the products are stored. A retailer can receive deliveries from distributor or plant central warehouses or late-customization center or from some other retailer. The product is delivered to customer if it is available in the retailer's warehouse. Otherwise the order is added to a queue for the particular product, according to a pre-assigned priority. The order is delivered when the product is received (from distributor or plant or late-customization center as the case may be).
6	Distributor	A distributor receives deliveries from plant central warehouses, or late-customization center or from other distributors. The distributor may have an associated warehouse. It supplies to the retailers or sometimes to other distributors. It may also supply to the late-customization center with information on customer specified requirements.
7	Transport Vehicle	Transportation vehicles move products from one node of the network to another. Each vehicle has characteristics in terms of products it can carry, capacity (in volume or weight), costs, and speed.
8	Warehouse	A warehouse is a storage facility that is characterized by the nature and capacity of the products it can store. A warehouse can be attached to the plant, the distributor, and the retailer. A warehouse can be used for storage of raw-material inventories, in-process inventories, and finished product inventories.

Table I.2 Main Supply Chain Policy Objects and Entities

1	Inventory Policy	Inventory policies guide the flow of materials in the supply chain networks. Different inventory policies include multi-echelon inventory policies, and EOQ policies.
2	Production Policy	The manufacturing policy can be make-to-stock or make-to-order or assemble-to-order or a combination of these policies. *Make-to-stock Policy (MTS):* The plant builds products according to advance plans, and pushes the finished products into the warehouses. *Make-to-order Policy (MTO):* The plant produces a product from its input parts only when an order for that product is received. *Assemble-to-order Policy (ATO):* The manufacturing plant produces components that can be assembled by the late customization center according to customer specification. *Engineering –to-order Policy (ETO):* this policy gives emphasis on the design, which is usually developed after receiving customer requirement approval.
2	Order Management Policy	The order management policy models the order processing and scheduling at any node of the supply chain. The delay incurred in the process is also considered. Different types of orders exist (complete order, partial orders, hybrid orders those types will be discussed later in details).
4	Demand Planning Policy	The demand planning policy generates forecasts of expected demands for future periods.
5	Supply Planning Policy	Supply planning is a critical process in determination of company's service and inventory levels. This models the allocation of production and distribution resources to meet the actual and forecasted demand under capacity and supply constraints.
6	Distribution Policy	The products distribution is the process of delivering demanded products from the supplier site to the end customer. The scheduling policies include routing and scheduling of vehicles to optimize delivery schedules.

Appendix II: Basic UCM Symbols

Table II. 1 Basic UCM Symboles (Abdelaziz, et al 2004)

UCM Notation	Notation Explanation
Start point End point Path	**Path:** Represents flow of events in the system. Path connects start points, stubs, responsibilities, forks, and end points of UCM. The start-point represents preconditions. The end-point represents post-conditions.
Do something	**Responsibility Point:** Represents the functions to be accomplished by the system at that point of the path.
	Or Fork: An OR fork means the path proceeds in only one out of two or more directions.
	Or Join: It means two or more paths merged it in one single path.
	**And Fork:** It means that a single path is distributed at the same time into many concurrent paths.
	**And Join:** It means that several concurrent Paths are merged at the same time into a single path.
	Static Stub: Associated with one plug-in (Sub UCM) as task to be achieved by the system, used as decomposition of complex maps.
	Dynamic Stub: Associated with several plug-ins, whose selection can be determined at run-time according to selection policy (often described with preconditions). It is also possible to select multiple plug-ins at once (sequentially or parallel).
	**Wait Point**: Path a waits for an event from path b.
	Structural Object: Component representing a Supply chain Structural object.

Appendix III: UML Classes and Model Details

This appendix presents UML models of the developed system. Each UML model consists of a number of UML class diagrams connected to each other to show the relationship between these classes. For the demonstration, Figure III.1 shows the LNDST Main UML model.

