DESIGNING THE SUPPLY CHAIN NETWORK THROUGH REGIONAL COORDINATION IN CONSIDERATION OF SUPPLY HUBS

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ABSTRACT

DESIGNING THE SUPPLY CHAIN NETWORK THROUGH REGIONAL COORDINATION IN CONSIDERATION OF SUPPLY HUBS

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Due to emerging global market conditions, expanding the operations through the international arena is an inevitable, but also a challenging task for most companies. Accordingly, establishing the right business model where cost of the operations is optimized has become a key concept for competitiveness. The process needs to be carried out without losing efficiency and effectiveness of the supply chain as a whole. This necessitates the continuous consideration and reevaluation of all parties' interactivities. The objective of this research is to define the traditional business procurement model of multinational companies and to develop an alternative business model for their regional operations which considers consolidation of

shipments in supply hubs and distribution to regional manufacturers. The analysis is carried out for multiple suppliers providing multiple products to regionally dispersed, multiple manufacturers. The products considered are high volume, high unit priced with deterministic demand and long lead times. We follow an approach that implements mathematical models and analytical methods to define the current operation and compare it with an alternative model which includes supply hubs. Specifically, we make a detailed analysis of cost structure and cost components for all parties, induced by several operating policies. Further analysis outlines the conditions for benefiting all parties involved in the alternative model. A detailed numerical implementation and parametric analysis of the model is presented for a real industry case, including the conditions for benefiting all parties.

Keywords: Supply Chain Network Design, Inventory Management, Supply Chain Coordination, Supply Hub

ÖZET

BÖLGESEL KOORDİNASYON İLE TEDARİK MERKEZLERİ

ÜZERİNDEN TEDARİK ZİNCİRİ AĞ TASARIMI

Göçer, Aysu

Lojistik Yönetimi Yüksek Lisansı, Lojistik Yönetimi Bölümü

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Ortaya çıkan küresel pazar şartları sebebiyle, bir çok şirket için, operasyonların uluslarasası sahaya doğru genişletilmesi kaçınılmaz, fakat aynı zamanda da zorlu bir konu olmaktadır. Dolayısıyla, operasyon maliyetlerinin eniyilendiği doğru iş modelinin kurulması, üstünlük için anahtar kavram haline gelmektedir. Bu sürecin, tüm tedarik zincirinin verimliliğini ve etkinliğini kaybetmeden, sürdürülmesi gerekmektedir. Bu, tüm partilerin etkileşimlerinin sürekli olarak göz önünde tutulmasını ve yeniden değerlendirilmesini gerektirmektedir. Bu tezin amacı, uluslarası şirketlerin geleneksel satın alma iş modellerini tanımlamak ve bu şirketlerin bölgesel operasyonlarının, tedarik merkezleri üzerinden yapılan konsolide edilmiş sevkiyatların bölgesel üreticilere dağıtılması temelinde kurgulanabilecek alternatif bir iş modeli geliştirmektir. Analiz, bölgede faaliyet gösteren birden fazla üreticiye birden fazla ürün sağlayan tedarikçiler modeli üzerinden yürütülmektedir. Yüksek alım hacimli, yüksek birim fiyatlı, uzun tedarik sürelerine sahip, ortak kullanımı ve belirgin talebi olan malzemeler kapsam içinde değerlendirilmektedir. Mevcut operasyonların tanımlanmasında ve tedarik dağıtım merkezleri içeren alternatif modelle karşılaştırılmasında, matematiksel modellerin ve analitik metodların uygulandığı bir yaklaşım izlenmektedir. Tedarik zincirinde yer alan firmaların çeşitli işletme politikaları sonucunda ortaya çıkan oluşan maliyet yapıları ve maliyet kalemleri üzerine detaylı bir analiz yapılmaktadır. Sonraki analizlerde tedarik zinciri mensuplarının alternatif model kapsamındaki fayda sağlama şartları özetlenmektedir. Modelin gerçek bir vaka üzerinden detaylı sayısal uygulaması ve parametrik analizi, her firmanın fayda sağladığı şartlar belirtilenerek sunulmaktadır.

Anahtar Kelimeler: Tedarik Zinciri Ağ Tasarımı, Envanter Yönetimi, Tedarik Zinciri Koordinasyonu, Tedarik Merkezi

To My Family

I would like to dedicate this thesis to my husband Besim Göçer and daughter Elif Göçer, for their love, patience, and understanding; they allowed me to spend many times on this thesis. Besides, I would like to express special thanks to my beloved husband Besim for his continuous support, for being always with me and encouraging me at every step of my study.

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CHAPTER I

INTRODUCTION

Today's global competitive marketplace forces companies to go beyond their boundaries and expand their operations worldwide. Companies search for opportunities all around the world to implement the most efficient business models as well as to sell their products in a broader market, in order to ensure long term presence.

As the platform of operations expands, coordinative approaches through the whole supply chain starts to be a key for competitiveness. Having realized this key concept, companies have already started to investigate ways for increasing the efficiency not only of their own operations individually, but also with the parties involved in their supply chain in an integrated approach.

The evolution of the supply chain concept relies on the era when materials flow (Forrester, 1961) issues are first addressed. As Christopher (1992) underlines, the real competition is experienced among supply chains instead of individual companies. Therefore, it is important to view supply chain management first as; "*the integration of key business processes from end user through original suppliers that provides products, services and information that add value for customers and other stakeholders*" (Lambert and Cooper, 2000, pp. 66). The idea of integration clearly necessitates multiple organizations and functions to align and operate together for running the supply chain efficiently.

Global operations bring companies opportunities for competitive advantage, thus sustainability. In return, they also require efficient management of the supply chains on long distanced operations to cope with higher costs incurred through worldwide businesses. This motivates the interest and efforts on supply chain network design through coordination, which needs to be performed according to the best appropriate operational setting for all the partners. The overall aim of this redesign is to ensure a more efficient and effective management of the supply chain and to reduce costs.

Supply chain network design then becomes a significant key focal consideration, especially for multinational companies, which already have an international structure involving multiple decision points and operation centers worldwide. With the traditional setup, long lead times and decentralized structure undermines the efficiency and effectiveness of the whole supply chain. Information through the chain becomes weak and unclear as the sizes of operations grow. Thus, the synchronization among chain members is very low (Childerhouse and Towill, 2000).

Therefore, the efficiency of traditional structures is recently questioned by both academicians and practitioners. This is now an open topic to continuous improvement for achieving long term success. Especially, in the cases, where cost reduction efforts with traditional process designs do not pay off as desired, redesigning the supply chain network can be a viable alternative in the path to increase efficiency through the whole chain and thus to reduce costs.

The concept of supply chain supports optimization at all levels by ensuring an appropriate integration (Erengüç et al., 1999, Simchi-Levi et al., 2000; Goetschalckx et al, 2002). Therefore, the motivation to improve supply chain network design also establishes the ground for coordinative initiatives among the supply chain partners. As Lee (2000) describes, supply chain coordination is a tool for redesigning decision rights, workflow, and resources among chain members for improving the performance.

Many practices of the coordination in the supply chain are achieved through buyer-supplier process integration, which is an important aspect for reaching a more cost-effective satisfaction of end customer requirements (Christopher, 1992). Operational models in supply chain coordination are further classified by Thomas and Griffin (1996) as buyer–vendor coordination, production–distribution coordination, and inventory–distribution coordination. Many facility location problems can also be viewed as part of supply chain network design, and they support the efficiency of a supply chain on tactical and operational levels.

Another emerging trend towards coordination in supply chains is through the transfer of the decision making power in inventory management, from manufacturers to vendors (or suppliers) gradually. Control and management of inventory is incurred by the manufacturers in manufacturer owned systems. The earlier concept of manufacturer owned inventory system in this field, now is being replaced by the vendor managed inventory system (Shah and Goh, 2006).

Vendor managed inventory systems prove better performance when implemented with supply hub concept. This is especially true for industries that are time sensitive, and have long distanced supply chains. A supply hub is defined as a location sited very near a manufacturer's facility where all or some of its supplies are warehoused with the agreement that the materials will be invoiced for only when consumed (Zuckerman, 2000) and are mostly operated with a 3rd party logistics provider. Operating globally through supply hubs demonstrate benefits for businesses which include vendor managed inventory systems, as well as for traditional inventory sourcing and for consignment inventory. Accordingly, using supply hubs pay off further by eased agility and flexibility.

Considering the significance of the challenges induced by the global necessities of today's business environment, this thesis is mainly built by the motivation of questioning the process, potential impacts and benefits of alternative coordinative supply chain design models through the use of supply hubs. Through the thesis, we also question and quantify the effects of these approaches on the supply chain performance.

The underlying supply chain structure involves a regionally managed multinational company. One specific region is within the thesis scope, having multiple manufacturers, multiple vendors. The products of the region are characterized by high volumes, high unit prices and long lead times. We assume that the demand is deterministic and constant. This assumption is justified by the commonality of the material. Evidence from real life multinational companies suggests that, the decentralized structures of the traditional business models need to keep high inventories for common materials supplied from long lead time vendors. Coupled with the fact that these materials are among the most expensive ones, there is a huge amount of cash bound to inventories, over the whole lead time. This then leads to poor cash flow management, affects the efficiency and effectiveness of the companies' operations and thus weakens their competitiveness. To this end, this thesis research aims to demonstrate alternative business models that allow better cash flow management for such companies as well as better inventory management opportunities.

1.1. Objective of the Thesis

The objective of the thesis is to provide a decision support tool that can be implemented by multinational companies to evaluate the performance of redesign alternatives in the regional supply chain network with the introduction of supply hubs.

The research basically looks for the answers of the following questions;

- How can the supply chain network design of a company operating in a global scale be designed with the introduction of supply hubs?
- What are the conditions under which all parties in the supply chain benefit through the alternative business model?
- What is the optimum number of supply hubs to be opened for the supply chain of the multinational company?
- Where should the supply hubs be located?
- In which costs can a company expect benefits from switching to collaborative operations management through supply hubs?

The thesis puts a specific emphasis on physical distribution of products throughout the supply chain channels and provides different insights to develop strategies for improving the channel distribution and service levels at downstream activities.

The thesis contributes to the literature in a number of ways. The originality of the thesis comes from the fact that the research problem is inspired from a real industry case. The company for which the idea of the study is originated is a leading multinational company which makes the modeling extremely critical. We should note that, the problems considered in the thesis are not specific to the company. The concepts and problems related with the global business environment are among the contemporary subjects that draw the attention of both researchers and practitioners.

The research develops a novel viewpoint on the cost structures and cost items within the supply chain, that are not extensively considered in previous studies; such as transportation costs of full and less than truck loads, handling costs, customs and agencies costs.

The thesis is organized as follows. Chapter 2 reviews literature on main components of the research topic. Chapter 3 includes the definition, modeling and analysis of the traditional setting including optimization of decision variables. In chapter 4, the analysis of the alternative model is presented in detail; the hub location problem is solved in this chapter as well. The chapter ends with a comparison of the alternative model with the traditional model. Chapter 5 is based on a real industry case. In that chapter, we summarize the case specifity and implement the developed model and perform numeric and parametric analyses. Finally, we present our conclusions and directions for further research in Chapter 6.

1.2. Methodology

In this thesis, we develop an insight to supply chain network design. We identify the decisions, costs, and responsibilities over the supply chain through an analytical approach that questions each of these. Even though the research problem refers to a strategic decision in scope, the concepts enabling the strategic framework have important components at operational levels. Therefore, the methodology followed in the thesis study is mainly structured on a strategic approach which necessitates the support of operational approaches to allow proper decisions to be made. For this, we utilize a repeated change of views from strategic to operational.

We develop a theoretical approach for the research problem. This approach involves system optimization over mathematical modeling. Having reviewed the main issues hindering the effective progress of the current system, a strategic viewpoint is generated on the supply network of multinational companies operating globally. The traditional network design is outlined in details, and by considering the main plague spots, an alternative network design is established. Both designs are optimized and evaluated in terms of total costs and in terms of cash flow management. This methodology of approaching the problem may be outlined as improving the business system through cost minimization.

Having defined the process frameworks of the business models and identified the costs, decisions and responsibilities, an operational approach is followed to extend the research on the theoretical models for being adoptable to practical implementations. Within this framework, the outlined business models are represented through quantitative methods on related costs and constraints associated on all sides in the supply chain. Mathematical models and analytical methods are also used as a supportive tool in presenting the conditions benefiting the sides.

The methodology we utilize in this thesis is mainly based on mathematical models and analytical methods. We use optimization methods in identifying the optimal values of operational and strategic variables such as production and dispatch lot sizes, frequency of shipments, production plans, site locations, optimal number of hub warehouses.

We first model and quantify the processes for the traditional and alternative business models. This is followed by a thorough analysis of the decision variables and cost structures of each party through mathematical modeling. Before completing this line of the research, we identify candidate locations for placing supply hub from all over the world. Among alternatives, we do this through a research over the busiest ports with highest transportation volumes.

This is followed by the use of optimization methodology and software in order to identify the optimal number and corresponding locations of supply hubs.

Thereafter, we complete the analysis on the business structure by reflecting the effect of the hub location decision on the analytical model. In doing so, we derive the feasibility conditions for both traditional and alternative business structures.

In the final chapter, we follow the methodology of quantitative analysis that is carried out based on a real industry case. This provides a model validation of the developed structure as well.

To allow the development of analytical models and mathematical formulations, we develop specific notations for each parameter, cost item and variable. We first formulate the costs for each party. Decomposition on the total costs is identified. The decomposition allows us to work on smaller sized problems and integrate these to suggest a solution to the overall problems. We also discuss and develop a viewpoint for safety stock decisions for the alternative business model.

Based on the decision making powers of the specified variables, the optimality formulas for each variable are outlined through taking the derivatives analysis. Interrelations among the decision variables and effects of parametric variations are outlined through numeric analysis. During this analysis, some feasibility conditions are outlined as well. Simultaneously benefiting conditions for each individual party and the whole chain is determined.

While working on the alternative business model, optimization methods are used to identify the optimal number and location of the hub warehouses. For this purpose, a mixed integer programming problem is modeled and solved using GAMS optimization software.

After formulating the two business models mathematically and outlining the total cost formula, a comparison analysis is carried out to show the basic differences between the two models.

A viewpoint on cash flow management is presented to highlight the importance of free cash on top of cost minimization purposes. Besides, a method for calculating the markup rate to better off the suppliers in common is also developed.

The decision tool that we develop for reassessing the current business model of a multinational company and for analyzing if an alternative business model can better of the supply chain in common is further tested numerically on the business model of a leading multinational tobacco company. The data necessary for running the model is provided by the company. A verification process is carried out prior to use of the data for the research that also serves the confidentiality concerns of the company.

The numeric study is followed by parametric analysis to assess the robustness of the findings. This is done through observing the effect of variations in parameters or cost items. Thus, the decisions suggested by the decision support tool developed in the thesis study, is further supported by numeric analysis. Finally, we present a methodology to calculate markup rate numerically.

1.3. Notations

Next, we give a list of notations that is used throughout the rest of the thesis. The notation is presented for a single product and for a single setting. When necessary for the analysis, we will employ additional indices to differentiate between materials and various scenario settings (e.g. traditional system vs. model with supply hub)

$\boldsymbol{D}$	total demand of manufacturer per forecast period
$\boldsymbol{d_s}$	demand of supplier per unit time
$\boldsymbol{d_{m_j}}$	demand of manufacturer *j* per unit time
$\boldsymbol{T}$	forecast period of manufacturer
$\boldsymbol{t_p}$	time required for production at supplier
$\boldsymbol{t_d}$	time between each dispatch from supplier to supply hub
$\boldsymbol{t_s}$	time between production runs at supplier
$\boldsymbol{t_{m_j}}$	time between shipments to manufacturer *j* and time between orders from manufacturer *j*
$\boldsymbol{Q_p}$	total production quantity at supplier
$\boldsymbol{Q_d}$	dispatch quantity per shipment from supplier
$\boldsymbol{Q_{m_j}}$	order quantity from manufacturer *j* and shipment quantity to manufacturer *j*
$\boldsymbol{s_s}$	safety stock level at supplier
$\boldsymbol{s_h}$	safety stock level at supply hub
$\boldsymbol{s_{m_j}}$	safety stock level at manufacturer *j*
$\boldsymbol{r_p}$	production rate at supplier

$\boldsymbol{TL}$ truck capacity in units per truck

$\boldsymbol{M_s}$ rate of markup for suppliers

$\boldsymbol{p_s}$ cost per unit produced at supplier

$\boldsymbol{K_p}$ fixed cost of production at supplier per production run

$\boldsymbol{K_{s_a}}$ fixed cost of transportation from supplier per shipment

$\boldsymbol{K_{h_a}}$ fixed cost of transportation from supply hub per shipment

$\boldsymbol{K_{h_g}}$ fixed cost of customs and agencies per dispatch received by supply hub from supplier

$\boldsymbol{K_{m_{jg}}}$ fixed cost of customs and agencies per shipment received by manufacturer *j*

$\boldsymbol{a_{s_f}}$ transportation cost per full truck load from supplier

$\boldsymbol{a_{h_f}}$ transportation cost per full truck load from supply hub to manufacturer

$\boldsymbol{a_{s_l}}$ transportation cost per less than truck load from supplier

$\boldsymbol{a_{h_l}}$ transportation cost per less than truck load from supply hub to manufacturer

$\boldsymbol{b_s}$ inventory holding cost at supplier per unit per unit time

$\boldsymbol{b_h}$ inventory holding cost at supply hub per unit per unit time

$\boldsymbol{b_{m_j}}$ inventory holding cost at manufacturer *j* per unit per unit time

$\boldsymbol{u_s}$ opportunity cost of supplier for tying up money to inventory per unit per unit time

$\boldsymbol{u_{m_j}}$ opportunity cost of manufacturer for tying up money to inventory per unit per unit time

$\boldsymbol{o_{m_j}}$ fixed cost of issuing an order by manufacturer *j*

$\boldsymbol{c_{m_j}}$ unit cost of a product for manufacturer *j*

$\boldsymbol{g_{h_1}}$ cost of customs and agencies per truck received by supply hub

$\boldsymbol{g_{m_{j1}}}$ cost of customs and agencies per truck received by manufacturer

$\boldsymbol{g_{h_2}}$ cost of customs and agencies per unit received by supply hub

$\boldsymbol{g_{m_{j2}}}$ cost of customs and agencies per unit received by manufacturer *j*

$\boldsymbol{r_h}$ receiving (handling) cost per unit received by supply hub

$\boldsymbol{r_{m_j}}$ receiving (handling) cost per unit received by manufacturer *j*

$\boldsymbol{B_s}$ total inventory holding cost at supplier per unit time

$\boldsymbol{U_s}$ total opportunity cost of inventory for supplier per unit time

$\boldsymbol{U_{m_j}}$ total opportunity cost of inventory for manufacturer per unit time

$\boldsymbol{Z_s}$ fixed cost of renting and operating supply hub per unit time

$\boldsymbol{O_{m_j}}$ total cost per order issued at manufacturer *j* per unit time composed of o_{mj} and c_{mj}

$\boldsymbol{G_h}$ total customs and agencies cost at supply hub per unit time composed of K_{hg}, g_{h1} and g_{h2}

$\boldsymbol{G_{m_j}}$ total of customs and agencies costs at manufacturer *j* per unit time composed of K_{mjg}, g_{mj1} and g_{mj2}

$\boldsymbol{R_h}$ total receiving costs at supply hub per unit time

$\boldsymbol{R_{m_j}}$ total receiving cost at manufacturer per unit time

$\boldsymbol{P_s}$ total costs related to production at supplier per unit time composed of K_p and p_s

$\boldsymbol{A_{m_j}}$ total costs of transportation at manufacturer *j* per unit time composed of K_{sa}, a_{sf} and a_{sl}

$\boldsymbol{A_h}$ total costs of transportation at supply hub per unit time composed of K_{ha}, a_{hf} and a_{hl}

$\boldsymbol{I_s}$ total costs related to carrying inventory at suppliers per unit time composed of B_s and U_s

$\boldsymbol{I_h}$ total inventory carrying costs at supply hub per unit time

$\boldsymbol{I_{m_j}}$ total costs related to carrying inventory at manufacturer *j* per unit time composed of B_{mj} and U_{mj}

$\boldsymbol{t_c}$ time interval at the end of which, out cycles to all manufacturer's repeat themselves; least common multiple of t_{mj}'s

$\boldsymbol{t_o}$ time interval at the end of which, both in and out cycles of suppliers repeat themselves; least common multiple of t_s and t_c (t_d)

$\boldsymbol{t_{o'}}$ time interval at the end of which, both in and out cycles of supply hub repeat themselves; least common multiple of t_d and t_c

The next table summarizes how we use the notation to denote the counterparts across scenarios.

Table 1.1: Notation used in Traditional and Alternative Models

SAME		
Notation	**Traditional**	**Alternative**
b_s	b_s	b_s
b_h	b_h	b_h
b_{mj}	b_{mj}	b_{mj}
u_s	u_s	u_s
u_{mj}	u_{mj}	u_{mj}
K_p	K_p	K_p
p_s	p_s	p_s
r_p	r_p	r_p
Q_d	Q_d	Q_d
t_d	t_d	t_d
r_h	r_h	r_h
K_{hg}	K_{hg}	K_{hg}
g_{h1}	g_{h1}	g_{h1}
g_{h2}	g_{h2}	g_{h2}
s_h	s_h'	s_h''
a_{sf}	a_{sf}	a_{sf}
a_{sl}	a_{sl}	a_{sl}
K_{sa}	K_{sa}	K_{sa}
a_{hf}	a_{hf}	a_{hf}
a_{hl}	a_{hl}	a_{hl}
K_{ha}	K_{ha}	K_{ha}
Z_s	Z_s	Z_s

DIFFERENT		
Notation	**Traditional**	**Alternative**
s_s	s_s'	s_s''
s_{mj}	s_{mj}'	s_{mj}''
Q_p	Q_p'	Q_p''
Q_{mj}	Q_{mj}'	Q_{mj}''
t_o	t_o'	t_o''
t_o'	t_o''	t_o'''
t_p	t_p'	t_p''
t_s	t_s'	t_s''
t_{mj}	t_{mj}'	t_{mj}''
t_c	t_c'	t_c''
r_{mj}	r_{mj}'	r_{mj}''
K_{mjg}	K_{mjg}'	K_{mjg}''
g_{mj1}	g_{mj1}'	g_{mj1}''
g_{mj2}	g_{mj2}'	g_{mj2}''
o_{mj}	o_{mj}'	o_{mj}''
c_{mj}	c_{mj}'	c_{mj}''

We wish to remark that some of the parameters or costs may remain unchanged across traditional and alternative models. Therefore, we will use the indices for differentiation wherever appropriate.

CHAPTER II

LITERATURE REVIEW

The structure of the literature review follows the steps of the development of the research idea. Looking from the broadest perspective, we first present a review of the literature on supply chain network design models and related studies derived over supply chains.

More recent works on supply chain network design involve an increasing consideration of supply chain coordination. This, we believe is mainly because collaborative, cooperative and coordinative attempts increase the efficiency of the supply chains through improving the production, distribution, procurement and inventory management in the overall chain. Therefore, we selected supply chain coordination as the next subject to review literature on.

After the topic of supply chain coordination, we present an overview of inventory management and supply hub literature.

Review of the literature provides guideline to define the framework and the structure for the alternative business procurement model. Further work in the thesis is carried out and developed over this ground.

2.1. Supply Chain Network Design

Though competition, mainly triggered by globalization, necessitates a re-evaluation on supply chain network designs for many companies operating worldwide to check whether any cost efficient opportunities can be taken (Thomas & Griffin, 1996), in the recent years, traditional supply chain structure with several organizations operating independently, having conflicting objectives is being replaced by interdependent organizations operating optimally with integrated objectives through re-designing their supply chain networks, which enables an effective and efficient management of the supply chain (Altıparmak et al., 2009).

Network design and supply chain network design are mostly considered in the literature as concepts very much similar to strategic supply chain planning (Vidal and Goetschalckx, 1997; Simchi-Levi et al., 1999; Meixell and Gargeya, 2005; Altıparmak et al., 2006; Chopra and Meindl, 2007). Supply chain network design allows coordination initiatives for optimizing the whole system. It involves a number of activities to decide; whether to open a facility or not, where to locate, which capacity and technology to choose, how to distribute products to facilities with minimum cost network design; while better satisfying customer demand.

Supply chain planning literature can be classified by two main viewpoints; strategic and tactical/operational (Shen, 2005). Studies on strategic levels mostly deal with the decisions on locating, opening or closing a facility as well as with the decisions on determining the number, capacity and technology requirements of those facilities. Inventory management and distribution decisions are considered as being at tactical and operational level. However, for a reliable optimization, all decisions at each level need to be evaluated in an integrated manner.

Sousa et al.’s (2008) study provides a decision support tool for long term investments and strategies and is derived over a real industry case with an aim of redesigning the supply chain network both in strategic and in operational levels by optimizing production and distribution systems. Thanh et al. (2008) provides a tool for strategic and tactical decisions for a company foreseeing to expand in volume in a multi echelon, multi commodity production-distribution network system with deterministic demand.

A conceptual framework is developed by Manzini et al. (2008) on Production Distribution Logistic System Design problem. Their study employs an integrated view of the strategic, tactical and operational levels of planning.

Considering the increasing agreement on the idea that competition is through supply networks, not companies (Christopher, 1992; Rich and Hines, 1997; Lambert and Cooper, 2000), studies on supply chain network configuration started to increase. For instance, the study conducted by Srai and Gregory (2008) develops a configuration framework on supply network design.

Various logistics activities are also considered as important drivers of supply chain network design. Several researches point on the ignorance of those activities in supply chain design. For instance, Vidal and Goetschalckx (1997)’s review paper highlights the gap on strategic models for logistics activities of supply chain design. Furthermore, Meixell and Gargeya (2005) review articles on global supply chain design, which focus mostly on the logistics activities, and emphasize the gap for practical settings supporting industry for global supply chain design.

The thesis research involves the presentation of an alternative supply chain network design for a multinational company, with feasibility conditions. The model developed in the research, demonstrates application of theory into practice with an emphasis on logistics activities. The thesis, therefore, is a contribution in filling the gap mentioned by Vidal and Goetschalckx (1997) and Meixell and Gargeya (2005) for global supply chain design.

One other topic considered in the thesis is the hub location problem. We formulate and solve the problems to decide on the optimal number and location of hub warehouses for a given supply chain structure. We also provide a parametric analysis that establishes the trajectory of the optimal solution

Clearly, facility location problems are another important area of supply chain network planning, which evaluates the decisions on establishing new facilities or even closures of new facilities, typically many customers to be served by one or several facilities. Bramel et al. (1997), Drezner and Hamacher (2004) and Nickel and Puerto (2005) provide a different viewpoint to the theory on location problems. Besides, Verter and Dinçer (1995)'s review paper outlines analytical models on facility location decisions. Other studies which are conducted on this area are carried out by Kalcsics et al (1999), Jayaraman and Pirkul (2001), Bender et al. (2002), Syam (2002), Jang et al. (2002), Syarif et al. (2002), Jayaraman and Ross (2003), Klose and Drexl (2005), Yeh (2005), Yeh (2006) and ReVelle et al. (2008). Furthermore, another location model for a dynamic two-echelon multi-commodity problem is developed by Hinojosa et al. (2008).

P-median problems, which consider total cost or distance minimization with p numbers of facilities to be located for meeting customer demands, are one of the simplest and widely studied facility location problems. In addition to Daskin (1995) and Drezner and Hamacher (2004)'s theoretical contributions on p-median problems, many other studies are carried out by several researchers at different eras; like Tansel et al. (1983), Resende and Werneck (2004), ReVelle and Eiselt (2005), Berman and

Drezner (2008), Elloumi (2010). Klose and Drexl (2005) extend location problems to multi-commodities whereas Melo et al. (2006) further considers multi-periods. Besides, Jang et al.'s (2002) study as well as Syam (2002)'s and Melo et al.'s (2006) studies consider multi layers in their models. Even though there is an extensive literature on this area, stochastic and multi period models have not been studied thoroughly (Melo et al, 2008).

Capacity and technology planning considerations are also included in supply chain design framework either for expansion or reduction purposes. In this context, Doğan and Goetschalckx (1999) consider demand seasonality problem in their studies whereas Mazzola and Neebe (1999) consider multiproduct capacitated facility location (MPCFL) problem. Verter and Dasci (2002) studies location, capacity and technology selection decisions simultaneously in a multi-commodity environment. Capacity and warehouse location problems in supply chains under uncertainty are analyzed by Aghezzaf (2005). Moreover, a multi-period investment problem is carried out by Ahmed and Sahinidis (2008) and a supply chain design problem is presented in Elhedhli and Gzara's (2008) study for three echelons, multiple commodities, which considers technology selection. The paper by Mathur and Shah (2008) proposes a price compliance regime for the cases in which new capacity installation, capacity enhancement or update is necessary under uncertainty of demand. The authors further analyze the impact of various penalty parameters on the supplier's capacity decision.

Inventory management, which is a key activity in supply chains, requires an integrated perspective to ensure optimal number of stock locations with optimal inventory levels (Williams and Tokar, 2008). This is prevalent even for decentralized systems. Although decentralized inventory models are characterized by disjoint decisions, they are still inter-dependent. A coordination mechanism is proposed in a study derived by Piplani and Fu (2004) to address this challenge and enable cost reductions with a framework defined through multi-agent technology, coordination theory and optimization technology. Javid and Azad's (2010) paper on inventory-location model, which extends a previous work by Shen and Qi (2007) optimizes a class of location, allocation, capacity, inventory and routing decisions simultaneously.

This thesis also contributes to the literature on capacity and technology re-assessment. We further provide numerical and parametric evidence for supporting the findings.

Decisions on safety stock levels with the consideration of lead times are inseparable part of inventory decisions and analyzed intensively in supply chain network design studies. Many studies include these decisions in their models (Liao and Shyu, 1993; Vidal and Goetschalckx, 1997; Hariga and Ben-Daya, 1999). Sourirajan et al. (2007) develop a Single Product Network Design Model with Lead time and Safety Stock Considerations. A distribution center location problem is studied by Sourirajan et al. (2009) for a two-stage supply chain with an aim of reducing inventory and safety stock costs by a simultaneous consideration of lead time and safety stock levels.

Both models (traditional and alternative) analyzed in the thesis involve the consideration of safety stock levels. In the traditional case, it is viewed and discussed as a policy decision by company managers. We argue that safety stock should be considered as an integral part of inventory management decisions and should be based on factors like the structure of the supply chain, sensitivity of the market and features of the products involved.

Recent articles on supply chain network design (e.g. Meixell and Gargeya, 2005) conclude the necessity to conduct further studies on the topic. Another review paper by Melo et al. (2008) on location decisions and supply chain network design presents the earliest studies in a clear framework. Similarly, Klibi et al. (2010) discusses supply chain network problem under uncertainty and provides discussions that involve the initiatives for further developing a supply chain design methodology.

Based on our analysis of the literature on supply chain network design, we have identified two aspects of this subject, which we believe need to be focused more on, for achieving success in improvement initiatives. The first one is the relationship management and the other one is sustainability concerns, which are usually overlooked in the literature.

Developing close ties with other supply chain members may not be an attractive alternative for most of the companies at first sight. However, partnerships are clearly desired due to evident benefits. This, points to the importance of relationship management aside. Therefore, in order to avoid conflicts in the transition process while building up ties with chain partners and integrating through, the people side of the process should not be underestimated (Dion et al.1995). The stability and continuity in supply chain collaboration can be achieved only if the process transition is managed properly and re-structuring is managed by considering both company specifics and human relationships. Thus, managing all the components of the changing environment is a strategic priority in an integration process to succeed. Christopher and Jüttner's (2000) paper describes this point as a priority issue of supply chain integration, presenting the insights of experienced practitioners and presents a systematic approach for relationship management.

The perspective on environmental friendly supply chain receives increasingly growing interest. This field is defined as sustainable supply chain network design (Winkler, 2010; Byrne et al., 2010). Global concerns on environment highlights the fact that this issue needs to be considered while redesigning the supply chain networks.

Although the model developed in this thesis does not consider the sustainability concerns, explicitly the models presented can be easily extended to include this consideration; for instance by modifying the model to include the objective of minimizing the emissions generated.

The literature on supply chain network design is closely interrelated with the literature on supply chain coordination. Therefore, we take a closer look at the studies in this area.

2.2. Integration, Coordination, Corporation, and Collaboration in Supply Chains

Both academicians and practitioners put significant effort for aligning and coordinating the individual business processes and activities managed by the channel members with an aim of improving overall effectiveness and performance of the supply chain. The coordination mechanism can be characterized vertically through the supply chain (e.g. between suppliers and customers) or horizontally (e.g. between suppliers serving to a common customer). The most commonly accepted definition of coordination in the literature is stated by Malone and Crowston (1994, pp.4) as "*an act of managing dependencies between entities*".

Clearly, supply chain coordination is not an easy task to handle. Coordination necessitates an integration process through the supply chain with an aim to increase the value added acts through the supply chain by redefining and connecting business processes and forming a new structure accordingly (Awad and Nassar, 2010). In the ideal case, the conditions for a "win-win" situation in a coordination mechanism are sought.

The level of integration depends on how coordination mechanisms are adapted to business processes. Arshinder and Deshmukh (2008) name each level (collaboration, cooperation) as a distinct method of coordination. Coordination among at least one of the operations is defined as cooperation, which necessitates transition from individual management of operations to joint management. Collaboration, however, is defined as a joint working approach which is basically a broader alignment than cooperation only. The broadest concept of all is defined is full integration, which means combining together and forming an internal whole.

The alternative model develop in the thesis can be viewed mainly as a cooperation. Our approach also involves a collaborative aspect as it establishes the conditions such that all players in supply chain benefit. However, we need to note that this framework does not demonstrate a full integration setting.

Coordinating a supply chain necessitates a transition from individual businesses optimization to overall supply chain business optimization by aligning all related processes. This sometimes results in decentralized systems allowing a centralized decision maker to operate the whole system. Spekman and Carraway (2006) address that, collaborative relationships in the supply chains, add a remarkable value to market capitalization. However, this does not mean that collaborative relationships always end up with success. Collaborative relationships amongst supply chain members may potentially benefit parties in the long run if the transition from individual practices to collaboration is managed successfully. The transition from pure competition to collaborative practices for all parties is a challenging task as it necessitates building up close ties with other parties and introduces new risks aside. Besides, giving up old managerial and operational habits, losing the power of individual decision making, developing a new viewpoint to old practices is not an easy task for any party. Spekman and Carraway's (2006) paper emphasizes this issue and outlines the critical elements to the transition process and main drivers of achieving a sustainable competitive advantage from the collaborative attempts.

Considering the importance of managing the transition process effectively, it can safely be emphasized that understanding the aspects of the collaboration strategy is first and foremost vital. Many companies overlook this concept and underestimate its scope by limiting it to only some strategic types of collaboration amongst supply chain members. For instance, they view collaboration as running processes like efficient consumer response; consignment inventory; vendor managed inventory; continuous replenishment; collaborative planning, forecasting and replenishment. This misinterpretation also adversely affects management of related strategic tasks. Companies fail to consider that, it is a major change both inside and outside of the company practices; thus requires a careful management. As reported in Daugherty et al.'s (2006) paper, Sabath and Fontanella (2002, p.24) points out this issue as *"...supply chain collaboration is at the same time the most used, the most frequently misunderstood, the most popular - and the most disappointing - strategy that has come along to date*". Holweg et al.'s (2005) study outlines the necessary efforts to succeed in collaborative initiatives and emphasizes the importance of conformity of collaboration strategies to internal and external operations, market environment and product specific characteristics. The importance of handling the process and managing it strategically is also emphasized by Daugherty et.al (2006). This paper presents the ideas of practitioners, academicians and consultants that in order to collaboration between parties to work. The study concludes that the relationships are given the highest importance.

The final result that will be drawn out of this thesis is the set of conditions for a cooperative initiative to result in lower system wide costs, higher inventory turnover rates and better cash flow management. We also provide evidence on capacity utilization, response time to market and quantity discount offerings.

An integrated production-inventory model for minimizing the total cost of buyer and vendor is presented in Sajadieh et al.'s (2009) paper under stochastic lead times where shortages are fully backordered. Optimal production and shipment policies as well as importance of profit sharing decisions under uncertainty are outlined accordingly. Seliaman and Ahmad (2008) work out total cost minimization under stochastic demand to coordinate production and inventory decisions for a three level supply chain. The study conducted by Jaber and Goyal (2008) discusses the coordination of order quantities through the members of a three-level supply chain which is structured on centralized decision making process. The model developed in that study ensures the local cost for each party does not increase after coordination. Chen and Chen (2005) study four decision making models to identify optimal inventory replenishment and production policies while considering the joint replenishment decisions together with channel coordination. Nikandish (2008) commented extends Chen and Chen's (2005) study to include the effects of starting and stopping times of the production. Khouja (2003) worked on three level supply chain and solved a cost minimization model for all parties involved through analyzing three coordination mechanisms and outlined of which can result with better costs off. Cardenas-Barron (2007) worked on an n-stage multi-customer supply chain and developed an algebraic approach to Khouja's (2003) study. Leung (2009) carried Khouja’s (2003) and Cardenas-Barron's (2007) work one step forward by including five realistic conditions and providing a more simplified optimal solution procedure through the use of perfect squares method. Sarmah et al. (2008) develops a model that proposes a coordination mechanism for improving supply chain performance between single manufacturers - multiple customers with heterogeneous structures and compares the effects of manufacturer’s dominance versus buyer's dominance in ex-site deliveries. The model is a quantitative tool, which provides the minimum and maximum amounts feasible for compensating the coordinative initiatives; thus can be used for coordination and negotiation purposes through supply chain members.