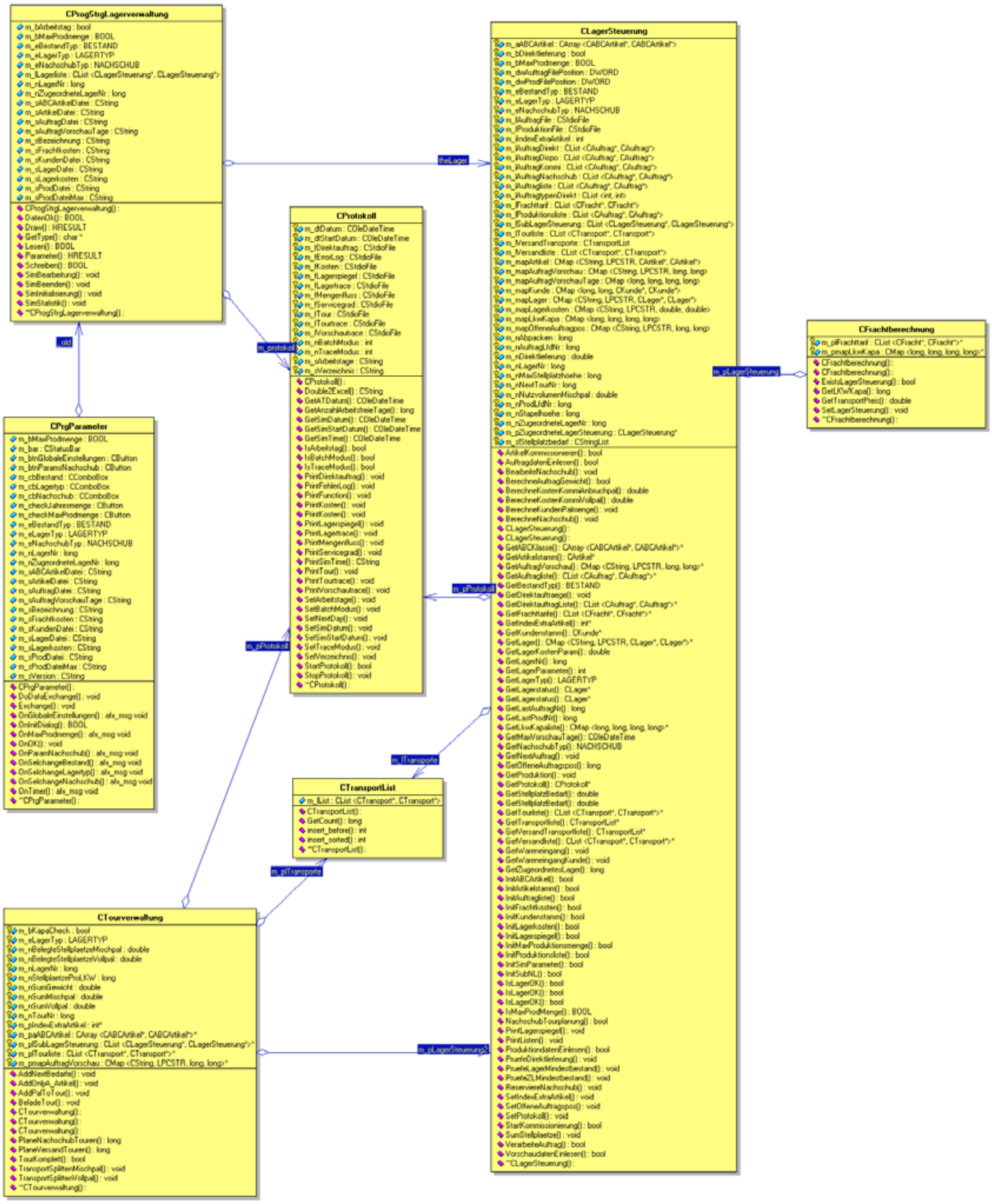


Figure III.1 Main LNDST UML Class Model

Appendix IV: Case Study Input Data Analysis

Demand Distribution Histograms ***Normality Test Graph***

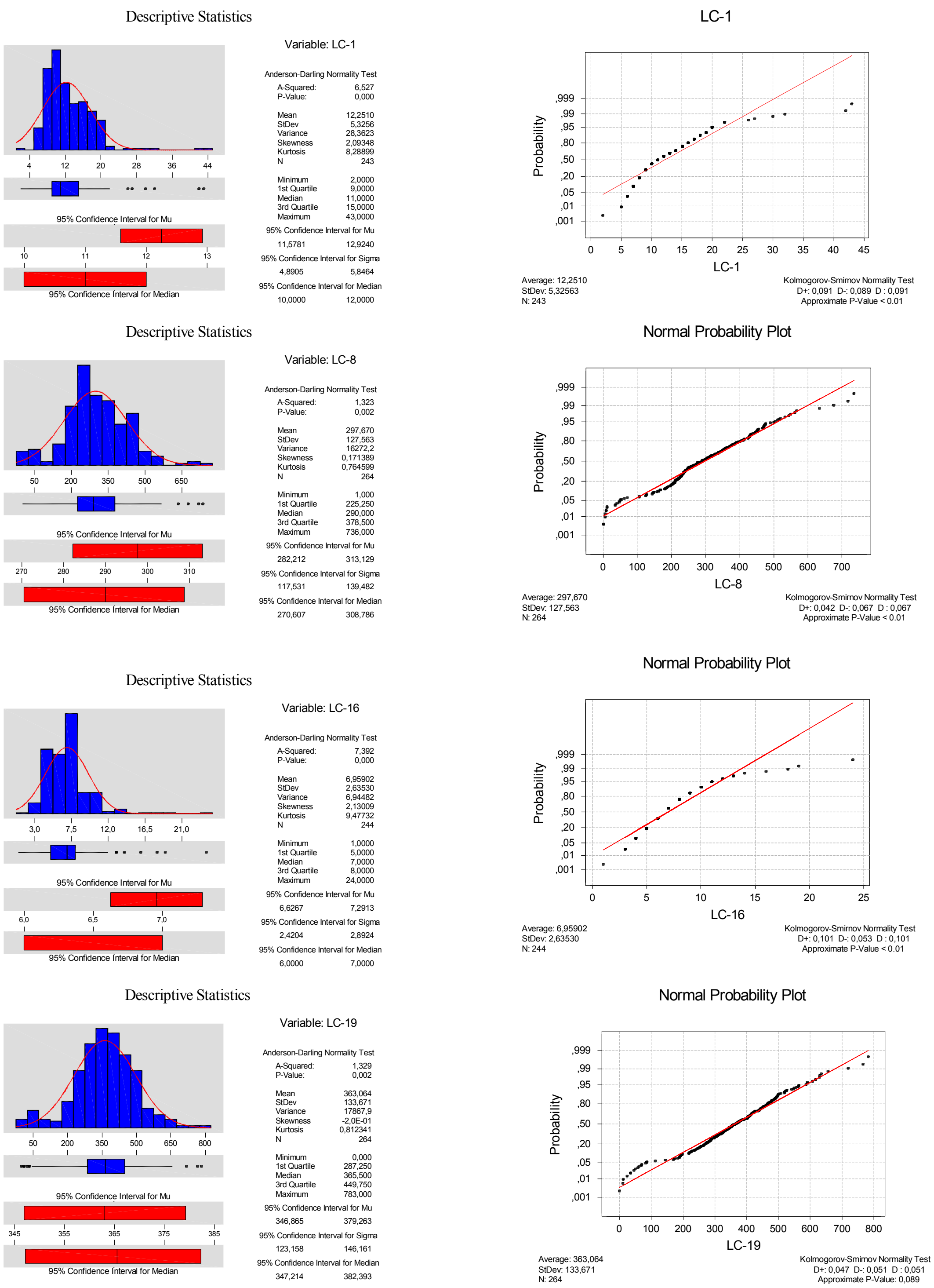


Figure IV.1 4 Logistic Center Hubs Demand Distribution Fitting Using MINTAB 7.0

Table IV.1 Customer Order Types, Average Daily Demand and Fitted Distribution

Location	Demand E($\overline{D}^{k}_{plt}$) (Pallet/ day) and Demand Type			Average Demand (Pal./day)	% Demand	Fitted Distribution
	Local	Retails	Wholesale			
LC-1	13	-	-	13	0.5 %	LogNormal
LC-2	18	21	43	82	2.86 %	Erlang
LC-3	15	13	40	69	2.40%	Weibull
LC-4	13	-	-	13	0.5 %	Possion
LC-5	16	19	74	109	4.07 %	Weibull
LC-6	20	12	29	61	1.82 %	Gamma
LC-7	18	25	36	78	2.58 %	Erlang
LC-8	37	94	178	309	11.97 %	Normal
LC-9	27	31	78	136	5.17 %	Normal
LC-10	17	27	76	121	4,53%	Normal
LC-11	20	-	-	20	0,75%	LogNormal
LC-12	22	24	60	106	3,93%	Normal
LC-13	25	16	34	75	2,75%	Normal
LC-14	14	28	74	115	4,35%	Erlang
LC-15	32	22	80	134	5,11%	Weibull
LC-16	7	-	-	7	0,28%	Beta
LC-17	31	16	51	98	3,58%	Erlang
LC-18	26	27	58	110	4,09%	Normal
LC-19	43	62	272	377	14,60%	Normal
LC-20	25	34	69	128	4,82%	Normal
LC-21	47	35	74	156	5,96%	Normal
LC-22	9	45	82	135	5,11%	Normal
LC-23	14	-	-	14	0,53%	Erlang
LC-24	21	35	147	203	7,77%	Beta

Table IV.2 The Number of Simulated Multi Products Allocated in Logistic Center Hubs (Before and After Direct Shipments Policy) and ABC Analysis

Logistic Center Hub ID	Number of Products		A Product Class %	B Product Class %	C Product Class %
	Without Direct Shipment	With Direct Shipment			
LC-1	88	88	23%	17%	60%
LC-2	138	106	21%	17%	62%
LC-3	137	108	20%	18%	63%
LC-4	86	86	23%	15%	62%
LC-5	142	113	19%	20%	61%
LC-6	124	104	23%	17%	60%
LC-7	132	110	18%	17%	65%
LC-8	194	134	12%	15%	72%
LC-9	175	114	22%	17%	62%
LC-10	160	109	19%	18%	64%
LC-11	82	82	18%	16%	66%
LC-12	139	110	16%	16%	68%
LC-13	139	110	24%	15%	61%
LC-14	166	109	23%	17%	60%
LC-15	175	107	23%	16%	61%
LC-16	81	81	30%	19%	52%
LC-17	164	113	21%	19%	60%
LC-18	152	115	16%	20%	64%
LC-19	186	112	13%	15%	73%
LC-20	147	104	14%	16%	69%
LC-21	172	125	21%	17%	62%
LC-22	171	107	23%	22%	56%
LC-23	92	92	28%	16%	55%
LC-24	190	109	19%	17%	64%
Total	**3432**	**2548**			

Table IV.3 Summarized Statistical Demand Data Based on Product Classification

Location	Products Class A					Products Class B					Products Class C				
	Avg.Daily Demand	Daily Standard Deviation	CV	Min Demand	Max Demand	Avg.Daily Demand	Daily Standard Deviation	CV	Min Demand	Max Demand	Avg.Daily Demand	Daily Standard Deviation	CV	Min Demand	Max Demand
LC-1	9,499	4,449	0,468	2,323	37,055	2,078	0,727	0,35	0,732	4,853	1,163	0,723	0,622	0,067	5,077
LC-2	44,202	22,304	0,505	3,455	127,496	8,911	3,973	0,446	0,525	28,281	5,534	4,154	0,751	0	40,131
LC-3	37,218	20,541	0,552	1,474	106,759	7,711	3,046	0,395	1,6	19,535	4,993	2,72	0,545	0,513	18,742
LC-4	9,912	2,688	0,271	0,078	17,858	1,937	0,721	0,372	0,368	4,797	1,333	0,838	0,629	0,068	4,849
LC-5	56,499	31,602	0,559	1	180,491	11,778	5,331	0,453	0,261	31,777	7,437	4,622	0,622	0,514	42,975
LC-6	30,981	15,777	0,509	9,491	90,019	6,258	2,484	0,397	0,485	19,978	3,98	2,276	0,572	0,015	18,356
LC-7	44,363	24,598	0,554	1,896	145,757	8,098	3,669	0,453	0,731	25,649	5,967	3,061	0,513	0,508	28,815
LC-8	177,508	77,13	0,435	1,813	471,617	36,129	18,931	0,524	0,031	118,7	22,937	14,015	0,611	0,293	110,516
LC-9	76,369	31,834	0,417	2,554	223,573	15,135	9,065	0,599	0,334	51,717	10,386	7,749	0,746	0,583	52,227
LC-10	64,038	30,937	0,483	1,575	178,659	13,46	6,485	0,482	1,083	40,328	8,685	5,824	0,671	0,804	41,836
LC-11	14,863	6,577	0,442	6,481	52,477	3,27	1,136	0,347	1,252	8,661	1,975	1,961	0,993	0,42	13,252
LC-12	62,973	29,487	0,468	0	179,056	13,942	5,21	0,374	5,17	41,068	8,51	5,149	0,605	1,775	30,656
LC-13	43,54	20,919	0,48	0,534	124,221	8,978	3,859	0,43	0,105	23,487	5,839	4,413	0,756	0,035	26,172
LC-14	57,149	30,885	0,54	0,818	221,305	12,424	6,95	0,559	0	52,805	7,932	4,928	0,621	0,7	35,151
LC-15	76,024	32,955	0,433	0,427	182,432	15,218	7,324	0,481	0,036	54,203	9,904	7,891	0,797	0,233	65,659
LC-16	5,607	2,069	0,369	1,032	18,652	1,12	0,447	0,399	0,088	3,645	0,72	0,509	0,707	0,039	5,27
LC-17	58,18	24,726	0,425	3,75	195,97	11,195	6,16	0,55	1,455	44,697	7,562	7,076	0,936	0,341	66,898
LC-18	68,118	35,854	0,526	0,229	213,806	12,622	4,759	0,377	0,125	26,688	8,836	5,563	0,629	0,059	29,617
LC-19	216,887	80,462	0,371	0	446,04	39,584	17,339	0,438	0	95,433	28,147	16,464	0,585	0	105,731
LC-20	76,705	36,022	0,47	0,616	264,922	16,6	8,028	0,484	0,016	57,298	10,173	6,162	0,606	0,094	41,319
LC-21	98,033	36,311	0,37	0,75	220,535	17,571	10,94	0,623	0,108	80,953	12,985	7,783	0,599	0,02	40,346
LC-22	75,584	31,512	0,417	0,375	195,639	15,163	8,734	0,576	0,168	57,129	9,993	8,358	0,836	0,031	85,018
LC-23	10,811	3,579	0,331	4,151	35,375	2,131	0,926	0,435	0,385	11,575	1,402	0,822	0,586	0,321	4,859
LC-24	114,21	48,775	0,427	4,639	328,144	21,689	12,015	0,554	1,661	74,711	14,638	9,88	0,675	0,767	56,814

Table IV.4 ABC-XYZ Product –Allocation Classification

Location	Class A			Class B			Class C		
	AX	AY	AZ	BX	BY	BZ	CX	CY	CZ
LC-1	10	9	1	4	9	0	7	40	8
LC-2	10	12	2	6	10	3	8	38	17
LC-3	11	11	4	10	4	3	9	41	15
LC-4	14	5	0	4	8	1	10	30	14
LC-5	14	16	0	5	10	5	8	37	18
LC-6	12	13	1	9	4	4	3	44	14
LC-7	9	10	2	8	9	1	10	40	21
LC-8	7	11	0	11	8	1	8	57	31
LC-9	9	13	2	6	8	4	3	45	24
LC-10	8	13	1	7	6	4	4	39	27
LC-11	9	5	1	5	5	2	6	33	16
LC-12	14	5	1	11	3	1	14	38	23
LC-13	17	10	0	7	6	2	4	45	19
LC-14	9	17	1	5	10	1	9	38	17
LC-15	4	24	1	0	12	4	3	30	29
LC-16	17	5	1	3	12	0	10	30	3
LC-17	15	11	0	7	6	5	9	44	16
LC-18	15	11	0	8	7	5	8	43	18
LC-19	8	7	0	10	6	2	8	49	22
LC-20	9	6	0	8	5	4	8	40	24
LC-21	20	3	1	5	10	4	8	46	28
LC-22	4	17	4	2	13	4	1	30	32
LC-23	13	9	3	7	5	2	8	33	12
LC-24	9	15	2	7	9	3	2	32	30

Table IV.5 Simulated $I^{k}_{All,t}$ and Safety Stock of Reference Model.

Location	$I^{k}_{All,t}$	$\sigma_{I^{k}_{All,t}}$	CV	Min $I^{k}_{All,t}$	Max $I^{k}_{All,t}$
LC-1	176	14	0,084	126	220
LC-2	365	37	0,101	279	467
LC-3	326	28	0,088	263	426
LC-4	187	17	0,091	135	243
LC-5	426	34	0,082	357	548
LC-6	404	36	0,089	334	517
LC-7	524	46	0,088	424	679
LC-8	1183	140	0,119	911	1769
LC-9	554	57	0,104	428	762
LC-10	444	44	0,101	350	578
LC-11	295	26	0,088	228	373
LC-12	509	49	0,098	413	665
LC-13	409	40	0,1	323	539
LC-14	503	48	0,097	350	696
LC-15	576	55	0,097	457	752
LC-16	132	9	0,071	105	164
LC-17	470	44	0,094	373	621
LC-18	533	54	0,102	417	731
LC-19	924	105	0,114	688	1252
LC-20	548	63	0,117	423	769
LC-21	777	83	0,107	631	1077
LC-22	923	82	0,089	788	1227
LC-23	195	15	0,078	159	247
LC-24	551	57	0,105	424	756
Total Supply Chain Safety Stock (Pallet/Day)				**9386**	**16078**

Appendix V: Thesis Main Design of Experiments

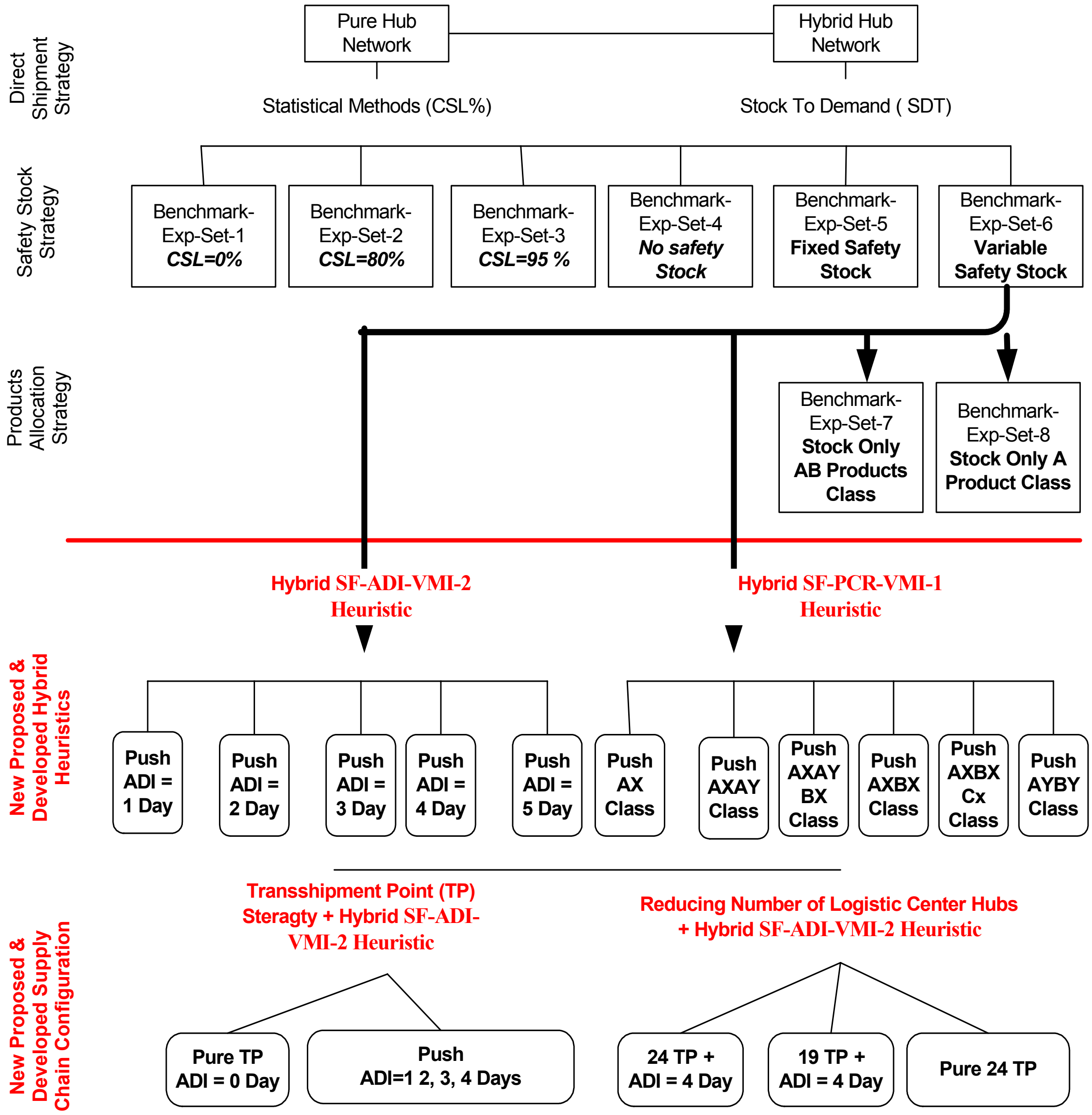


Figure V.1 Summary Proposed and Designed Simulation Experiments and Strategy

Appendix VI: Simulation Experiments Outputs

Part VI.1 Benchmark Experiments Output Results

Table VI.5 Benchmark Group-1 Simulated $I^{k}_{All,t}$ in Logistic Center Hubs

Location/ Model	B-Exp-set2	B-Exp-set3	B-Exp-set4	B-Exp-set5	B-Exp-set6
LC-1	153	167	138	148	176
LC-2	327	353	305	329	365
LC-3	295	311	274	292	326
LC-4	159	173	146	160	187
LC-5	369	395	345	368	426
LC-6	364	386	344	364	404
LC-7	447	494	402	443	524
LC-8	1149	1277	1028	1117	1183
LC-9	520	572	481	512	554
LC-10	409	444	368	392	444
LC-11	266	291	233	248	295
LC-12	443	473	414	443	509
LC-13	369	397	337	365	409
LC-14	421	449	397	426	503
LC-15	518	573	484	511	576
LC-16	119	127	111	118	132
LC-17	426	452	396	426	470
LC-18	483	514	440	479	533
LC-19	865	948	785	840	924
LC-20	493	529	463	495	548
LC-21	678	726	630	684	777
LC-22	670	710	615	695	923
LC-23	170	189	158	170	195
LC-24	500	537	470	495	551
Sum	10613	11487	9764	10520	11934
$\mu_{I^{k}_{All,t}}$	442	478	406	438	497
$\sigma_{I^{k}_{All,t}}$	231	255	208	227	252
cv	0,523	0,533	0,512	0,518	0,507