Minner (2007) has presented a different methodology to compute economic order quantities which simply compares costs in a finite horizon without using differential calculus or without taking derivatives. Minner’s assumption, which expresses cost function over optimal cycle length, is re-worked by Wee et al. (2009) by expressing cost function over optimal batch size and further extended by deriving optimal fill rate through cost comparisons. With an aim of conformity to real world production and inventory control problems, Pasandideh et al. (2010) extends economic order quantity models developed in the literature for several products in a single supplier and single retailer supply chain under vendor managed inventory system by considering a limited warehouse capacity at supplier's premises, by putting an upper bound to the number of orders and by allowing shortages to be backordered.

The review paper by Arshinder and Deshmukh et al. (2008) categorizes supply chain coordination strategies as; buyer-vendor coordination as in Sarmah et al. (2006), production-distribution coordination as in Sarmiento and Nagi (1999), inventory-distribution coordination as in Thomas and Griffin (1996), procurement-production coordination as in Goyal and Deshmukh (1992), multi-plant coordination as in Bhatnagar et al. (1993).

Referring to this classification, we may note that this thesis study also reveals the fact that it is not always appropriate to classify coordination mechanisms by two counterparts. We hereby emphasize that, a coordination strategy which considers production and distribution coordination explicitly affects inventory processes of the parties involved, which is most probably one of the most important cost items for each party. Thus, in such a setting, inventory coordination is inevitably incorporated to production, procurement and distribution coordination and should be analyzed all together.

Coordination in a supply chain requires a proper transfer of costs and decision-making authorities for defining structure of the least costly operations in the supply chain. During the thesis study, we have experienced that redefinition of distribution of decision making power, rather than the cost structure, is one of the most challenging components of cooperation. Thus, joint decision making in supply chain coordination is not only a mechanism, it is a primary key element which actually determines the objective functions to be optimized. The cost structure and owners of each cost item for an optimum coordination clearly depends on which party the decision making rights are assigned to. Accordingly, for determining the best policy in certain supply chain coordination, it is necessary to first determine which one of the parties will best decide on which variable for the benefit of the whole supply chain. This will be mainly based on the supply chain's operations structure. Simultaneously, the decisions on which party should incur which cost element, is directly interrelated with the decision on which party incurs the decision making authority.

We now provide a detailed review on inventory management systems literature.

2.3. Inventory Management Systems

The literature on this subject can be classified as studies on inventory management for traditional sourcing systems, consignment inventory systems, vendor managed inventory systems (VMI) and consignment & vendor managed inventory systems. Some inventory systems are structured on a network through supply hubs which is also named as vendor hubs. The literature has remarkable number of studies on this area.

Reviewing the inventory management models in the literature is important for this thesis mainly for understanding the potential opportunities in developing an alternative model. One of the most prominent models in this area is vendor managed inventory. Although the conceptual framework of vendor managed inventory is described by Magee (1958), it became a popular concept by early 1990’s. Vendor managed inventory was initially practiced in early 1980’s by some major retail companies as Wal-Mart and Procter and Gamble. This system improved Procter and Gamble’s on-time deliveries to Wal-Mart and increased inventory turns (Buzzel and Ortmeyer 1995). Many researches have to work on identifying the conditions in a vendor managed inventory setting that benefits both parties involved. Many companies like Campbell Soup, Johnson & Johnson and Barilla employed vendor managed inventory in their operations (Waller et al., 1999). In a vendor managed inventory system, the supplier incurs right and responsibility on inventory management and determination of the order quantity for its customer, to such a case supplier has access to customer’s demand and inventory data. This helps the vendor to plan its operations more efficiently while saving the customer from ordering costs or high inventory carrying costs. As introduced in Yang et al. (2009), such a model usually results in frequent replenishments and lower inventory levels, reduced stock-outs, improved service level and reduced demand distortion (Aviv and Federguen, 1998; Angulo et al., 2004; Yang et al., 2009).

As reported in Ru and Wang’s (2010) study, consignment inventory system is another inventory management strategy which can be defined as "the process of a supplier placing goods at a customer location without receiving payment until after the goods are used or sold" (APICS Dictionary, 11th ed., p.20). The decision on the amount of order quantity in a period can be owned either by the downstream (buyer or customer) or by the upstream member (supplier). Big retailers like Wal-Mart, Target, Ahold USA, Meijer Stores rely on vendor managed consignment inventory arrangement (Lee and Chu, 2005; Rungtusanatham et al., 2007). Ru and Wang’s (2010) paper try to find out which of the retailer managed consignment inventory program and vendor managed consignment inventory program works better under a price sensitive and uncertain demand environment. They conclude that vendor's authority performs better for the whole supply chain. Besides, as reported in Ru and Wang (2010), shifting inventory ownership to suppliers (consignment), is outlined to be one of the top best practices in a recent annual International Monetary Fund (IMR) survey (IMR June 2004) for reducing inventory costs.

The literature contains several studies that outline the areas in which a vendor managed inventory system proves benefits. Çetinkaya and Lee (2000) identify a model for shipment and transportation decision making in vendor managed inventory systems. A time based consolidation policy which considers a replenishment quantity is presented. The methodology aims to minimize the costs associated with procurement, transportation, inventory carrying and waiting while satisfying customer's expectations. A vendor managed inventory decision support system is developed by Achabal et al. (2000) which consider inventory optimization methods and promotional response models distinctively. The study combines the management science and marketing perspectives in one model. Sales forecasting model aims more accurate results where inventory management models look for less uncertainty regarding inventory turnover and increased customer service levels. The decision support system proves that for an effective retail supply chain, a vendor managed sales forecasting and inventory replenishment gives better results. The problem analyzed in Çetinkaya and Lee (2000) is also considered in Axsater (2001) for an exact formulation and additional comments. The article improves the approximation of Çetinkaya and Lee (2000).

Another study on vendor managed inventory system's benefits emphasizes that those benefits can be achieved better in the long run and only in a fully integrated supply chain (Dong and Xu, 2002).

A decision support system has been developed in Disney and Towill (2002) that helps to outline best vendor managed inventory parameters for minimizing production adaptation and inventory holding costs.

Another study by Dong and Xu (2002) evaluate short and long term impacts of VMI on supply chain profitability by analyzing the inventory systems of the parties involved. Vendor managed inventory's positive impact on the bullwhip effect that many companies suffer with is proved by Disney and Towill (2003).

Another study carried out by Yao and Dresner (2008) differentiates clearly that vendor managed inventory and continuous replenishment planning serves for different concepts basically. An analysis is extended over previous studies to show that the inventory cost saving benefit sharing of inventory sourcing, continuous replenishment planning and vendor managed inventory vary between the retailers and manufacturers. Such differentiations are clarified accordingly and the importance of vendor managed inventory is being highlighted as through reducing both the cycle inventory and safety stock of the manufacturer. This is further evaluated as, vendor managed inventory benefiting the upstream participant more than the downstream one. A warehouse location and inventory replenishment decision making problem of a warehouse, staying between a supplier and multiple retailers forming a network of three tier distribution system, is analyzed by Üster et al. (2008) with an aim of reducing transportation and inventory costs. The interrelation between the location and inventory decisions is constructed considering transportation costs mainly.

Another prominent study on inventory management systems is the one carried out by Gümüş et al. (2008) which makes a comparison between inventory sourcing, consignment inventory and vendor managed inventory and defines the conditions for benefiting both the vendors and customers through analytical models. Al-Ameri et al. (2008) figures out detailed and aggregate models separately for representing a shipping-based vendor managed inventory system efficiently and a combination of the two are presented in the study accordingly. Wong et al. (2009) highlights in one of the studies that vendor managed inventory partnership improves the coordination through the supply chain and provides a basis for sales rebate contracts and concludes that the combination of vendor managed inventory with sales rebate contracts enhance the supply chain performance to a remarkable extend. Another study carried out by Bichescu and Fry (2009) demonstrates that the division of channel power has a remarkable impact on the performance of the vendor managed inventory systems in terms of the amount of savings and highlights the importance of a leader-follower relationship to be considered significantly as well. It is emphasized by Zavanella and Zanoni (2009) that a coordinated inventory management in a single vendor multi buyer system through consignment stock will potentially benefit the whole supply chain, but the degree of the benefits depend on the chain structure.

An investigation on a decentralized supply chain with revenue sharing perspective is carried out by Li et al. (2009). Bookbinder et al. (2009) further identified the benefits and conditions supporting those benefits under vendor managed inventory systems. Besides, Kauremaa et al. (2009) analyzed the benefits of vendor managed inventory from both strategic and operational perspectives while Yang et al. (2009) analyzed the effects of distribution centers on the system performance and so on the profit.

Baatinia et al. (2010) analyses and provides numerical evidence to the benefits and value of a consignment stock policy, as compared to the traditional approach for the whole supply chain and to individual parties involved. The evaluation is performed in terms of economic and logistics perspectives in single vendor and multiple retailers' multi echelon inventory system.

Yao et al. (2010) emphasizes that gaining market share for the manufacturer is possible by a better stock out management through incentive contracts which induces the conversion of potential lost sales to backorders by the distributors in result of lower inventory levels on the manufacturer side.

Kiesmuller and Broekmeulen (2010) demonstrate their model through vendor managed inventory system to show that under stochastic demand environment lower supply chain costs require that the inventory holding costs should be lower than sum of handling and transportation costs.

During the thesis study, we place special emphasis on the characteristics of the inventory management systems. We specifically consider continuous replenishment planning, consignment inventory and vendor managed inventory, jointly utilized them to develop a model to optimize the business flow through supply hubs.

There are numerous studies on supply hubs; however, we had difficulty to access the English version of this branch of literature conducted by Chinese academicians. Below, we review the accessible part of literature on supply hubs and provide numerous insights on the hub operations.

Barnes et al. (2000), highlights the dynamics effecting the operations at the supply hubs through some real cases. Gaonkar and Viswanadham (2001) consider the planning and scheduling of hub activities, through a linear programming model, assuming a perfect information flow between the stakeholders in the supply hub. Shah and Goh (2006) consider constraints such as backordering, minimum and maximum inventory levels on the operations of the supply hubs and imply vendor managed inventory concept into the process for better management of the suppliers.

A prominent study on the supply hubs is the one which is carried out by Cheong et al. (2007) with an aim of minimizing the total logistics costs of a network through the hubs. An optimization of the number, location and operations of the supply hubs is performed through integer linear optimization model.

Trappey et al.'s (2007) study develops an integrated model for business and logistics hub for the automobile industry which integrates the information flow and material flow considerations jointly.

The paper by Jizi et al. (2008) considers supply chain design using with bill of material and analytically proves that supply hub can reduce the total cost of the supply chain while reducing the extent of bullwhip effect.

In what follows, we describe the traditional and alternative model structures and provide detailed cost analysis.

The rest of the thesis is organized as follows:

In the next chapter, we define and analyze traditional business procurement model of the multinational company. In that chapter, we also provide a discussion on the decision variables and show the calculations of optimal values for decision variables. The numeric and parametric analysis on some specific items are also presented.

In the subsequent chapter, alternative business procurement model is defined and analyzed. We extend the discussions regarding decision variables on the previous chapter, derive comparative analysis and present the outlined observations and comments.

Next chapter presents a numeric implementation of the decision tool developed in the thesis. Numeric study is based on a real case scenario of a multinational company. In this chapter, we also provide detailed numeric and parametric analyses on some specified key items.

We finally conclude with remarks and further research alternatives.

CHAPTER III

TRADITIONAL BUSINESS PROCUREMENT MODEL

3.1. Traditional Business Procurement Model

We consider a multinational company operating in geographically dispersed regional settlements. In any region, there are multiple manufacturing facilities. The facilities supply end products to the markets mainly in the region which they operate. These manufacturing facilities are supplied by multiple suppliers for multiple products. Therefore, the supply chain of the multinational company is structured with multiple regions, each having multiple manufacturers that are supplied of multiple products by multiple suppliers.

The traditional business procurement model of the multinational company is structured by the issuance of individual orders by each manufacturer directly to the associated suppliers. Hence, the system is a two-echelon system; suppliers and regional manufacturers. Each party keeps its safety stocks on its site. We refer to the safety stock at the supplier *s* and manufacturer *j* as s_s and s_{mj} respectively. Safety stock levels are defined by the parties themselves.

The following figure demonstrates the main business flow in the traditional model as follows;

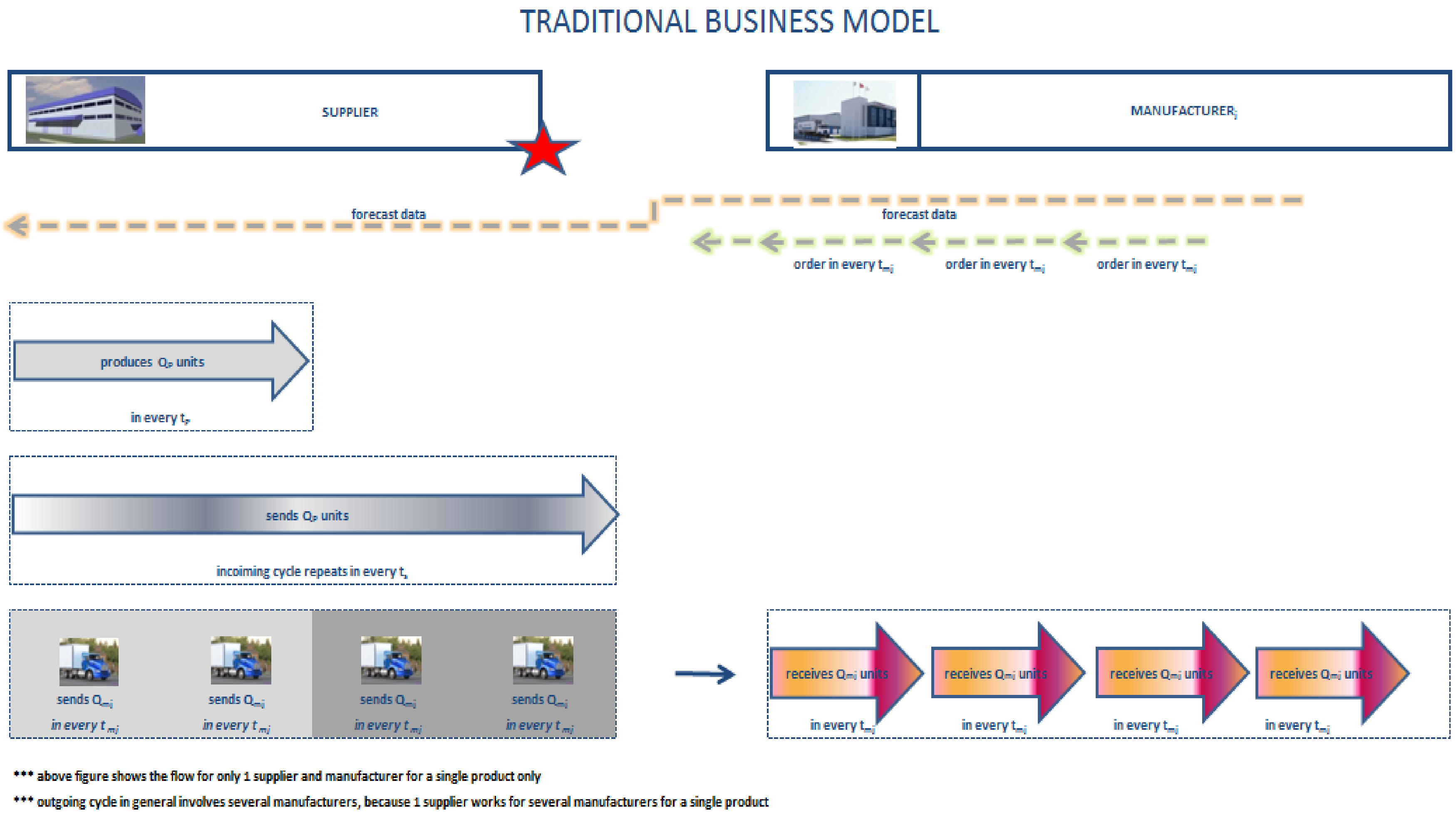

Figure 3.1: Business Flow in Traditional Business Model

The procurement process is triggered by the demand forecast, *D*, of the regional manufacturers. We assume that this information is available to the suppliers. With the demand forecast, order amounts are determined by the manufacturers. The flow in the process involves direct shipments from the suppliers to the manufacturers based on the order amounts. The frequency and quantities of shipments are fixed.

On the manufactures' side, the manufacturers decide on the quantity of their orders, Q_{mj}, and on the time interval, t_{mj}, between issuances of two consecutive orders. Note that it is the manufacturers who decide on the quantity and time interval of the shipments from the suppliers to the manufacturers. The replenishment process on the manufacturers' side demonstrates cycles of repeated activities. Thus, each regional manufacturer *j* issues orders of Q_{mj}'s directly to the suppliers every t_{mj} periods. Suppliers consolidate the orders of all manufacturers, produce Q_p units and send shipments to each manufacturer *j* (Q_{mj} units per t_{mj} periods).

We assume that the agreement between the suppliers and manufacturers is based upon the ex-works sales of the products. In ex-works agreements, the products are delivered to other party at supplier's premises and all costs generated then after are owned by the other party. Thus, transportation cost from the suppliers to the manufacturers is incurred by the manufacturers themselves. Besides, invoices for orders are issued by the supplier to the manufacturer as soon as the orders are shipped from the supplier's facilities. This then implies that the associated costs during the lead time are incurred by the manufacturer.

Aforementioned cycle at the manufacturer's side generate a transportation cost, A_{mj}, inventory carrying cost, I_{mj}, receiving cost, R_{mj}, customs and agencies cost, G_{mj} and ordering cost, O_{mj}, each per unit time.

Transportation cost is composed of a fixed cost, K_{sa}, per shipment as well as a full truck load cost, a_{sf}, and a less than truck load cost, a_{sl}. Inventory cost includes the inventory holding cost, b_{mj}, and opportunity cost, u_{mj}, which occurs due to the inventory kept at the manufacturer's own site. Receiving cost is taken as a single variable cost, r_{mj}, per unit received, whereas ordering cost is the sum of a fixed cost, o_{mj}, per order and a variable cost, c_{mj}, per item received. Finally, customs and agencies cost has three components; a fixed cost per shipment arriving to customs, K_{mjg}, plus a cost per truck arriving to customs, g_{mj1}, plus cost per unit arriving to customs, $g_{mj2.}$

On the supplier's side, the production runs at the suppliers are triggered once the inventory levels at the suppliers reduce down to the safety stock, s_s. This necessitates the suppliers to analyze the requirements of all associated manufacturers collectively, check the inventory levels at their own location and plan production runs accordingly. Each supplier decides on its production lot size, Q_p, and on the frequency of production runs, t_s. Production technology owned by the supplier is characterized by the production speed, r_p, which, combined with the decision on production lot size, determines the production period, t_p,.

We assume that a best policy of the supplier includes the optimal decision on Q_p, t_p and r_p and that based on the optimal decisions, production, inventory, shipping processes are replicated in cycles throughout the planning horizon. These cycles at the supplier's side generate a production cost, P_s, and inventory holding cost, I_s, per unit time. Production cost is composed of a fixed cost, K_p, per production run and a variable cost, p_s, per unit time, whereas the inventory carrying cost is composed of a variable cost, b_s and opportunity cost, u_s per unit stored per unit time.

The key decision variables and distribution relevant supply chain costs for each party based on the defined business environment are summarized in the table below;

Table 3.1: Cost Parameters and Decision Variables in the Traditional Business Model

TRADITIONAL BUSINESS MODEL			
Responsible	**Decision**		**Cost**
	Decision Definition	**Decision Variable (DV)**	
Supplier	total production quantity at supplier	Q_p	Inventory Cost (I_s) Production Cost (P_s)
	time required for production at supplier	t_p	
	time between production runs at supplier	t_s	
Manufacturer	order quantity from manufacturer *j* and shipment quantity to manufacturer *j*	Q_{mj}	Inventory Cost (I_{mj}) Transportation Cost (A_{mj}) Receiving Cost (R_{mj}) Customs and Agencies Cost (G_{mj}) Ordering Cost (O_{mj})
	time between shipments to manufacturer *j* and time between orders from manufacturer *j*	t_{mj}	

In order to facilitate the analytical perception of the business flows, we identify and analyze the associated cycles for each party. We then present the integration of the analysis of individual cycles to allow for the optimization of the overall system. We further identify “incoming” and “outgoing” cycles within each cycle. Then, we consider that the overal length of cycle is repeated at the least common multiple of the lengths of incoming and outgoing cycles.

The overall cycle for the manufacturer is quietly alike with the traditional economic order quantity model. This is repeated at every t_{mj} periods. We, therefore, utilize the related assumptions, detailed information is provided further.

The incoming cycle on the supplier’s side starts with a production period of t_p time units and ends at the time all production is shipped. The length of the incoming cycle is denoted by t_s. The outgoing cycle of the supplier is characterized by repeating cycles of shipments to manufacturers. The outgoing cycle per t_{mj} for each manufacturer *j*, repeats every least common multiples of the collection of t_{mj} values. This value is denoted by t_c. Consider, for instance the case with 3 manufacturers who call for the same product from the same supplier every t_{m1}, t_{m2} and t_{m3} periods. Assume $t_{m1} = 2$, $t_{m2} = 5$ and $t_{m3} = 8$. In this case, the outgoing cycle at the supplier’s side repeats itself in every LCM (2,5,8) periods; which is 40 weeks.

With a similar mind of thinking, the overall cycle for the supplier is repeated at the least common multiple of the lengths of incoming and outgoing cycles. Thus, the cycle length, t_o, for the supplier is equal to LCM (t_s, t_c). Considering the previous example, where we had $t_c = 40$, if we assume the incoming cycle repeats itself every 2 weeks, then the overall cycle length is, t_o = LCM (2,40) = 40 weeks.

3.1.1. Cost Formulations for All Parties

We next provide a detailed analysis and formulation of the cost structures for each party. The traditional business flow recalls that the business setting involves multiple suppliers, multiple manufacturers and multiple products. We present the analysis first for the case with a single product, single manufacturer, and single product.

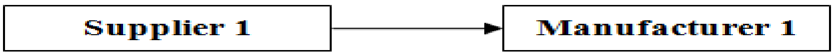

Figure 3.2: Initial Setting in Traditional Model

We then show how the results can be extended to multiple suppliers, multiple manufacturers and multiple products.

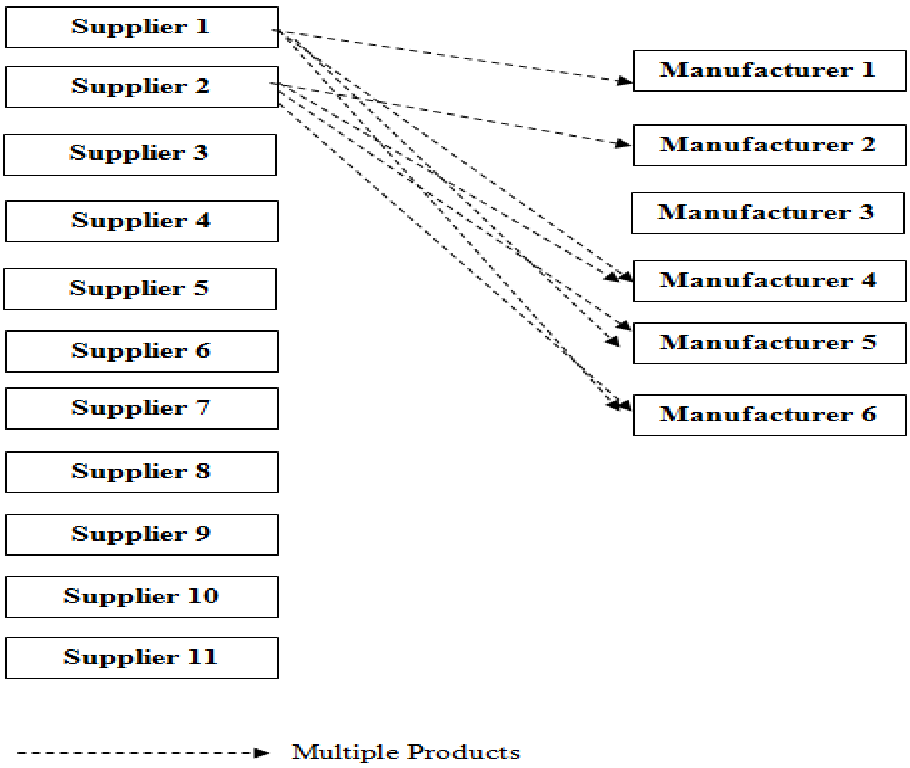

Figure 3.3: Main Setting in Traditional Model

We further prove that the overall optimization for multiple suppliers, multiple manufacturers and multiple products can be decomposed on products; hence enhancing an analysis for each product type and combining them to do the overall optimization. This result mainly relies on the assumption that each product is supplied from a single supplier only.

We have thus shown that the problem of optimizing the decisions for multiple suppliers, multiple products and multiple manufacturers can be solved by solving the problem for a single supplier, single product and multiple manufacturers. Thereafter, we can combine the optimal solutions for each supplier, for each product to reach the optimal solution to the overall problem. Hence, the problem decomposes by supplier and by product. However, the same is not true for manufacturers.

Therefore, the majority of the analysis in the rest of the thesis will assume a setting with a single supplier, single product and multiple manufacturers as shown in Figure 3.4;

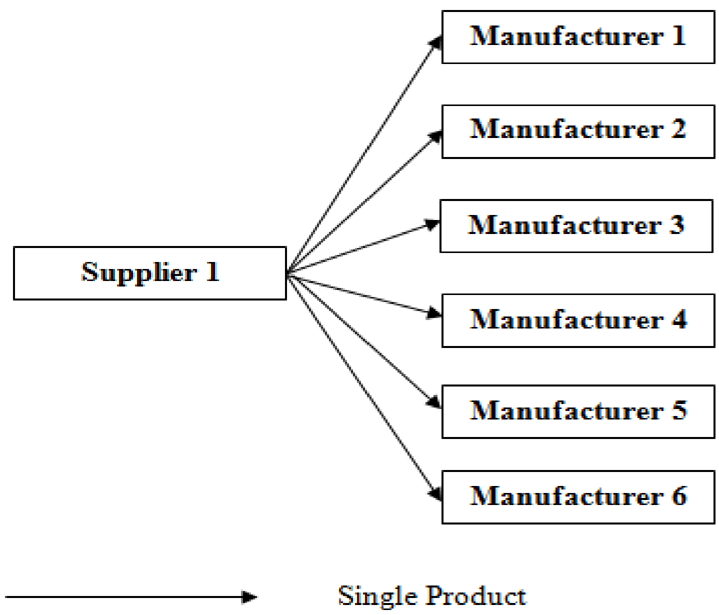

Figure 3.4: Decomposition Analyses in Traditional Model

We also note that there exist parameters of the system that are attributable to a set of suppliers, rather than to a single supplier (e.g. rent cost of a common hub warehouse). For now, we will simply assume that a decomposition of such parameters is possible. We also provide a discussion of how this decomposition can be done in Chapter 4.

We now outline the formulations of each cost item at each party's side.

3.1.2. Cost Components of Manufacturers

We now calculate the total cost of a manufacturer for a single product. We assume that the manufacturer computes its optimal policy using the economic order quantity (EOQ) approach. This information then is sent to the supplier as an order. Therefore, the manufacturer process can be defined using the traditional EOQ model.

The total cost of a manufacturer is composed of the inventory carrying cost at the manufacturers location, transportation cost of shipments from suppliers, receiving cost of shipments, customs and agencies cost (which occurs due to the payments realized for duty or to agencies involved) and finally ordering cost for each order issued to the suppliers.

We consider transportation costs both full and less than truck load shipments. Customs and agencies costs include the duty paid for each unit and payments made to agencies for other transactional costs. Receiving cost represents the costs charged for handling operations when loading and unloading.

We first construct the cost formulations for a single manufacturer and a single product. We then sum up in order to extent to multiple manufacturers and multiple products.

B_{m_j}

Total Cost of the Manufacturer = Inventory Cost per unit time + Transportation Cost per unit time + Receiving Cost per unit time + Customs & Agencies Cost per unit time + Ordering Cost per unit time

Equation 3.1

$$TC_{m_j} = I_{m_j} + A_{m_j} + R_{m_j} + G_{m_j} + O_{m_j}$$

Computation of Inventory Cost of the Manufacturer

I_{m_j} Total inventory carrying cost incurred by the manufacturer per unit time

Equation 3.2

$$I_{m_j} = B_{m_j} + U_{m_j}$$

The first term of the equation represents the inventory holding cost at the manufacturer per unit time and the second term represents the opportunity cost of the manufacturer for tying up money to inventory kept per unit time.

Due to long lead times of the suppliers, manufacturers need to keep high levels of safety stock at their own sites. Thus, opportunity cost of holding inventory at the manufacturer's location will be remarkable. Therefore, it is important to consider it in the related formulations explicitly.

B_{m_j} Total inventory holding cost incurred by the manufacturer per unit time (cycle repeats in every "t_{mj}" period)

We will make use of the following figure for the discussion of the manufacturer's inventory process.

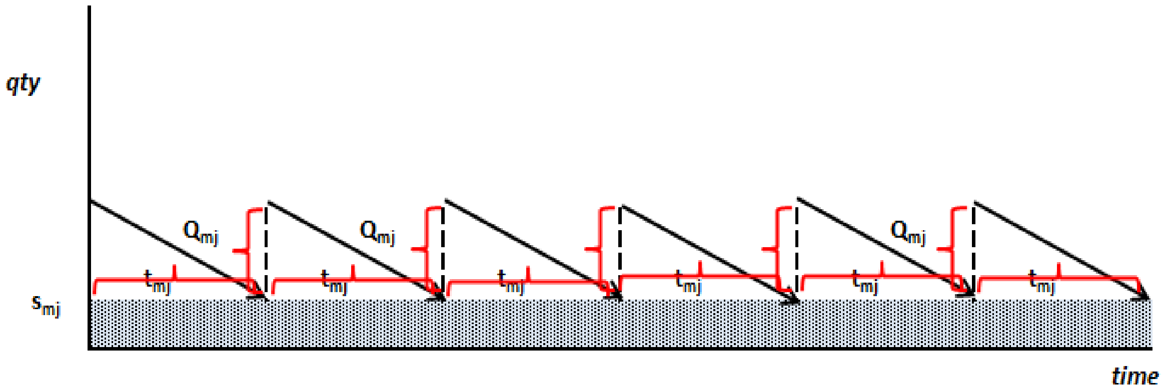

Figure 3.5: Inventory Flow of the Manufacturer in Traditional Business Model

Total inventory (excluding safety stock) carried by manufacturers *j* over (0, t_{mj}) can be calculated as the area under the curve; $\frac{Q_{m_j} t_{m_j}}{2}$.

Hence, the total inventory per unit time held by manufacturer *j*;

$$B_{m_j} = \frac{b_{m_j}\frac{Q_{m_j} t_{m_j}}{2}}{t_{m_j}} = b_{m_j}\frac{Q_{m_j}}{2}$$

Safety stock is kept at the manufacturer as a policy decision and is added over the inventory calculating the inventory cost.

Therefore, the inventory cost of a manufacturer *j* per unit time is as;

<u>Equation 3.3</u>

$$B_{m_j} = b_{m_j}\left(s_{m_j} + \frac{Q_{m_j}}{2}\right)$$

U_{m_j} Total opportunity cost incurred by the manufacturers for tying up money to inventory held at the manufacturer's location

U_{mj} can simply be computed as;

Equation 3.4

$$\boldsymbol{U_{m_j}} = \boldsymbol{u_{m_j}} \left(\boldsymbol{s_{m_j}} + \frac{\boldsymbol{Q_{m_j}}}{\boldsymbol{2}} \right)$$

Computation of Transportation Cost of the Manufacturer

$\boldsymbol{A_{m_j}}$ Total transportation cost incurred by the manufacturer per unit time

The formulation for A_{mj} is as follows;

$$\boldsymbol{A_{m_j}} = \frac{\left(\left\lfloor {Q_{m_j}}/{TL} \right\rfloor a_{sf} \right) + \left(\left(\left\lceil {Q_{m_j}}/{TL} \right\rceil - \left\lfloor {Q_{m_j}}/{TL} \right\rfloor \right) a_{sl} \right) + K_{sa}}{t_{m_j}}$$

The first term in the numerator represents the cost of full truck load shipments from the supplier to manufacturer *j*, the second term represents the cost of sending less than truck load shipments from the supplier to manufacturer *j* (which is actually "1") and the third term represents the fixed cost per shipment. The denominator is the length of the cycle, hence resulting in the cost per unit time.

The cost can be further simplified to;

Equation 3.5

$$A_{m_j} = \frac{\left(\left\lceil {Q_{m_j}}/{TL} \right\rceil a_{sf}\right) + a_{sl} + K_{sa}}{t_{m_j}}$$

Computation of Receiving Cost of the Manufacturer

R_{m_j} Total cost per unit time of receiving incurred by the manufacturer

This cost can be formulated as;

Equation 3.6

$$R_{m_j} = \frac{r_{m_j} Q_{m_j}}{t_{m_j}}$$

The numerator is the units received in a cycle times the unit receiving cost. The denominator is the cycle length, resulting in the cost per unit time.

Computation of Customs and Agencies Cost of the Manufacturer

G_{m_j} Total cost of customs and agencies per unit time incurred by the manufacturer

The formulation for G_{mj} is as follows;

Equation 3.7

$$\boldsymbol{G_{m_j}} = \frac{K_{m_{jg}} + \left(g_{m_{j1}} \left\lceil Q_{m_j}/_{TL} \right\rceil\right) + \left(g_{m_{j2}} Q_{m_j}\right)}{t_{m_j}}$$

The first term in the numerator is the fixed cost paid to relevant agencies per shipment received from a specific supplier whereas the second term represents the variable customs and agencies costs per cycle and the last term is the customs and agencies cost. The cost per unit time is obtained by dividing the sum with t_{mj}.

Computation of Ordering Cost of the Manufacturer

$\boldsymbol{O_{m_j}}$ Total cost of issuing an order

The formulation for O_{mj} is as follows;

Equation 3.8

$$\boldsymbol{O_{m_j}} = \frac{\boldsymbol{o_{m_j}} + \left(\boldsymbol{c_{m_j} Q_{m_j}}\right)}{\boldsymbol{t_{m_j}}}$$

The term in the numerator represents the fixed cost of ordering per cycle of ordering per cycle and a variable cost, c_{mj}. The denominator is the cycle length.

Computation of the Total Cost of the Manufacturer

The total cost of a manufacturer can be formulated by adding each cost components calculated earlier as represented by Equations 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8. Some of the decision variables and parameters (as mentioned in Table 3.1 and the preceding discussion) are dependent on the particular scenario. We therefore use the index "I" to show stand for the traditional model. The total cost per unit time of a single manufacturer, for a single product and single supplier in the traditional model is given by 3.9.The total cost is composed of inventory carrying cost, opportunity cost, transportation cost, receiving cost, customs and agencies and ordering cost.

Equation 3.9

$$
\begin{aligned}
\boldsymbol{TC_{m_j}}^{I} = {} & \left(b_{m_j}\left(s_{m_j}{}^{I} + \frac{Q_{m_j}{}^{I}}{2}\right)\right) + \left(u_{m_j}\left(s_{m_j}{}^{I} + \frac{Q_{m_j}{}^{I}}{2}\right)\right) \\
& + \left(\frac{\left(\left\lceil {Q_{m_j}{}^{I}}/{TL} \right\rceil a_{sf}{}^{I}\right) + a_{sl}{}^{I} + K_{sa}{}^{I}}{t_{m_j}{}^{I}}\right) + \left(\frac{r_{m_j}{}^{I} Q_{m_j}{}^{I}}{t_{m_j}{}^{I}}\right) \\
& + \left(\frac{K_{m_{jg}}{}^{I} + \left(g_{m_{j1}}{}^{I}\left\lceil {Q_{m_j}{}^{I}}/{TL} \right\rceil\right) + \left(g_{m_{j2}}{}^{I} Q_{m_j}{}^{I}\right)}{t_{m_j}{}^{I}}\right) \\
& + \left(\frac{o_{m_j}{}^{I} + \left(c_{m_j}{}^{I} Q_{m_j}{}^{I}\right)}{t_{m_j}{}^{I}}\right)
\end{aligned}
$$

3.1.3. Cost Components of Suppliers

In this section, we formulate the total cost of a single supplier for a given product for distribution to multiple manufacturers.