Table VI.6 Simulated $I_{All,t}^{k}$ and Safety Stock of Logistic Center Hubs with Spatial Postponement with (STO) Concept

	Benchmark Experiments Set 7						Benchmark Experiments Set 8					
Location	% Stoked Products	Avg.Ending Invnetory	Sdev Ending Invnetory	CV	Min Ending Invnetory	Max Ending Invnetory	% Stoked Products	Avg.Ending Invnetory	Sdev Ending Invnetory	CV	Min Ending Invnetory	Max Ending Invnetory
LC-1	40%	100	16	0,17	34	145	23%	92	16	0,18	20	133
LC-2	38%	255	31	0,12	165	333	21%	241	28	0,12	121	296
LC-3	38%	210	24	0,12	131	291	20%	199	24	0,12	97	263
LC-4	38%	98	17	0,18	35	147	23%	88	17	0,19	20	131
LC-5	39%	240	26	0,11	161	334	19%	222	25	0,11	118	300
LC-6	40%	213	27	0,13	139	296	23%	200	24	0,12	101	263
LC-7	35%	271	34	0,13	177	384	18%	252	32	0,13	133	347
LC-8	27%	953	106	0,11	644	1331	12%	759	92	0,12	425	1034
LC-9	39%	437	47	0,11	286	594	22%	348	40	0,12	166	454
LC-10	37%	317	35	0,11	187	407	19%	293	34	0,12	138	374
LC-11	34%	152	24	0,16	87	220	18%	140	23	0,17	69	201
LC-12	32%	287	39	0,14	186	396	16%	271	34	0,13	139	361
LC-13	39%	256	33	0,13	173	359	24%	233	30	0,13	129	314
LC-14	40%	268	35	0,13	119	397	23%	265	32	0,12	96	360
LC-15	39%	338	43	0,13	196	454	23%	305	39	0,13	146	409
LC-16	49%	80	10	0,14	39	113	30%	75	11	0,16	24	106
LC-17	40%	296	38	0,13	203	407	21%	268	35	0,13	149	359
LC-18	36%	359	42	0,12	241	498	16%	298	37	0,13	156	408
LC-19	28%	714	85	0,12	480	948	13%	545	70	0,13	301	727
LC-20	30%	377	47	0,13	241	521	14%	343	43	0,13	178	452
LC-21	38%	480	60	0,13	322	670	21%	412	55	0,14	238	584
LC-22	45%	378	40	0,11	214	494	23%	357	39	0,11	160	448
LC-23	44%	112	15	0,14	67	161	28%	102	14	0,14	49	149
LC-24	36%	369	44	0,12	191	519	19%	344	40	0,12	145	458
Total Supply Chain Safety Stock (Pallet/Day)					**4718**	**10419**	**Total Supply Chain Safety Stock (Pallet/Day)**				**3318**	**8931**
% Gap to Base Case					**-49,73%**	**-35,20%**	% Gap to Base Case				**-64,65%**	**-44,45%**

Table VI.7 Simulated Benchmark Group-1 $DLS-1$ % and $DLS-7$ % of Supply Chain Logistic Center Hubs

Location/ Model	DLS-1 %					DLS-7 %				
	B-Exp-set2	B-Exp-set3	B-Exp-set4	B-Exp-set5	B-Exp-set6	B-Exp-set2	B-Exp-set3	B-Exp-set4	B-Exp-set5	B-Exp-set6
LC-1	98,80%	99,40%	97,20%	98,80%	98,30%	78,60%	86,80%	65,30%	78,40%	73,60%
LC-2	94,90%	96,00%	92,90%	94,70%	94,80%	58,90%	63,90%	48,40%	57,30%	56,20%
LC-3	95,00%	95,90%	92,90%	94,80%	94,80%	55,20%	59,20%	46,10%	53,10%	51,20%
LC-4	98,00%	98,90%	96,40%	98,10%	97,90%	67,90%	76,50%	61,30%	68,50%	69,40%
LC-5	94,30%	95,30%	92,80%	94,40%	93,80%	45,40%	51,80%	39,00%	46,20%	42,50%
LC-6	97,60%	98,20%	96,30%	97,70%	97,60%	76,50%	82,60%	65,70%	77,10%	76,20%
LC-7	98,00%	98,50%	96,60%	98,00%	98,00%	74,20%	78,90%	65,00%	73,90%	74,70%
LC-8	93,30%	94,70%	90,90%	93,50%	94,80%	48,60%	55,80%	41,10%	49,60%	56,70%
LC-9	93,90%	95,20%	92,00%	93,70%	94,10%	51,50%	58,00%	42,10%	50,70%	50,90%
LC-10	94,50%	95,30%	92,50%	94,30%	94,50%	51,90%	55,60%	43,70%	50,90%	51,20%
LC-11	97,90%	98,70%	96,60%	97,90%	98,10%	64,90%	73,70%	57,50%	66,10%	67,40%
LC-12	97,00%	97,80%	95,80%	97,20%	97,30%	66,90%	73,30%	59,80%	67,80%	70,70%
LC-13	94,90%	95,80%	93,40%	94,90%	95,10%	59,30%	64,40%	51,80%	59,30%	59,10%
LC-14	95,10%	96,00%	93,60%	95,10%	94,90%	71,30%	76,10%	63,50%	71,20%	69,60%
LC-15	94,20%	95,50%	92,00%	94,00%	94,20%	56,00%	62,20%	45,40%	54,50%	55,00%
LC-16	98,60%	99,20%	97,10%	98,70%	98,20%	78,70%	85,90%	66,30%	78,70%	75,50%
LC-17	95,80%	96,60%	94,10%	95,80%	95,90%	57,90%	62,90%	47,90%	58,50%	56,80%
LC-18	97,30%	98,00%	96,10%	97,40%	97,50%	73,30%	79,30%	64,10%	74,40%	73,30%
LC-19	92,40%	93,70%	89,90%	92,70%	93,50%	47,70%	52,80%	39,90%	48,40%	51,10%
LC-20	95,20%	96,00%	93,40%	95,10%	95,60%	65,10%	70,50%	55,60%	64,20%	67,60%
LC-21	95,50%	96,50%	94,30%	95,70%	96,40%	61,00%	67,40%	52,60%	60,30%	65,30%
LC-22	94,50%	95,80%	92,20%	94,20%	94,60%	54,30%	60,60%	44,00%	53,50%	53,30%
LC-23	98,80%	99,30%	97,50%	98,80%	98,60%	73,70%	81,10%	62,40%	72,80%	72,60%
LC-24	91,60%	93,50%	89,30%	91,60%	92,30%	44,10%	51,10%	37,70%	43,60%	47,00%
μ_{DLS}	95,71%	96,66%	93,99%	95,71%	**95,87%**	61,79%	67,93%	52,76%	61,63%	**61,95%**
σ_{DLS}	2,05%	1,77%	2,39%	2,08%	**1,84%**	10,85%	11,25%	9,96%	11,03%	**10,39%**
Cv	0,021	0,018	0,025	0,022	**0,019**	0,176	0,166	0,189	0,179	**0,168**

Table VI.8 Benchmarks 7, 8 Simulated Logistic Center Hubs $DLS-1$ %, $DLS-7$ % Performance Measures

Model/ Location	**Ref-M**	**B-Exp-set-7**	**B-Exp-set-8**	**Ref-M**	**B-Exp-set-7**	**B-Exp-set-8**
	DLS-1	**DLS-1**	**DLS-1**	**DLS-7**	**DLS-7**	**DLS-7**
LC-1	98,30%	91,20%	79,90%	73,60%	40,00%	35,10%
LC-2	94,80%	86,90%	70,80%	56,20%	24,60%	9,60%
LC-3	94,80%	87,70%	74,80%	51,20%	26,70%	12,40%
LC-4	97,90%	91,00%	78,70%	69,40%	40,20%	34,80%
LC-5	93,80%	86,90%	76,00%	42,50%	20,90%	13,50%
LC-6	97,60%	91,00%	72,60%	76,20%	31,20%	11,70%
LC-7	98,00%	87,10%	63,60%	74,70%	22,70%	10,70%
LC-8	94,80%	76,80%	44,60%	56,70%	11,00%	4,70%
LC-9	94,10%	81,50%	60,60%	50,90%	16,50%	7,50%
LC-10	94,50%	83,80%	66,50%	51,20%	16,80%	6,80%
LC-11	98,10%	89,30%	72,40%	67,40%	38,70%	34,50%
LC-12	97,30%	88,30%	62,60%	70,70%	22,50%	8,40%
LC-13	95,10%	86,20%	67,90%	59,10%	21,40%	7,10%
LC-14	94,90%	88,80%	74,90%	69,60%	38,10%	10,40%
LC-15	94,20%	82,30%	66,10%	55,00%	16,00%	9,20%
LC-16	98,20%	94,30%	87,70%	75,50%	46,70%	38,00%
LC-17	95,90%	85,20%	69,20%	56,80%	16,80%	9,90%
LC-18	97,50%	87,60%	70,40%	73,30%	21,80%	8,10%
LC-19	93,50%	75,90%	47,00%	51,10%	12,00%	5,90%
LC-20	95,60%	82,30%	56,30%	67,60%	17,90%	7,80%
LC-21	96,40%	81,50%	58,70%	65,30%	12,80%	6,30%
LC-22	94,60%	84,50%	63,80%	53,30%	17,30%	6,90%
LC-23	98,60%	91,70%	80,30%	72,60%	40,70%	35,00%
LC-24	92,30%	83,20%	64,80%	47,00%	19,20%	6,50%
μ_{DLS}	95,87%	86,04%	67,93%	61,95%	24,69%	14,20%
σ_{DLS}	1,84%	4,57%	10,12%	10,39%	10,57%	11,36%
CV	0,02	0,05	0,15	0,17	0,43	0,8

Part VI.2 Proposed SF-PCR-VMI-1 and SF-ADI-VMI-2 Experiments Output Results

Table VI.9 Activity Based Costing % Gap according to SF-PCR-VMI-1 Model

Simulated Scenarios		AX	AXAY	AXAYBX	AXAYBXBY
Cost Description		Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network
Activity Based Costing Model	Order Cost	-2,61%	-2,61%	-2,62%	-2,63%
	P-CW Outgoing Cost	68,50%	56,60%	50,39%	40,78%
	LC-Hubs Outgoing Cost	0,47%	0,48%	0,48%	0,48%
	LC-Hubs Incoming Goods	99,20%	82,21%	73,29%	59,52%
	Handling Cost (Orderpicking)	0,20%	0,21%	0,21%	0,21%
Transportation Cost	Long Haul Transportation Cost	58,97%	48,05%	41,10%	29,95%
	Short Haul Transportation Cost	2,33%	2,34%	2,34%	2,33%
Inventory Model	Inventory Cost	1631,26%	1355,71%	1203,23%	971,06%
Supply Chain Service Level	Orderline Service Level (P1- DLS1)	3,39%	3,45%	3,46%	3,49%
	Delivery Service Level (P4- DLS7)	44,60%	45,71%	45,88%	46,64%
Total Supply Chain Model Cost		79,84%	66,05%	58,03%	45,56%

Simulated Scenarios		AXBX	AXBXCX	AY	AYBY
Cost Description		Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network
Activity Based Costing Model	Order Cost	-2,62%	-2,62%	-2,61%	-2,62%
	P-CW Outgoing Cost	62,70%	63,66%	67,07%	63,88%
	LC-Hubs Outgoing Cost	0,47%	0,47%	0,48%	0,48%
	LC-Hubs Incoming Goods	90,87%	92,25%	97,20%	92,67%
	Handling Cost (Orderpicking)	0,20%	0,20%	0,21%	0,21%
Transportation Cost	Long Haul Transportation Cost	53,10%	52,04%	59,63%	55,23%
	Short Haul Transportation Cost	2,33%	2,33%	2,34%	2,33%
Inventory Model	Inventory Cost	1490,50%	1509,08%	1610,93%	1534,26%
Supply Chain Service Level	Orderline Service Level (P1- DLS1)	3,41%	3,41%	3,44%	3,48%
	Delivery Service Level (P4- DLS7)	44,87%	44,91%	45,48%	46,18%
Total Supply Chain Model Cost		72,68%	72,82%	79,44%	74,99%

Table VI.10 Simulated Supply Chain Service Levels Based on SF-PCR-VMI-1 Strategy

Model	Base	AX	AXAY	AXAYBX	AXAYBXBY	AXBX	AXBXCX	AY	AYBY	Base	AX	AXAY	AXAYBX	AXAYBXBY	AXBX	AXBXCX	AY	AYBY
Location	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7
LC-1	98,30%	98,50%	98,50%	98,50%	98,50%	98,50%	98,50%	98,50%	98,50%	73,60%	78,40%	78,40%	78,40%	78,40%	78,40%	78,40%	78,40%	78,40%
LC-2	94,80%	95,40%	97,50%	97,60%	98,50%	95,60%	95,50%	96,90%	98,00%	56,20%	58,40%	69,00%	69,70%	78,70%	59,00%	58,90%	64,60%	73,30%
LC-3	94,80%	95,80%	98,00%	98,00%	98,30%	95,80%	95,80%	97,00%	97,30%	51,20%	56,10%	73,20%	72,90%	76,50%	56,30%	56,30%	64,40%	67,30%
LC-4	97,90%	97,90%	97,90%	97,90%	97,90%	97,90%	97,90%	97,90%	97,90%	69,40%	69,40%	69,40%	69,40%	69,40%	69,40%	69,40%	69,40%	69,40%
LC-5	93,80%	95,50%	97,90%	97,80%	98,50%	95,50%	95,50%	96,30%	97,10%	42,50%	50,80%	69,30%	69,00%	80,10%	50,80%	50,90%	55,20%	61,80%
LC-6	97,60%	98,10%	99,00%	99,10%	99,20%	98,20%	98,20%	98,60%	98,60%	76,20%	79,20%	87,40%	87,80%	88,90%	79,40%	79,40%	83,60%	83,90%
LC-7	98,00%	98,30%	99,00%	99,00%	99,10%	98,30%	98,30%	98,70%	98,90%	74,70%	76,60%	84,30%	83,90%	85,40%	76,40%	76,60%	81,10%	82,70%
LC-8	94,80%	95,90%	96,80%	97,20%	97,50%	96,60%	96,40%	96,10%	96,10%	56,70%	59,80%	67,40%	69,10%	72,00%	62,40%	62,10%	63,60%	63,70%
LC-9	94,10%	94,60%	96,90%	96,80%	97,00%	94,70%	94,70%	96,80%	96,70%	50,90%	52,10%	66,70%	65,20%	66,20%	52,20%	52,30%	65,90%	64,70%
LC-10	94,50%	95,00%	96,70%	97,40%	98,00%	95,70%	95,70%	96,20%	96,90%	51,20%	53,10%	61,70%	70,50%	77,50%	59,80%	59,80%	58,50%	63,80%
LC-11	98,10%	98,10%	98,10%	98,10%	98,10%	98,10%	98,10%	98,10%	98,10%	67,40%	67,40%	67,40%	67,40%	67,40%	67,40%	67,40%	67,40%	67,40%
LC-12	97,30%	98,30%	98,50%	98,70%	98,80%	98,40%	98,40%	97,70%	97,70%	70,70%	77,40%	81,50%	83,00%	83,30%	79,00%	79,50%	73,90%	73,90%
LC-13	95,10%	95,90%	97,30%	97,30%	97,60%	95,90%	95,90%	96,60%	97,10%	59,10%	62,40%	70,90%	70,90%	74,40%	62,50%	62,50%	66,00%	70,30%
LC-14	94,90%	95,40%	97,60%	97,60%	97,80%	95,50%	95,50%	97,10%	97,40%	69,60%	70,20%	80,10%	80,60%	81,50%	70,80%	70,80%	78,60%	78,90%
LC-15	94,20%	94,70%	96,90%	96,90%	97,20%	94,70%	94,70%	96,50%	96,70%	55,00%	57,50%	69,10%	69,10%	70,50%	57,50%	57,50%	64,30%	64,80%
LC-16	98,20%	98,20%	98,20%	98,20%	98,20%	98,20%	98,20%	98,20%	98,20%	75,50%	75,50%	75,50%	75,50%	75,50%	75,50%	75,50%	75,50%	75,50%
LC-17	95,90%	97,00%	97,80%	98,00%	98,30%	97,40%	97,40%	96,60%	96,90%	56,80%	65,50%	72,70%	73,90%	76,60%	67,40%	67,50%	60,80%	61,50%
LC-18	97,50%	98,00%	98,70%	98,70%	98,80%	98,00%	98,00%	98,40%	98,50%	73,30%	76,80%	83,30%	83,80%	84,30%	76,80%	77,00%	78,90%	79,70%
LC-19	93,50%	94,70%	95,90%	96,30%	97,20%	95,20%	95,30%	95,00%	95,80%	51,10%	54,70%	62,20%	64,60%	69,30%	56,90%	56,60%	58,70%	62,50%
LC-20	95,60%	96,40%	97,20%	97,20%	97,80%	96,50%	96,50%	96,50%	97,00%	67,60%	71,70%	76,50%	76,40%	79,00%	71,90%	72,10%	71,20%	73,40%
LC-21	96,40%	97,10%	97,30%	97,20%	97,60%	97,10%	97,10%	96,60%	97,10%	65,30%	69,60%	71,90%	71,40%	74,70%	69,80%	70,90%	66,50%	69,30%
LC-22	94,60%	95,10%	97,00%	97,10%	97,40%	95,30%	95,30%	96,70%	96,70%	53,30%	54,50%	66,10%	67,10%	68,70%	55,40%	55,40%	65,10%	64,90%
LC-23	98,60%	98,60%	98,60%	98,60%	98,60%	98,60%	98,60%	98,60%	98,60%	72,60%	72,60%	72,60%	72,60%	72,60%	72,60%	72,60%	72,60%	72,60%
LC-24	92,30%	92,40%	92,60%	92,90%	93,00%	92,70%	93,20%	92,50%	92,60%	47,00%	47,40%	47,90%	48,40%	48,40%	47,60%	49,30%	47,40%	47,50%
Average	95,87%	96,45%	97,50%	97,59%	97,87%	96,60%	96,61%	97,00%	97,27%	61,95%	64,88%	71,85%	72,53%	74,97%	65,63%	65,78%	67,98%	69,63%
Stdev	1,84%	1,66%	1,31%	1,24%	1,20%	1,58%	1,52%	1,38%	1,30%	10,39%	10,09%	8,52%	8,19%	8,23%	9,73%	9,69%	8,78%	8,20%
CV	0,019	0,017	0,013	0,013	0,012	0,016	0,016	0,014	0,013	0,168	0,156	0,119	0,113	0,110	0,148	0,147	0,129	0,118