The total cost is composed of inventory carrying cost and production cost. Inventory carrying cost occurs due to the inventory kept at the supplier's location. Production cost occurs due to the production runs at the supplier's facilities. Inventory carrying cost is formed up of two parts; cost of holding inventory which represents the storage cost of each item; and opportunity cost which is associated with money tied up to the inventory held at supplier's premises.

For the traditional scenario, transportation cost is not included in the total cost of the supplier since it is not incurred by the suppliers as the agreements are based upon ex-works sales of the products. In ex-works agreements, the products are delivered to other party at supplier's premises and all costs generated then after are owned by the other party. Therefore, transportation costs are assumed to be incurred by the manufacturers. In this case, transportation arrangements are also managed directly by the manufacturers.

Before going further in cost formulations, we wish to rephrase the "supplier" using the predefined notations.

Based on orders in quantities Q_{mj} from several manufacturers to be shipped every t_{mj} periods, the supplier wants to decide on the production quantity, Q_p, and time between consecutive production runs, t_s. The production technology owned by the supplier determines the production speed, r_p, and hence production period (per each run), t_p, is determined.

In result, the supplier decides on the optimal values of Q_p, t_p and t_s to minimize its total cost.

In order to derive the optimal value for each decision variable, we first need to analyze the cost structure of the suppliers in detail.

Total Cost per unit time of the Supplier = Inventory Cost per unit time + Production Cost per unit time

Equation 3.10

$$\boldsymbol{TC_s} = \boldsymbol{I_s} + \boldsymbol{P_s}$$

Computation of the Inventory Cost of the Supplier

$\boldsymbol{I_s}$ Total inventory carrying cost per unit time incurred by the supplier.

Before further analysis, we recall that there is an optimal policy for the supplier in which the supplier decides on the values Q_p, t_p, and t_s for once. Thereafter, the supplier repeats these decisions each time, which means, the supplier process is composed of replicated cycles. We exploit this result in the rest of the thesis.

In order to compute the total costs per unit time, we calculate each cost component per cycle, and then divide by the cycle length.

Clearly, we need also to determine the cycle length for each cost component in order to utilize this approach.

I_s has two components, inventory holding cost and opportunity cost. It is then appropriate to denote I_s as;

Equation 3.11

$$\boldsymbol{I_s = B_s + U_s}$$

We now argue that, an optimal inventory policy requires equality of rate of incoming inventory to rate of outgoing inventory in the long run. If incoming rate is greater than the outgoing rate, there will be an increasing inventory build-up. Likewise, if outgoing rate is greater than the incoming rate, there will be an increasing stock out situation.

The incoming inventory at supplier's site increases with every Q_p units produced. This is repeated every t_s, in the long run, the incoming inventory will be built up at a rate of Q_p/t_s. Now, every manufacturer *j* requires a shipment of Q_{mj} units every t_{mj} periods from the suppliers. This process involves multiple manufacturers with unequal t_{mj} values. Hence, if the process for one manufacturer *j* repeats itself every t_{mj} periods, we need t_c = LCM (t_{mj}; j=1,2…J) periods for the overall cycle to repeat itself. Note that within t_c periods, each manufacturer *j* gets t_c/t_{mj} shipments of Q_{mj} units. For instance, if we have 3 manufacturers with manufacturer 1 requiring 1000 units every 2 weeks, manufacturer 2 requiring 2000 units every 4 weeks and manufacturer 3 requiring 3000 units every 3 weeks; the outgoing cycle will repeat itself every LCM (2, 4, 3) = 12. In this case, manufacturer 1 will get shipments every 2/12 weeks. Therefore, in the long run, inventory from the supplier will be depleted at a rate of sum of $(t_c/\ t_{mj})*Q_{mj}$ values for each manufacturer *j*. Hence the equality of rate in and rate out can be stated as;

$$\frac{Q_p}{t_s} = \frac{\sum_{j=1}^{J} \frac{Q_{m_j} t_c}{t_{m_j}}}{t_c}$$

The left hand side of the equation represents the inventory buildup rate (rate-in) and the right side represents inventory depletion (rate-out).

It is now straightforward to verify that the expression can be simplified as;

<u>Equation 3.12</u>

$$\frac{Q_p}{t_s} = \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}$$

In order to calculate B_s, we need to calculate the area under the net inventory graph until the period where overall inventory cycle repeats itself;

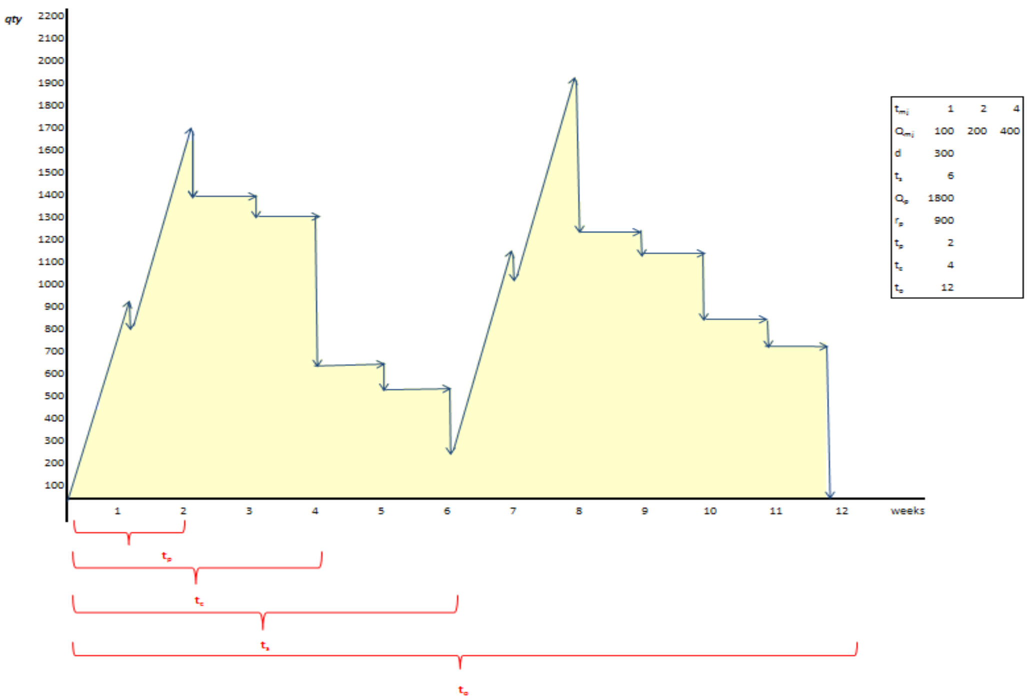

Figure 3.6: Net Inventory Flow of the Supplier in Traditional Business Model

We can then obtain B_s by dividing the cost within the overall cycle, by dividing the cost with the cycle length.

Now observe that the overall cycle repeats itself at some time point where both "in" and "out" cycles repeat themselves. Since the in-out cycle repeats itself every t_s periods and the out cycle repeats itself every t_c periods; the overall cycle repeats itself every t_o = LCM (t_s,t_c) periods. This approach also enhances a decomposition analysis to be applied. In order to calculate the net inventory within an augmented cycle length of t_o periods, we first compute the in-inventory cost within t_o time units using the incoming cycle. Then, we compute the cost of out-inventory within t_o time units using the outgoing cycle. We then subtract the second value from the first to obtain the net inventory cost within t_o time units. We finally divide the resulting net cost by t_o to obtain the net inventory cost per unit time.

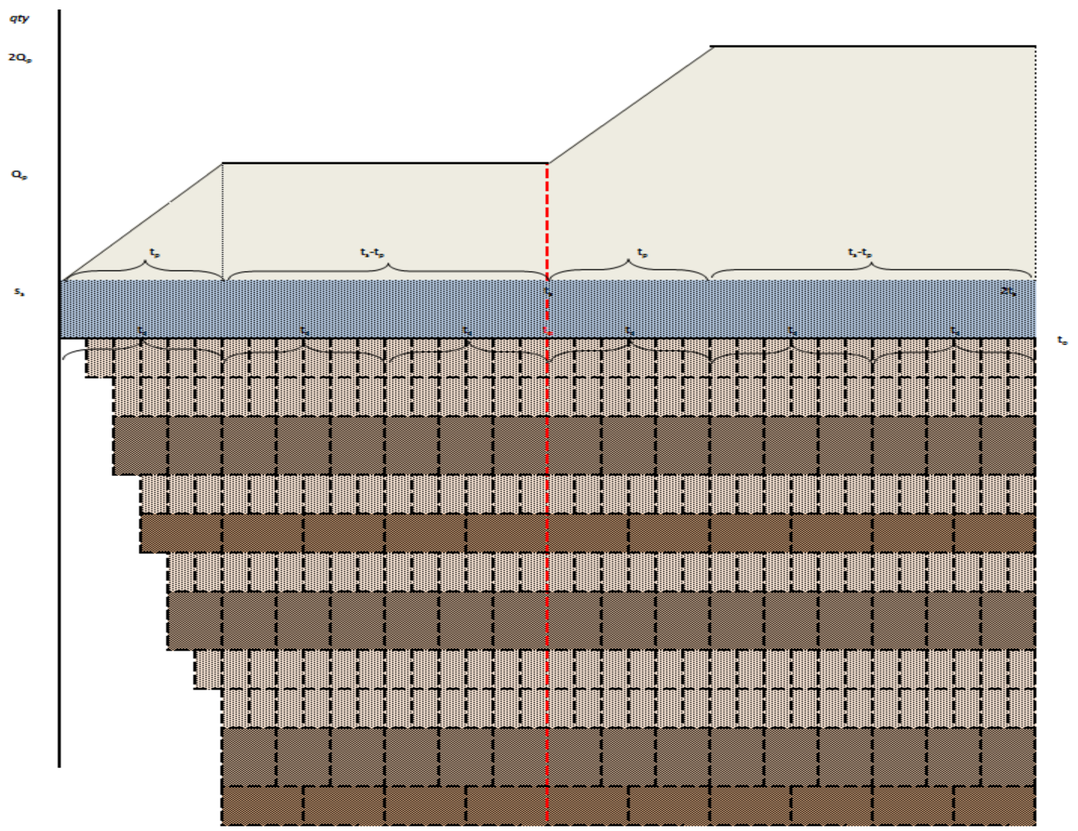

Figure 3.7: Inventory Flow of the Supplier in Traditional Business Model

We now demonstrate how the formulation for B_s (extracted from Equation 3.11), is derived using the above idea.

Calculation of Incoming Area

We will use Figure 3.8 (extracted from Figure 3.7) to compute the incoming area;

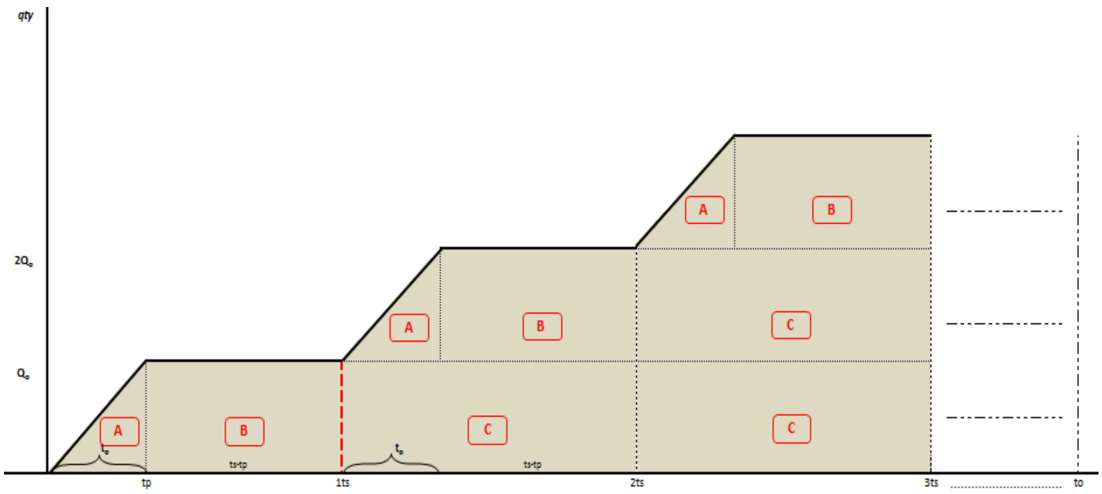

Figure 3.8: Incoming Inventory Flow of the Supplier in Traditional Business Model

We have one area "A" and one area "B" every t_s. Therefore, we have t_o/t_s of them.

The first term in the summation takes care of these areas. We have zero rectangles "C" in the first cycle, 1 rectangle "C" in the second cycle, 2 rectangles "C" in the third cycle and so on. The second term in the summation takes care of these areas.

$$= \left[\left(\underbrace{\frac{Q_p t_p}{2}}_{A} + \underbrace{Q_p(t_s - t_p)}_{B}\right)\frac{t_o}{t_s}\right] + \left[\underbrace{Q_p t_s}_{C}\left(1 + 2 + 3 \ldots + \left(\frac{t_o}{t_s} - 1\right)\right)\right]$$

$$= \left[\left(t_s - \frac{t_p}{2}\right) Q_p \frac{t_o}{t_s}\right] + \left[Q_p t_s \frac{1}{2}\left(\frac{t_o}{t_s} - 1\right)\frac{t_o}{t_s}\right]$$

$$= Q_p t_o \left(1 - \frac{t_p}{2t_s} + \frac{t_o}{2t_s} - \frac{1}{2}\right)$$

This implies that the total incoming inventory in a cycle of length t_o is equal to;

<u>Equation 3.13</u>

$$= \frac{1}{2} Q_p t_o \left(\frac{t_o - t_p}{t_s} + 1\right)$$

Calculation of Outgoing Area

We now make use of Figure 3.7 to calculate the total outgoing inventory in a cycle of length t_o. The total outgoing inventory is the area under the outgoing inventory curve.

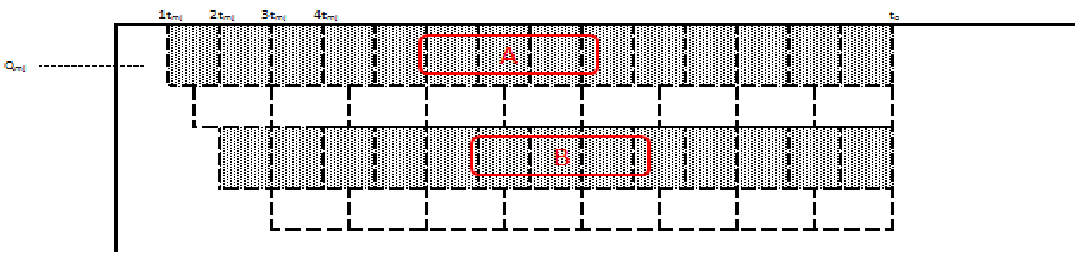

Figure 3.9: Outgoing Inventory Flow of the Supplier in Traditional Business Model

In order to compute the total area, we first calculate the total area associated with shipments to a single manufacturer only. The first shipment to manufacturer *j* occurs at t_{mj} and is composed of a shipment of Q_{mj} units.

The area induced is then $(t_o - t_{mj})*Q_{mj}$.

The first term of the summation denotes this area. The second shipment is again of Q_{mj} units, but happens at time $2t_{mj}$. The second term in the summation stands for this area.

We have t_o/t_{mj} shipments for each manufacturer *j*; hence the last term in the summation.

Finally, we take the total over all manufacturer *j* to obtain the total area.

$$= \underbrace{\sum_{j=1}^{J} Q_{m_j}\left(t_o - t_{m_j}\right)}_{A} + \underbrace{\sum_{j=1}^{J} Q_{m_j}\left(t_o - 2t_{m_j}\right)}_{B} + \cdots + \sum_{j=1}^{J} Q_{m_j}\left(t_o - \left(\frac{t_o}{t_{m_j}} - 1\right)t_{m_j}\right)$$

$$= \sum_{j=1}^{J} Q_{m_j} t_o \left(\frac{t_o}{t_{m_j}} - 1\right) - \sum_{j=1}^{J} Q_{m_j} t_{m_j}\left(1 + 2 + 3.. + \left(\frac{t_o}{t_{m_j}} - 1\right)\right)$$

$$= \sum_{j=1}^{J} Q_{m_j} t_o \left(\frac{t_o}{t_{m_j}} - 1\right) - \frac{1}{2}\sum_{j=1}^{J} Q_{m_j} t_{m_j}\left(\frac{t_o}{t_{m_j}} - 1\right)\frac{t_o}{t_{m_j}}$$

$$= \left[\sum_{j=1}^{J} Q_{m_j}\left(\frac{t_o}{t_{m_j}} - 1\right)\right]\left[t_o - \frac{t_o}{2}\right]$$

which simplifies to;

Equation 3.14

$$= \frac{\mathbf{1}}{\mathbf{2}}\left[\sum_{j=1}^{J} Q_{m_j}\, t_o \left(\frac{t_o}{t_{m_j}} - \mathbf{1}\right)\right]$$

We are now in a position to state the inventory cost per unit time of the supplier using 3.13 and 3.14;

$$B_s = b_s\left[s_s + \left[\frac{\left[\frac{1}{2} Q_p t_o\left(\frac{t_o - t_p}{t_s} + 1\right)\right] - \left[\frac{1}{2}\sum_{j=1}^{J} Q_{m_j}\, t_o\left(\frac{t_o}{t_{m_j}} - 1\right)\right]}{t_o}\right]\right]$$

We further simplify the above to have;

Equation 3.15

$$B_s = b_s\left[s_s + \left[\frac{1}{2}\left[\left[Q_p\left(\frac{t_o - t_p}{t_s} + 1\right)\right] - \left[\sum_{j=1}^{J} Q_{m_j}\left(\frac{t_o}{t_{m_j}} - 1\right)\right]\right]\right]\right]$$

From the formulation, one can see that, as a policy decision, safety stock per unit time, which is kept at the supplier, is added over the calculated inventory cost.

Second term represents the inventory which is built up (as a result of the production runs) at the supplier and the last term stands for the outgoing inventory; i.e. shipments to multiple manufacturers.

Observe that the second term can be re-written as "$t_o \frac{Q_p}{t_s} - t_p \frac{Q_p}{t_s} + Q_p$". This suggests the interpretation of the formulation from a different viewpoint as incoming inventory is compromised of rate in t_o periods, less, rate in in t_p periods plus the production batch size Q_p.

Likewise, the last term can be rewritten as "$\boldsymbol{t_o \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} - \sum_{j=1}^{J} Q_{m_j}}$". Now observing that $\boldsymbol{\frac{Q_{m_j}}{t_{m_j}}}$ can be interpreted as the demand rate for manufacturer j, $\boldsymbol{\sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}}$ is the total demand rate. The expression, then can be rewritten as; "$\boldsymbol{t_o d_s - \sum_{j=1}^{J} Q_{m_j}}$"; where d_s is the total demand per unit time. This is the total demand over a cycle of length t_o less the sum of shipment lot sizes to all manufacturers.

Based on this analysis, we can compute U_s;

$\boldsymbol{U_s}$ Total opportunity cost incurred by the supplier for tying up money to inventory held at the supplier's location.

As opportunity cost is generated by the net inventory kept at the supplier's premises, the formulation for U_s, is extracted from Equation 3.11 and 3.15, as follows;

<u>Equation 3.16</u>

$$\boldsymbol{U_s = u_s \left[s_s + \left[\frac{1}{2} \left[\left[Q_p \left(\frac{t_o - t_p}{t_s} + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j} \left(\frac{t_o}{t_{m_j}} - 1 \right) \right] \right] \right] \right]}$$

Computation of Production Cost of the Supplier

$\boldsymbol{P_s}$ Total production cost per unit time incurred by the supplier for producing Q_p units

This cost involves only the "incoming" cycle of the supplier. Similar to the calculation of inventory cost, it can be computed by calculating the areas below the incoming curve and dividing by the cycle length.

We can now deduce from Figure 3.8 that at each cycle, production continues for t_p periods, but the next production run starts after t_s periods. Thus, the production cycle repeats itself in every t_s periods.

Therefore, the formulation for P_s is written as follows;

Equation 3.17

$$\boldsymbol{P_s = \frac{K_p + (p_s Q_p)}{t_s}}$$

The first term in the numerator represents the fixed cost per production run at the supplier whereas, the second term represents the variable cost per unit produced.

Computation of the Total Cost of the Supplier

Now, we can add up the costs per unit time to compute the total cost per unit time of a single supplier. We use the resulting Equations 3.15, 3.16 and 3.17. Where appropriate, we use the superscript "I" to represent the "traditional model" (refer Table 3.1). The total cost per unit time of a single supplier, for a single product and multiple manufacturers in the traditional model which is composed of inventory carrying cost and production cost is given by;

Equation 3.18

$$TC_s{}^I = \left(b_s \left[s_s{}^I + \left[\frac{1}{2} \left[\left[Q_p{}^I \left(\frac{t_o{}^I - t_p{}^I}{t_s{}^I} + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j}{}^I \left(\frac{t_o{}^I}{t_{m_j}{}^I} - 1 \right) \right] \right] \right] \right] \right)$$

$$+ \left(u_s \left[s_s + \left[\frac{1}{2} \left[\left[Q_p \left(\frac{t_o - t_p}{t_s} + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j} \left(\frac{t_o}{t_{m_j}} - 1 \right) \right] \right] \right] \right] \right)$$

$$+ \left(\frac{K_p + \left(p_s Q_p{}^I \right)}{t_s{}^I} \right)$$

3.1.4. Total Cost of the Supply Chain in Traditional Procurement Model

Our analysis was based on the idea of decomposition by suppliers and by products. When we wish to compute total cost of the supply chain that contains multiple suppliers producing and selling multiple products to multiple manufacturers, we need to extend the formulations accordingly.

The total cost per unit time for a manufacturer was derived, based on a single manufacturer buying a single product from a single supplier. However, in the actual scenario, multiple manufacturers buy multiple products from multiple suppliers since that one product is procured extensively from a single supplier.

Therefore, the total cost formulation for a single manufacturer can be extended to multiple suppliers, multiple manufacturers and multiple products accordingly;

Equation 3.19

$$TC_{m_j}{}^{I} = \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K}\left(b_{m_j}{}^{k}\left(s_{m_j}{}^{I^k}{}_{i} + \frac{Q_{m_j}{}^{I^k}{}_{i}}{2}\right)\right)$$

$$+\left(u_{m_j}{}^{k}\left(s_{m_j}{}^{I^k}{}_{i} + \frac{Q_{m_j}{}^{I^k}{}_{i}}{2}\right)\right)$$

$$+\left(\frac{\left(\left\lceil Q_{m_j}{}^{I^k}{}_{i}/TL^k \right\rceil a_{sf}{}^{I^k}{}_{i}\right) + a_{sl}{}^{I^k}{}_{i} + K_{sa}{}^{I^k}{}_{i}}{t_{m_j}{}^{I^k}{}_{i}}\right)$$

$$+\left(\frac{r_{m_j}{}^{I^k}{}_{i} Q_{m_j}{}^{I^k}{}_{i}}{t_{m_j}{}^{I^k}{}_{i}}\right)$$

$$+\left(\frac{K_{m_{jg}}{}^{I^k}{}_{i} + \left(g_{m_{j1}}{}^{I^k}{}_{i}\left\lceil Q_{m_j}{}^{I^k}{}_{i}/TL^k \right\rceil\right) + \left(g_{m_{j2}}{}^{I^k}{}_{i} Q_{m_j}{}^{I^k}{}_{i}\right)}{t_{m_j}{}^{I^k}{}_{i}}\right)$$

$$+\left(\frac{o_{m_j}{}^{I^k}{}_{i} + \left(c_{m_j}{}^{I^k}{}_{i} Q_{m_j}{}^{I^k}{}_{i}\right)}{t_{m_j}{}^{I^k}{}_{i}}\right)$$

Similarly, the single supplier cot must be extended to include multiple suppliers, with the inclusion of multiple products as;

Equation 3.20

$$\boldsymbol{TC_s}^{\boldsymbol{I}} = \sum_{i=1}^{I}\sum_{k=1}^{K}\left(\boldsymbol{b_s}^{\boldsymbol{k}}{}_{\boldsymbol{i}}\left[\boldsymbol{s_s}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\right.\right.$$

$$\left.\left.+\left[\frac{\boldsymbol{1}}{\boldsymbol{2}}\left[\left[\boldsymbol{Q_p}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\left(\frac{\boldsymbol{t_o}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}-\boldsymbol{t_p}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}{\boldsymbol{t_s}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}+\boldsymbol{1}\right)\right]-\left[\sum_{j=1}^{J}\boldsymbol{Q_{m_j}}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\left(\frac{\boldsymbol{t_o}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}{\boldsymbol{t_{m_j}}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}-\boldsymbol{1}\right)\right]\right]\right]\right]\right)$$

$$+\left(\boldsymbol{u_s}^{\boldsymbol{k}}{}_{\boldsymbol{i}}\left[\boldsymbol{s_s}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\right.\right.$$

$$\left.\left.+\left[\frac{\boldsymbol{1}}{\boldsymbol{2}}\left[\left[\boldsymbol{Q_p}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\left(\frac{\boldsymbol{t_o}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}-\boldsymbol{t_p}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}{\boldsymbol{t_s}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}+\boldsymbol{1}\right)\right]-\left[\sum_{j=1}^{J}\boldsymbol{Q_{m_j}}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\left(\frac{\boldsymbol{t_o}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}{\boldsymbol{t_{m_j}}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}-\boldsymbol{1}\right)\right]\right]\right]\right]\right)$$

$$+\left(\frac{\boldsymbol{K_p}^{\boldsymbol{k}}{}_{\boldsymbol{i}}+\left(\boldsymbol{p_s}^{\boldsymbol{k}}{}_{\boldsymbol{i}}\boldsymbol{Q_p}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}\right)}{\boldsymbol{t_s}^{\boldsymbol{I^k}}{}_{\boldsymbol{i}}}\right)$$

In the actual scenario, total supply chain cost is formed up of multiple suppliers, sending multiple products to multiple manufacturers. Therefore, the total cost of the supply chain for the traditional model is derived using Equation 3.19 and Equation 3.20 as follows;

Equation 3.21

$$TC_{SC}{}^{I} = \sum_{j=1}^{J} \sum_{i=1}^{I} \sum_{k=1}^{K} \left(b_{m_j}{}^{k} \left(s_{m_j}{}^{I^k}{}_{i} + \frac{Q_{m_j}{}^{I^k}{}_{i}}{2} \right) \right) + \left(u_{m_j}{}^{k} \left(s_{m_j}{}^{I^k}{}_{i} + \frac{Q_{m_j}{}^{I^k}{}_{i}}{2} \right) \right) + \left(\frac{ \left(\left\lfloor Q_{m_j}{}^{I^k}{}_{i} / TL^k \right\rfloor a_{sf}{}^{I^k}{}_{i} \right) + a_{sl}{}^{I^k}{}_{i} + K_{sa}{}^{I^k}{}_{i} }{ t_{m_j}{}^{I^k}{}_{i} } \right) + \left(\frac{ r_{m_j}{}^{I^k}{}_{i} Q_{m_j}{}^{I^k}{}_{i} }{ t_{m_j}{}^{I^k}{}_{i} } \right) + \left(\frac{ K_{m_{jg}}{}^{I^k}{}_{i} + \left(g_{m_{j1}}{}^{I^k}{}_{i} \left\lceil Q_{m_j}{}^{I^k}{}_{i} / TL^k \right\rceil \right) + \left(g_{m_{j2}}{}^{I^k}{}_{i} Q_{m_j}{}^{I^k}{}_{i} \right) }{ t_{m_j}{}^{I^k}{}_{i} } \right) + \left(\frac{ o_{m_j}{}^{I^k}{}_{i} + \left(c_{m_j}{}^{I^k}{}_{i} Q_{m_j}{}^{I^k}{}_{i} \right) }{ t_{m_j}{}^{I^k}{}_{i} } \right) + \sum_{i=1}^{I} \sum_{k=1}^{K} \left(b_{s}{}^{k}{}_{i} \left[s_{s}{}^{I^k}{}_{i} + \left[\frac{1}{2} \left[\left[Q_{p}{}^{I^k}{}_{i} \left(\frac{ t_{o}{}^{I^k}{}_{i} - t_{p}{}^{I^k}{}_{i} }{ t_{s}{}^{I^k}{}_{i} } + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j}{}^{I^k}{}_{i} \left(\frac{ t_{o}{}^{I^k}{}_{i} }{ t_{m_j}{}^{I^k}{}_{i} } - 1 \right) \right] \right] \right] \right] \right) + \left(u_{s}{}^{k}{}_{i} \left[s_{s}{}^{I^k}{}_{i} + \left[\frac{1}{2} \left[\left[Q_{p}{}^{I^k}{}_{i} \left(\frac{ t_{o}{}^{I^k}{}_{i} - t_{p}{}^{I^k}{}_{i} }{ t_{s}{}^{I^k}{}_{i} } + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j}{}^{I^k}{}_{i} \left(\frac{ t_{o}{}^{I^k}{}_{i} }{ t_{m_j}{}^{I^k}{}_{i} } - 1 \right) \right] \right] \right] \right] \right) + \left(\frac{ K_{p}{}^{k}{}_{i} + \left(p_{s}{}^{k}{}_{i} Q_{p}{}^{I^k}{}_{i} \right) }{ t_{s}{}^{I^k}{}_{i} } \right)$$

3.2. Analysis and Findings on Traditional Model

Identification of the cost structures of the parties in the traditional business model allows an insightful analysis of the decision variables and their impact on the total cost understanding of the level of interactions among all and helps to clarify the strongest dependencies. This will further be utilized to benchmark the cost of the current model with other alternatives.

We will also present very detailed numeric examples using the formulations. Among other uses, numeric examples will provide a basis for an understanding and validation of the findings of the analysis.

To this end, we will also identify critical decision variables for minimizing the total cost for each party.

Finally, key elements to outline the conditions for benefiting all parties will be emphasized. This will form the basis for the decision support tool for the supply chain design.

3.2.1. Notes for Manufacturers

The cost formulation for a single manufacturer reveals that manufacturer's total cost per unit time is composed of both fixed and variable costs.

I_{mj}, as being the inventory carrying cost, is similar to the inventory cost in the traditional EOQ model. Receiving cost, R_{mj}, consists of variable cost components. Transportation cost, A_{mj}, and customs and agencies cost, G_{mj}, consists of fixed cost per shipment and per truck as well as variable costs per unit.

One can argue that the optimal policy of the manufacturer can be derived using the traditional EOQ model, based on the fixed and variable costs. However, this inclusion is not direct. One needs to analyze the cost structure in detail to make an assessment.

Given per unit time demand, d_{mj}, each manufacturer *j* needs to decide on the optimal values of Q_{mj} and t_{mj}. Now, since an optimal policy requires the rate of incoming inventory equal to the rate of outgoing inventory in the long run, we have $Q_{mj}/t_{mj} = d_{mj}$ or;

<u>Equation 3.22</u>

$$\boldsymbol{t_{m_j} = \frac{Q_{m_j}}{d_{m_j}}}$$

It then turns out that identification of the optimal policy requires the identification of the optimal value of Q_{mj}; or t_{mj}. The other may be obtained using Equation 3.22.

In order to determine the best value of, say, Q_{mj}, the derivative of the total per unit time cost of a manufacturer will be written as a function of Q_{mj}. Taking the derivative and equating to zero will lead to the optimal value.

Since the closest integer operators "$\lceil \quad \rceil$ **and** $\lfloor \quad \rfloor$" in the total cost formulation are not analytically tractable, we first drop them from the formula, replace the closest integer values with the exact values. We then prove that this approximation has negligible effect on the value of the total cost.

$$\boldsymbol{\frac{dTC_{m_j}}{dQ_{m_j}} = 0}$$

Now, making this modification in the total cost and replacing t_{mj} with Q_{mj}/d_{mj}, we rewrite the total cost per unit time of a manufacturer given in Equation 3.9 as;

$$\boldsymbol{TC_{m_j} = \left(b_{m_j}\left(s_{m_j} + \frac{Q_{m_j}}{2}\right)\right) + \left(u_{m_j}\left(s_{m_j} + \frac{Q_{m_j}}{2}\right)\right)}$$

$$\boldsymbol{+ \left(\frac{\left(\left\lfloor {}^{Q_{m_j}}/_{TL}\right\rfloor a_{sf}\right) + a_{sl} + K_{sa}}{{}^{Q_{m_j}}/_{d_{m_j}}}\right) + \left(\frac{r_{m_j}Q_{m_j}}{{}^{Q_{m_j}}/_{d_{m_j}}}\right)}$$

$$\boldsymbol{+ \left(\frac{K_{m_{jg}} + \left(g_{m_{j1}} \left\lceil {}^{Q_{m_j}}/_{TL}\right\rceil\right) + \left(g_{m_{j2}}Q_{m_j}\right)}{{}^{Q_{m_j}}/_{d_{m_j}}}\right)}$$

$$\boldsymbol{+ \left(\frac{o_{m_j} + \left(c_{m_j}Q_{m_j}\right)}{{}^{Q_{m_j}}/_{d_{m_j}}}\right)}$$

which then is equal to;

$$\boldsymbol{TC_{m_j} = b_{m_j}\left(s_{m_j} + \frac{Q_{m_j}}{2}\right) + u_{m_j}\left(s_{m_j} + \frac{Q_{m_j}}{2}\right) + \frac{a_{sf}d_{m_j}}{TL} + \frac{a_{sl}d_{m_j}}{Q_{m_j}} + \frac{K_{sa}d_{m_j}}{Q_{m_j}}}$$

$$\boldsymbol{+ r_{m_j}d_{m_j} + \frac{K_{m_{jg}}d_{m_j}}{Q_{m_j}} + \frac{g_{m_{j1}}d_{m_j}}{TL} + g_{m_{j2}}d_{m_j} + \frac{o_{m_j}d_{m_j}}{Q_{m_j}} + c_{m_j}d_{m_j}}$$

Taking the derivative of the above,

$$\boldsymbol{\frac{dTC_{m_j}}{dQ_{m_j}} = 0}$$

$$\frac{b_{m_j}}{2}+\frac{u_{m_j}}{2}-a_{sl}d_{m_j}Q_{m_j}{}^{-2}-K_{sa}d_{m_j}Q_{m_j}{}^{-2}-K_{m_{jg}}d_{m_j}Q_{m_j}{}^{-2}-o_{m_j}d_{m_j}Q_{m_j}{}^{-2}=0$$

$$\frac{b_{m_j}}{2}+\frac{u_{m_j}}{2}=\frac{a_{sl}d_{m_j}+K_{sa}d_{m_j}+K_{m_{jg}}d_{m_j}+o_{m_j}d_{m_j}}{Q_{m_j}{}^{2}}$$

$$Q_{m_j}{}^{2}=\frac{2\left(a_{sl}d_{m_j}+K_{sa}d_{m_j}+K_{m_{jg}}d_{m_j}+o_{m_j}d_{m_j}\right)}{b_{m_j}+u_{m_j}}$$

which leads to;

Equation 3.23

$$Q_{m_j}{}^{*}=\sqrt{\frac{2\left(a_{sl}+K_{sa}+K_{m_{jg}}+o_{m_j}\right)d_{m_j}}{b_{m_j}+u_{m_j}}}$$

Observe that this is very similar to the traditional EOQ formula (given in right hand side of the Equation 3.24).

Equation 3.24

$$\sqrt{\frac{2\left(a_{sl}+K_{sa}+K_{m_{jg}}+o_{m_j}\right)d_{m_j}}{b_{m_j}+u_{m_j}}}\equiv\sqrt{\frac{2K\lambda}{h}}$$

(Nahmias, Steven, 5th Edition, 2005)

It then follows that optimal value of the time between orders; t_{mj} is;

$$t_{m_j}{}^{*}=\frac{Q_{m_j}{}^{*}}{d_{m_j}{}^{*}}$$

Equation 3.25

$$t_{m_j}{}^{*} = \sqrt{\frac{2\left(a_{sl} + K_{sa} + K_{m_{jg}} + o_{m_j}\right)}{\left(b_{m_j} + u_{m_j}\right) d_{m_j}}}$$

3.2.2. Notes for Suppliers

Based on the inputs and the parameters, each supplier first decides on which policy to proceed within its operations. This requires identifying those values of the decision variables which best fits to its cost structure. The supplier can choose to produce based on individual manufacturer orders and schedule a production run for each manufacturer. Alternately, the same supplier can produce by considering all manufacturers' requirements collectively, in one production run.

It can be shown that, ideally, with certain demand rate of the manufacturers, producing in bigger batches by consolidating all requirements brings more benefits to the suppliers than producing individually for each manufacturer.

The optimal policy on the supplier side is derived based on the order amounts of Q_{mj}'s and their frequencies (implied by t_{mj}'s). These are decisions of the manufacturers and considered as parameters for suppliers.

Demand per unit time is denoted by d_s and calculated by "*D*/*T*" where *D* is the forecast information of the manufacturers in time horizon of *T*.

The production rate per unit time of r_p is also a parameter for the supplier, which is a representative technology owned by the supplier. We assume the technology will not be changed for a long term.

Although the incoming inventory movements are smoother at the supplier side, the outgoing counterpart, which represents the shipments to several manufacturers, is more complicated (see figures 3.7, 3.8, and 3.9).