Table VI.11 Supply Chain Performance Measures % Gap to B-Exp-set-6 with SF-ADI-VMI-2 Strategy

Simulated Scenarios		ADI =1Day	ADI =2Day	ADI =3Day	ADI =4Day	ADI =5Day
Cost Description		Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network
Activity Based Costing Model	Order Cost	-0,25%	-0,70%	-1,38%	-2,06%	-2,16%
	P-CW Outgoing Cost	-0,03%	-0,04%	-0,09%	-0,12%	-0,14%
	LC-Hubs Outgoing Cost	0,11%	0,18%	0,27%	0,41%	0,46%
	LC-Hubs Incoming Goods	0,02%	0,06%	0,09%	0,22%	0,22%
	Handling Cost (Orderpicking)	0,05%	0,07%	0,10%	0,19%	0,22%
Transportation Cost	Long Haul Trans. Cost	-1,37%	-1,77%	-2,12%	-2,62%	-3,53%
	Short Haul Trans.Cost	-0,02%	0,20%	1,12%	1,80%	1,91%
Inventory Model	Inventory Cost	-0,23%	-0,80%	-0,80%	-0,41%	1,89%
Supply Chain Service Level	N-DLS1%	0,12%	0,64%	1,36%	3,08%	3,31%
	N-DLS7%	1,80%	10,40%	21,42%	42,61%	46,32%
Total Supply Chain Model Cost		-0,62%	-0,74%	-0,58%	-0,54%	-0,84%

Table VI.12 Simulated Supply Chain Service Levels Based on SF-ADI-VMI-2 Strategy

ADI Model	**Base**	**1day**	**2day**	**3day**	**4day**	**5day**	**Base**	**1day**	**2day**	**3day**	**4day**	**5day**
Index	**DLS-1**	**DLS-1**	**DLS-1**	**DLS-1**	**DLS-1**	**DLS-1**	**DLS-7**	**DLS-7**	**DLS-7**	**DLS-7**	**DLS-7**	**DLS-7**
LC-1	**98,30%**	98,50%	98,60%	98,80%	99,50%	99,60%	**73,60%**	78,40%	79,90%	83,20%	94,20%	96,00%
LC-2	**94,80%**	95,10%	95,90%	96,80%	99,20%	99,80%	**56,20%**	57,90%	65,00%	72,10%	91,60%	97,30%
LC-3	**94,80%**	95,20%	96,60%	98,00%	99,70%	100,00%	**51,20%**	55,30%	69,80%	81,90%	96,60%	99,50%
LC-4	**97,90%**	97,90%	98,00%	98,40%	99,30%	99,60%	**69,40%**	69,80%	72,50%	80,10%	89,60%	96,20%
LC-5	**93,80%**	94,20%	95,30%	96,50%	99,10%	99,50%	**42,50%**	46,40%	57,80%	69,40%	91,70%	95,00%
LC-6	**97,60%**	97,60%	98,00%	98,30%	99,70%	99,90%	**76,20%**	76,20%	80,60%	85,70%	97,20%	99,20%
LC-7	**98,00%**	98,10%	98,30%	98,70%	99,70%	99,70%	**74,70%**	75,30%	79,80%	85,70%	95,70%	96,40%
LC-8	**94,80%**	94,90%	95,30%	95,90%	97,80%	97,90%	**56,70%**	57,10%	61,60%	69,00%	82,40%	81,00%
LC-9	**94,10%**	94,20%	94,60%	95,40%	97,70%	98,00%	**50,90%**	51,40%	55,20%	61,20%	75,80%	78,70%
LC-10	**94,50%**	94,60%	95,10%	96,50%	98,30%	98,60%	**51,20%**	52,70%	58,30%	70,00%	83,40%	84,40%
LC-11	**98,10%**	98,10%	98,40%	98,70%	99,50%	99,80%	**67,40%**	67,60%	72,20%	79,20%	90,70%	96,80%
LC-12	**97,30%**	97,30%	97,60%	97,90%	99,50%	99,60%	**70,70%**	71,10%	75,60%	79,40%	94,20%	96,00%
LC-13	**95,10%**	95,30%	96,10%	97,10%	99,10%	99,50%	**59,10%**	60,10%	69,00%	77,80%	93,60%	95,50%
LC-14	**94,90%**	95,00%	95,50%	95,90%	97,90%	98,40%	**69,60%**	70,20%	75,00%	78,90%	88,50%	90,40%
LC-15	**94,20%**	94,20%	94,90%	95,80%	98,30%	98,50%	**55,00%**	55,30%	61,80%	68,20%	84,00%	84,60%
LC-16	**98,20%**	98,30%	98,40%	98,70%	99,30%	99,40%	**75,50%**	76,00%	77,20%	80,80%	90,70%	95,30%
LC-17	**95,90%**	96,00%	96,70%	97,30%	99,20%	99,40%	**56,80%**	58,00%	66,00%	72,50%	90,60%	93,00%
LC-18	**97,50%**	97,50%	97,80%	98,30%	99,50%	99,60%	**73,30%**	73,70%	77,40%	82,60%	93,80%	96,10%
LC-19	**93,50%**	93,60%	94,10%	94,90%	97,30%	97,10%	**51,10%**	51,60%	56,20%	63,30%	74,90%	72,60%
LC-20	**95,60%**	95,80%	96,40%	97,40%	99,20%	99,50%	**67,60%**	68,40%	72,00%	79,10%	90,90%	94,10%
LC-21	**96,40%**	96,50%	96,90%	97,30%	98,80%	98,80%	**65,30%**	66,20%	70,10%	75,30%	86,60%	87,30%
LC-22	**94,60%**	94,70%	95,20%	96,30%	98,30%	98,40%	**53,30%**	54,10%	59,10%	69,00%	81,90%	83,60%
LC-23	**98,60%**	98,60%	98,70%	99,00%	99,80%	99,90%	**72,60%**	73,30%	75,80%	81,90%	93,50%	97,60%
LC-24	**92,30%**	92,40%	93,10%	94,10%	96,00%	96,40%	**47,00%**	47,60%	53,60%	59,10%	68,30%	69,00%
Average	95,87%	95,98%	96,48%	97,17%	98,82%	99,04%	61,95%	63,07%	68,40%	75,23%	88,35%	90,65%
Stdev	1,84%	1,79%	1,60%	1,37%	0,94%	0,95%	10,39%	10,11%	8,65%	7,67%	7,41%	8,55%
CV	0,019147	0,018657	0,016581	0,0140741	0,0095301	0,00956	0,167667	0,160326	0,1264054	0,101995	0,0838588	0,0943138

Table VI.13 Average Truck Filling Degree $E(\eta\%)$ with SF-ADI-VMI-2 at ADI= 2 and ADI=4 day

ADI = 2 Days				ADI = 4 Days			
LC-HUB/CW_Plants	**P-CW-1**	**P-CW-2**	**P-CW-3**	**LC-HUB/CW_Plants**	**P-CW-1**	**P-CW-2**	**P-CW-3**
LC-1	15,00%	6,50%	16,00%	**LC-1**	15,00%	7,25%	15,75%
LC-2	40,25%	12,00%	63,75%	**LC-2**	41,00%	12,25%	66,25%
LC-3	36,50%	12,25%	46,50%	**LC-3**	37,75%	12,25%	47,75%
LC-4	18,75%	6,00%	12,25%	**LC-4**	20,50%	6,50%	12,50%
LC-5	45,00%	17,25%	61,00%	**LC-5**	49,25%	18,00%	63,00%
LC-6	25,25%	14,75%	45,50%	**LC-6**	26,25%	15,25%	45,50%
LC-7	24,75%	17,75%	62,00%	**LC-7**	25,50%	18,00%	63,50%
LC-8	**84,75%**	50,50%	**84,00%**	**LC-8**	**90,00%**	54,25%	**90,50%**
LC-9	66,75%	38,25%	**83,75%**	**LC-9**	**72,00%**	38,75%	**88,25%**
LC-10	47,50%	24,50%	**81,75%**	**LC-10**	48,50%	24,75%	**85,25%**
LC-11	32,75%	9,25%	14,50%	**LC-11**	34,25%	9,50%	14,25%
LC-12	55,25%	24,00%	61,75%	**LC-12**	58,25%	24,00%	62,25%
LC-13	38,25%	34,50%	61,00%	**LC-13**	39,50%	35,75%	61,25%
LC-14	33,50%	35,75%	**86,00%**	**LC-14**	34,00%	38,50%	**87,00%**
LC-15	54,25%	63,50%	**83,25%**	**LC-15**	55,00%	68,00%	**87,75%**
LC-16	5,50%	4,50%	12,00%	**LC-16**	6,00%	4,75%	12,50%
LC-17	51,50%	25,50%	**70,75%**	**LC-17**	56,50%	25,25%	**70,75%**
LC-18	43,25%	22,50%	68,50%	**LC-18**	44,50%	22,75%	68,75%
LC-19	**87,25%**	68,75%	**91,00%**	**LC-19**	**91,75%**	**74,00%**	**96,50%**
LC-20	**76,75%**	19,25%	**79,25%**	**LC-20**	**78,75%**	19,50%	**79,75%**
LC-21	58,00%	32,25%	**87,00%**	**LC-21**	62,00%	32,25%	**91,75%**
LC-22	53,75%	27,25%	**86,50%**	**LC-22**	62,50%	27,25%	**92,25%**
LC-23	14,50%	8,00%	17,50%	**LC-23**	15,00%	8,25%	17,50%
LC-24	66,25%	55,25%	**91,75%**	**LC-24**	**74,50%**	54,00%	**96,50%**
$E(\eta\%)$	**44,80%**	**26,25%**	**61,14%**	$E(\eta\%)$	**47,43%**	**27,13%**	**63,21%**
$\sigma(\eta\%)$	21,96%	18,19%	27,64%	$\sigma(\eta\%)$	23,62%	19,25%	29,27%
$CV(\eta\%)$	0,49	0,69	0,45	$CV(\eta\%)$	0,5	0,71	0,46

Part VI.3 Proposed SF-ADI-VMI-2 and Transshipment Points Experiments Output Results

Table VI.14 Activity Based Costing % Gap of Transshipment Point with SF-ADI-VMI-2 Models

Simulated Scenerios		TP+ADI=1	TP+ADI=2	TP+ADI=3	TP+ADI=4
Cost Description		Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network	Hybrid Hubs Network
Activity Based Costing Model	Order Cost	-0,51%	-0,72%	-0,76%	-0,78%
	P-CW Outgoing Cost	-0,03%	-0,03%	-0,03%	-0,03%
	LC-Hubs Outgoing Cost	0,01%	0,06%	0,15%	0,19%
	LC-Hubs Incoming Goods	0,02%	0,13%	0,23%	0,27%
	Handling Cost (Orderpicking)	0,03%	0,07%	0,14%	0,16%
Transportation Cost	Long Haul Transportation Cost	-8,63%	-10,59%	-11,41%	-11,89%
	Short Haul Transportation Cost	-0,74%	-0,72%	-0,58%	-0,53%
Inventory Model	Inventory Cost	11,22%	31,02%	54,72%	78,94%
Supply Chain Service Level	N-DLS1%	33,50%	42,43%	46,33%	48,28%
	N-DLS7%	63,27%	89,64%	103,40%	111,65%
Total Supply Chain Model Cost		-4,12%	-4,87%	-5,03%	-5,07%

Table VI.15 Simulated Supply Chain Service Levels of Transshipment Point Models with SF-ADI-VMI-2 Strategy

Index	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-1	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7	DLS-7
LC-1	**98,30%**	76,00%	87,20%	90,90%	92,80%	94,50%	**73,60%**	50,00%	56,30%	63,90%	66,10%	68,00%
LC-2	**94,80%**	54,50%	74,20%	81,10%	84,70%	85,80%	**56,20%**	5,80%	18,80%	25,60%	30,50%	30,40%
LC-3	**94,80%**	62,40%	80,40%	85,20%	86,60%	89,40%	**51,20%**	7,80%	20,40%	34,90%	34,90%	43,50%
LC-4	**97,90%**	74,10%	86,50%	90,80%	93,10%	94,30%	**69,40%**	50,10%	61,50%	64,80%	67,30%	76,10%
LC-5	**93,80%**	58,60%	78,10%	83,20%	85,00%	85,80%	**42,50%**	6,70%	21,60%	27,20%	29,30%	29,90%
LC-6	**97,60%**	59,60%	78,30%	84,50%	87,60%	88,70%	**76,20%**	9,40%	32,80%	39,80%	42,80%	42,80%
LC-7	**98,00%**	61,50%	78,40%	82,60%	85,20%	86,80%	**74,70%**	7,60%	24,70%	26,50%	28,40%	31,20%
LC-8	**94,80%**	32,70%	53,50%	57,10%	58,50%	58,70%	**56,70%**	2,30%	4,70%	4,50%	4,60%	4,40%
LC-9	**94,10%**	44,10%	66,30%	71,00%	73,50%	74,40%	**50,90%**	5,20%	12,30%	14,00%	14,70%	15,00%
LC-10	**94,50%**	51,50%	71,50%	79,40%	80,50%	82,00%	**51,20%**	6,60%	16,80%	21,90%	23,90%	26,20%
LC-11	**98,10%**	67,40%	83,00%	88,30%	91,40%	92,70%	**67,40%**	50,00%	57,70%	61,70%	65,50%	61,40%
LC-12	**97,30%**	50,10%	72,30%	78,60%	81,60%	82,10%	**70,70%**	7,00%	18,20%	23,10%	28,60%	29,90%
LC-13	**95,10%**	49,10%	73,20%	81,70%	84,00%	85,40%	**59,10%**	7,40%	20,80%	28,90%	31,60%	32,70%
LC-14	**94,90%**	54,10%	73,20%	76,80%	80,40%	82,30%	**69,60%**	5,40%	14,60%	17,70%	20,20%	23,70%
LC-15	**94,20%**	45,00%	69,60%	76,10%	77,70%	78,50%	**55,00%**	7,50%	19,90%	20,60%	21,60%	22,60%
LC-16	**98,20%**	85,70%	91,80%	94,20%	95,50%	96,40%	**75,50%**	50,20%	54,70%	60,00%	66,80%	68,60%
LC-17	**95,90%**	50,50%	71,80%	78,00%	81,20%	82,10%	**56,80%**	8,40%	19,00%	22,70%	26,80%	27,60%
LC-18	**97,50%**	52,70%	73,50%	79,70%	81,50%	82,50%	**73,30%**	7,10%	14,40%	18,60%	21,50%	23,30%
LC-19	**93,50%**	38,50%	60,60%	63,20%	64,10%	64,50%	**51,10%**	4,00%	8,60%	8,40%	8,50%	8,60%
LC-20	**95,60%**	47,80%	69,30%	73,90%	76,40%	78,40%	**67,60%**	6,30%	13,30%	16,20%	16,60%	16,70%
LC-21	**96,40%**	36,70%	57,80%	60,80%	62,70%	63,10%	**65,30%**	5,10%	9,30%	9,20%	9,60%	9,70%
LC-22	**94,60%**	56,60%	72,40%	75,90%	76,10%	76,50%	**53,30%**	5,10%	13,10%	13,70%	13,60%	13,40%
LC-23	**98,60%**	74,20%	86,40%	90,70%	92,70%	93,90%	**72,60%**	50,00%	58,70%	63,80%	65,30%	64,50%
LC-24	**92,30%**	45,40%	64,60%	68,90%	71,60%	71,50%	**47,00%**	5,80%	13,20%	15,50%	15,50%	14,60%
Average	95,87%	55,37%	73,91%	78,86%	81,02%	82,10%	61,95%	15,45%	25,23%	29,30%	31,43%	32,70%
Stdev	1,84%	13,13%	9,43%	9,61%	9,78%	10,14%	10,39%	18,19%	18,00%	19,30%	20,22%	20,87%
CV	0,02	0,24	0,13	0,12	0,12	0,12	0,17	1,18	0,71	0,66	0,64	0,64