As evident from an investigation of the Figure 3.71 presented earlier showing the net inventory graph of a particular supplier, the supplier has to optimally determine the values of Q_p, t_p and t_s based on the given parameters Q_{mj}, t_{mj} and r_p.

We start with a feasibility analysis which simply requires production rate per unit time to be greater than or equal to the demand per unit time. In other words, the capacity of the supplier should meet the demand rate of the manufacturers. This is a necessary condition for feasibility but not sufficient by itself.

Equation 3.26

$$\boldsymbol{r_p \geq d_s}$$

As discussed earlier in Section 3.1.3, an optimal policy should avoid inventory build-up and shortages. Therefore, a further attempt to ensure feasibility will be through ensuring the “rate in” and “rate out” equality.

This requires incoming flow to be the same with the outgoing flow in the long run. If incoming flow is greater than the outgoing flow, there will be increasing inventory buildup, which practically is infeasible. The opposite way around, if outgoing flow is greater than the incoming flow, there will be increasing inventory shortage, which is also infeasible.

The incoming inventory in a cycle is the production rate per unit time multiplied by production period. This simply gives the production quantity, Q_p . The outgoing inventory in a cycle is simply the demand within a cycle. That is the demand per unit time multiplied by the length of the cycle of the outgoing cycle.

In order to avoid below scenarios;

If $\boldsymbol{Q_p \geq t_s d_s}$ inventory built up situation exists,

If $\boldsymbol{Q_p \leq t_s d_s}$ inventory shortage situation exists

We now have inflow = outflow;

Equation 3.27

$$\boldsymbol{Q_p = t_s d_s} \quad \textbf{or} \quad \boldsymbol{t_p r_p = t_s d_s}$$

This feasibility condition also ensure that the production quantity, until the next production run, exactly covers the shipments until that time while avoiding inventory imbalances.

We can rewrite this as;

$$\boldsymbol{t_s = \frac{t_p r_p}{d_s}}$$

Considering that, $\boldsymbol{r_p \geq d_s}$, $\boldsymbol{\frac{r_p}{d_s} \geq 1}$ as well.

We finally have another condition for feasibility;

Equation 3.28

$$\boldsymbol{t_s \geq t_p}$$

Keeping t_s and t_p closer, we would expect lower inventories. However, this also necessitates making more frequent production runs thus increased fixed production costs. Hence, the optimization of t_p and t_s are closely related.

Now, observed that Equation 3.27 relates Q_p with t_s, which will be an important input for us while analyzing other dependencies.

Given Q_p, one can determine t_p using the production speed.

Equation 3.29

$$\boldsymbol{Q_p = t_p r_p} \qquad \left(\boldsymbol{t_p = \frac{Q_p}{r_p}, r_p = \frac{Q_p}{t_p}}\right)$$

Combining the above equation with Equation 3.27, we can conclude that for given t_s, the optimal values of Q_p and t_p can be determined. This implies that the three decision variables are interdependent. Identifying one determines the optimal values of the remaining two. Hence, once we do the optimization on, say, t_s, to minimize the total cost of the supplier, we have the best Q_p and t_p values as well.

Considering the aforementioned trade off, best value of t_s is at the point that optimally balances the reduction in the inventory cost and the increase in fixed production costs.

Once we formulate the total cost of the supplier as a function of t_s, we can take the derivative with respect to t_s to find the minimizing value of t_s.

That is;

$$\boldsymbol{\frac{dTC_s}{dt_s} = 0}$$

For this, we rewrite the total cost formulation by representing Q_p and t_p as functions of t_s.

That is;

Replace $t_p = Q_p/r_p$

$Q_p = t_s d_s$

$t_o = t_s t_c$

We need to note that we initially defined t_o to be LCM (t_s, t_c). However, since the operator LCM is not analytically tractable, we replace it by "ts*tc" which is simply a multiple of the original value. Since the overall cycle repeats itself every LCM (t_s, t_c), it also repeats in every multiple of LCM (t_s,t_c); the previous analysis is still valid with this redefinition.

Referring to Equation 3.18 and above replacements, total cost formula is now re-written as follows;

$$\boldsymbol{TC_s = \left(b_s \left[s_s + \left[\frac{1}{2} \left[\left[t_s d_s \left(\frac{t_s t_c - \frac{t_s d_s}{r_p}}{t_s} + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j} \left(\frac{t_s t_c}{t_{m_j}} - 1 \right) \right] \right] \right] \right] \right)}$$

$$\boldsymbol{+ \left(u_s \left[s_s \right. \right.}$$

$$\boldsymbol{\left. \left. + \left[\frac{1}{2} \left[\left[t_s d_s \left(\frac{t_s t_c - \frac{t_s d_s}{r_p}}{t_s} + 1 \right) \right] - \left[\sum_{j=1}^{J} Q_{m_j} \left(\frac{t_s t_c}{t_{m_j}} - 1 \right) \right] \right] \right] \right] \right)}$$

$$\boldsymbol{+ \left(\frac{K_p + (p_s t_s d_s)}{t_s} \right)}$$

The algebraic manipulation of TC formula simplifies the above as follows;

$$\begin{aligned} TC_s = (b_s s_s) + \left(b_s\, {}^{1}\!/_{2}\, t_s d_s \left(t_c - \frac{d_s}{r_p}\right)\right) + \left(b_s\, {}^{1}\!/_{2}\, t_s d_s\right) \\ - \left(b_s\, {}^{1}\!/_{2}\, t_s t_c \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}\right) + \left(b_s\, {}^{1}\!/_{2} \sum_{j=1}^{J} Q_{m_j}\right) + (u_s s_s) \\ + \left(u_s\, {}^{1}\!/_{2}\, t_s d_s \left(t_c - \frac{d_s}{r_p}\right)\right) + \left(u_s\, {}^{1}\!/_{2}\, t_s d_s\right) \\ - \left(u_s\, {}^{1}\!/_{2}\, t_s t_c \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}\right) + \left(u_s\, {}^{1}\!/_{2} \sum_{j=1}^{J} Q_{m_j}\right) + \left(\frac{K_p}{t_s}\right) + (p_s d_s) \end{aligned}$$

Taking the derivative and equating to zero;

$$\frac{dTC\,(supplier)}{dt_s} = 0$$

$$\begin{aligned} b_s\, {}^{1}\!/_{2}\, d_s \left(t_c - \frac{d_s}{r_p}\right) + b_s\, {}^{1}\!/_{2}\, d_s - b_s\, {}^{1}\!/_{2}\, t_c \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} + u_s\, {}^{1}\!/_{2}\, d_s \left(t_c - \frac{d_s}{r_p}\right) \\ + u_s\, {}^{1}\!/_{2}\, d_s - u_s\, {}^{1}\!/_{2}\, t_c \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} + -K_p t_s^{-2} = 0 \end{aligned}$$

$$\frac{K_p}{t_s^2} = \frac{b_s + u_s}{2}\left(d_s t_c - \frac{{d_s}^2}{r_p} + d_s - t_c \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}\right)$$

$$t_s^* = \sqrt{\frac{K_p}{\frac{b_s + u_s}{2}\left(d_s t_c - \frac{{d_s}^2}{r_p} + d_s - t_c \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}\right)}}$$

Recall that $\boldsymbol{d_s} = \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}$

Whereby we finally have;

Equation 3.30

$$\boldsymbol{t_s^* = \sqrt{\frac{2K_p}{(b_s + u_s)d_s\left(1 - \frac{d_s}{r_p}\right)}}}$$

This formula clearly shows the interrelation between K_p, b_s with t_s. When fixed cost of production of K_p increases, the optimal value of t_s increases as well. When unit inventory holding cost b_s increases, the optimal value of t_s decreases.

It is important to note that, increasing t_s means increasing the period where supplier does not make production.

Using $\boldsymbol{Q_p = t_s d_s}$; for feasibility, we can obtain the best value of Q_p as;

$$\boldsymbol{Q_p^* = t_s^* d_s}$$

$$\boldsymbol{Q_p^* = \sqrt{\frac{2K_p}{(b_s+u_s)d_s\left(1-\frac{d_s}{r_p}\right)}}\, d_s}\text{ , or}$$

$$\boldsymbol{Q_p^* = \sqrt{\frac{2K_p {d_s}^2}{(b_s+u_s)d_s\left(1-\frac{d_s}{r_p}\right)}}}\text{ , finally}$$

Equation 3.31

$$\boldsymbol{Q_p^* = \sqrt{\frac{2K_p d_s}{(b_s + u_s)\left(1 - \frac{d_s}{r_p}\right)}}}$$

Equation 3.31 looks exactly alike with the optimal order quantity for the EOQ model with finite production rate. We can then state that the inventory structure of the more complex model with single supplier, multiple manufacturers is proven to be optimally managed similar to the simpler EOQ model with a single supplier.

<u>Equation 3.32</u>

$$\sqrt{\frac{\boldsymbol{2K_p d_s}}{(\boldsymbol{b_s} + \boldsymbol{u_s})\left(\boldsymbol{1} - \frac{\boldsymbol{d_s}}{\boldsymbol{r_p}}\right)}} \equiv \sqrt{\frac{\boldsymbol{2K\lambda}}{\boldsymbol{h}\left(\boldsymbol{1} - \frac{\boldsymbol{\partial}}{\boldsymbol{p}}\right)}}$$

(Nahmias, Steven, 5th Edition, 2005)

An observation of Figure 3.6 and 3.10 reveals the importance of the analogy.

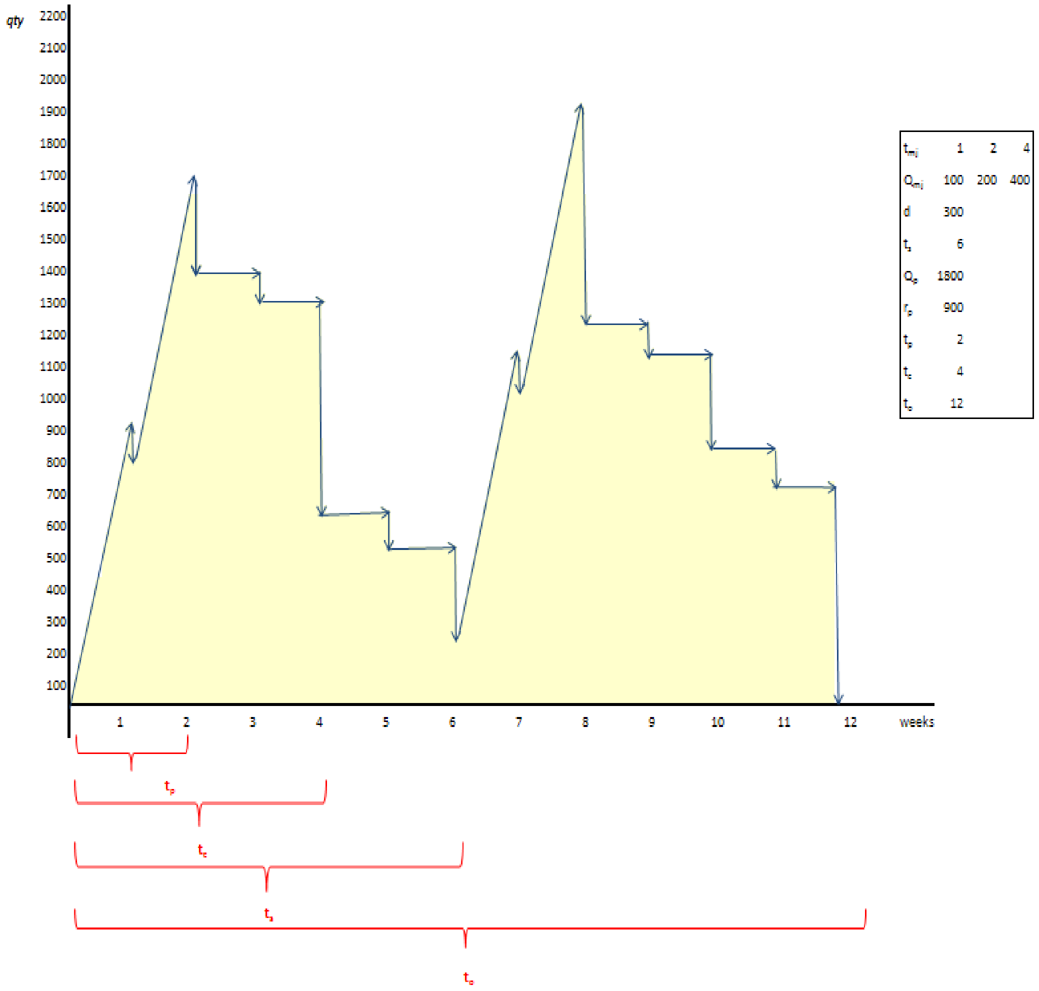

Figure 3.6: Net Inventory Flow of the Supplier in Traditional Business Model

versus

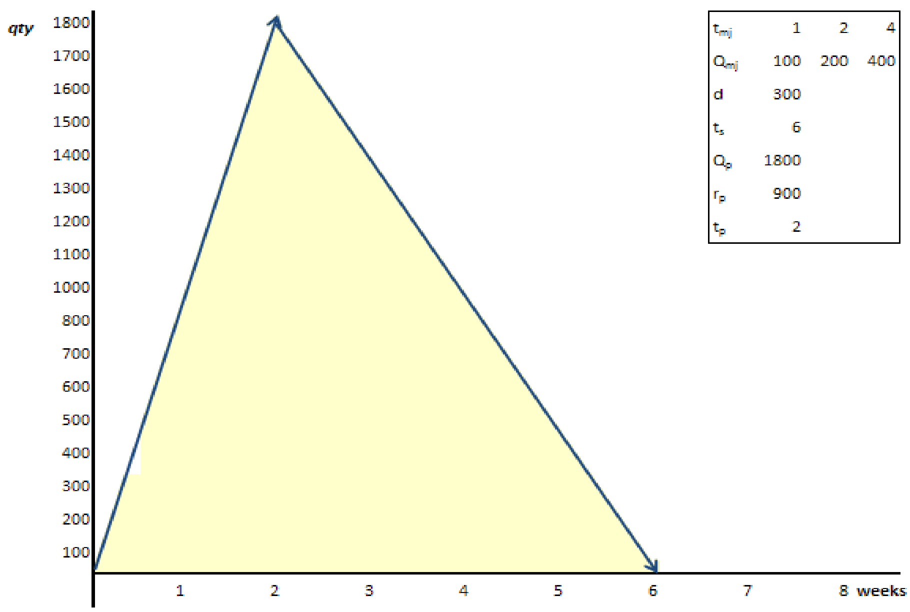

Figure 3.10: Net Inventory Flow of the Supplier in EOQ Model

It is now clear that decision variables at the supplier's side are implied by the total per unit time demand, d_s. Regardless of the distribution of the manufacturers' orders, the optimal policy remains unchanged as long as the per unit time net demand is the same. This suggests that it's a worthwhile to question the effect of use of better technology (for a better response to demand).

The table below is a summary of the numeric analysis carried out by varying the production rate of the suppliers and examining the effect on the total cost. All other parameters are kept constant throughout.

Table 3.2: Effect of Changes in Production Rate of Suppliers on Costs

t_s	r_p	t_p	B_s	% change in B_s	U_s	P_s	TOTAL COST	% change in TC
4	5.000	2	2.200		1.100	18.500,00	21.800,00	
4	10.000	6	27.800	11,64	13.900,00	18.500,00	60.200,00	1,76
4	16.000	3	37.400	0,35	18.700,00	18.500,00	74.600,00	0,24
4	20.000	2	40.600	0,09	20.300,00	18.500,00	79.400,00	0,06
4	30.000	2	44.867	0,11	22.433,33	18.500,00	85.800,00	0,08
4	40.000	1	47.000	0,05	23.500,00	18.500,00	89.000,00	0,04
8	5.000	13	-17.000		-8.500	17.250,00	- 8.250,00	
8	10.000	6	34.200	- 3,01	17.100,00	17.250,00	68.550,00	- 9,31
8	16.000	4	53.400	0,56	26.700,00	17.250,00	97.350,00	0,42
8	20.000	3	59.800	0,12	29.900,00	17.250,00	106.950,00	0,10
8	30.000	2	68.333	0,14	34.166,67	17.250,00	119.750,00	0,12
8	40.000	2	72.600	0,06	36.300,00	17.250,00	126.150,00	0,05
16	5.000	26	-55.400		-27.700	16.625,00	- 66.475,00	
16	10.000	13	47.000	- 1,85	23.500,00	16.625,00	87.125,00	- 2,31
16	16.000	8	85.400	0,82	42.700,00	16.625,00	144.725,00	0,66
16	20.000	6	98.200	0,15	49.100,00	16.625,00	163.925,00	0,13
16	30.000	4	115.267	0,17	57.633,33	16.625,00	189.525,00	0,16
16	40.000	3	123.800	0,07	61.900,00	16.625,00	202.325,00	0,07
32	5.000	51	-132.200		-66.100	16.312,50	- 181.987,50	
32	10.000	26	72.600	- 1,55	36.300,00	16.312,50	125.212,50	- 1,69
32	16.000	16	149.400	1,06	74.700,00	16.312,50	240.412,50	0,92
32	20.000	13	175.000	0,17	87.500,00	16.312,50	278.812,50	0,16
32	30.000	9	209.133	0,20	104.566,67	16.312,50	330.012,50	0,18
32	40.000	6	226.200	0,08	113.100,00	16.312,50	355.612,50	0,08

The analysis, presented in Table 3.2, uses 6 different values of r_p. Each choice of r_p is tested for 4 different t_s values. Q_p and t_p are computed as dependent on t_s. One can observe that, for certain increase in r_p, there is a significant decrease on the total cost. However, better technology, increased production speed does not always result in lower overall costs.

The numeric study also agrees with the feasibility conditions which have been outlined in Equations 3.26 and 3.28. The results of the analyses are also presented in Figure 3.11. The inventory cost, B_s, is negative where $\boldsymbol{t_s \leq t_p}$ and $\boldsymbol{r_p \leq d_s}$. Furthermore, it is also important to note here that, although ideal r_p seems to be the value where B_s is zero, the amount of production technology at that point may not be sufficient to meet the demand. (i.e. at $t_s = 4$, B_s is zero for a value of r_p below 5000, which is not feasible as demand per unit time is 8000). The feasibility region starts at the point where production technology captures the demand per unit time.

This example further suggests that, it is now possible to identify the ideal r_p as well as minimum feasible r_p. The value of ideal r_p is where inventory holding cost, B_s, is zero; whereas minimum feasible r_p is that value greater than or equal to d_s which has the minimum total cost. The condition at which minimum feasible r_p provides zero B_s supports just-in-time setting.

Another observation is that B_s, as a function of r_p, never follows a downward trend. The B_s curve is steeper up to a certain value of r_p and becomes flatter then after. Moreover, the switch from steepness to lower slope occurs at the same value of r_p, regardless of the choice of t_s. This can be interpreted as: increasing production technology up to a range means “produce and store” and this rapidly increases B_s. However, beyond some value of r_p, there is a considerably smoother increase. (This is due to the reverse effect of r_p to B_s)

These ranges may provide valuable information in deciding on the choice of change of production technology and speed.

If the current value of r_p is within the "smooth" range, r_p can further be increased without significant increase in inventory costs.

In such a case, resulting extra capacity can be allocated for the production of some other product, hence providing additional revenue. This may also increase utilization of the production capacity. Similarly if current r_p is in the "steep" range increase in r_p may be regarded with the consideration of significant increase in inventory cost.

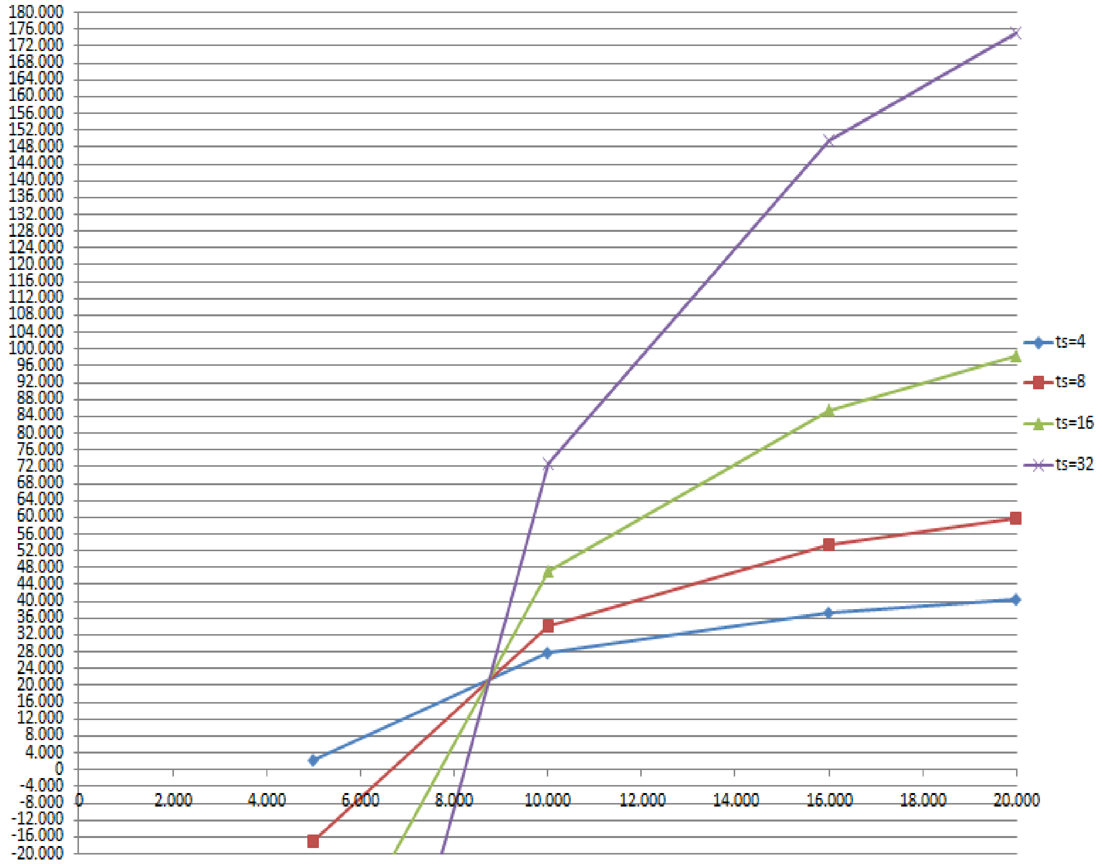

Figure 3.11: Effect of Changes in Production Rate of Suppliers on Inventory Holding Cost

The formula for the optimal decisions of the supplier (Equation 3.30) suggests that d_s is the main driver of supplier's all decisions.

To further analyze the decision variables, say t_s, we look at the derivative of the optimal t_s* with respect to d_s.

Since;

$$t_s^* = \sqrt{\frac{2K_p}{b_s d_s\left(1-\frac{d_s}{r_p}\right)}}$$

We look at;

$$\frac{d\left(d_s\left(1-{d_s}/{r_p}\right)\right)}{d(d_s)} = 1 - \frac{2d_s}{r_p}$$

Reminding the necessary condition of $r_p \geq d_s$ (Equation 3.26); it follows that; $1 - \frac{2d_s}{r_p} \geq 0$. Thus; $\frac{2d_s}{r_p} \leq 1$.

Now, if;

$r_p \geq 2d_s$; $\frac{d\left(d_s\left(1-\frac{d_s}{r_p}\right)\right)}{d(d_s)} \geq 0$; which means as d_s increases, the optimal value of t_s decreases. That is, the demand increase is met by more frequent production cycles.

On the other hand, if;

$r_p < 2d_s$; $\frac{d\left(d_s\left(1-\frac{d_s}{r_p}\right)\right)}{d(d_s)} < 0$; which means as d_s increases, the optimal value of t_s increases as well. In this case the demand increase is met by producing in higher lot sizes, thus less setups.

CHAPTER IV

ALTERNATIVE BUSINESS PROCUREMENT MODEL

4.1. Alternative Business Procurement Model

It may be possible to improve procurement process of a company through an alternative model that proposes to replenish the consolidated requirements of the regional manufacturers from suppliers through supply hubs located in proper places for all manufacturers.

The system, in such a model, consists of three levels, two echelons; suppliers, supply hubs and manufacturers. Suppliers may use same hubs commonly.

The following figure is to provide a schematic view of the process flows for the alternative business model;

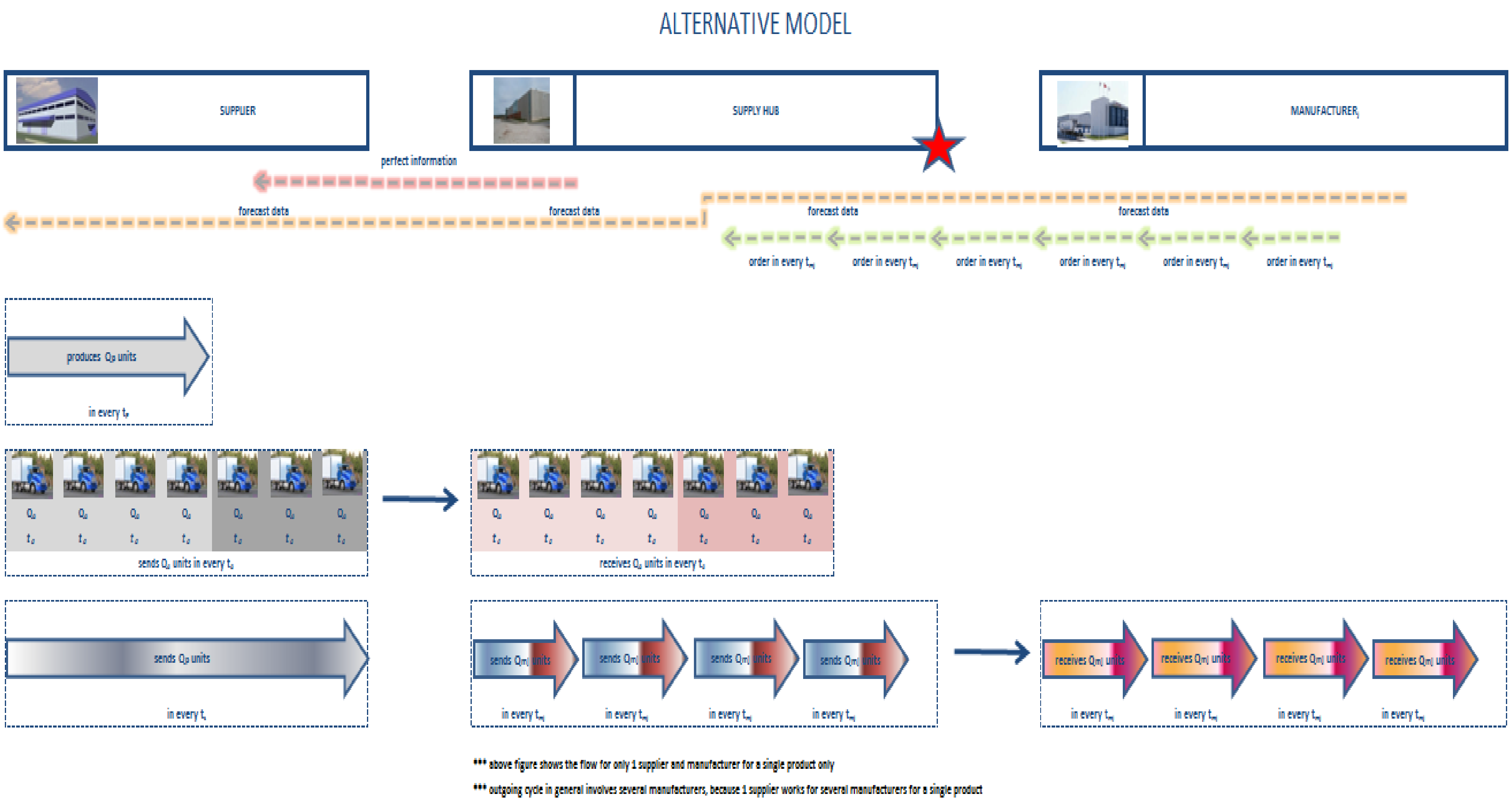

Figure 4.1: Business Flow in Alternative Business Model

We assume that throughout the chapter that in such an environment defined levels of safety stock is carried at each level of the supply chain. We further assume, perfect inventory information on the supply hubs is assumed to be available for each supplier. The part of the system from the supplier until the shipments from the supply hubs is assumed to be controlled by the suppliers. Fair enough, this entails the decision making authority within that part of the supply chain, to be carried out by the suppliers. For instance, safety stock levels at the suppliers and supply hubs are determined by the suppliers themselves. This viewpoint shows that supply hubs play the role of a stocking point for the suppliers, act as a transition warehouse and do not have decision making responsibility at all.

The whole process under consideration is triggered by the forecast information of the regional manufacturers received by the suppliers. The process involves replenishments from suppliers to supply hubs and shipments from the supply hubs to manufacturers in defined periods and for defined quantities.

Production runs at the suppliers are triggered once the inventory level at the supply hub is less than a predefined level. This whole process is repeated in a cycle. This setting necessitates the suppliers to analyze the requirements of all manufacturers collectively, check the inventory levels at their own location as well as at the supply hub and plan for their production runs accordingly. Each supplier decides on the frequency of production runs and how much to produce at each production run.

It is also the supplier who decides on the quantity, frequency of shipments from its site to the associated supply hub. Products are stored by the supply hub and consolidated for combined distribution to the manufacturers, based on orders received from the manufacturers. The manufacturers decide on the quantity of their orders and on the time interval of the shipment of orders.

One other issue that we consider in this model is the invoicing periods. As a deviation from the traditional model, the time of invoicing of an order is now realized at a later time; when the time the shipments are made from the supply hub to the manufacturer. This is different from the practice in the traditional case, where the invoicing is done as the shipment leaves the supplier's location. An important consequence of this will be the financial ownership of the inventory being transferred from the manufacturer to the supplier.

Supply chain network design comes out as a need for business development. The products that we consider both in the traditional and in the alternative model are the common high volume ones and the higher priced ones with long lead times.

We assume the demand for the most common products is more definite in the long term, analyzing the commonly used products is likely to demonstrate high inventory turnover, hence less obsolescence risk at the supply hub. This also sets the grounds of benefiting from economies of scale in many areas. Besides, high volume-high price products make any policy doubly important both in terms of cost optimization and in term of cash flow management.

Furthermore, the new supply chain infrastructure is expected to provide more flexibility and much lower lead time risks to manufacturers through use of supply hubs. That is enhanced by using closer supply hubs to substitute further away many manufacturers; hence reducing lead times. There is also a postponement of the decision on the ownerships of the products with the use of supply hubs. As the allocations of products to the manufacturers' demand are postponed, uncertainty situations are better covered. Besides, for unexpected situations, keeping aggregate inventory at the supply hub's site provides risk pooling as well. All improve the service levels through the whole supply chain.

Clearly, the model is also expected to bring some challenges to all parties involved, but on the other hand, if carefully managed, it can also provide significant benefits. Therefore, it becomes more important here to correctly identify, define and determine the decision variables for each party, based on the new system's structure. For instance, the number of less than truck load shipments will reduce or the postponement on the invoicing period will benefit the manufacturers on their cash flow management as the financial ownership of the inventory will be transferred to the manufacturers at a later step; however this will surely increase suppliers' costs.

To this end, within the context of this chapter, we first identify the optimal decisions for all parties with respect to the alternative model. We then search for conditions that these decisions are converted into benefit for all parties involved. For that, we will try to identify conditions for benefiting all parties and go into additional related discussions.

For a better understanding of the model, it is important to review each process involved in details.

Recalling that the system involves multiple manufacturers and multiple suppliers in scope, the alternative business process, as with the traditional model, is based on the forecast information for demand of products, D, provided by each regional manufacturer to the suppliers for related products over a planning period, T.

For a particular product, the sum of demands of manufacturers per unit time is then D/T. For a specific manufacturer j, this quantity is denoted by d_{mj}. The demand information is assumed to be deterministic and we further assume that each product is purchased from a single supplier.

The lead time is assumed to be fixed as in the traditional case. Backlogging is not allowed at any part of the supply chain, therefore, reasonable amount of safety stock is kept whereas necessary. The suppliers and regional manufacturers decide on their own safety stock levels. The safety stock levels at supply hubs are determined by the suppliers based on demand forecasts and lead times.

On a regional manufacturer side, continuous shipments of Q_{mj} units are received from the supply hub in every t_{mj} periods. Therefore, the inventory level at the manufacturer can be easily kept above the defined safety stock level of s_{mj} units. Each manufacturer *j* undertakes a fixed ordering cost of o_{mj} for each order issued and variable cost of c_{mj} per unit purchased. This sum up the total ordering cost per unit time, O_{mj}.

The cost structure at the manufacturer is similar to the "incoming" costs at a supply hub. Shipments of Q_{mj} units from the supply hub are received every t_{mj} periods as per the orders of the manufacturers. Each shipment has a fixed cost of K_{ha} and each per truck load cost is composed of full or less than truck load costs. There is a cost, a_{hf}, per full truck load of *TL* shipped from the supply hub and a cost, a_{hl}, per less than truck load of *TL* shipped. Together with the fixed cost, K_{ha}, per shipment forms the total transportation cost, A_{mj} per unit time. Customs and agencies cost of g_{mj1} per truck, g_{mj2} per unit and K_{mjg} per shipment received is incurred at the manufacturer's side every t_{mj} periods. The three components sum up to a customs and agencies cost of G_{mj} per unit time. For each unit received at the manufacturer's facilities, there is a handling cost of r_{mj}. This sum up to a cost of R_{mj} per unit time at the end.

The inventory stored by the manufacturer has a cost of b_{mj} per unit per unit time, along with an opportunity cost, u_{mj}, per unit per unit time. The total inventory cost per unit time of the manufacturer *j* then is I_{mj}.

The overall process described above repeats itself over cycles. We utilize this phenomenon in order to compute related costs per unit time.

Inventory movements for the alternative model at the suppliers' site may be modeled in analogy with those in traditional model. The incoming cycle will again repeat itself in every t_s periods. The main difference will be observed in terms of the outgoing inventory.

In the traditional model, one supplier is sending a single product to multiple manufacturers by one shipment for each supplier. In the alternative model, there are still multiple manufacturers, however, the supplier observes a single customer; the supply hub. That is why, the decisions variables of the supplier will not include the variables (t_{mj}, Q_{mj} and t_c) associated with manufacturers. The supplier will only face one consolidated demand point which is the supply hub and consider the replenishment periods as well as quantities to the hub only. Letting t_d represent the replenishment periods from the supplier to the supply hub and Q_d represent the replenishment quantities, the decision variables for the supplier in this case will be t_d and Q_d. Clearly, Q_d and t_d will, in part, be implied by the manufacturer parameters.

In summary, the incoming cycle for the supplier will repeat itself in every t_s periods and the outgoing cycle will repeat itself in every t_d periods. Accordingly, the whole system, including both the incoming and outgoing cycle, repeats itself in every t_o periods. In this case, t_o is taken as the least common multiple of t_s and t_d. This suggests that the structure is very similar with the previous model; with t_c being replaced by t_d.

As with the traditional case, each supplier collect demand information for the related products from the regional manufacturers, decide on its economic production quantity, Q_p, start producing at a rate of r_p and complete production in t_p periods. A fixed cost of K_p is incurred per production run at the supplier's side plus a variable cost of p_s per unit produced. This production related costs are incurred once in every cycle of t_s periods. This is the production run (incoming) cycle of the supplier and involves the production and shipment to the supply hub of Q_p units, We denote by P_s, the production cost per unit time of the supplier.

We assume that shipments in Q_d unit batches per t_d periods from the suppliers to the supply hub start immediately after the production starts. Thus the end of the production time period, t_p, part of the produced amount of Q_p is already sent to the supply hub. Each shipment of Q_d units generates a fixed shipment cost of K_{sa}.

Furthermore, the dispatch shipments may not be a multiple of truck load, *TL*. If this is the case, it is likely that last truck of every shipment is a less than truck load shipment. However, a business policy, which allows dispatch shipments in multiples of truck load, *TL*, eliminates less than truck load shipments from the supplier to the supply hub. We calculate the shipment cost in terms full and less than truck load shipments per each truck with a full truck cost of a_{sf} and a less than truck cost of a_{sl}.

This is helpful in analyzing the economies of scale in transportation in the alternative model in comparison to the traditional one. Fixed and per unit costs of transportation from supplier to the supply hub sum up to A_s which is the part of the total transportation cost per unit time incurred and managed by the suppliers. But, it an ex-works invoicing setting, these costs are re-invoiced to the manufacturers. Thus, we find it convenient to assume that suppliers take into consideration transportation cost from their sites to the supply hubs in the optimization of their decision variables;

but thereafter these costs are transferred to manufacturers by directly re-invoicing or by adding a sales price markup.

During that supplier cycle, inventory levels at the suppliers start to increase at a rate of r_p with the start of the production run. Inventory decreases by Q_d units every t_d periods, due to shipments to the supply hubs. The length of the production run is t_p periods. After that, the inventory is non-increasing, but the dispatch shipments to supply hubs decrease the inventory.

Finally, the inventory level reduces down to the supplier's safety stock level of s_s units when all the produced Q_p units are sent to the supply hub. This process repeats itself every t_o periods.

The supplier incurs a cost of b_s per unit time for each unit of inventory carried at its location, where the total inventory carrying cost per unit time at the supplier's location is B_s. Note that, instead of invoicing the materials to the manufacturers at the time of shipment, the suppliers in this business model send the items to an intermediate location. Thus, suppliers keep inventory at their locations as well as at supply hubs.

Due to the postponement of invoicing until the shipments are made from supply hubs to manufacturers, suppliers tie up money to their inventory for a longer time period as compared to the traditional case. This postponement in invoicing generates an additional opportunity cost. We denote by U_s the total opportunity per unit time in this business model. The total inventory carrying cost of the supplier per unit time, I_s, is the sum of B_s and U_s. Besides, as suppliers own the products until the products leave the supply hubs, the risks of transportation are now considered as suppliers' problems between the supplier and supply hubs.

Using a supply hub in the procurement model, results in an additional hub cost, Z_s. We assume this cost accounts for the rent and operating expenses for the hub and is a fixed cost stated as per unit time cost.

With perfect information on supply hub inventory levels, suppliers follow the policy of keeping inventory level of the hubs above the safety stock level.

This is done by replenishment cycles of Q_d units in periods of t_d. The safety stock level of the hub is a quantity determined in agreement by regional manufacturers and is based on the demand information.

The hub receives the dispatches, it incurs customs and agency costs of g_{h1} per truck, g_{h2} per unit and K_{hg} per shipment received. So, all customs and agencies related costs sum up to a total cost of G_h. This is undertaken by the supply hub per unit time.

Loading and unloading operations at the supply hub generates additional handling cost of r_h per unit. This totals to the receiving cost of R_h per unit time.

The supply hub receives Q_d units from the suppliers in every t_d periods. This inventory is accumulated until t_{mj} whereby Q_{mj} units are sent to the regional manufacturers *j*. Thus, the supply hub receives Q_d units of products in every t_d periods and sends Q_{mj} units to regional manufacturers *j* in every t_{mj} periods.

An inventory carrying cost of b_h per unit stored per unit time results in an inventory carrying cost per unit time, I_h, at the supply hub.

The incoming cycle at the supply hub repeats itself every t_d periods, whereas the outgoing cycle repeats itself in every least common multiple of t_{mj} periods. We denote this timeline with t_c. The whole system of incoming and outgoing cycles at the supply hub repeats itself in every least common multiple of t_d and t_c. This is denoted by t_o[1]. For instance, if the hub receives shipments from the supplier every 2 weeks and manufacturers 1, 2 and 3 require shipments every 3, 6 and 4 weeks, we have $t_d = 2$ for the incoming cycle and outgoing cycle repeats itself at least common multiple of 3,6 and 4, whereby $t_c = 12$. Thus, the cycle will repeat itself in every least common multiple of t_d and t_c. That is, LCM (2 ,12) = 12. Hence, we have $t_o^1 = 12$.

The next table summarizes key decision variables and parameters for the alternative business model;

Table 4.1: Cost Parameters and Decision Variables in Alternative Business Model

ALTERNATIVE BUSINESS MODEL			
Responsible	Decision		Cost
	Decision Definition	Decision Variable (DV)	
Supplier	total production quantity at supplier	Q_p	Inventory Cost (I_1) Production Cost (P_1) Transportation Cost (As) Supply Hub Cost (Z_1)
	time required for production at supplier	t_p	
	time between production runs at supplier	t_1	
	dispatch quantity per shipment from supplier	Q_d	
	time between each dispatch from supplier to supply hub	t_d	
Supply Hub	N/A	N/A	Inventory Cost (I_h) Receiving Cost (R_h) Customs and Agencies Cost (G_h)
Manufacturer	order quantity from manufacturer *j* and shipment quantity to manufacturer *j*	Q_{mj}	Inventory Cost (I_{mj}) Transportation Cost (A_{mj}) Receiving Cost (R_{mj}) Customs and Agencies Cost (G_{mj}) Ordering Cost (O_{mj})
	time between shipments to manufacturer *j* and time between orders from manufacturer *j*	t_{mj}	

Observe that, as a significant deviation from the traditional system, here the supplier decides, in addition to production related quantities, Q_p, t_p and t_s, also Q_d and t_d regarding shipments. We assume the hub does not have a decision making responsibility in the alternative business model. It is also reasonable to assume that with the alternative business models, manufacturers act, as they would in the traditional model.

4.1.1. Cost Formulations for all Parties

We follow the line of analysis as we do for the traditional case. We decompose the problem on products and carry out our analysis for a single product, single supplier and multiple manufacturers. We then demonstrate how the resulting analysis can be generalized to multiple suppliers, multiple manufacturers and multiple products. Further evidence on the decomposition of the multiple products and multiple suppliers are also presented within the cost formulations.

Since a single inventory is kept for a product at the supply hub for multiple manufacturers who follow different policies, decomposition on manufacturers is not valid. Therefore, our analysis involves multiple manufacturers.

We now derive the cost formulations for a single supplier providing a single product to the hub for distribution to many manufacturers.

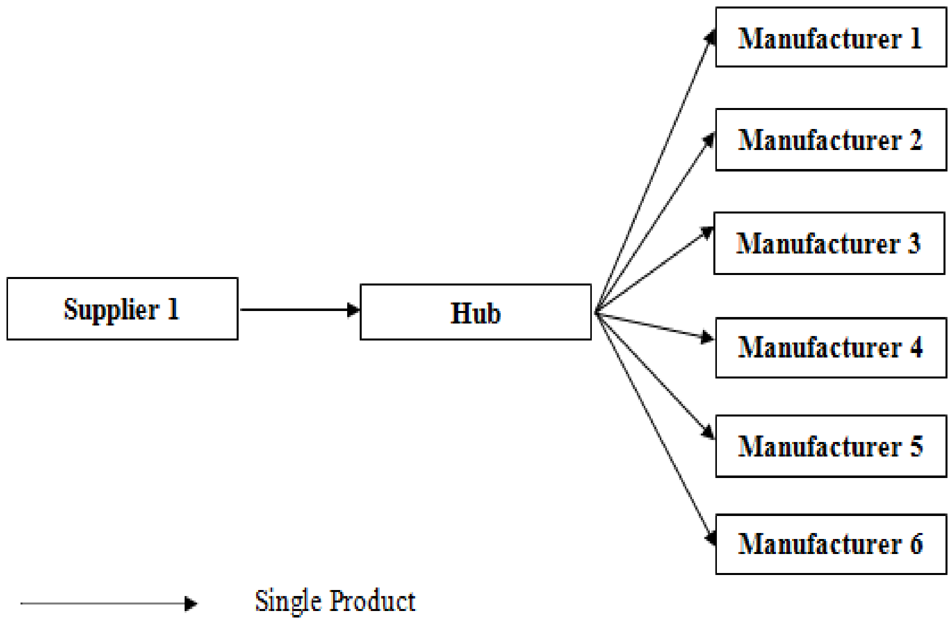

Figure 4.2: Decomposition Analysis in Alternative Model

Although we have developed the preceding discussion by implicitly assuming one single hub in the business process, the analysis we are about to present can easily be extended to include multiple hubs. To this end, we also include a discussion to decide on the optimal number and location of supply hubs.

Having reviewed the structure of the alternative model, it is now necessary to clarify the hub location problem as well. As all calculations on alternative model depend on the number and location of supply hubs, it is necessary to follow a simultaneous decision making on number / location of hubs and cost structures. Therefore, the model for defining the optimal location and number of hubs will be outlined before going further in cost formulations.

Since these decisions concerning the number and locations of hubs are strategic and also affect the subsequent decisions, we follow an approach that optimizes these decisions first. We then perform the rest of the analysis assuming the hub locations are known.

4.1.2. Hub Location Problem

The supply chain in the alternative system consists of multiple suppliers and multiple manufacturers trading multiple products over supply hub through the echelons. The decision on location and number of supply hub is an important strategic decision. This decision is usually a onetime decision and has a significant effect on system costs. For instance, transportation costs, customs costs and hub opening costs are the main cost items which, depend directly on the locations of supply hubs.

We will use mathematical programming approach to decide on the location and the number of the supply hubs. Here, we followed an assumption that direct shipments from the suppliers to the manufacturers are not allowed and each individual manufacturer is assigned to a supply hub.

We use index *i* for suppliers, *j* for manufacturers, *k* for products and *h* for supply hubs.

The cost components and related data are;

c1t(i,h)	transportation costs from supplier *i* to supply hub *h* per truck
c2t(h,j)	transportation costs from supply hub *h* to manufacturer *j* per truck
st(i,k)	total truckload supply of supplier *i* for product *k*
dt(j,k)	total truckload demand of manufacturer *j* for product *k*

vc(i,j,k)	customs and agencies cost per unit for product *k* from supplier *i* to manufacturer *j*
qty(i,j,k)	units of product *k* supplied from supplier *i* to manufacturer *j*
f(h)	fixed cost of opening supply hub *h*

The decision variables are;

s(i,h,k)	the number of trucks for product *k* transporting from supplier *i* to supply hub *h*
p(h,j,k)	the number of trucks for product *k* transporting from supply hub *h* to manufacturer *j*
z(h)	1 if supply hub *h* is opened and 0 otherwise
x(i,h,k)	1 if supplier *i* sends product k to supply hub *h* and 0 otherwise

Objective function;

$$\min \sum_{i=1}^{I}\sum_{h=1}^{H}\sum_{k=1}^{K} s_{ihk} c1t_{ih} + \sum_{h=1}^{H}\sum_{j=1}^{J}\sum_{k=1}^{K} p_{hjk} c2t_{hj} + \sum_{h=1}^{H} f_h z_h + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} vc_{ijk} qty_{ijk} \qquad \text{H}$$

Subject to;

$$\sum_{h=1}^{H} s_{ihk} \leq st_{ik} \qquad \forall \quad i,k \qquad \text{H.1}$$

$$\sum_{h=1}^{H} p_{hjk} \geq dt_{jk} \qquad \forall \quad j,k \qquad \text{H.2}$$

$$\sum_{i=1}^{I} s_{ihk} = \sum_{j=1}^{J} p_{hjk} \qquad \forall \quad h,k \qquad \text{H.3}$$

$$Mz_h \geq \sum_{i=1}^{I}\sum_{k=1}^{K} s_{ihk} \qquad \forall \quad h \qquad \text{H.4}$$

$$s_{ihk} \leq Mx_{ihk} \qquad \forall \quad i,h,k \qquad \text{H.5}$$

$$\sum_{h=1}^{H} x_{ihk} = 1 \qquad \forall \quad i,k \qquad \text{H.6}$$

$$\sum_{h=1}^{H} z_h = l \qquad \text{H.7}$$

The objective function tries to minimize transportation costs from suppliers to supply hubs and from hubs to manufacturers, *which are shown as the first and the second terms in the objective function, respectively*, plus the fixed cost of opened supply hubs and customs and agencies costs from suppliers to manufacturers, *which are the third and fourth terms in the objective function, respectively*. The part of the total cost which is the last term in the objective function is a constant value and will not affect the decision variables.

Constraint set H.1 ensures that the number of trucks transported from supplier *i* to supply hub *h* does not exceed the total supply available at the supplier. Constraint set H.2 states that the number of trucks transported from supply hub *h* to manufacturer *j* should not exceed the total demand of the manufacturer. Constraint set H.3 ensures that what is sent to the supply hubs from suppliers should be directed to manufacturers (controls total supply and total demand to be equal). Constraint set H.4 is necessary to ensure that any trucks are assigned to supply hub *h* only if the hub is opened. *M*, in this constraint, represents a big value.

For providing operational efficiency, each supplier is assigned to a single hub by constraint set H.5 and H.6. The number of supply hubs to be opened is limited to *l* in constraint H.7. The value of *l* can be chosen by the decision makers the constraint can be totally omitted to make the model decide on the optimal value. The two set of constrains serve to operational convenience and efficiency and improve the negotiation power.

The decisions on number and location of supply hubs can be made running the above model. The formulation can be run to allow a parametric analysis with significant insights. We demonstrate detailed examples in the next chapter.

Next we reveal the costs and optimal decisions for each party in the alternative model. In doing so, we assume that the decision on the number and location of hubs are made a priori, using the formulation above.

4.1.3. Cost Components of Manufacturers

In this section, we calculate the total cost of a specific manufacturer for a given product. The total cost of a manufacturer is composed of inventory cost which occurs due to the inventory kept at the manufacturers' location, transportation cost which occurs due to the shipments to the manufacturers from the supply hub, receiving cost of shipments received from the supply hub, customs and agencies cost for payments to related parties for the shipments received and ordering cost which occurs due to an order issued to the supply hub.

Transportation cost from the supply hub to the manufacturers is included because of the assumed ex-works sale that implies a delivery at the supply hub premises. As discussed the cost of transportation from suppliers to supply hub is managed by suppliers and re-invoiced to manufacturers.

In what follows, we give the formulation for a single manufacturer, single supplier and a single product.

Total Cost of the Manufacturer = Inventory Cost per unit time + Transportation Cost per unit time + Receiving Cost per unit time + Customs & Agencies Cost per unit time + Ordering Cost per unit time

Equation 4.1

$$\boldsymbol{TC_{m_j}} = \boldsymbol{I_{m_j}} + \boldsymbol{A_{m_j}} + \boldsymbol{R_{m_j}} + \boldsymbol{G_{m_j}} + \boldsymbol{O_{m_j}}$$

Computation of the Inventory Cost of the Manufacturer

$\boldsymbol{I_{m_j}}$ Total inventory carrying cost incurred by the manufacturer per unit time

The inventory carrying cost of the manufacturers is the sum of inventory holding cost and opportunity cost.

Equation 4.2

$$\boldsymbol{I_{m_j}} = \boldsymbol{B_{m_j}} + \boldsymbol{U_{m_j}}$$

$\boldsymbol{B_{m_j}}$ Total inventory holding cost incurred by the manufacturer per unit time

As with the traditional system, the manufacturer computes its economic order quantity (EOQ) and sends it to the supply hub this time, as an order. Therefore, the inventory figure of the manufacturer is again derived from EOQ model;

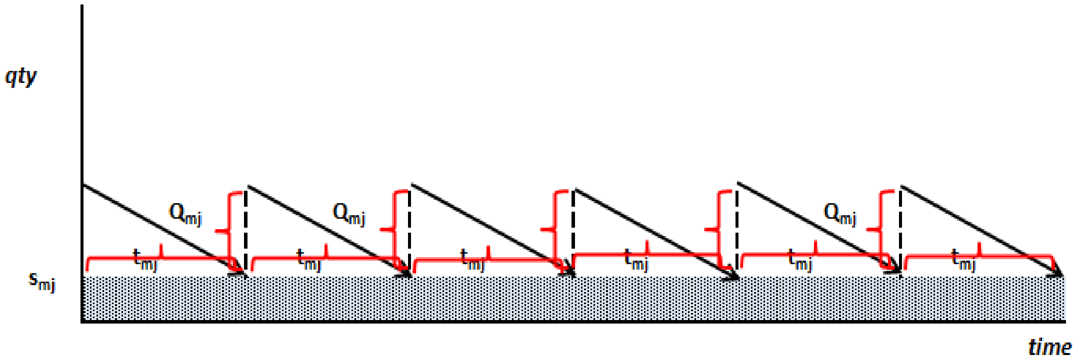

Figure 4.3: Inventory Flow of the Manufacturer in Alternative Business Model

Total inventory carried within (0, t_m) is equal to;

$$b_{m_j}\frac{Q_{m_j}t_{m_j}}{2}$$

Total inventory carried at the manufacturer per unit:

$$B_{m_j} = \frac{b_{m_j}\frac{Q_{m_j}t_{m_j}}{2}}{t_{m_j}} = b_{m_j}\frac{Q_{m_j}}{2}$$

Cost of safety stock is added over the inventory cost.

Therefore, the inventory cost of a specific manufacturer per unit time is formulated as follows;

<u>Equation 4.3</u>

$$B_{m_j} = b_{m_j}\left[s_{m_j} + \frac{Q_{m_j}}{2}\right]$$

This formulation can be extended to multiple manufacturers by adding a summation index for the manufacturers and products.

$\boldsymbol{U_{m_j}}$ Total opportunity cost per unit time incurred by the manufacturers for the inventory held at the manufacturer’s location

It follows that;

Equation 4.4

$$\boldsymbol{U_{m_j} = u_{m_j}\left(s_{m_j} + \frac{Q_{m_j}}{2}\right)}$$

Computation of the Transportation Cost of the Manufacturer

$\boldsymbol{A_{m_j}}$ Total transportation cost per unit time incurred by the manufacturers

In what follows, we compute the costs based on a single manufacturer. That is why we do not calculate the unit cost over the overall cycle, rather over the specific manufacturer’s cycle.

We have;

$$\boldsymbol{A_{m_j} = \frac{\left(\left\lfloor Q_{m_j}/TL \right\rfloor a_{hf}\right) + \left(\left(\left\lceil Q_{m_j}/TL \right\rceil - \left\lfloor Q_{m_j}/TL \right\rfloor\right) a_{hl}\right) + (K_{ha})}{t_{m_j}}}$$

The first term represents the cost of transportation of full truck loads per truck, the second term is for the less than truck load shipments and the third term is the fixed cost shipment.

The above can be re-written as follows;

Equation 4.5

$$A_{m_j} = \frac{\left(\left\lfloor {Q_{m_j}}/{TL} \right\rfloor a_{hf}\right) + a_{hl} + K_{ha}}{t_{m_j}}$$

Computation of the Receiving Cost of the Manufacturer

R_{m_j} Total cost per unit time of receiving incurred by the manufacturer

Equation 4.6

$$R_{m_j} = \frac{r_{m_j} Q_{m_j}}{t_{m_j}}$$

The formulation considers the receiving cost per unit.

Computation of the Customs and Agencies Cost of the Manufacturer

G_{m_j} Total cost of customs and agencies per unit time incurred by the manufacturer

Equation 4.7

$$G_{m_j} = \frac{K_{m_{jg}} + \left(g_{m_{j1}} \left\lceil {Q_{m_j}}/{TL} \right\rceil\right) + \left(g_{m_{j2}} Q_{m_j}\right)}{t_{m_j}}$$

The first term in the formulation represents the fixed cost paid to relevant parties per shipment received, the second term represents the variable costs per truck received and the third term is cost per unit received.

Computation of the Ordering Cost of the Manufacturer

$\boldsymbol{O_{m_j}}$ Total fixed cost per unit time of issuing orders incurred by the manufacturer

Equation 4.8

$$\boldsymbol{O_{m_j}} = \frac{\boldsymbol{o_{m_j}} + \left(\boldsymbol{c_{m_j} Q_{m_j}}\right)}{\boldsymbol{t_{m_j}}}$$

The first is the fixed cost of ordering and the second term is variable cost of each quantity purchased. We explicitly consider the unit cost even though it is policy- independent, in order to facilitate the discussions on markups that are presented further in the thesis.

Computation of the Total Cost of the Manufacturer

We are now in a position to give the total cost per unit time for a manufacturer (using Equations 4.3, 4.4, 4.5, 4.6, 4.7 and 4.8).

We use the superscript "*II*" to denote the alternative model.

Equation 4.9

$$\boldsymbol{TC_{m_j}}^{II} = \left(b_{m_j}\left[s_{m_j}{}^{II} + \frac{Q_{m_j}{}^{II}}{2}\right]\right) + \left(u_{m_j}\left[s_{m_j}{}^{II} + \frac{Q_{m_j}{}^{II}}{2}\right]\right)$$

$$+ \left(\frac{\left(\left\lceil {Q_{m_j}{}^{II}}/{TL} \right\rceil a_{hf}\right) + a_{hl} + K_{ha}}{t_{m_j}{}^{II}}\right) + \left(\frac{r_{m_j}{}^{II} Q_{m_j}{}^{II}}{t_{m_j}{}^{II}}\right)$$

$$+ \left(\frac{K_{m_{jg}}{}^{II} + \left(g_{m_{j1}}{}^{II}\left\lceil {Q_{m_j}{}^{II}}/{TL} \right\rceil\right) + \left(g_{m_{j2}}{}^{II} Q_{m_j}{}^{II}\right)}{t_{m_j}{}^{II}}\right)$$

$$+ \left(\frac{o_{m_j}{}^{II} + \left(c_{m_j}{}^{II} Q_{m_j}{}^{II}\right)}{t_{m_j}{}^{II}}\right)$$

4.1.4. Cost Components of Suppliers

As discussed earlier, we develop the analysis considering a single supplier, single product, single hub, and multiple manufacturers. The findings can be extended to the general case.

Total cost incurred by a supplier is composed of inventory carrying cost that occurs due to the inventory kept at the supplier's location, the opportunity cost that occurs due to money tied up to the inventory kept at the supplier's and at supply hub's location, the production cost related with production realized at the supplier's entity, the transportation cost of shipments realized from the supplier to the supply hub and finally the supply hub cost for hiring and operating a hub as a warehouse for inventory keeping and distribution purposes.

The alternative model involves an additional transportation cost generated at the supplier's site for the shipments from the supplier to the supply hub. In the alternative model, suppliers are the owners of the products until the products are shipped from the supply hub to the manufacturers. These costs will be included in the total cost of suppliers to be considered while determining the optimal values of decision variables. As mentioned earlier, these will then re-invoiced to the manufacturers or reflected to the sales price as markups.

The supplier decides on t_d which represents the frequency of shipments from the supplier to the supply hub as well as on Q_d quantity of shipments to the supply hub. Like in the traditional case, t_p and Q_p are also decided by the supplier. The operating policy for the suppliers is the same with the traditional model, in that there is a cycle of production and shipments. However, in the traditional model the supplier ships to multiple manufacturers, whereas in the alternative model, the supplier ships to one single hub only. Working with a supply hub instead of multiple manufacturers is important. This, in turn, induces a simpler business structure for the supplier and is expected to increase their operational efficiency.

In the alternative model, the opportunity cost of the supplier induces the opportunity cost of inventory held at a hub. Suppliers incur an opportunity cost for holding inventory at their own side as well as at the hub side. This is mainly related with the fact that it is the suppliers who own the inventory at supply hub.

The inventory of multiple products is depleted by multiple manufacturers; however our presentation is based on a derivation that accounts for a single manufacturer and a single product. We update our formulations later in order to accommodate multiple manufacturers and multiple products.

Total Cost of the Supplier per unit time = Inventory Cost per unit time + Transportation Cost per unit time + Production Cost per unit time + Supply Hub Cost per unit time

Equation 4.10

$$\boldsymbol{TC_s} = \boldsymbol{I_s} + \boldsymbol{A_s} + \boldsymbol{P_s} + \boldsymbol{Z_s}$$

Computation of the Inventory Cost of the Supplier

$\boldsymbol{I_s}$ Total inventory carrying cost per unit time incurred by the supplier

The inventory cycle involves the incoming flow at the suppliers which repeats by consecutive production runs, and the outgoing flow of the products which repeats by the shipments to the supply hub. We compute the costs related to these cycles considering an augmented cycle during which we observe the repetition of both incoming and outgoing cycles. This time period is denoted by t_o.

The first component, I_s, of the total cost (Equation 4.10) is given by;

Equation 4.11

$$\boldsymbol{I_s} = \boldsymbol{B_s} + \boldsymbol{U_s}$$

The first term is the inventory holding cost per unit time and the second term is the opportunity cost of the supplier per unit time.

$\boldsymbol{B_s}$ Total inventory holding cost per unit time incurred by the supplier

Similar to the traditional model, the rate in and rate out equality at the supplier's site is a necessary condition for feasibility. The incoming cycle will look exactly alike. As different from the traditional model, in this version, the suppliers see only one demand point; supply hub. Therefore, this time, the supplier ships Q_d units every t_d periods to the supply hub only. During the cycle time t_o, the outgoing inventory will be t_o/t_d times Q_d resulting in an outgoing inventory rate $t_o/t_d * Q_d/t_o = Q_d/t_d$: The necessary condition then turns into;

Equation 4.12

$$\frac{\boldsymbol{Q_p}}{\boldsymbol{t_s}} = \frac{\boldsymbol{Q_d}}{\boldsymbol{t_d}}$$

The following figure demonstrates the in an out cycles of the supplier over a time interval length t_o;

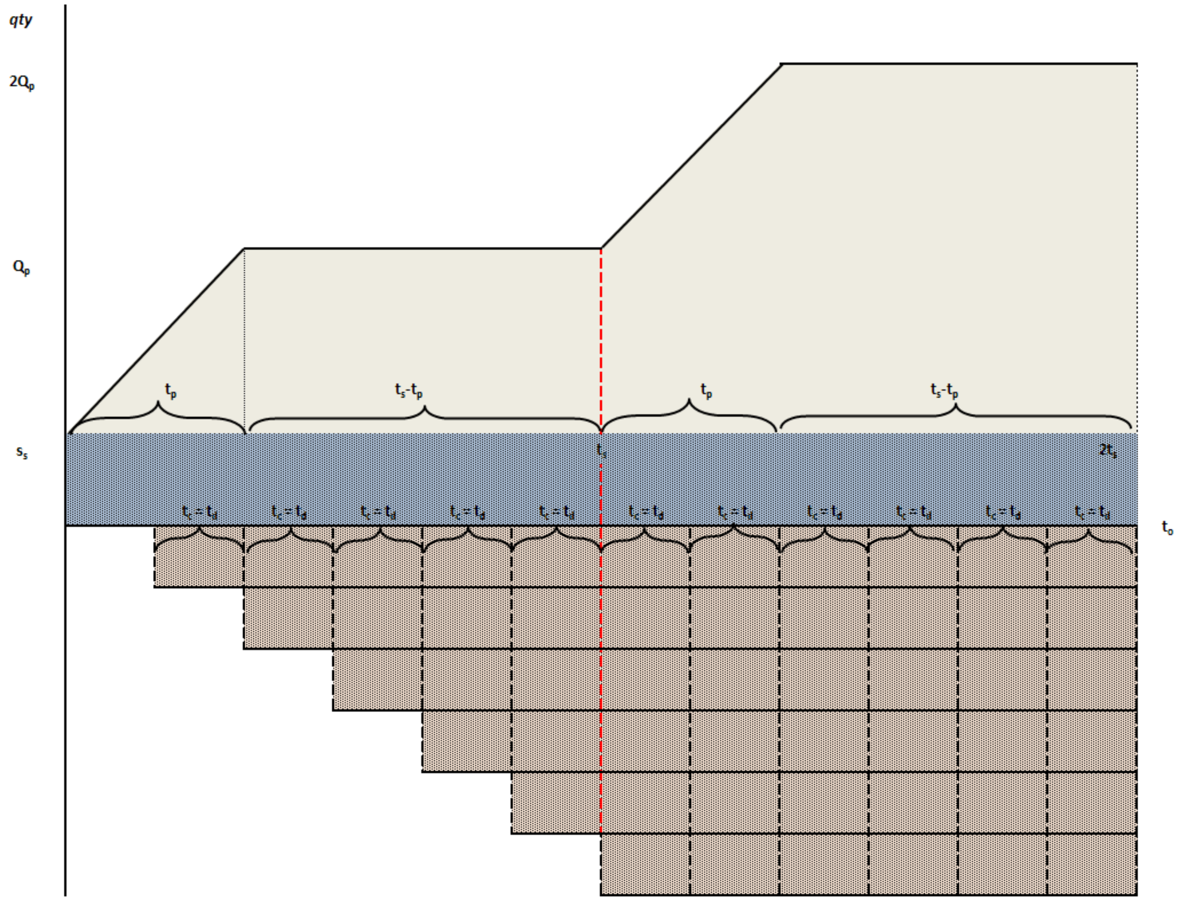

Figure 4.4: In and Out Flows of the Supplier in Alternative Business Model

We now observe that this figure demonstrates a special case of its counterpart in the traditional model. Hence, we can deduce the formulation for B_s replacing Q_{mj} with Q_d and t_{mj} with t_d in Equation 3.15. That is, we can depict the situation in the alternative model, as the traditional model with a single manufacturer asking for shipments of Q_d units per time period t_d.

Thus, the formulation for cost of holding inventory will be derived as follows;

Equation 4.13

$$\boldsymbol{B_s} = \boldsymbol{b_s}\left[\boldsymbol{s_s} + \left[\frac{\mathbf{1}}{\mathbf{2}}\left[\left[\boldsymbol{Q_p}\left(\frac{\boldsymbol{t_o} - \boldsymbol{t_p}}{\boldsymbol{t_s}} + \mathbf{1}\right)\right] - \left[\boldsymbol{Q_d}\left(\frac{\boldsymbol{t_o}}{\boldsymbol{t_d}} - \mathbf{1}\right)\right]\right]\right]\right]$$

Safety stock is again kept at the supplier as a policy decision, the cost of which added over the inventory level of the inventory cost. The second term represents the incoming inventory cost per unit time and the third term represents the outgoing inventory cost per unit time.

Now, we compute the opportunity cost of the supplier;

$\boldsymbol{U_s}$ Total opportunity cost per unit time incurred by the supplier for holding inventory at the supplier's and at the supply hub

Considering that, each one of the multiple products is stored at the supply hub's location for multiple manufacturers which follow different ordering policies; the inventory level calculation of the supply hub will include multiple manufacturers.

The component of this cost that is associated with carrying inventory at the supplier's side, can be computed following the same lines as in the computation of B_s; the only difference being the per unit per unit time cost, b_s, replaced by u_s.

That part of opportunity cost on the supply hub side, involves computing the average inventory per unit time at the supply hub. This is characterized by an incoming cycle of Q_d units every t_d periods and a collection of outgoing cycles of Q_{mj} units every t_{mj} for manufacturer *j*. This, then is, exactly alike with the inventory cycle of the supplier for the traditional case; difference is the incoming cycle, t_d, instead of t_s. This necessarily requires a different notation, t_o^1, for the cycle length of the supply hub to represent the least common multiples incoming flow, t_d, and outgoing flow, t_c. Thus, we can compute the average inventory of the supply hub by making the appropriate change of variables in (Equation 4.13, Equation 4.23) representing the inventory flow of the supplier with the traditional case.

For this, we replace the length of the incoming cycle t_s with t_d, leave the length of the outgoing cycle as t_c, replace the incoming amount per cycle Q_p with Q_d and leave outgoing amounts as Q_{mj}'s. Finally, we replace t_o = LCM (t_s, t_c) with t_o^1 = LCM (t_d, t_c).

This leads to;

Equation 4.14

$$\boldsymbol{U_s = u_s}\left[\left(\left[\boldsymbol{s_s} + \left[\frac{\mathbf{1}}{\mathbf{2}}\left[\left[\boldsymbol{Q_p}\left(\frac{\boldsymbol{t_o - t_p}}{\boldsymbol{t_s}} + \mathbf{1}\right)\right] - \left[\boldsymbol{Q_d}\left(\frac{\boldsymbol{t_o}}{\boldsymbol{t_d}} - \mathbf{1}\right)\right]\right]\right]\right]\right) + \left(\left[\boldsymbol{s_h} + \left[\frac{\boldsymbol{Q_d}}{\mathbf{2}}\left(\frac{\boldsymbol{t_{o^1}}}{\boldsymbol{t_d}} - \mathbf{1}\right) - \frac{\mathbf{1}}{\mathbf{2}}\left[\sum_{j=1}^{J}\boldsymbol{Q_{m_j}}\left(\frac{\boldsymbol{t_{o^1}}}{\boldsymbol{t_{m_j}}} - \mathbf{1}\right)\right]\right]\right]\right)\right]$$

Similarly, the first row above refers to the per unit time costs associated the inventory kept at the supplier's location and the second row refers the opportunity cost per unit time associated with inventory kept at the supply hub's location.

We discuss the inventory model of the hub in detail in Section 4.1.5.

<u>Computation of the Transportation Cost of the Supplier</u>

$\boldsymbol{A_s}$ Total transportation cost per unit time incurred by the supplier

This cost is incurred for a single shipment of Q_d units every t_d periods. It follows that;

$$\boldsymbol{A_s} = \frac{\left(\left\lfloor {Q_d}/{TL} \right\rfloor a_{sf}\right) + \left(\left(\left\lceil {Q_d}/{TL} \right\rceil - \left\lfloor {Q_d}/{TL} \right\rfloor\right) a_{sl}\right) + K_{sa}}{t_d}$$

The first term is the cost of full truck loads from the supplier to the supply hub and the second term is the cost of less than truck load shipments (This is always equal to 1 a_{sl}). The third term is the fixed cost of per shipment.

Simplifying, we have;

<u>Equation 4.15</u>

$$\boldsymbol{A_s} = \frac{\left(\left\lfloor {Q_d}/{TL} \right\rfloor a_{sf}\right) + a_{sl} + K_{sa}}{t_d}$$

<u>Computation of the Production Cost of the Supplier</u>

$\boldsymbol{P_s}$ Total production cost per unit time incurred by the supplier

As with the traditional case, the production runs for t_p periods to produce Q_p units. The time between start of two consecutive production runs is t_s.

The formulation for P_s, as with the traditional case (Equation 3.17) is;

Equation 4.16

$$P_s = \frac{K_p + (p_s Q_p)}{t_s}$$

Computation of the Supply Hub Cost of the Supplier

Z_s Fixed cost per unit time of renting and operating the hub incurred by the supplier

Equation 4.17

$$Z_s$$

We wish to remark that, normally the total fixed cost for renting and operating a single hub for a single product is shared between the suppliers based on various key parameters such as volume, distance, costs, and product specifications. We assume that Z_s represents the share of the specific supplier under consideration. Hence, the total fixed cost of a hub will be the sum of all Z_s allocated to all related suppliers.

Concerning our numerical analysis, we used the demand of suppliers as the key to allocate total fixed cost of suppliers. The choice of demand of suppliers is based on the fact that it closely affects main parameters like volume, fixed costs, holding costs and since it maintains other variables that identify the policy of the suppliers such as shipment frequencies and production cycles.

We also note that the decision on demand of suppliers may require a priori information on the fixed hub cost. This means, the allocation of total rent cost and decision on the main policy variables are mutually dependent. Thus, a simultaneous decision making process is needed. In order not to make the analysis much more complicated, we follow a sequential analysis. That is, we first identify the allocation of the hub cost to each supplier, and then identify the optimal values for the key decision variables accordingly.

Computation of the Total Cost of the Supplier

Based on the previous discussion, total cost per unit time of a single supplier can be formulated by summing up the cost components (Equations 4.13, 4.14, 4.15, 4.16 and 4.17)

Where necessary, we use the superscript "*II*" differentiate the parameters and variables from their counterparts in the traditional model.

Equation 4.18

$$
\begin{aligned}
\boldsymbol{TC_s}^{II} = & \left(b_s \left[s_s^{II} + \left[\frac{1}{2} \left[\left[Q_p^{II} \left(\frac{t_o^{II} - t_p^{II}}{t_s^{II}} + 1 \right) \right] - \left[Q_d \left(\frac{t_o^{II}}{t_d} - 1 \right) \right] \right] \right] \right] \right) \\
& + \left(u_s \left[\left(\left(\left[s_s^{II} + \left[\frac{1}{2} \left[\left[Q_p^{II} \left(\frac{t_o^{II} - t_p^{II}}{t_s^{II}} + 1 \right) \right] - \left[Q_d \left(\frac{t_o^{II}}{t_d} - 1 \right) \right] \right] \right] \right] \right) \right. \right. \right. \\
& + \left. \left. \left. \left(\left[s_h + \left[\frac{Q_d}{2} \left(\frac{t_{o^1}^{II}}{t_d} - 1 \right) - \frac{1}{2} \left[\sum_{j=1}^{J} Q_{m_j}^{II} \left(\frac{t_{o^1}^{II}}{t_{m_j}^{II}} - 1 \right) \right] \right] \right] \right) \right) \right] \right) \\
& + \left(\frac{\left(\left\lceil Q_d / TL \right\rceil a_{sf}^{II} \right) + a_{sl}^{II} + K_{sa}^{II}}{t_d} \right) + \left(\frac{K_p + \left(p_s Q_p^{II} \right)}{t_s^{II}} \right) + Z_s
\end{aligned}
$$

4.1.5. Cost Components of Supply Hubs

We now formulate the total cost per unit time of a supply hub based on a single supplier, single product and multiple manufacturers.

The total cost of a supply hub is composed of inventory carrying cost which occurs due to the inventories of several products kept for distribution to several manufacturers, receiving cost which occurs due to the shipments received from the suppliers and customs and agencies cost which occurs due to the payments realized for duty or to other parties for the shipments received from the suppliers.

Considering that each one of the multiple products is stored individually at the supply hub's location prior to shipment to associated manufacturers, the calculation of the inventory cost at the supply hub is carried out for multiple manufacturers.

For extending the formulations to multiple suppliers, multiple products and multiple hubs, we take the sum over associated parties and associated products.