Table VI.16 Average Truck Filling Degree $E(\eta\%)$ of Transshipment Point's Experiments

	Pure TP without SF-ADI-VMI-2			TP with SF-ADI-VMI-2 at ADI= 2 day			TP with SF-ADI-VMI-2 at ADI= 4 day		
LC-HUB/CW_Plants	**P-CW-1**	**P-CW-2**	**P-CW-3**	**P-CW-1**	**P-CW-2**	**P-CW-3**	**P-CW-1**	**P-CW-2**	**P-CW-3**
LC-1	12,50%	6,00%	15,00%	35,75%	15,50%	43,25%	57,00%	24,75%	67,25%
LC-2	42,50%	10,75%	58,75%	**85,00%**	31,25%	**94,75%**	**94,00%**	50,25%	**97,50%**
LC-3	36,25%	11,00%	45,75%	**78,00%**	31,00%	**85,25%**	**87,75%**	51,00%	**92,75%**
LC-4	16,75%	5,75%	11,75%	48,75%	15,75%	34,25%	**75,25%**	24,75%	55,00%
LC-5	48,25%	15,50%	57,00%	**88,75%**	44,75%	**92,25%**	**94,25%**	66,50%	**96,25%**
LC-6	25,00%	13,50%	46,75%	69,25%	39,50%	**88,00%**	**82,00%**	62,75%	**91,50%**
LC-7	23,50%	15,75%	65,25%	66,50%	45,75%	**96,25%**	**79,25%**	**72,00%**	**98,25%**
LC-8	**83,25%**	46,50%	**72,50%**	**99,75%**	**90,00%**	**99,25%**	**100,00%**	**95,25%**	**100,00%**
LC-9	**70,25%**	33,25%	69,75%	**98,75%**	**75,25%**	**98,25%**	**99,50%**	**88,75%**	**99,75%**
LC-10	52,25%	21,50%	66,75%	**88,50%**	59,00%	**97,25%**	**94,75%**	**78,25%**	**99,25%**
LC-11	29,00%	8,00%	13,25%	**73,50%**	23,00%	38,75%	**85,75%**	37,25%	62,75%
LC-12	59,75%	21,50%	57,75%	**94,75%**	60,00%	**92,00%**	**98,00%**	**80,50%**	**96,50%**
LC-13	39,00%	30,50%	58,25%	**84,25%**	**76,25%**	**93,00%**	**89,50%**	**90,50%**	**97,50%**
LC-14	32,25%	31,50%	69,75%	**77,75%**	**75,25%**	**98,25%**	**86,00%**	**90,00%**	**99,75%**
LC-15	52,75%	50,50%	67,75%	**89,75%**	**90,50%**	**98,75%**	**96,50%**	**96,00%**	**99,75%**
LC-16	5,50%	4,50%	11,00%	14,50%	10,75%	31,75%	23,25%	17,50%	49,75%
LC-17	60,50%	21,00%	64,00%	**93,50%**	59,75%	**95,75%**	**97,50%**	**78,75%**	**97,75%**
LC-18	46,25%	20,50%	68,00%	**88,00%**	58,50%	**98,50%**	**94,25%**	**81,75%**	**99,25%**
LC-19	**81,50%**	57,50%	**72,00%**	**99,75%**	**94,25%**	**99,50%**	**100,00%**	**98,25%**	**100,00%**
LC-20	**70,75%**	16,25%	65,25%	**99,25%**	46,75%	**96,25%**	**99,75%**	**71,25%**	**98,50%**
LC-21	68,25%	29,25%	**75,75%**	**97,00%**	**80,00%**	**99,50%**	**99,00%**	**84,75%**	**100,00%**
LC-22	57,50%	24,00%	**72,50%**	**92,25%**	65,00%	**99,50%**	**97,25%**	**81,75%**	**99,75%**
LC-23	12,50%	7,25%	17,25%	35,75%	20,50%	49,00%	57,75%	32,75%	**75,75%**
LC-24	67,00%	41,00%	**72,75%**	**97,75%**	**110,50%**	**99,25%**	**99,75%**	**125,00%**	**99,75%**
$E(\eta\%)$	45,54%	22,61%	53,94%	**79,03%**	54,95%	**84,10%**	**87,00%**	**70,01%**	**90,59%**
$\sigma(\eta\%)$	22,58%	14,81%	22,44%	23,33%	28,05%	23,88%	18,25%	27,34%	15,67%
$CV(\eta\%)$	0,5	0,66	0,42	0,3	0,51	0,28	0,21	0,39	0,17

Table VI.17 Simulated Supply Chain Service Levels of Sub Transshipment Point's Model with SF-ADI-VMI-2 Strategy

Model/Location	DLS-1%				DLS-7%			
	19 LCH-Hybrid_ADI=2_CLCH DC	19 LCH-Hybrid_ADI=2_CLCH Cross Docking	TP_Hybrid_ADI=2	TP_Pull	19 LCH-Hybrid_ADI=2_CLCH DC	19 LCH-Hybrid_ADI=2_CLCH Cross Docking	TP_Hybrid_ADI=2	TP_Pull
LC-1			0,981	0,997			0,708	0,988
LC-2	0,999	0,999	0,962	0,998	0,982	0,982	0,644	0,981
LC-3	0,997	0,997	0,953	0,999	0,997	0,997	0,561	0,993
LC-4			0,976	0,998			0,663	0,992
LC-5	0,997	0,997	0,942	0,997	0,978	0,978	0,471	0,976
LC-6	0,984	0,994	0,972	1	0,774	0,907	0,682	0,997
LC-7	0,999	0,999	0,973	0,998	0,98	0,98	0,667	0,979
LC-8	0,966	0,966	0,915	0,96	0,685	0,685	0,416	0,642
LC-9	0,98	0,98	0,92	0,978	0,79	0,79	0,42	0,777
LC-10	0,989	0,989	0,94	0,988	0,897	0,896	0,552	0,889
LC-11			0,972	1			0,64	0,996
LC-12	0,998	0,998	0,958	0,997	0,98	0,98	0,567	0,973
LC-13	0,998	0,998	0,949	0,997	0,982	0,982	0,552	0,979
LC-14	0,981	0,987	0,948	0,987	0,855	0,891	0,651	0,889
LC-15	0,984	0,984	0,92	0,983	0,844	0,844	0,469	0,84
LC-16			0,987	0,996			0,758	0,972
LC-17	0,98	0,992	0,953	0,996	0,701	0,894	0,519	0,962
LC-18	0,997	0,997	0,969	0,996	0,96	0,96	0,671	0,96
LC-19	0,964	0,964	0,915	0,958	0,7	0,7	0,466	0,663
LC-20	0,959	0,987	0,953	0,991	0,625	0,844	0,635	0,9
LC-21	0,985	0,985	0,942	0,981	0,824	0,824	0,487	0,789
LC-22	0,982	0,982	0,939	0,98	0,817	0,817	0,538	0,808
LC-23			0,98	0,999			0,68	0,992
LC-24	0,943	0,966	0,913	0,966	0,563	0,704	0,443	0,724
Average	98,33%	98,74%	95,13%	98,92%	83,86%	87,66%	57,75%	90,25%
Stdev	1,57%	1,16%	2,28%	1,27%	13,63%	10,30%	10,03%	11,19%
CV	0,02	0,01	0,02	0,01	0,16	0,12	0,17	0,12

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