Total Cost of the Supply Hub = Inventory Cost per unit time + Receiving Cost per unit time + Customs and Agencies Cost per unit time

Equation 4.19

$$\boldsymbol{TC_{sh}} = \boldsymbol{I_h} + \boldsymbol{R_h} + \boldsymbol{G_h}$$

Computation of the Inventory Cost of the Supply Hub

$\boldsymbol{I_h}$ Total inventory carrying cost per unit time at the supply hub

For an analysis of the inventory process of the supply hub, we again follow the "Rate In = Rate Out" approach at the hub site (This observation exposes other equalities which provides a valuable input for further analysis)

At the hub site, the incoming inventory is build up with every Q_d received, in every t_d. With a cycle length t_o, the accumulated incoming inventory is t_o/t_d times Q_d; thereby, an incoming rate Q_d/t_d at the hub site. On outgoing side, a shipment of Q_{mj} amounts is shipped to manufacturer j every t_{mj} periods. Over a cycle length t_c, the total inventory depleted is sum of (t_c/t_{mj} * Q_{mj}) values over j. Therefore, the outgoing inventory is built up at a rate of sum of all Q_{mj}/t_{mj}'s.

Now, rate in = rate out becomes;

<u>Equation 4.20</u>

$$\frac{Q_d}{t_d} = \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} = \frac{D}{T} = d$$

The algebraic sum of the incoming and outgoing inventories, result in the net inventory flow of the supply hub. This is shown in the following figure. Observe the overall cycle of length of t_o^1.

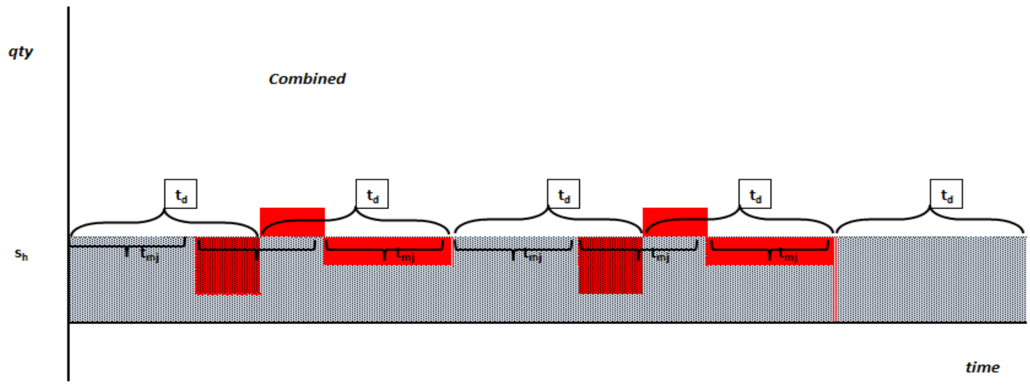

Figure 4.5: Net Inventory Flow of the Supply Hub in Alternative Business Model

The analysis turns out to be much complicated when attempted over the net inventory. We therefore, follow the analysis based on the in and out cycles. Thereafter, we take the sum (difference) to result in the new inventory flow.

The following figure shows the in and out cycles of a hub for a single manufacturer;

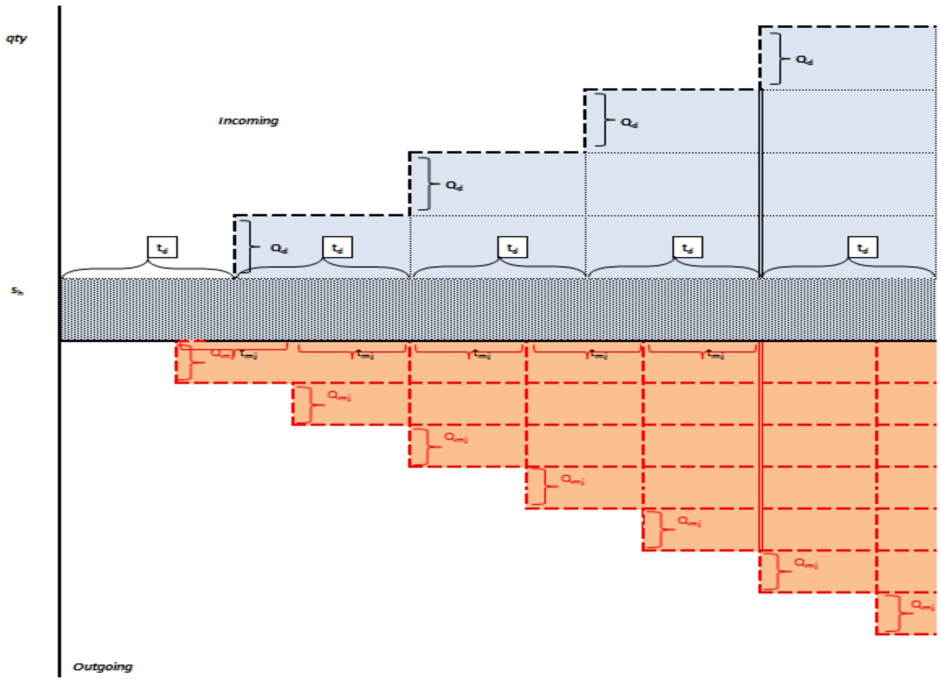

Figure 4.6: Inventory Flow of the Supply Hub in Alternative Business Model (Single Manufacturer)

The following figure shows the in and out inventory cycles of the hub with single supplier and multiple manufacturers.

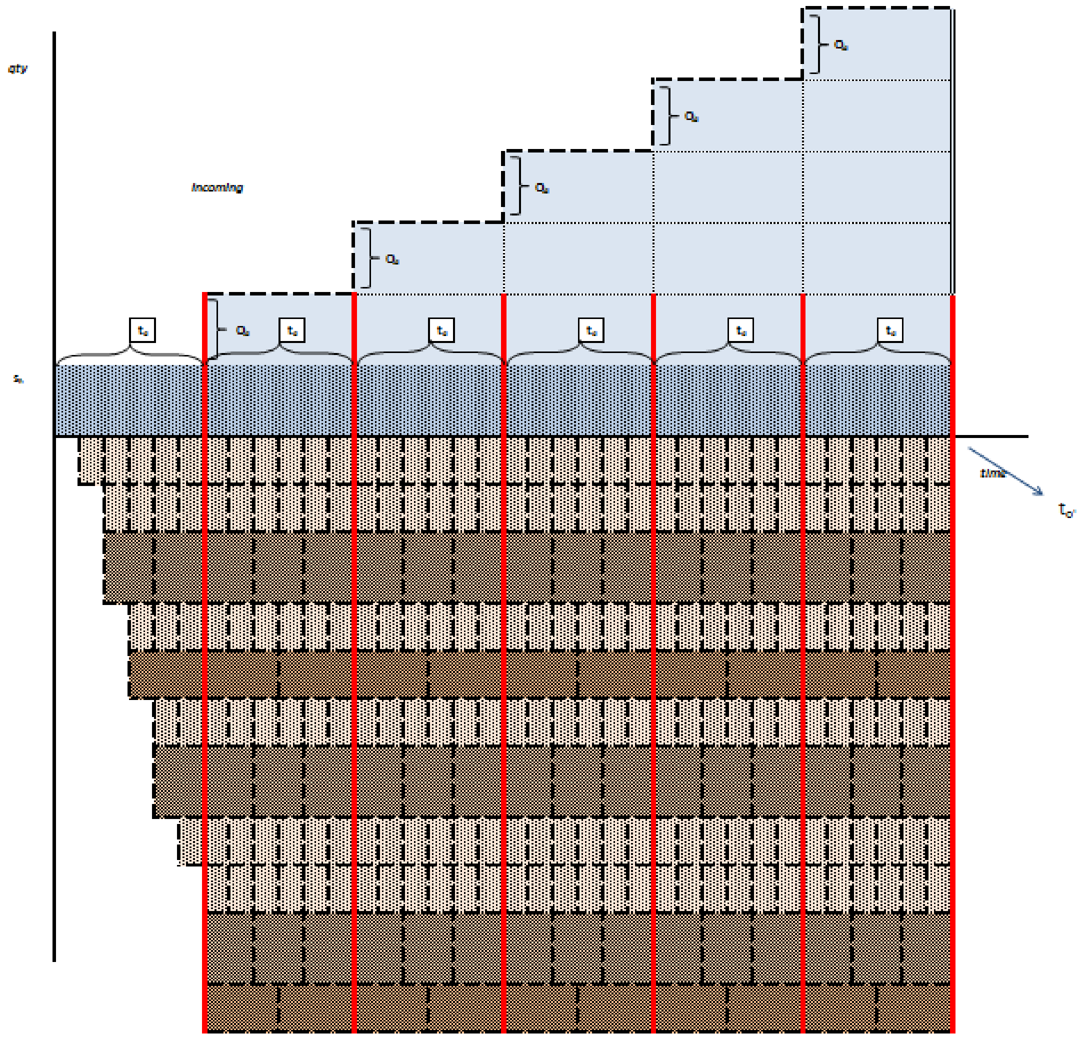

Figure 4.7: Inventory Flow of the Supply Hub in Alternative Business Model (Multiple Manufacturers)

Area (Incoming)

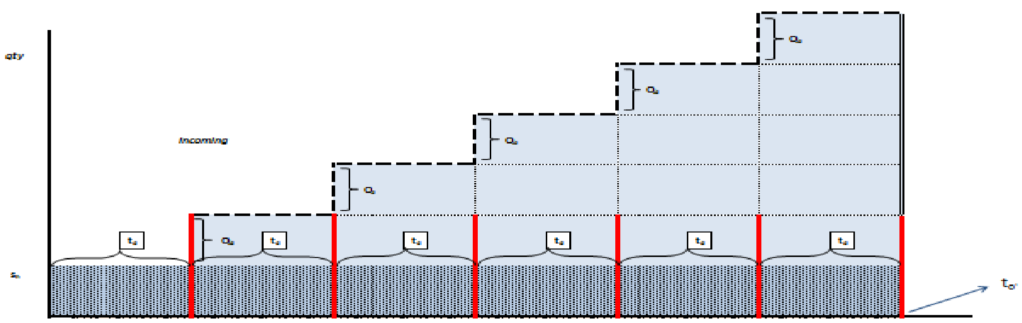

Figure 4.8: Incoming Inventory Flow of the Supply Hub in Alternative Business Model

Incoming Inventory = $\boldsymbol{Q_d t_d}\left(\left(\mathbf{1+2+3}\ldots\left(\frac{t_{o^1}}{t_d}-\mathbf{1}\right)\right)\right) = \boldsymbol{Q_d t_d}\frac{t_{o^1}}{t_d}\left(\frac{t_{o^1}}{t_d}-\mathbf{1}\right)\frac{\mathbf{1}}{\mathbf{2}}$

<u>Equation 4.21</u>

Incoming Inventory = $\frac{Q_d t_{o^1}}{2}\left(\frac{t_{o^1}}{t_d}-\mathbf{1}\right)$

Area (Outgoing)

We make use of the following figure to compute the outgoing inventory cost. The figure demonstrates inventory from resulting from shipments to multiple manufacturers.

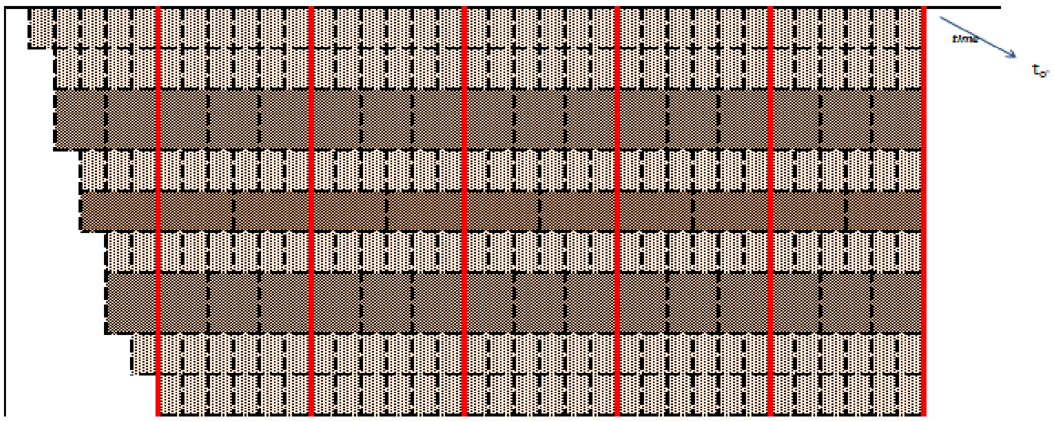

Figure 4.9: Outgoing Inventory Flow of the Supply Hub in Alternative Business Model

The area here is very similar to supplier's outgoing inventory (Figure 3.9, Section 3.1.3). The only difference the cycle length, that is, t_o in Section 3.1.3, t_o^1 in this case.

Hence, the formula can be derived similarly by replacing t_o in Equation 3.14 with t_o^1;

Equation 4.22

Outgoing Inventory = $\frac{1}{2}\left[\sum_{j=1}^{J} \boldsymbol{Q_{m_j}}\, \boldsymbol{t_{o^1}} \left(\frac{t_{o^1}}{t_{m_j}} - \mathbf{1}\right)\right]$

Thereby,

$$\boldsymbol{I_h = b_h} * \left[\boldsymbol{s_h} + \left[\frac{\frac{\boldsymbol{Q_d t_{o^1}}}{\mathbf{2}}\left(\frac{\boldsymbol{t_{o^1}}}{\boldsymbol{t_d}} - \mathbf{1}\right) - \frac{\mathbf{1}}{\mathbf{2}}\left[\sum_{j=1}^{J} \boldsymbol{Q_{m_j}}\, \boldsymbol{t_{o^1}}\left(\frac{\boldsymbol{t_{o^1}}}{\boldsymbol{t_{m_j}}} - \mathbf{1}\right)\right]}{\boldsymbol{t_{o^1}}}\right]\right]$$

The equation can further be simplified as;

Equation 4.23

$$\boldsymbol{I_h = b_h} * \left[\boldsymbol{s_h} + \left[\frac{\boldsymbol{Q_d}}{\mathbf{2}}\left(\frac{\boldsymbol{t_{o^1}}}{\boldsymbol{t_d}} - \mathbf{1}\right) - \frac{\mathbf{1}}{\mathbf{2}}\left[\sum_{j=1}^{J} \boldsymbol{Q_{m_j}}\left(\frac{\boldsymbol{t_{o^1}}}{\boldsymbol{t_{m_j}}} - \mathbf{1}\right)\right]\right]\right]$$

Computation of the Receiving Cost of the Supply Hub

$\boldsymbol{R_h}$ Total cost of receiving incurred by the supply hub per unit time

The formulation for R_h is as follows;

Equation 4.24

$$R_h = \frac{r_h Q_d}{t_d}$$

The formulation considers the handling cost per unit, r_h, which accounts for the loading and unloading operations at the supply hub.

Computation of the Customs and Agencies Cost of the Supply Hub

G_h Total cost per unit time of customs and agencies incurred by the supply hub

The formulation for G_h is as follows;

Equation 4.25

$$G_h = \frac{K_{hg} + \left(g_{h1} \left\lceil Q_d / TL \right\rceil\right) + (g_{h2} Q_d)}{t_d}$$

The first term represents the fixed cost paid to other parties per shipment whereas the second term represents the variable costs per truck received and the third term is the for the cost per unit received.

Computation of the Total Cost of the Supply Hub

Now, we are in a position to compute the total cost per unit time of a supply hub (using Equations 4.23, 4.24 and 4.25)

The superscript “*II*” is used to denote the alternative model.

Equation 4.26

$$TC_h{}^{II} = \left(b_h * \left[s_h + \left[\frac{Q_d}{2}\left(\frac{t_{o^1}{}^{II}}{t_d} - 1\right) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}{}^{II} \left(\frac{t_{o^1}{}^{II}}{t_{m_j}{}^{II}} - 1 \right) \right] \right] \right] \right) + \left(\frac{r_h Q_d}{t_d} \right)$$

$$+ \left(\frac{K_{hg} + \left(g_{h1} \left\lceil Q_d / TL \right\rceil \right) + (g_{h2} Q_d)}{t_d} \right)$$

4.1.6. Total Cost of the Supply Chain in Alternative Procurement Model

On the manufacturer side, total cost formulations are derived based on a single manufacturer buying a single product from a single supplier through supply hub. However, in business model, there are multiple manufacturers, buying multiple products from multiple suppliers which, in alternative business model,

In the alternative model, multiple manufacturers receive multiple products from multiple numbers of supply hubs.

The total cost formulation for a single manufacturer is extended to multiple manufacturers and multiple products while considering the hub transshipments accordingly.

We include indices *j*, *k* and *h* to differentiate between manufacturers, products and hubs, respectively.

Equation 4.27

$$
\begin{aligned}
&\boldsymbol{TC_m}^{\boldsymbol{II}} \\
&= \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{k=1}^{K}\left(\boldsymbol{b_{m_j}}^{\boldsymbol{k}}\left[\boldsymbol{s_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}} + \frac{\boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}{\boldsymbol{2}}\right]\right) + \left(\boldsymbol{u_{m_j}}^{\boldsymbol{k}}\left[\boldsymbol{s_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}} + \frac{\boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}{\boldsymbol{2}}\right]\right) \\
&+ \left(\frac{\left(\left\lceil \boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}} \big/ \boldsymbol{TL^k} \right\rceil \boldsymbol{a_{hf}}^{\boldsymbol{k}}{}_{\boldsymbol{h_j}}\right) + \boldsymbol{a_{hl}}^{\boldsymbol{k}}{}_{\boldsymbol{h_j}} + \boldsymbol{K_{ha}}^{\boldsymbol{k}}{}_{\boldsymbol{h_j}}}{\boldsymbol{t_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}\right) + \left(\frac{\boldsymbol{r_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}\boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}{\boldsymbol{t_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}\right) \\
&+ \left(\frac{\boldsymbol{K_{m_{jg}}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}} + \left(\boldsymbol{g_{m_{j1}}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}\left\lceil \boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}} \big/ \boldsymbol{TL^k}\right\rceil\right) + \left(\boldsymbol{g_{m_{j2}}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}\boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}\right)}{\boldsymbol{t_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}\right) \\
&+ \left(\frac{\boldsymbol{o_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}} + \left(\boldsymbol{c_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}\boldsymbol{Q_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}\right)}{\boldsymbol{t_{m_j}}^{\boldsymbol{II^k}}{}_{\boldsymbol{h}}}\right)
\end{aligned}
$$

For the supplier side, total cost formulations are derived based on a single supplier producing and selling a single product to multiple manufacturers through a defined supply hub. However, in the business model, there are multiple suppliers who produce and sell multiple products to multiple manufacturers. Therefore, we can extend the formulation to multiple suppliers and multiple products.

For generality in the number of supply hubs, we add the subscript *h* as the supply hub index. We also differentiate the supply hub cost to account for the dependency on the particular products, suppliers, and manufacturers.

Thereby, the hub cost for a single product, over all suppliers and hence products using the supply hub, is;

<u>Equation 4.28</u>

$$\boldsymbol{Z_s^k = \sum_{i=1}^{I} {Z_s}^k{}_i}$$

Now, we have;

<u>Equation 4.29</u>

$$TC_s{}^{II} = \Bigg[\sum_{h=1}^{H} \sum_{i=1}^{I} \sum_{k=1}^{K} \Bigg(b_s{}^{k}{}_{i} \Big[s_s{}^{II^k}{}_{i_h}$$

$$+ \Bigg[\frac{1}{2} \Bigg[\Bigg[Q_p{}^{II^k}{}_{i} \Big(\frac{t_o{}^{II^k}{}_{i_h} - t_p{}^{II^k}{}_{i}}{t_s{}^{II^k}{}_{i}} + 1 \Big) \Bigg] - \Bigg[Q_d{}^{k}{}_{i_h} \Big(\frac{t_o{}^{II^k}{}_{i_h}}{t_d{}^{k}{}_{i_h}} - 1 \Big) \Bigg] \Bigg] \Bigg] \Bigg] \Bigg)$$

$$+ \Bigg(u_s{}^{k}{}_{i} \Bigg[\Bigg(\Bigg(\Bigg[s_s{}^{II^k}{}_{i_h}$$

$$+ \Bigg[\frac{1}{2} \Bigg[\Bigg[Q_p{}^{II^k}{}_{i} \Big(\frac{t_o{}^{II^k}{}_{i_h} - t_p{}^{II^k}{}_{i}}{t_s{}^{II^k}{}_{i}} + 1 \Big) \Bigg] - \Bigg[Q_d{}^{k}{}_{i_h} \Big(\frac{t_o{}^{II^k}{}_{i_h}}{t_d{}^{k}{}_{i_h}} - 1 \Big) \Bigg] \Bigg] \Bigg] \Bigg] \Bigg)$$

$$+ \Bigg(\Bigg(\Bigg[s_h{}^{k}{}_{i_h}$$

$$+ \Bigg[\frac{Q_d{}^{k}{}_{i_h}}{2} \Bigg(\frac{t_{o^1}{}^{II^k}{}_{i_h}}{t_d{}^{k}{}_{i_h}} - 1 \Bigg) - \frac{1}{2} \Bigg[\sum_{j=1}^{J} Q_{m_j}{}^{II^k}{}_{h} \Bigg(\frac{t_{o^1}{}^{II^k}{}_{i_h}}{t_{m_j}{}^{II^k}{}_{h}} - 1 \Bigg) \Bigg] \Bigg] \Bigg] \Bigg) \Bigg] \Bigg)$$

$$+ \left(\frac{\left(\left(\left[Q_d{}^{k}{}_{i_h} \middle/ TL^k \right] a_{sf}{}^{II^k}{}_{i_h} \right) + a_{sl}{}^{II^k}{}_{i_h} + K_{sa}{}^{II\,k}{}_{i_h} \right)}{t_d{}^{k}{}_{i_h}} \right)$$

$$
+\left(\frac{K_{p\,i}^{\;k}+\left(p_{s\,i}^{\;k}Q_{p\;\;i}^{\;IIk}\right)}{t_{s\;\;i}^{\;IIk}}\right)+Z_{s\;\;i_h}^{\;k}\Bigg]
$$

For convenience, we set the associated quantities to be zero when k is not shipped from i to j.

In the alternative model, there is a third party involved in the business. That is the supply hub. Total cost of the supply chain will certainly include the costs associated with the supply hub. The number of hubs is also an important decision variable. The system may propose a single hub or multiple hubs to be opened.

<u>Equation 4.30</u>

$$TC_h{}^{II} = \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K}\left(b_h{}^k{}_h \right.$$

$$* \left[s_h{}^k{}_{i_h} \right.$$

$$+ \left[\frac{Q_d{}^k{}_{i_h}}{2}\left(\frac{t_{o^1}{}^{II^k}{}_{i_h}}{t_d{}^k{}_{i_h}} - 1 \right) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}{}^{II^k}{}_h \left(\frac{t_{o^1}{}^{II^k}{}_{i_h}}{t_{m_j}{}^{II^k}{}_h} - 1 \right) \right] \right] \left. \right] \left. \right)$$

$$+ \left(\frac{r_h{}^k{}_{i_h} Q_d{}^k{}_{i_h}}{t_d{}^k{}_{i_h}} \right)$$

$$+ \left(\frac{K_{hg}{}^k{}_{i_h} + \left(g_{h1}{}^k{}_{i_h} \left[{Q_d{}^k{}_{i_h}}/{TL^k} \right] \right) + \left(g_{h2}{}^k{}_{i_h} Q_d{}^k{}_{i_h} \right)}{t_d{}^k{}_{i_h}} \right)$$

Finally, the total cost per unit time of the supply chain for the alternative model is derived from Equations 4.27, 4.29 and 4.30 as follows;

<u>Equation 4.31</u>

$$TC_{SC}^{II} = \sum_{j=1}^{J}\sum_{h=1}^{H}\sum_{k=1}^{K}\left(b_{m_j}{}^{k}\left[s_{m_j}{}^{II^k}{}_{h} + \frac{Q_{m_j}{}^{II^k}{}_{h}}{2}\right]\right) + \left(u_{m_j}{}^{k}\left[s_{m_j}{}^{II^k}{}_{h} + \frac{Q_{m_j}{}^{II^k}{}_{h}}{2}\right]\right) + \left(\frac{\left(\left|Q_{m_j}{}^{II^k}{}_{h}/TL^k\right| a_{hf}{}^{k}{}_{hj}\right) + a_{hl}{}^{k}{}_{hj} + K_{ha}{}^{k}{}_{hj}}{t_{m_j}{}^{II^k}{}_{h}}\right) + \left(\frac{r_{m_j}{}^{II^k}{}_{h} Q_{m_j}{}^{II^k}{}_{h}}{t_{m_j}{}^{II^k}{}_{h}}\right) +$$

$$\left(\frac{K_{m_{jg}}{}^{II^k}{}_{h} + \left(g_{m_{j1}}{}^{II^k}{}_{h}\left|Q_{m_j}{}^{II^k}{}_{h}/TL^k\right|\right) + \left(g_{m_{j2}}{}^{II^k}{}_{h} Q_{m_j}{}^{II^k}{}_{h}\right)}{t_{m_j}{}^{II^k}{}_{h}}\right) + \left(\frac{o_{m_j}{}^{II^k}{}_{h} + \left(c_{m_j}{}^{II^k}{}_{h} Q_{m_j}{}^{II^k}{}_{h}\right)}{t_{m_j}{}^{II^k}{}_{h}}\right) +$$

$$\left[\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K}\left(b_{s}{}^{k}{}_{i}\left[s_{s}{}^{II^k}{}_{ih} + \left[\frac{1}{2}\left[\left[Q_{p}{}^{II^k}{}_{i}\left(\frac{t_o{}^{II^k}{}_{ih} - t_p{}^{II^k}{}_{i}}{t_s{}^{II^k}{}_{i}} + 1\right)\right] - \left[Q_{d}{}^{k}{}_{ih}\left(\frac{t_o{}^{II^k}{}_{ih}}{t_d{}^{k}{}_{ih}} - 1\right)\right]\right]\right]\right]\right) + \left(u_{s}{}^{k}{}_{i}\left[\left(\left(\left[s_{s}{}^{II^k}{}_{ih} + \left[\frac{1}{2}\left[\left[Q_{p}{}^{II^k}{}_{i}\left(\frac{t_o{}^{II^k}{}_{ih} - t_p{}^{II^k}{}_{i}}{t_s{}^{II^k}{}_{i}} + 1\right)\right] - \left[Q_{d}{}^{k}{}_{ih}\left(\frac{t_o{}^{II^k}{}_{ih}}{t_d{}^{k}{}_{ih}} - 1\right)\right]\right]\right]\right]\right) +$$

$$\left(\left[s_{h}{}^{k}{}_{ih} + \left[\frac{Q_d{}^{k}{}_{ih}}{2}\left(\frac{t_{o^1}{}^{II^k}{}_{ih}}{t_d{}^{k}{}_{ih}} - 1\right) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}{}^{II^k}{}_{h}\left(\frac{t_{o^1}{}^{II^k}{}_{ih}}{t_{m_j}{}^{II^k}{}_{h}} - 1\right)\right]\right]\right]\right)\right]\right) +$$

$$\left(\frac{\left(\left|Q_d{}^{k}{}_{ih}/TL^k\right| a_{sf}{}^{II^k}{}_{ih}\right) + a_{sl}{}^{II^k}{}_{ih} + K_{sa}{}^{II\,k}{}_{ih}}{t_d{}^{k}{}_{ih}}\right) + \left(\frac{K_p{}^{k}{}_{i} + \left(p_s{}^{k}{}_{i} Q_p{}^{II^k}{}_{i}\right)}{t_s{}^{II^k}{}_{i}}\right) +$$

$$\left.{Z_s}^{k}{}_{i_h}\right] + \sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{k=1}^{K}\left({b_h}^{k}{}_{h} * \right.$$

$$\left[{s_h}^{k}{}_{i_h} + \left[\frac{{Q_d}^{k}{}_{i_h}}{2}\left(\frac{{t_{o^1}}^{IIk}{}_{i_h}}{{t_d}^{k}{}_{i_h}} - \mathbf{1}\right) - \frac{1}{2}\left[\sum_{j=1}^{J} {Q_{m_j}}^{IIk}{}_{h}\left(\frac{{t_{o^1}}^{IIk}{}_{i_h}}{{t_{m_j}}^{IIk}{}_{h}} - \mathbf{1}\right)\right]\right]\right]\right) + \left(\frac{{r_h}^{k}{}_{i_h}{Q_d}^{k}{}_{i_h}}{{t_d}^{k}{}_{i_h}}\right) +$$

$$\left(\frac{{K_{hg}}^{k}{}_{i_h} + \left({g_{h1}}^{k}{}_{i_h}\left\lceil {Q_d}^{k}{}_{i_h}/_{TL^k}\right\rceil\right) + \left({g_{h2}}^{k}{}_{i_h}{Q_d}^{k}{}_{i_h}\right)}{{t_d}^{k}{}_{i_h}}\right)$$

4.2. Analysis and Findings on Alternative Model

4.2.1. Notes for Manufacturers

At manufacturer's side, main decision variables are order quantities and their frequencies. Therefore, manufacturers decide on their best Q_{mj} and t_{mj} in order to minimize their own costs which are generated from inventory holding, transportation, receiving, customs and agencies and ordering costs.

The analysis on defining best Q_{mj} and t_{mj} is derived over $TC_{manufacturer}$ (Equation 4.9). We take the derivate of $TC_{manufacturer}$ with respect to Q_{mj} and equated to zero to define the best policy for manufacturers.

We take Q_{mj} to be the independent variable and make the change of variable;

Replace $t_{mj} = Q_{mj}/d_{mj}$

Thus, total cost of the manufacturer is re-written as;

$$TC_{m_j} = \left(b_{m_j}\left[s_{m_j} + \frac{Q_{m_j}}{2}\right]\right) + \left(u_{m_j}\left[s_{m_j} + \frac{Q_{m_j}}{2}\right]\right) + \left(\frac{\left(\left\lfloor {Q_{m_j}}/{TL} \right\rfloor a_{hf}\right) + a_{hl} + K_{ha}}{\frac{Q_{m_j}}{d_{m_j}}}\right) + \left(\frac{r_{m_j} Q_{m_j}}{\frac{Q_{m_j}}{d_{m_j}}}\right) + \left(\frac{K_{m_{jg}} + \left(g_{m_{j1}} \left\lceil {Q_{m_j}}/{TL} \right\rceil\right) + \left(g_{m_{j2}} Q_{m_j}\right)}{\frac{Q_{m_j}}{d_{m_j}}}\right) + \left(\frac{o_{m_j} + \left(c_{m_j} Q_{m_j}\right)}{\frac{Q_{m_j}}{d_{m_j}}}\right)$$

That is;

$$TC_{m_j} = b_{m_j} s_{m_j} + b_{m_j}\frac{Q_{m_j}}{2} + u_{m_j} s_{m_j} + u_{m_j}\frac{Q_{m_j}}{2} + \frac{a_{hf} d_{m_j}}{TL} + \frac{a_{hl} d_{m_j}}{Q_{m_j}} + \frac{K_{ha} d_{m_j}}{Q_{m_j}} + r_{m_j} d_{m_j} + \frac{K_{m_{jg}} d_{m_j}}{Q_{m_j}} + \frac{g_{m_{j1}} d_{m_j}}{TL} + g_{m_{j2}} d_{m_j} + \frac{o_{m_j} d_{m_j}}{Q_{m_j}} + c_{m_j} d_{m_j}$$

Now, the derivative with respect to Q_{mj} is;

In Chapter 3, we note that "$\lceil \quad \rceil$ ***and*** $\lfloor \quad \rfloor$" is acceptable to remove.

$$\frac{dTC_{m_j}}{dQ_{m_j}} = 0$$

$$\frac{b_{m_j}}{2}+\frac{u_{m_j}}{2}-a_{hl}d_{m_j}Q_{m_j}{}^{-2}-K_{ha}d_{m_j}Q_{m_j}{}^{-2}-K_{m_{jg}}d_{m_j}Q_{m_j}{}^{-2}-o_{m_j}d_{m_j}Q_{m_j}{}^{-2}$$

$$=0$$

<u>Equation 4.32</u>

$$Q_{m_j}{}^{*}=\sqrt{\frac{2\left(a_{hl}+K_{ha}+K_{m_{jg}}+o_{m_j}\right)d_{m_j}}{b_{m_j}+u_{m_j}}}$$

Best value for the time between orders, Q_{mj}, for the manufacturer can then be obtained using $t_{mj}^{*} = Q_{mj}^{*}/d_{mj}$.

The formula shows the effect of full and less than truck load transportation costs from the supply hub to the manufacturer on manufacturer's best ordering policy in the alternative business model.

Recalling the traditional model, the optimal value of Q_{mj} in that case was given by Equation 3.23. That also included full and less than truck load transportation costs, this time from the supplier to the manufacturer. Other than that, the two formulas are the same (see Equation 4.33).

<u>Equation 4.33</u>

$$\sqrt{\frac{2\left(a_{sl}+K_{sa}+K_{m_{jg}}+o_{m_j}\right)d_{m_j}}{b_{m_j}+u_{m_j}}}\;vs\;\sqrt{\frac{2\left(a_{hl}+K_{ha}+K_{m_{jg}}+o_{m_j}\right)d_{m_j}}{b_{m_j}+u_{m_j}}}$$

From the managerial perspective, operational differences between the traditional model and alternative model are significant. In the traditional business model, manufacturers work directly with several suppliers whereas in the alternative model, manufacturers work directly with the supply hub only. This may, for instance, possibly leads manufacturers to work with less expertise while supplying products, it may, on the other hand, bring operational efficiency due to a simpler process structure and negotiation power in the management of the supply process as well.

Any change in the value of Q_{mj} changes manufacturer's operations, which in turn changes manufacturer's total cost. However, it is not direct to argue whether the traditional model or the alternative model induces smaller cost by just looking at the values of Q_{mj}* for each scenario. Clearly, the cost depends on other parameters such as supplier - hub distances, manufacturer – supplier distances.

In the next chapter, we present a detailed numeric study to establish a basis for comparing the two business models.

Another important observation regarding the above formula is that, the best value for Q_{mj} is independent of Q_d. This implies that, it does not make sense to give the decision making authority on the determination of Q_d to the manufacturer. This, coupled with the earlier discussion, shows that with rational decision making, it should be the supplier who decides on the value of Q_d.

4.2.2. Notes for Suppliers

Each supplier decides on their best production and dispatch quantities and frequencies, based on the associated inventory holding, production, transportation and fixed supply hub costs.

Fixed cost of supply hub is a fixed (rent) cost and is invariant of the actual costs generated at the supply hub. Therefore, while deciding on the best values for Q_p, Q_d, t_s, t_d and t_p, supplier would consider only the costs associated with its own site, including the fixed cost of the hub, and not consider the actual costs that are realized at the supply hub. However, not considering the actual supply hub costs may in turn hinder rational decision making. This is because, supplier's decisions on, for instance, dispatch quantity and its frequency, directly affects the decisions on space to be rented at the supply hub as it induces the inventory level at the supply hub. This, in return, affects what the fixed cost of supply hub will be. Moreover, suppliers need to rationally decide on their dispatch quantity and its frequencies considering the fact that these will be stored at a limited space in the hub which is defined by both parties in advance. Therefore, the collaboration between the suppliers and third parties necessitates the consideration of the actual costs generated at their site as well as at the hub site while deciding on the optimal values of their key decision variables. If only fixed costs are considered, supplier sends everything to hub.

To this end, we will derive best values of Q_p, Q_d, t_s, t_d and t_p in an attempt to minimize the sum of supplier cost and hub cost per unit time. We also include a discussion that assumes the associated decisions are made by considering only the costs at the associated party. That is, by considering supplier's cost or hub cost only. We do this in order to provide an insightful discussion that is made possible by a comparison of merits of decisions for both settings.

Recall that, we have $Q_d = d_s * t_d$ and $Q_p = r_p * t_p$. Furthermore, $t_s = d_s * Q_p$. We take Q_p and Q_d as the independent variables and

Replace $t_d = Q_d/d_s$

$t_p = Q_p/r_p$

$t_s = Q_p/d_s$

As with the analysis in the traditional case, we redefine t_o = LCM (ts, tc) to be $t_o = t_s * t_c$ and t_o^1 = LCM (t_d, t_c) to be $t_o^1 = t_d * t_c$

Now, with the change of variables $t_o = (Q_p/d_s)(Q_d/d_s)$ and t_o^1 =is $(Q_d/d_s)t_c$

Through these change of variables, we have;

$$TC_s = b_s\left[s_s + \left[\frac{1}{2}\left[\left[Q_p\left(\frac{\frac{Q_d}{d_s}\frac{Q_p}{d_s} - \frac{Q_p}{r_p}}{\frac{Q_p}{d_s}} + 1\right)\right] - \left[Q_d\left(\frac{\frac{Q_d}{d_s}\frac{Q_p}{d_s}}{\frac{Q_d}{d_s}} - 1\right)\right]\right]\right]\right]$$

$$+ u_s\left[\left(\left[s_s + \left[\frac{1}{2}\left[\left[Q_p\left(\frac{\frac{Q_d}{d_s}\frac{Q_p}{d_s} - \frac{Q_p}{r_p}}{\frac{Q_p}{d_s}} + 1\right)\right] - \left[Q_d\left(\frac{\frac{Q_d}{d_s}\frac{Q_p}{d_s}}{\frac{Q_d}{d_s}} - 1\right)\right]\right]\right]\right]\right)$$

$$+ \left(\left[s_h + \left[\frac{Q_d}{2}\left(\frac{t_c\frac{Q_d}{d_s}}{\frac{Q_d}{d_s}} - 1\right) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}\left(\frac{t_c\frac{Q_d}{d_s}}{t_{m_j}} - 1\right)\right]\right]\right]\right)\right]$$

$$+ \frac{\left(\left[{}^{Q_d}/_{TL}\right] a_{sf}\right) + a_{sl} + K_{sa}}{\frac{Q_d}{d_s}} + \frac{K_p + (p_s Q_p)}{\frac{Q_p}{d_s}} + Z_s$$

One can verify that upon some algebraic manipulation, the above is simplified as;

$$TC_s = b_s s_s + \frac{b_s Q_d Q_p}{2d_s} - \frac{b_s Q_p d_s}{2r_p} + \frac{b_s Q_p}{2} - \frac{b_s Q_d Q_p}{2d_s} + \frac{b_s Q_d}{2} + u_s s_s + \frac{u_s Q_d Q_p}{2d_s}$$

$$- \frac{u_s Q_p d_s}{2r_p} + \frac{u_s Q_p}{2} - \frac{u_s Q_d Q_p}{2d_s} + \frac{u_s Q_d}{2} + u_s s_h + \frac{u_s t_c Q_d}{2} - \frac{u_s Q_d}{2}$$

$$- \frac{u_s t_c Q_d}{2d_s}\sum_{j=1}^{J}\frac{Q_{m_j}}{t_{m_j}} + \frac{u_s}{2}\sum_{j=1}^{J} Q_{m_j} + \frac{da_{sf}}{TL} + \frac{da_{sl}}{Q_d} + \frac{dK_{sa}}{Q_d} + \frac{dK_p}{Q_p}$$

$$+ p_s d_s + Z_s$$

We can now examine the decision based on supplier's costs only. Best value of Q_p for the supplier can be identified by taking the derivative of total cost of the supplier with respect to Q_p and equating it to zero.

For each formulation of the optimal values for the decision variables in the thesis by taking derivatives, we made sure that this gives the minimum point, by looking at the second derivative also, but did not show it here. One interested reader can easily verify this.

$$\frac{dTC_s}{dQ_p} = 0$$

$$\frac{b_s Q_d}{2d_s} - \frac{b_s d_s}{2r_p} + \frac{b_s}{2} - \frac{b_s Q_d}{2d_s} + \frac{u_s Q_d}{2d_s} - \frac{u_s d_s}{2r_p} + \frac{u_s}{2} - \frac{Q_d u_s}{2d_s} - K_p d_s {Q_p}^{-2} = 0$$

It can be verified that the above equality turns into;

Equation 4.34

$${Q_p}^* = \sqrt{\frac{2K_p d_s}{(b_s + u_s)\left(1 - \frac{d_s}{r_p}\right)}}$$

We can now compute the best values of the dependent variables t_s and t_p using Q_p/d_s and Q_p/r_p, respectively.

Revisiting Equation 3.31 that states the best production batch size, Q_p^*, for traditional business model, we observe that, it is the exact same formula of the best Q_p^* for alternative business model. If we assume that the parameters K_p, d_s and r_p of the system do not change in the alternative model, Q_p^* will exactly be the same for the suppliers. This means, changing the business model do not affect the production quantity decision of the suppliers, if all other parameters remain unchanged.

In order to give a comprehensive definition of the best policy at the supplier's side, it is necessary to identify best value of Q_d as well. Best Q_d for the supplier can be identified by taking the derivative of total cost per unit time of the supplier with respect to Q_d and equating it to zero;

$$\frac{dTC_s}{dQ_d} = 0$$

$$\frac{b_s Q_p}{2d_s} - \frac{b_s Q_p}{2d_s} + \frac{b_s}{2} + \frac{u_s Q_p}{2d_s} - \frac{u_s Q_p}{2d_s} + \frac{u_s}{2} + \frac{u_s t_c}{2} - \frac{u_s}{2} - \frac{u_s t_c}{2d_s}\sum_{j=1}^{J}\frac{Q_{m_j}}{t_{m_j}} - d_s a_{sl} {Q_d}^{-2} - K_{sa} d_s {Q_d}^{-2} = 0$$

It can be verified easily that the formula can be further simplified as;

$$\frac{b_s}{2} + \frac{u_s t_c}{2} - \frac{u_s t_c}{2d_s}\sum_{j=1}^{J}\frac{Q_{m_j}}{t_{m_j}} = d_s a_{sl} {Q_d}^{-2} + K_{sa} d_s {Q_d}^{-2}$$

<u>Equation 4.35</u>

$${Q_d}^{*} = \sqrt{\frac{2d_s(a_{sl} + K_{sa})}{b_s}}$$

Best Q_d at the supplier's side changes as proportionate with the square root of the fixed cost of transportation per shipment plus less than truck load cost per truck shipped. Q_d^* is inversely proportionate with the square root of unit inventory holding cost at the supplier's site.

We now extend the analysis to the decision making situation where a joint consideration of supplier and hub costs is in effect.

Performing the changes of variables a before, we rewrite the hub cost per unit time as;

$$TC_h = \left(b_h * \left[s_h + \left[\frac{Q_d}{2}\left(\frac{t_c \frac{Q_d}{d_s}}{\frac{Q_d}{d_s}} - 1 \right) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}\left(\frac{t_c \frac{Q_d}{d_s}}{t_{m_j}} - 1 \right) \right] \right] \right] \right) + \left(\frac{r_h Q_d}{\frac{Q_d}{d_s}} \right)$$
$$+ \left(\frac{K_{hg} + \left(g_{h1} \left| {Q_d}/{TL} \right| \right) + (g_{h2} Q_d)}{\frac{Q_d}{d_s}} \right)$$

Upon some algebraic manipulation, the formula can be simplified as;

$$TC_h = \left(b_h * \left[s_h + \left[\frac{Q_d}{2}(t_c - 1) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}\left(\frac{t_c \frac{Q_d}{d_s}}{t_{m_j}} - 1 \right) \right] \right] \right] \right) + (r_h d_s)$$
$$+ \left(\frac{K_{hg} d_s}{Q_d} + \frac{g_{h1}\, d_s}{TL} + g_{h2} d_s \right)$$

$$TC_h = b_h s_h + \frac{b_h t_c Q_d}{2} - \frac{b_h Q_d}{2} - \frac{b_h t_c Q_d}{2 d_s} \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} + \frac{b_h}{2} \sum_{j=1}^{J} Q_{m_j} + r_h d_s + \frac{K_{hg} d_s}{Q_d}$$
$$+ \frac{g_{h1}\, d_s}{TL} + g_{h2} d_s$$

Summing the supplier total cost per unit time and hub total cost per unit time, we have;

$$TC_{s+h} = b_s s_s + \frac{b_s Q_d Q_p}{2d_s} - \frac{b_s Q_p d_s}{2r_p} + \frac{b_s Q_p}{2} - \frac{b_s Q_d Q_p}{2d_s} + \frac{b_s Q_d}{2} + u_s s_s + \frac{u_s Q_d Q_p}{2d_s}$$
$$- \frac{u_s Q_p d_s}{2r_p} + \frac{u_s Q_p}{2} - \frac{u_s Q_d Q_p}{2d_s} + \frac{u_s Q_d}{2} + u_s s_h + \frac{u_s t_c Q_d}{2} - \frac{u_s Q_d}{2}$$
$$- \frac{u_s t_c Q_d}{2d_s} \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} + \frac{u_s}{2} \sum_{j=1}^{J} Q_{m_j} + \frac{d_s a_{sf}}{TL} + \frac{d_s a_{sl}}{Q_d} + \frac{d_s K_{sa}}{Q_d} + \frac{d_s K_p}{Q_p}$$
$$+ p_s d_s + Z_s + b_h s_h + \frac{b_h t_c Q_d}{2} - \frac{b_h Q_d}{2} - \frac{b_h t_c Q_d}{2d_s} \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}$$
$$+ \frac{b_h}{2} \sum_{j=1}^{J} Q_{m_j} + r_h d_s + \frac{K_{hg} d_s}{Q_d} + \frac{g_{h1} d_s}{TL} + g_{h2} d_s$$

which simplifies to;

$$TC_{s+h} = b_s s_s - \frac{b_s Q_p d_s}{2r_p} + \frac{b_s Q_p}{2} + \frac{b_s Q_d}{2} + u_s s_s - \frac{u_s Q_p d_s}{2r_p} + \frac{u_s Q_p}{2} + u_s s_h$$
$$+ \frac{u_s t_c Q_d}{2} - \frac{u_s t_c Q_d}{2d_s} \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}} + \frac{u_s}{2} \sum_{j=1}^{J} Q_{m_j} + \frac{d_s a_{sf}}{TL} + \frac{d_s a_{sl}}{Q_d} + \frac{d_s K_{sa}}{Q_d}$$
$$+ \frac{d_s K_p}{Q_p} + p_s d_s + Z_s + b_h s_h + \frac{b_h t_c Q_d}{2} - \frac{b_h Q_d}{2} - \frac{b_h t_c Q_d}{2d_s} \sum_{j=1}^{J} \frac{Q_{m_j}}{t_{m_j}}$$
$$+ \frac{b_h}{2} \sum_{j=1}^{J} Q_{m_j} + r_h d_s + \frac{K_{hg} d_s}{Q_d} + \frac{g_{h1} d_s}{TL} + g_{h2} d_s$$

Best value for Q_p can be identified by taking the derivative of total cost with respect to Q_p and equating it to zero;

$$\frac{dTC_{s+h}}{dQ_p} = 0$$

$$-\frac{b_s d_s}{2r_p} + \frac{b_s}{2} - \frac{u_s d_s}{2r_p} + \frac{u_s}{2} - K_p d_s {Q_p}^{-2} = 0$$

which can be restated as;

<u>Equation 4.36</u>

$$Q_p^{\,*} = \sqrt{\frac{2K_p d_s}{(b_s + u_s)\left(1 - \frac{d_s}{r_p}\right)}}$$

This is the same as the optimal value of Q_p when only the supplier cost is considered.

It turns out that, with all other parameters being constant, the optimal production batch size for the suppliers will be the same for traditional model and for alternative model both when we consider supplier's costs explicitly and when we consider both supplier's and supply hub's costs.

Similarly, the best value of Q_d can be determined policy by taking the derivative of total cost of the supplier and hub with respect to Q_d and equating it to zero;

$$\frac{dTC_{s+h}}{dQ_d} = 0$$

$$\frac{b_s}{2} + \frac{u_s t_c}{2} - \frac{u_s t_c}{2d_s}\sum_{j=1}^{J}\frac{Q_{m_j}}{t_{m_j}} - a_{sl} d_s {Q_d}^{-2} - K_{sa} d_s {Q_d}^{-2} + \frac{b_h t_c}{2} - \frac{b_h}{2} - \frac{b_h t_c}{2d_s}\sum_{j=1}^{J}\frac{Q_{m_j}}{t_{m_j}} - K_{hg} d_s {Q_d}^{-2} = 0$$

The formula is simplified as;

$$\frac{b_s - b_h}{2} = \frac{d_s\left(a_{sl} + K_{sa} + K_{hg}\right)}{{Q_d}^2}$$

Thus, best value of Q_d is outlined as;

<u>Equation 4.37</u>

$$Q_d^* = \sqrt{\frac{2d_s\left(a_{sl} + K_{sa} + K_{hg}\right)}{b_s - b_h}}$$

Now recalling best value of Q_d identified by considering the supplier's cost only (Equation 4.35), we observe that the two formulas are different. Fixed customs and agencies cost of the hub is now included in the numerator. Moreover, the unit inventory holding cost for the hub, b_h, appears with a (-) sign in the denominator. As b_h increases, (b_s – b_h) decreases, which in turn increases the best Q_d value.

One significant implication of this result on Q_d^* is that the formula admits a feasible result only if "$b_s > b_h$". This addresses a rational approach since it states that, it makes sense to keep inventory at the supply hub only if the inventory holding cost at the supplier is larger than the inventory holding cost at the supply hub.

Otherwise, it is rational to keep any inventory at the supplier rather than sending it to a more expensive hub. The best policy or the supplier would be to use the hub only as a cross dock. We also note that, as b_h gets larger, (b_s - b_h) gets smaller. This increases the Q_d* value which calls for sending larger batches in less frequency to the supply hub resulting in savings from fixed cost of shipments.

In order to provide further insight, we now analyze how the best value of Q_d would be computed if we took hub cost only into consideration. For this, we take the derivative of total per unit time of the hub with respect to Q_d and equated to zero;

That is;

$$TC_h = b_h s_h + \frac{b_h t_c Q_d}{2} - \frac{b_h Q_d}{2} - \frac{b_h t_c Q_d}{2d_s}\sum_{j=1}^{J}\frac{Q_{m_j}}{t_{m_j}} + \frac{b_h}{2}\sum_{j=1}^{J} Q_{m_j} + r_h d_s + \frac{K_{hg} d_s}{Q_d}$$
$$+ \frac{g_{h1} d_s}{TL} + g_{h2} d_s$$

$$\frac{dTC_h}{dQ_d} = 0$$

$$-\frac{b_h}{2} - K_{hg} d_s {Q_d}^{-2} = 0$$

<u>Equation 4.38</u>

$${Q_d}^* = \sqrt{\frac{2d_s K_{hg}}{-b_h}}$$

It turns out that transferring the decision making responsibility on the best value of Q_d to the supply hub is an infeasible approach by considering hub costs extensively.

This makes sense, since with rational decision making, supply hub will always propose smaller and smaller Q_d to arrive and incur smaller and smaller costs. That is, use hub as a cross dock, in order to minimize hub costs in total ignorance of costs at the supplier's side.

These findings clearly suggest that, the decision making responsibility on the best Q_d policy should not be given to the supply hub. It is best to led suppliers decide on the best Q_d by joint consideration of suppliers costs and hub costs.

4.3. Comparison on Total Supply Chain Costs Traditional Model and Alternative Model

Since we now have a statement of the total cost per unit time for all parties involved, for both models, we are now in a position to make a side-by-side comparison of the two.

That is, we look at the difference of the total cost of the players of the supply chain per unit time for the traditional model with that for the alternative model. We expect this, to provide insights on the conditions for the alternative business model to suggest benefits for each party in the overall supply chain.

4.3.1. Manufacturers

Total costs per unit time for manufacturers for the traditional model and the alternative model are given by Equations 3.9 and 4.9, respectively. Like we did for the suppliers, we look at the difference of the two.

Here, we use the change of the variables; Replace $t_{mj} = Q_{mj}/t_{mj}$

$$TC_{m_j}{}^{II} - TC_{m_j}{}^{I}$$

$$= \Bigg[\left(b_{m_j} \left[s_{m_j}{}^{II} + \frac{Q_{m_j}{}^{II}}{2} \right] \right) + \left(u_{m_j} \left[s_{m_j}{}^{II} + \frac{Q_{m_j}{}^{II}}{2} \right] \right)$$

$$+ \left(\frac{\left(\left[{Q_{m_j}{}^{II}}/{TL} \right] a_{hf} \right) + a_{hl} + K_{ha}}{\frac{Q_{m_j}{}^{II}}{d}} \right) + \left(\frac{r_{m_j}{}^{II} Q_{m_j}{}^{II}}{\frac{Q_{m_j}{}^{II}}{d}} \right)$$

$$+ \left(\frac{K_{m_{jg}}{}^{II} + \left(g_{m_{j1}}{}^{II} \left| {Q_{m_j}{}^{II}}/{TL} \right| \right) + \left(g_{m_{j2}}{}^{II} Q_{m_j}{}^{II} \right)}{\frac{Q_{m_j}{}^{II}}{d}} \right)$$

$$+ \left(\frac{o_{m_j}{}^{II} + \left(c_{m_j}{}^{II} Q_{m_j}{}^{II} \right)}{\frac{Q_{m_j}{}^{II}}{d}} \right) \Bigg]$$

$$- \Bigg[\left(b_{m_j} \left(s_{m_j}{}^{I} + \frac{Q_{m_j}{}^{I}}{2} \right) \right) + \left(u_{m_j} \left(s_{m_j}{}^{I} + \frac{Q_{m_j}{}^{I}}{2} \right) \right)$$

$$+\left(\frac{\left(\left[\left.Q_{m_j}{}^{I}\middle/TL\right.\right]a_{sf}{}^{I}\right)+a_{sl}{}^{I}+K_{sa}{}^{I}}{\frac{Q_{m_j}{}^{I}}{d}}\right)+\left(\frac{r_{m_j}{}^{I}Q_{m_j}{}^{I}}{\frac{Q_{m_j}{}^{I}}{d}}\right)$$

$$+\left(\frac{K_{m_{jg}}{}^{I}+\left(g_{m_{j1}}{}^{I}\left[\left.Q_{m_j}{}^{I}\middle/TL\right.\right]\right)+\left(g_{m_{j2}}{}^{I}Q_{m_j}{}^{I}\right)}{\frac{Q_{m_j}{}^{I}}{d}}\right)$$

$$\left.+\left(\frac{o_{m_j}{}^{I}+\left(c_{m_j}{}^{I}Q_{m_j}{}^{I}\right)}{\frac{Q_{m_j}{}^{I}}{d}}\right)\right]$$

Upon some algebraic manipulation, the formula is further simplified as;

$$\begin{aligned}
TC_{m_j}{}^{II}-TC_{m_j}{}^{I}\\
&=b_{m_j}s_{m_j}{}^{II}+\frac{b_{m_j}Q_{m_j}{}^{II}}{2}+u_{m_j}s_{m_j}{}^{II}+\frac{u_{m_j}Q_{m_j}{}^{II}}{2}+\frac{a_{hf}d}{TL}+\frac{a_{hl}d}{Q_{m_j}{}^{II}}\\
&+\frac{K_{ha}d}{Q_{m_j}{}^{II}}+r_{m_j}{}^{II}d+\frac{K_{m_{jg}}{}^{II}d}{Q_{m_j}{}^{II}}+\frac{g_{m_{j1}}{}^{II}d}{TL}+g_{m_{j2}}{}^{II}d+\frac{o_{m_j}{}^{II}d}{Q_{m_j}{}^{II}}\\
&+c_{m_j}{}^{II}d-b_{m_j}s_{m_j}{}^{I}-\frac{b_{m_j}Q_{m_j}{}^{I}}{2}-u_{m_j}s_{m_j}{}^{I}-\frac{u_{m_j}Q_{m_j}{}^{I}}{2}-\frac{a_{sf}{}^{I}d}{TL}\\
&-\frac{a_{sl}{}^{I}d}{Q_{m_j}{}^{I}}-\frac{K_{sa}{}^{I}d}{Q_{m_j}{}^{I}}-r_{m_j}{}^{I}d-\frac{K_{m_{jg}}{}^{I}d}{Q_{m_j}{}^{I}}-\frac{g_{m_{j1}}{}^{I}d}{TL}-g_{m_{j2}}{}^{I}d-\frac{o_{m_j}{}^{I}d}{Q_{m_j}{}^{I}}\\
&-c_{m_j}{}^{I}d
\end{aligned}$$

Re-grouping with respect to common parameters;

<u>Equation 4.39</u>

$$TC_{m_j}{}^{II} - TC_{m_j}{}^{I}$$

$$= \left[b_{m_j} \left(s_{m_j}{}^{II} - s_{m_j}{}^{I} \right) + \left(\frac{Q_{m_j}{}^{II} - Q_{m_j}{}^{I}}{2} \right) \right]$$

$$- \left[u_{m_j} \left(s_{m_j}{}^{I} - s_{m_j}{}^{II} + \frac{Q_{m_j}{}^{I}}{2} - \frac{Q_{m_j}{}^{II}}{2} \right) \right]$$

$$+ \left[d \left(\left(\frac{a_{hf} - a_{sf}{}^{I} + g_{m_{j1}}{}^{II} - g_{m_{j1}}{}^{I}}{TL} \right) \right. \right.$$

$$+ \left(\frac{a_{hl} + K_{ha} + K_{m_{jg}}{}^{II} + o_{m_j}{}^{II}}{Q_{m_j}{}^{II}} \right) - \left(\frac{a_{sl}{}^{I} - K_{sa}{}^{I} - K_{m_{jg}}{}^{I} - o_{m_j}{}^{I}}{Q_{m_j}{}^{I}} \right)$$

$$\left. \left. + \left(r_{m_j}{}^{II} - r_{m_j}{}^{I} \right) + \left(g_{m_{j2}}{}^{II} - g_{m_{j2}}{}^{I} \right) + \left(c_{m_j}{}^{II} - c_{m_j}{}^{I} \right) \right) \right]$$

The conclusion we draw from above is in line with what we have for the supplier costs. The difference is a function of locations, distances and changes in customs and agencies unit costs, receiving costs and ordering related costs. However, it is difficult to make any further conclusions. We also revisit this equation as part of the numeric analysis in the next chapter.

Even though an investigation of cost differences is very important in order to decide whether or not to go with the alternative business model, this information alone is insufficient in making such a decision that may change the business structure. For that purpose, we extend our analysis to incorporate the notion of “free cash”. Free cash is defined to be the cash generated by the operations and made available for use either to invest in business or to be paid as dividends. Since opportunity gained from free cash amount is extremely significant for decisions in many companies, we also compare the free cash generated by the two models.

This phenomenon and comparison is best reflected by a numeric analysis. The related discussion will be presented in Chapter 5.

We now provide a discussion on another important consideration, safety stocks. In general, the safety stocks are kept at many locations in the supply chain. The costs associated with safety stock are significant; however they are usually taken as policy decision and are left out of scope of analytical approaches.

4.3.2. Suppliers

We now will subtract the total cost per unit time of the suppliers in the traditional model from that in the alternative model in an attempt to highlight the main differences.

We make the following change of variables in order to reduce the number of variables in both cost formulae.

Replace $t_s = Q_p/d_s$

$t_p = Q_p/r_p$

$t_d = Q_d/ d_s$

$t_o = t_cQ_p/ d_s$ in traditional model

$t_o = (Q_p/ d_s) (Q_d/ d_s)$ in alternative model

$t_o^1 = t_cQ_d/ d_s$

$$TC_s^{II} - TC_s^{I} = \left[\left(b_s \left[s_s^{II} \right.\right.\right.$$

$$+ \left[\frac{1}{2}\left[\left[Q_p^{II}\left(\frac{\frac{Q_p^{II}}{d}\frac{Q_d}{d} - \frac{Q_p^{II}}{r_p}}{\frac{Q_p^{II}}{d}} + 1\right)\right] - \left[Q_d\left(\frac{\frac{Q_p^{II}}{d}\frac{Q_d}{d}}{\frac{Q_d}{d}} - 1\right)\right]\right]\right]\Bigg]\Bigg)$$

$$+ \left(u_s \left[\left(\left[s_s^{II} \right.\right.\right.\right.$$

$$+ \left[\frac{1}{2}\left[\left[Q_p^{II}\left(\frac{\frac{Q_p^{II}}{d}\frac{Q_d}{d} - \frac{Q_p^{II}}{r_p}}{\frac{Q_p^{II}}{d}} + 1\right)\right] - \left[Q_d\left(\frac{\frac{Q_p^{II}}{d}\frac{Q_d}{d}}{\frac{Q_d}{d}} - 1\right)\right]\right]\right]\Bigg]\Bigg)$$

$$+ \left(\left[s_h + \left[\frac{Q_d}{2}\left(\frac{\frac{Q_d}{d}t_c}{\frac{Q_d}{d}} - 1\right) - \frac{1}{2}\left[\sum_{j=1}^{J} Q_{m_j}{}^{II}\left(\frac{\frac{Q_d}{d}t_c}{t_{m_j}{}^{II}} - 1\right)\right]\right]\right]\right)\Bigg]\Bigg)$$

$$+ \left(\frac{\left(\left[{}^{Q_d}/_{TL}\right] a_{sf}{}^{II}\right) + a_{sl}{}^{II} + K_{sa}{}^{II}}{\frac{Q_d}{d}}\right) + \left(\frac{K_p + \left(p_s Q_p{}^{II}\right)}{\frac{Q_p{}^{II}}{d}}\right)$$

$$+ Z_s \Bigg]$$

$$
-\left[\left(b_s\left[{s_s}^I\right.\right.\right.
$$

$$
+\left[\frac{1}{2}\left[\left[{Q_p}^I\left(\frac{\frac{{Q_p}^I}{d}t_c-\frac{{Q_p}^I}{r_p}}{\frac{{Q_p}^I}{d}}+1\right)\right]-\left[\sum_{j=1}^{J}{Q_{m_j}}^I\left(\frac{\frac{{Q_p}^I}{d}t_c}{{t_{m_j}}^I}-1\right)\right]\right]\right]\right)
$$

$$
+\left(u_s\left[{s_s}^I\right.\right.
$$

$$
+\left[\frac{1}{2}\left[\left[{Q_p}^I\left(\frac{\frac{{Q_p}^I}{d}t_c-\frac{{Q_p}^I}{r_p}}{\frac{{Q_p}^I}{d}}+1\right)\right]-\left[\sum_{j=1}^{J}{Q_{m_j}}^I\left(\frac{\frac{{Q_p}^I}{d}t_c}{{t_{m_j}}^I}-1\right)\right]\right]\right]\right)
$$

$$
+\left(\frac{K_p+\left(p_s{Q_p}^I\right)}{\frac{{Q_p}^I}{d}}\right)\right]
$$

Upon some algebraic manipulation, the formula can be further simplified as;

$$TC_s{}^{II} - TC_s{}^{I} = b_s s_s{}^{II} - \frac{b_s Q_p{}^{II} d}{2r_p} + \frac{b_s Q_p{}^{II}}{2} + \frac{b_s Q_d}{2} + u_s s_s{}^{II} - \frac{u_s Q_p{}^{II} d}{2r_p} + \frac{u_s Q_p{}^{II}}{2}$$

$$+ u_s s_h + \frac{u_s}{2}\sum_{j=1}^{J} Q_{m_j}{}^{II} + \frac{a_{sf}{}^{II} d}{TL} + \frac{a_{sl}{}^{II} d}{Q_d} + \frac{K_{sa}{}^{II}\, d}{Q_d} + \frac{K_p d}{Q_p{}^{II}} + Z_s$$

$$- b_s s_s{}^{I} + \frac{b_s Q_p{}^{I} d}{2r_p} - \frac{b_s Q_p{}^{I}}{2} - \frac{b_s}{2}\sum_{j=1}^{J} Q_{m_j}{}^{I} - u_s s_s{}^{I} + \frac{u_s Q_p{}^{I} d}{2r_p}$$

$$- \frac{u_s Q_p{}^{I}}{2} - \frac{u_s}{2}\sum_{j=1}^{J} Q_{m_j}{}^{I} - \frac{K_p d}{Q_p{}^{I}}$$

Re-grouping with respect to common parameters, we have;

<u>Equation 4.40</u>

$$TC_s{}^{II} - TC_s{}^{I} = \left[b_s \left((s_s{}^{II} - s_s{}^{I}) + \left(\left(\frac{Q_p{}^{II} - Q_p{}^{I}}{2} \right) \left(1 - \frac{d}{r_p} \right) \right) - \frac{\sum_{j=1}^{J} Q_{m_j}{}^{I}}{2} \right.\right.$$

$$\left.\left. + \frac{Q_d}{2} \right) \right]$$

$$+ \left[u_s \left(s_s{}^{II} - s_s{}^{I} + s_h + \frac{Q_p{}^{I} d}{2r_p} - \frac{Q_p{}^{II} d}{2r_p} + \frac{Q_p{}^{II}}{2} - \frac{Q_p{}^{I}}{2} + \frac{\sum_{j=1}^{J} Q_{m_j}{}^{II}}{2} \right.\right.$$

$$\left.\left. - \frac{\sum_{j=1}^{J} Q_{m_j}{}^{I}}{2} \right) \right] + \left[\frac{d}{Q_d} \left(a_{sl}{}^{II} + K_{sa}{}^{II} \right) \right] + \frac{a_{sf}{}^{II} d}{TL}$$

$$+ \left[K_p d \left(\frac{1}{Q_p{}^{II}} - \frac{1}{Q_p{}^{I}} \right) \right] + Z_s$$

Although Equation 4.40 outlines main variables effecting two model’s difference in terms of cost, it cannot be easily stated from the formula of the difference in which cases it will be positive or negative or the magnitude. This certainly shows that, the difference depends on factors such as location of the facilities, distances between them, unit cost parameters, technology, demand per unit time.

To this end we believe that an analysis for a specific case may provide additional insight. Therefore, we will revisit this equation in the next chapter which we devote to numeric analysis.

4.3.3. Safety Stock

Members of the supply chain keep safety stocks mainly for two reasons. First is to overcome possible problems that may result from unexpected occurrences destroying the flow along the supply chain. For this purpose, every member of the supply chain keeps a safety stock against uncertainties downstream or asks the downstream to keep associated safety stocks. The other motivation to keep safety stocks is to avoid stock outs that may result because of the lack of synchronization between the downstream and upstream of the supply chain.

The total cost formulations we present include a safety stock component, however the safety stock levels are not calculated explicitly; they are taken as policy decisions. Safety stock levels do not affect decisions on the optimal (Q_p, Q_d, Q_{mj}, t_p, t_s, t_d, t_{mj}) values of other decision variables. If we attempted to optimize all decisions simultaneously with the inclusion of the decision on safety stock levels, it would be technically too much complicated. Therefore, we choose to first take safety stock levels as given, identify optimal values for the remaining decision variables, then, we will decide on the safety stock levels with the joint consideration of the two aforementioned motivations for keeping safety stocks.

We demonstrate our approach in the context of the numeric analysis in the next chapter. We take the company decisions for safety stock against uncertainty and compute the safety stock requirements ensuring nonnegative inventory levels through the system, considering lead times of related parties.

Lead times of the related parties and company specific policies play an important role while defining safety stock levels. Company specific policies are ground rules that cannot be theoretically or numerically justified. These are typically results of past experiences, factors like market conditions, supplier's reliability or some other intangibles.

Now, recall that cycle in both models end up with zero inventories, but this does not mean that inventory levels without safety stocks are always positive throughout the cycle. We may observe negative inventory values during the flow of incoming and outgoing inventories. We then determine the safety stock level to be the amount cover the lowest level of inventory (highest value of stock out) through the cycle length.

4.3.4. Markup

With the alternative business model, we may expect cases where the total cost of suppliers increases as compared to the traditional business model. In such a case, it may be reasonable to subsidize the suppliers' loss by adding a markup level to sales prices.

One may propose alternative approaches to deciding the markup level. Within the scope of the thesis, we do not go into details of an optimization methodology for the markup level. As a representative approach, we follow a scheme that tries to compensate the overall loss by a uniform markup to all suppliers.

Define M_s to be the price markup given to suppliers by the manufacturers. We have;

Equation 4.41:

$$\boldsymbol{M_s = \frac{TC_s{}^{II} - TC_s{}^{I}}{\sum_{i=1}^{I} c_{m_j} * d_{m_j}}}$$

CHAPTER V

CASE STUDY

5.1. Introduction

The initial inspiration of the thesis topic comes from the company analyzed in this chapter. The preceding chapters of the thesis were devoted to the development of a decision support tool through mathematical modeling. The tool is derived through a detailed analysis of the costs of supply chain members with respect to a traditional model and an alternative model. We also provide a thorough discussion on feasibility conditions for proper business flow in each model.

In this chapter, we demonstrate how the decision support tool can actually be utilized to provide insights and benefits for a company. We do this, via a real life case based on a multinational company. The content of the chapter supports the previous findings numerically and also proves the serviceability of the decision tool developed in the thesis.

In the rest of the chapter, we first introduce the company laying out the supply chain and business structures. We then continue with a discussion of background issues which trigger the need for business development. We present a detailed numerical analysis along with selected robustness parametric analysis. Discussions of the findings are also included.

5.1.1. General Company Background

The case study in this chapter is based on business procurement model of an international tobacco company, which is one of the largest global tobacco companies in the world with a global market share of around 10% and market capitalization of approximately $30 billion.

Eight of the company's brands are showing up among the market leads, some of which are among top five worldwide sold cigarette brands. Manufacturing takes place in around 25 countries and the end products are sold in 100 countries.

The company employs about 20,000 people from 50 countries around the world and carries an international and multicultural internal business perception.

The business organization of the multinational company is structured in regions. There are 6 main regions worldwide. Each manufacturing facility is assigned to one of the 6 main regions, based on geographical locations. Furthermore, for each region, one facility is appointed as the leader.

The multinational company's current business flow is taken to fit into the traditional model explained extensively in Chapter 3. Currently, procurement process in each region is managed individually through supplier-manufacturer interactions. Each manufacturer purchase several product groups from several suppliers. Each manufacturing facility manages its own procurement process individually within a framework defined centrally.

We consider one specific region of the company, which reports a need for business development in its procurement operations, and carry out numeric study for the region.

Before we go into the numeric analysis, we review the characteristics of the region that motivate the analysis.

5.1.2. Background Issues Triggering the Need for Development

In recent years, competitiveness concerns increased the importance of better cash flow management and flexibility improvement efforts. This poses a significant bottleneck especially for the international companies having global suppliers, hence with long lead times. This becomes an even crucial task when we consider expensive products transported from long distance suppliers.

Accordingly, the need for development in the business model of the multinational company is triggered by expensive products purchased from suppliers with long lead times. This alone results in a huge amount of cash to be allocated to material inventories for long periods of time in advance.

Therefore, the company inevitably starts to question whether it is feasible to switch to a new business model, which involves a redesign of the supply chain. One promising alternative is to augment the supply chain by adding a supply hub. The hub can be used to consolidate and disseminate the common expensive materials purchased from long distance suppliers aiming for potential savings and a more efficient supply chain management.

Although the company actually considers the opinion of a single hub only, we go further in our analysis and determine the optimal number of supply hubs for the company.

5.1.3. Case Scope

The analysis that we are about to present considers one specific region of the company among six; namely the Middle East and Africa region.

This region has 6 manufacturers. The locations of the manufacturing facilities are Tunisia, South Africa, Iran, Tanzania, Jordan and Turkey. Turkey facility is appointed as the leading manufacturer in its region.

The regional manufacturers purchase a number of product groups. Among these we consider those three product groups that are purchased from long distance suppliers within scope. These are high volume, high priced products; namely we consider outer cover material, adhesive material and inner core material.

Commonality of the product groups makes it possible to view almost constant deterministic demand and eliminate obsolescence risk.

We consider 4 types of outer cover material, 4 types of adhesive material and 4 types of inner core material used commonly by 6 regional manufacturers. Material ex-changes among these product groups are mostly unusual and will not be considered.

Agreements with the product suppliers and transportation companies are negotiated globally for each product. Therefore, we leave supplier and transportation company selection decisions out of the research scope.

There are 10 suppliers serving to the manufacturers in the region for selected product groups. We use the locations of suppliers in defining them. Suppliers of the region are; Japan, United Kingdom, United States of America, Turkey, Germany, Italy, Malaysia, Spain, Austria and France.

A single supplier serves to multiple manufacturers in the region, whereas each one of the products is supplied by one single supplier only.

The mapping to follow shows the supply network for each material and thus for the whole region;

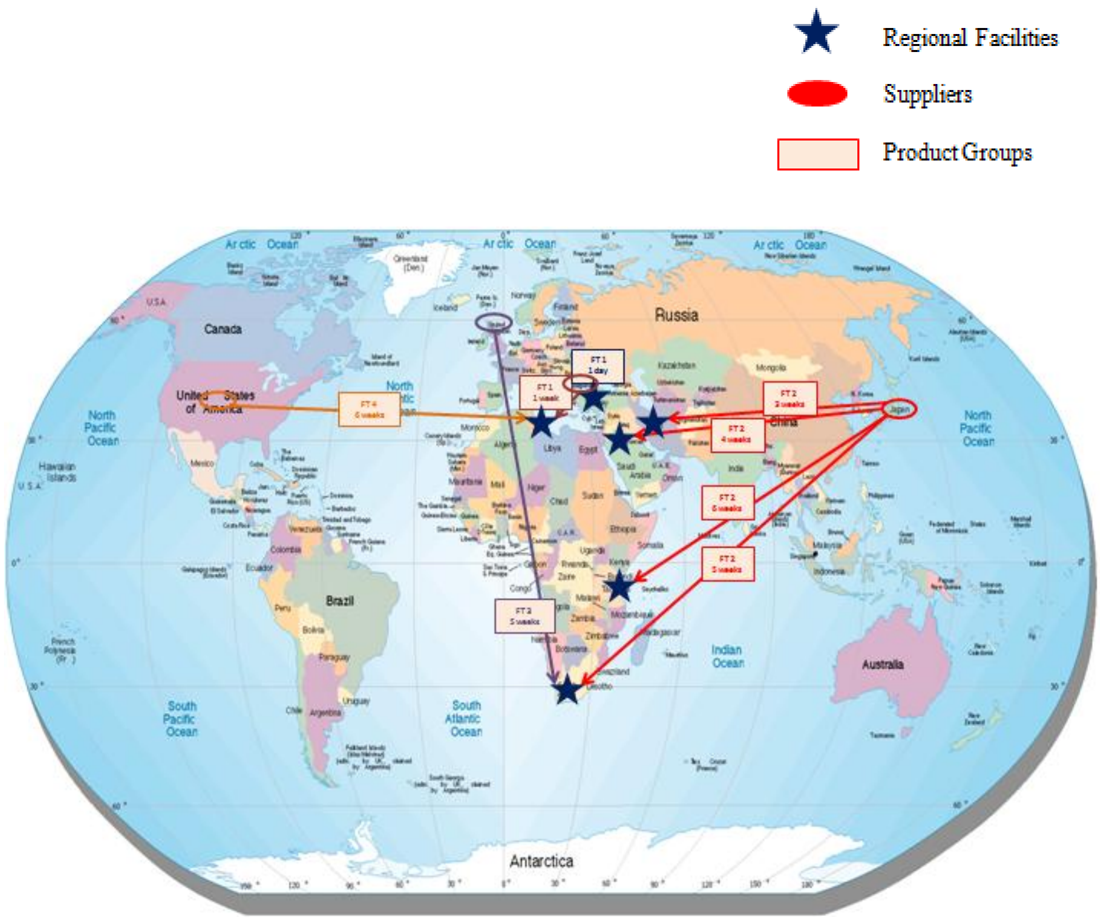

Figure 5.1: Inner Core Material's Regional Supply Network

Figure 5.2: Adhesive Material's Regional Supply Network

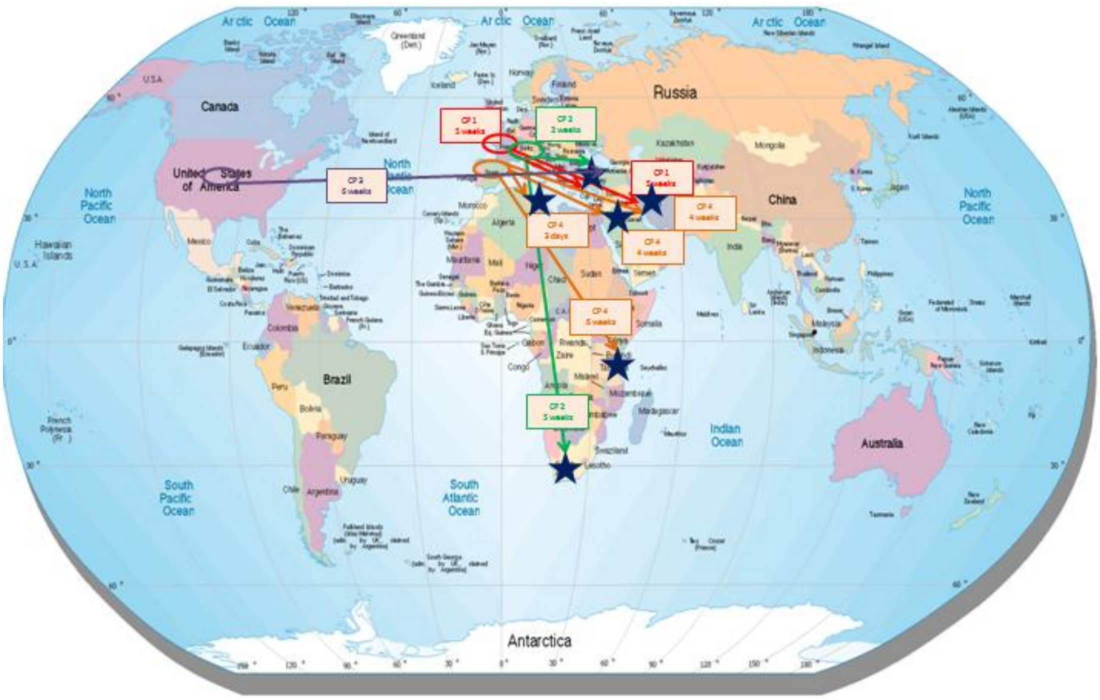

Figure 5.3: Outer Cover Material's Regional Supply Network

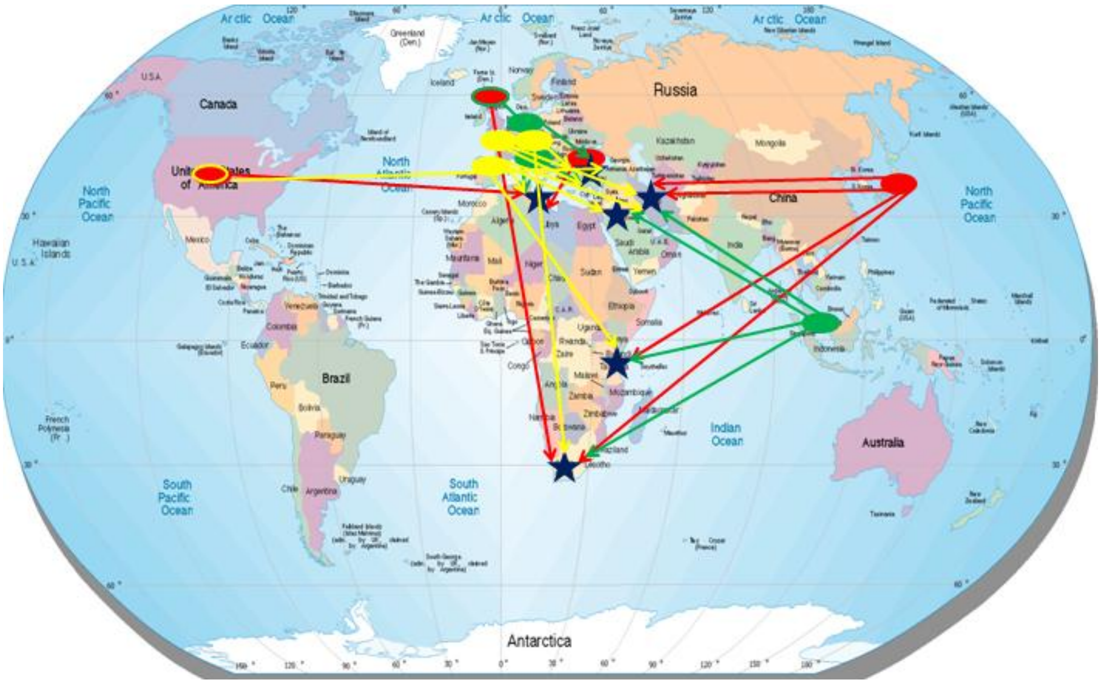

Figure 5.4: Regional Supply Network for FT, PP, CP

We now proceed with the numeric analysis which also demonstrates the implementation of the decision tool developed.

5.2. Numeric Study with Data

We now give a brief description of the steps of the data collection process.

The data regarding 10 suppliers of the region for the specified products and 6 facilities are used for the numeric study, provided by the lead factory in Turkey. Contents of the data are basically the parameters. Namely, lead times of the suppliers, demand of the products, prices of the products, safety stock policies, inventory holding costs, opportunity costs, production rates, fixed and variable costs of production, receiving costs, ordering costs, customs and agencies costs, truck load capacities, full and less than truck load costs and fixed cost of transportation.

We take the unit time to be weeks. Therefore, unless otherwise stated, the data in to follow represent weekly values.

Unit of measure for outer cover material and adhesive material is bobbins, and for inner core is kilogram.

Table 5.1 summarizes the data regarding the suppliers.

Table 5.1: Parameters related to Suppliers

Suppliers	Product	b_s	u_s	TL	c_m	r_p	K_p	p_s	d_s
Austria (TR&SA)	CP_2	0,011	0,017	4.080	30	9.000	73,05	2,73	1.346
France (TR&IR)	CP_1	0,010	0,017	4.608	30	8.500	68,99	2,73	2.885
Germany (TR)	PP_1	0,025	0,017	2.240	30	1.500	12,18	2,73	288
Italy (TR&TN)	PP_3	0,025	0,017	2.240	30	500	4,06	2,73	154
Japan	FT_2	0,003	0,003	18.000	5	200.000	270,56	0,45	50.962
Malaysia	PP_4	0,025	0,017	2.240	30	2.500	20,29	2,73	654
Spain	CP_4	0,011	0,017	4.080	30	10.000	81,17	2,73	3.269
Turkey (TR&TN)	FT_1	0,001	0,003	18.000	5	120.000	162,34	0,45	38.846
UK (TR)	PP_2	0,029	0,017	1.920	30	800	6,49	2,73	96
UK (SA)	FT_3	0,003	0,003	18.000	5	250.000	338,20	0,45	1.923
USA (TR)	CP_3	0,010	0,017	4.608	30	6.000	48,70	2,73	192
USA (TN)	FT_4	0,003	0,003	18.000	5	250.000	338,20	0,45	4.423

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Table 5.2 gives the data regarding the manufacturers. Supplier information is given the first column in parenthesis. The second column is for products.

Table 5.2: Parameters related to Manufacturers

Manufacturers	Product	b_{mj}	u_{mj}	r_{mj}	o_{mj}	c_{mj}	K_{mjg}	g_{mj1}	g_{mj2}	$LTT_{s\text{-}m}$	D_{mj}	T_{mj}	d_{mj}	a_{sf}	a_{sl}	Ksa	truck capacity
Iran (SP)	CP_4	0,006	0,017	0,001	0,002	30	0,08	0,23	1,20	2,0	50.000	52	962	2.169	2.234	200	4.080
Iran (FR)	CP_1	0,005	0,017	0,001	0,001	30	0,08	0,23	1,20	2,0	50.000	52	962	2.416	2.489	200	4.608
Iran (JP)	FT_2	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	5,0	1.250.000	52	24.038	2.741	2.823	200	18.000
Iran (ML)	PP_4	0,012	0,017	0,002	0,004	30	0,08	0,23	1,20	3,0	15.000	52	288	3.108	3.201	200	2.240
Jordan (JP)	FT_2	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	5,0	500.000	52	9.615	4.090	4.213	200	18.000
Jordan (ML)	PP_4	0,012	0,017	0,002	0,004	30	0,08	0,23	1,20	3,0	6.000	52	115	3.100	3.193	200	2.240
Jordan (SP)	CP_4	0,006	0,017	0,001	0,002	30	0,08	0,23	1,20	2,0	40.000	52	769	1.626	1.675	200	4.080
Tanzania (ML)	PP_4	0,012	0,017	0,002	0,004	30	0,08	0,23	1,20	2,0	10.000	52	192	3.450	3.554	200	2.240
Tanzania (JP)	FT_2	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	4,0	750.000	52	14.423	3.676	3.786	200	18.000
Tanzania (SP)	CP_4	0,006	0,017	0,001	0,002	30	0,08	0,23	1,20	5,0	60.000	52	1.154	3.240	3.337	200	4.080
Turkey (FR)	CP_1	0,005	0,017	0,001	0,001	30	0,03	0,09	0,48	2,0	100.000	52	1.923	1.750	1.803	200	4.608
Turkey (AU)	CP_2	0,006	0,017	0,001	0,002	30	0,03	0,09	0,48	2,0	50.000	52	962	2.862	2.947	200	4.080
Turkey (US)	CP_3	0,005	0,017	0,001	0,001	30	0,08	0,23	1,20	6,0	10.000	52	192	2.500	2.575	200	4.608
Turkey (TR)	FT_1	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	0,1	2.000.000	52	38.462	100	103	200	18.000
Turkey (GE)	PP_1	0,012	0,017	0,002	0,004	30	0,03	0,09	0,48	2,0	15.000	52	288	1.260	1.298	200	2.240
Turkey (UK)	PP_2	0,014	0,017	0,002	0,004	30	0,03	0,09	0,48	3,0	5.000	52	96	1.520	1.566	200	1.920
Turkey (IT)	PP_3	0,012	0,017	0,002	0,004	30	0,03	0,09	0,48	2,0	5.000	52	96	910	937	200	2.240
Tunisia (TR)	FT_1	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	1,0	20.000	52	385	1.600	1.648	200	18.000
Tunisia (US)	FT_4	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	5,0	230.000	52	4.423	2.878	2.964	200	18.000
Tunisia (IT)	PP_3	0,012	0,017	0,002	0,004	30	0,08	0,23	1,20	1,0	3.000	52	58	2.800	2.884	200	2.240
Tunisia (SP)	CP_4	0,006	0,017	0,001	0,002	30	0,08	0,23	1,20	1,0	20.000	52	385	2.121	2.185	200	4.080
Safrica (AU)	CP_2	0,006	0,017	0,001	0,002	30	0,08	0,23	1,20	4,0	20.000	52	385	3.950	4.069	200	4.080
Safrica (JP)	FT_2	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	4,0	150.000	52	2.885	3.980	4.099	200	18.000
Safrica (UK)	FT_3	0,001	0,003	0,000	0,000	5	0,01	0,04	0,20	4,0	100.000	52	1.923	4.631	4.770	200	18.000
Safrica (ML)	PP_4	0,012	0,017	0,002	0,004	30	0,08	0,23	1,20	3,0	3000	52	58	3.430	3.533	200	2.240

The transportation costs that we use are also real values for the associated origin destination pairs. These are taken from a logistics service provider that has operations worldwide. Transportation costs given in Table 5.2 represent full and less than truck load costs from suppliers to manufacturers. Note that, we also need the full and less than truck load costs from the suppliers to the supply hub and from supply hub to the manufacturers for the analysis of the alternative business model. We present this data later. Since transportation costs and part of the remaining data depends on the location of the supply hub, we defer that part of the data to follow the selection of the hub location. Lead times of suppliers in Table 5.2 are made of transportation lead times only. Note that these need to be updated to include production lead times. We do this after the decision on the optimal production lot size is made.

Based on the preceding discussion, we conclude that the current business process of the company fits into what we describe as traditional model in Chapter 3.

We take the alternative model with the inclusion of the hub to the model in Chapter 4.

Before proceeding further, we note that although the current business model is taken to fit into the traditional model, what we compute as the optimal values for decision variables for the traditional system does not necessarily match the actual practice. This is obviously due to the fact that the current system is most probably not derived over the optimal values. In the current structure, the parties in the supply chain decide on their own decision variables, usually based on intangible company policies. Therefore, the comparison we do does not exactly refer to the current cost of the supply chain; rather to an idealized version of the current situation.

We can, on the other hand, safely state that, the comparison surely possesses a valid insight to the business problem as the baseline structures of the current business flow and traditional business flow are the same.

5.2.1. Numeric Study on Traditional Business Model

We use the given data (Table 5.1, Table 5.2) to compute the optimal values of the relevant decision variables. Restating that the decision variables in traditional model at the supplier's side are Q_p, t_p and t_s and those at the manufacturer's side are Q_{mj} and t_{mj}. We compute the optimal values using Equations 3.31, 3.29, 3.30, 3.23, and 3.25 simultaneously for each decision variable.

Upon computing the optimal production lead time, t_p, we up-date the lead time of the suppliers by adding it to the transportation lead times, given in Table 5.2. As a byproduct of the optimization process, we also have t_c and t_o which are the lengths of the outgoing and overall cycles at the supplier, respectively.

Table 5.3: Decision Variables at Suppliers' side in Traditional Business Model

Suppliers	Product	s_s	Q_p	t_p	t_s	t_o
Austria (TR&SA)	CP_2	5.385	2.835	0,32	2,11	496
France (TR&IR)	CP_1	11.538	4.737	0,56	1,64	45
Germany (TR)	PP_1	1.154	456	0,30	1,58	18
Italy (TR&TN)	PP_3	615	208	0,42	1,35	420
Japan (SA&TZ&JR&IR)	FT_2	203.846	81.041	0,41	1,59	2002
Malaysia (SA&TZ&JR&IR)	PP_4	2.615	927	0,37	1,42	2772
Spain (TZ&TN&JR&IR)	CP_4	13.077	5.236	0,52	1,60	2576
Turkey (TR&TN)	FT_1	155.385	66.168	0,55	1,70	47
UK (TR)	PP_2	385	176	0,22	1,83	34
UK (SA)	FT_3	7.692	15.253	0,06	7,93	238
USA (TR)	CP_3	769	849	0,14	4,41	36
USA (TN)	FT_4	17.692	23.249	0,09	5,26	90

Safety stock at the supplier's side is calculated using the company policy stated as keeping an inventory equal to 1 month's demand at the supplier's premises.

Table 5.4: Decision Variables at Manufacturers' side in Traditional Business Model

Manufacturers	Product	s_{mj}	Q_{mj}	t_{mj}	$LT_{s\text{-}m}$	t_c
Iran (SP)	CP_4	6.273	14.254	14,82	2,5	2576
Iran (FR)	CP_1	6.305	15.303	15,91	2,6	45
Iran (JP)	FT_2	226.087	184.729	7,68	5,4	2002
Iran (ML)	PP_4	2.126	8.144	28,23	3,4	2772
Jordan (JP)	FT_2	90.435	141.145	14,68	5,4	2002
Jordan (ML)	PP_4	850	5.145	44,59	3,4	2772
Jordan (SP)	CP_4	5.018	11.190	14,55	2,5	2576
Tanzania (ML)	PP_4	1.225	6.986	36,33	2,4	2772
Tanzania (JP)	FT_2	121.229	164.302	11,39	4,4	2002
Tanzania (SP)	CP_4	10.989	18.824	16,31	5,5	2576
Turkey (FR)	CP_1	12.610	18.676	9,71	2,6	45
Turkey (AU)	CP_2	6.072	16.209	16,86	2,3	496
Turkey (US)	CP_3	1.950	6.952	36,15	6,1	36
Turkey (TR)	FT_1	180.548	73.973	1,92	0,7	47
Turkey (GE)	PP_1	1.818	5.405	18,74	2,3	18
Turkey (UK)	PP_2	694	3.276	34,07	3,2	34
Turkey (IT)	PP_3	617	2.719	28,28	2,4	420
Tunisia (TR)	FT_1	2.135	18.268	47,50	1,6	47
Tunisia (US)	FT_4	40.219	81.065	18,33	5,1	18
Tunisia (IT)	PP_3	312	3.468	60,12	1,4	420
Tunisia (SP)	CP_4	2.124	8.923	23,20	1,5	2576
Safrica (AU)	CP_2	3.198	11.939	31,04	4,3	496
Safrica (JP)	FT_2	24.246	76.309	26,45	4,4	2002
Safrica (UK)	FT_3	15.502	66.989	34,83	4,1	34
Safrica (ML)	PP_4	425	3.816	66,14	3,4	2772

Safety stock levels at the manufacturers are calculated over the policy of keeping a stock equal to the demand of 1 month plus lead time.

After identifying the optimal values for the decision variables and other relevant parameters and variables, it is now possible to calculate the total inventory figures for the suppliers and manufacturers. For this we use Equations 3.15 and 3.3.

Table 5.5: Total Inventory per unit time at Supplier's side

Suppliers	Product	IN	OUT	IN-OUT	$s_{(s\ or\ h)}$	Total Inventory
Austria (TR&SA)	CP_2	335.052	319.772	15.280	5.385	20.664
France (TR&IR)	CP_1	66.468	47.914	18.554	11.538	30.092
Germany (TR)	PP_1	2.780	-106	2.886	1.154	4.040
Italy (TR&TN)	PP_3	32.380	29.214	3.165	615	3.781
Japan (SA&TZ&JR&IR)	FT_2	51.042.696	50.729.257	313.438	203.846	517.284
Malaysia (SA&TZ&JR&IR)	PP_4	906.573	894.186	12.387	2.615	15.003
Spain (TZ&TN&JR&IR)	CP_4	4.212.531	4.184.174	28.357	13.077	41.434
Turkey (TR&TN)	FT_1	935.259	866.764	68.495	155.385	223.879
UK (TR)	PP_2	1.712	-4	1.716	385	2.100
UK (SA)	FT_3	236.414	195.352	41.062	7.692	48.755
USA (TR)	CP_3	3.872	-15	3.887	769	4.656
USA (TN)	FT_4	210.457	158.506	51.952	17.692	69.644

Table 5.6: Total Inventory per unit time at Manufacturer's side

Manufacturers	Product	IN-OUT	s_{mj}	Total Inventory
Iran (SP)	CP_4	7.126,78	6.272,65	13.399,43
Iran (FR)	CP_1	7.651,42	6.305,04	13.956,46
Iran (JP)	FT_2	92.364,37	226.086,64	318.451,01
Iran (ML)	PP_4	4.072,12	2.126,14	6.198,26
Jordan (JP)	FT_2	70.572,58	90.434,66	161.007,23
Jordan (ML)	PP_4	2.572,31	850,45	3.422,77
Jordan (SP)	CP_4	5.594,81	5.018,12	10.612,93
Tanzania (ML)	PP_4	3.492,80	1.225,12	4.717,92
Tanzania (JP)	FT_2	82.151,10	121.228,91	203.380,00
Tanzania (SP)	CP_4	9.412,00	10.988,71	20.400,71
Turkey (FR)	CP_1	9.338,00	12.610,07	21.948,07
Turkey (AU)	CP_2	8.104,72	6.072,16	14.176,88
Turkey (US)	CP_3	3.476,17	1.950,28	5.426,46
Turkey (TR)	FT_1	36.986,54	180.548,43	217.534,96
Turkey (GE)	PP_1	2.702,27	1.818,42	4.520,69
Turkey (UK)	PP_2	1.638,19	694,20	2.332,39
Turkey (IT)	PP_3	1.359,50	616,84	1.976,35
Tunisia (TR)	FT_1	9.134,10	2.135,15	11.269,25
Tunisia (US)	FT_4	40.532,60	40.219,03	80.751,63
Tunisia (IT)	PP_3	1.734,10	312,41	2.046,52
Tunisia (SP)	CP_4	4.461,74	2.124,44	6.586,18
Safrica (AU)	CP_2	5.969,37	3.198,10	9.167,46
Safrica (JP)	FT_2	38.154,73	24.245,78	62.400,51
Safrica (UK)	FT_3	33.494,53	15.501,94	48.996,47
Safrica (ML)	PP_4	1.907,83	425,23	2.333,06

Table 5.5 and 5.6 provide the data to calculate total costs of suppliers and manufacturers using Equations 3.15, 3.16, 3.17, 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8 simultaneously.

Table 5.7: Total Costs of Suppliers in Traditional Business Model

Suppliers	Product	Bs	Us	A_s	P_s	Z_s	TC_s
Austria (TR&SA)	CP_2	237	358	0	3.706	0	4.300
France (TR&IR)	CP_1	287	521	0	7.909	0	8.717
Germany (TR)	PP_1	99	70	0	794	0	964
Italy (TR&TN)	PP_3	93	65	0	423	0	581
Japan (SA&TZ&JR&IR)	FT_2	1.423	1.492	0	23.334	0	26.249
Malaysia (SA&TZ&JR&IR)	PP_4	368	260	0	1.798	0	2.426
Spain (TZ&TN&JR&IR)	CP_4	475	717	0	8.967	0	10.159
Turkey (TR&TN)	FT_1	308	646	0	17.753	0	18.706
UK (TR)	PP_2	60	36	0	266	0	362
UK (SA)	FT_3	134	141	0	917	0	1.191
USA (TR)	CP_3	44	81	0	536	0	661
USA (TN)	FT_4	192	201	0	2.075	0	2.467

Table 5.8: Total Costs of Manufacturers in Traditional Business Model

Manufacturers	Product	B_{mj}	U_{mj}	A_{mj}	R_{mj}	G_{mj}	O_{mj}	TC_{mj}
Iran (SP)	CP_4	77	231,91	603,05	0,8	1.442	0,00011	2.355
Iran (FR)	CP_1	67	241,55	624,45	0,7	1.442	0,00009	2.376
Iran (JP)	FT_2	438	918,61	3.961	4,8	6.010	0,00005	11.331
Iran (ML)	PP_4	76	107,28	451	0,5	433	0,00013	1.067
Jordan (JP)	FT_2	221	464,44	2.251	1,9	2.404	0,00003	5.343
Jordan (ML)	PP_4	42	59,24	215	0,2	173	0,00008	490
Jordan (SP)	CP_4	61	183,69	352	0,6	1.154	0,00011	1.751
Tanzania (ML)	PP_4	58	81,66	388	0,3	288	0,00010	817
Tanzania (JP)	FT_2	280	586,67	3.254	2,9	3.606	0,00004	7.729
Tanzania (SP)	CP_4	117	353,09	1.011	1,0	1.731	0,00010	3.213
Turkey (FR)	CP_1	105	379,87	927	1,3	1.154	0,00014	2.567
Turkey (AU)	CP_2	81	245,37	696	0,8	577	0,00010	1.600
Turkey (US)	CP_3	26	93,92	146	0,1	288	0,00004	554
Turkey (TR)	FT_1	299	627,50	366	7,7	9.615	0,00021	10.915
Turkey (GE)	PP_1	55	78,24	214	0,5	173	0,00019	522
Turkey (UK)	PP_2	33	40,37	96	0,2	58	0,00012	228
Turkey (IT)	PP_3	24	34,21	72	0,2	58	0,00013	189
Tunisia (TR)	FT_1	15	32,51	73	0,1	96	0,00001	217
Tunisia (US)	FT_4	111	232,94	801	0,9	1.106	0,00002	2.251
Tunisia (IT)	PP_3	25	35,42	98	0,1	87	0,00006	245
Tunisia (SP)	CP_4	38	113,99	286	0,3	577	0,00007	1.015
Safrica (AU)	CP_2	53	158,67	392	0,3	577	0,00005	1.180
Safrica (JP)	FT_2	86	180,00	764	0,6	721	0,00002	1.752
Safrica (UK)	FT_3	67	141,34	542	0,4	481	0,00001	1.231
Safrica (ML)	PP_4	29	40,38	108	0,1	87	0,00005	264

In the numeric studies for the traditional model as well as for the alternative model, while calculating the ordering cost, product's unit price of c_{mj} is excluded from the main formula, as it is standing at the profit side whereas the thesis study is reviewing the cost side. It will only be used while calculating the markup rate for the suppliers.

Based on the above, the total cost of the supply chain in traditional business model is calculated by Equation 3.21 as $137,986 per week.

5.2.2. Numeric Study on Alternative Business Model

In this section, we compute the total cost of the alternative model as applied to the specified region of the company. We start the analysis with decisions regarding the supply hubs.

Since the company actually considers a single hub, we present the analysis for a single supply hub. We still identify the optimal number of hubs to be opened for this case and derive some scenarios to check the decision's robustness and advice accordingly.

Location of Supply Hub

We use the model developed earlier in Section 4.1.2. In order to solve the resulting problem to optimality, we use the General Algebraic Modeling System (GAMS) software.

We then identify 7 candidate hub locations worldwide. The locations are representatives from all around the world. These candidate locations are USA, Brazil, Belgium, Turkey, South Africa, Dubai, and Shanghai.

The unit costs per truck from suppliers to candidate hub locations and from each candidate hub to each manufacturer are calculated. Customs and agencies cost per unit transported from suppliers to the related supply hubs are also considered, as this adds an incremental cost depending on which hub the products are assigned to.

In computing the fixed cost of opening a hub, we use two main inputs. One is the cost per unit area in the candidate location. The other is the storage area required if the hub is opened at a particular location. The latter is calculated based on the assumption that an average inventory equal to the demand during lead time between each manufacturer and each hub is to be kept.

For this example, we take a flat cost of $3.5 per square meter at each candidate location per month. The lead times are taken from Table 5.4 along with the assumption that 2 pallets can conveniently be stored per square meter. The resulting GAMS model is given in Appendix A.

Table 5.9: Calculation of Z_s for each Candidate Supply Hub

						LEAD TIME (Production + Transportation)								Demand per Lead Time							Demand per Lead Time in Pallets						
Supplier	Product	Yearly Demand	Palet Size	Truck Size	Pallets per Truck	USA	Brazil	Belgium	Turkey	Safrica	Dubai	Shanghai	weekly demand	USA	Brazil	Belgium	Turkey	Safrica	Dubai	Shanghai	USA	Brazil	Belgium	Turkey	Safrica	Dubai	Shanghai
FRANCE	CP_1	150.000	144	32	4608	11	11	6	7	10	10	11	2.885	30.992	30.992	16.569	19.453	28.107	28.107	30.992	215	215	115	135	195	195	215
AUSTRIA	CP_2	70.000	120	34	4080	9	9	4	5	8	8	9	1.346	11.586	11.586	4.855	6.201	10.239	10.239	11.586	97	97	40	52	85	85	97
USA	CP_3	10.000	144	32	4608	2	2	7	7	8	8	9	192	468	468	1.430	1.430	1.622	1.622	1.814	3	3	10	10	11	11	13
SPAIN	CP_4	170.000	120	34	4080	10	10	5	6	9	9	10	3.269	33.049	33.049	16.703	19.972	29.780	29.780	33.049	275	275	139	166	248	248	275
TURKEY-	FT_1	2.020.000	500	36	18000	9	9	5	4	7	7	8	38.846	351.952	351.952	196.568	157.721	274.260	274.260	313.106	704	704	393	315	549	549	626
JAPAN	FT_2	2.650.000	500	36	18000	10	10	9	8	6	6	4	50.962	496.463	496.463	445.501	394.539	292.616	292.616	190.693	993	993	891	789	585	585	381
UK	FT_3	100.000	500	36	18000	6	6	1	2	5	5	6	1.923	11.990	11.990	2.374	4.297	10.067	10.067	11.990	24	24	5	9	20	20	24
USA	FT_4	230.000	500	36	18000	1	1	6	6	7	7	8	4.423	6.005	6.005	28.120	28.120	32.543	32.543	36.966	12	12	56	56	65	65	74
GERMANY	PP_1	15.000	56	40	2240	12	12	7	8	11	11	12	288	3.507	3.507	2.065	2.353	3.219	3.219	3.507	63	63	37	42	57	57	63
UK	PP_2	5.000	48	40	1920	12	12	7	8	11	11	12	96	1.163	1.163	682	778	1.067	1.067	1.163	24	24	14	16	22	22	24
ITALY	PP_3	8.000	56	40	2240	21	21	16	17	20	20	21	154	3.165	3.165	2.396	2.550	3.011	3.011	3.165	57	57	43	46	54	54	57
MALAYSIA	PP_4	34.000	56	40	2240	13	13	11	10	9	9	11	654	8.381	8.381	7.073	6.419	5.765	5.765	7.073	150	150	126	115	103	103	126
																					2.616	2.616	1.870	1.751	1.995	1.995	1.975
																			for corridors and roundup for safety		4157	4157	2988	2858	3118	3118	3118
																			m^2 cost / pallet / week	0,44							
																			Z_s per week		1.819	1.819	1.307	1.250	1.364	1.364	1.364
																			Z_s per year		94.574	94.574	67.975	65.020	70.930	70.930	70.930

We set the number of hubs to one. The model results in "Turkey" as the optimal location for the single regional hub.

Table 5.10: Decision on Location of Supply Hub in GAMS

```
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----     173 VARIABLE tc.L                    =  3071177.200  objective function va
                                                               lue

----     173 VARIABLE z.L  1 if supply hub h is opened and 0 otherwise

Turkey 1.000
```

Based on this result, the revised supply chain network of the region will be as follows;

Figure 5.5: Re-designed Supply Network of the Region

Once the decision on the hub location is made, we now continue with the calculation of the optimal values of the decision variables that are summarized at Table 4.1. Thereafter, we can calculate the costs for each party for the alternative business model. Recall that the decision variables at the supplier's side are Q_p, t_p, t_s, Q_d, and t_d and at the manufacturer's side, Q_{mj} and t_{mj}. We use Equations 4.34, 4.37 and 4.32 to compute the optimal values of Q_p, Q_d, Q_{mj} simultaneously. We then compute t_p, t_s, t_d and t_{mj}. Finally, lengths of the cycle times t_o, t_o^1 and t_c are calculated as least common multiples of optimal values of t_s, t_d; $t_{d,}$ t_c and t_{mj} values respectively.

The alternative business model demonstrates a considerable level of consolidation of shipments to and from a supply hub. In the traditional model, where there was hub, shipments from a supplier would be directed to many manufacturers. Likewise, shipments to a manufacturer would originate from different supplier locations. The consolidation of these shipments and increased number of total shipments poses economies of scale efficiency to be benefited in terms of transportation costs. Upon information obtained from logistics companies, we find it reasonable to assume that the multinational company can use its negotiation power to get a 25% discount in unit transportation costs.

We take 25% discount rate at the base scenario and repeat our analysis for various levels of the discount rate.

Table 5.11: Transportation Costs from Suppliers to Supply Hub in Alternative Model

Suppliers	Product	$K_{s,u}$	$a_{s,f}$	$a_{s,l}$
Austria (TR&SA)	CP_2	200	2146,2	2210,586
France (TR&IR)	CP_1	200	892,5	919,275
Germany (TR)	PP_1	200	945	973,35
Italy (TR&TN)	PP_3	200	756	778,68
Japan (SA&TZ&JR&IR)	FT_2	200	2400	2472
Malaysia (SA&TZ&JR&IR)	PP_4	200	2325	2394,75
Spain (TZ&TN&JR&IR)	CP_4	200	682,5	702,975
Turkey (TR&TN)	FT_1	200	75	77,25
UK (TR)	PP_2	200	960	988,8
UK (SA)	FT_3	200	960	988,8
USA (TR)	CP_3	200	1875	1931,25
USA (TN)	FT_4	200	1875	1931,25

The following table demonstrates the optimal values of the decision variables for the alternative business model.

Table 5.12: Decision Variables at Suppliers' side in Alternative Business Model

Suppliers	Product	s_s	Q_p	t_p	t_s	t_o	Q_d	t_d	$t_{o,f}$
Austria (TR&SA)	CP_2	0	2.835	0,32	2,11	120	28.560,00	21,22	840
France (TR&IR)	CP_1	0	4.737	0,56	1,64	12	27.648,00	9,58	36
Germany (TR)	PP_1	0	456	0,30	1,58	8	6.720,00	23,30	184
Italy (TR&TN)	PP_3	0	208	0,42	1,35	714	4.480,00	29,12	20.706
Japan (SA&TZ&JR&IR)	FT_2	0	81.041	0,41	1,59	20	342.000,00	6,71	60
Malaysia (SA&TZ&JR&IR)	PP_4	0	927	0,37	1,42	8568	13.440,00	20,56	42.840
Spain (TZ&TN&JR&IR)	CP_4	0	5.236	0,52	1,60	2640	24.480,00	7,49	18.480
Turkey (TR&TN)	FT_1	0	66.168	0,55	1,70	52	144.000,00	3,71	156
UK (TR)	PP_2	0	176	0,22	1,83	14	3.840,00	39,94	546
UK (SA)	FT_3	0	15.253	0,06	7,93	175	54.000,00	28,08	700
USA (TR)	CP_3	0	849	0,14	4,41	44	13.824,00	71,88	781
USA (TN)	FT_4	0	23.249	0,09	5,26	15	90.000,00	20,35	60

In alternative business model, we assume that suppliers do not keep safety stock at their premises. Instead, safety stock is kept at the supply hub side in order to cover potential variations in demand of the manufacturers and other uncertainties. We describe the safety stock policy in Section 4.3.3.

The choice on the location of the hub also affects the cost parameters on the manufacturer's side. We compute transportation costs to include the cost of travel from the supply hub to the manufacturers and revise customs and agencies cost based on the location of the hub, Turkey.

Revised cost parameters are shown in Table 5.13.

Table 5.13: Additional Parameters and Revised Costs (Supply Hub to Manufacturers)

Manufacturers	Product	K_{mjg}	g_{mj1}	g_{mj2}	a_{hf}	a_{hl}
Iran (SP)	CP_4	0,075	0,225	1,2	1.300	1.339
Iran (FR)	CP_1	0,075	0,225	1,2	1.300	1.339
Iran (JP)	FT_2	0,013	0,038	0,2	1.300	1.339
Iran (ML)	PP_4	0,075	0,225	1,2	1.300	1.339
Jordan (JP)	FT_2	0,013	0,038	0,2	1.966	2.025
Jordan (ML)	PP_4	0,075	0,225	1,2	1.966	2.025
Jordan (SP)	CP_4	0,075	0,225	1,2	1.966	2.025
Tanzania (ML)	PP_4	0,075	0,225	1,2	3.150	3.245
Tanzania (JP)	FT_2	0,013	0,038	0,2	3.150	3.245
Tanzania (SP)	CP_4	0,075	0,225	1,2	3.150	3.245
Turkey (FR)	CP_1	0,030	0,090	0,5	100	103
Turkey (AU)	CP_2	0,030	0,090	0,5	100	103
Turkey (US)	CP_3	0,075	0,225	1,2	100	103
Turkey (TR)	FT_1	0,013	0,038	0,2	100	103
Turkey (GE)	PP_1	0,030	0,090	0,5	100	103
Turkey (UK)	PP_2	0,030	0,090	0,5	100	103
Turkey (IT)	PP_3	0,030	0,090	0,5	100	103
Tunisia (TR)	FT_1	0,013	0,038	0,2	2.000	2.060
Tunisia (US)	FT_4	0,013	0,038	0,2	2.000	2.060
Tunisia (IT)	PP_3	0,075	0,225	1,2	2.000	2.060
Tunisia (SP)	CP_4	0,075	0,225	1,2	2.000	2.060
Safrica (AU)	CP_2	0,075	0,225	1,2	2.410	2.482
Safrica (JP)	FT_2	0,013	0,038	0,2	2.410	2.482
Safrica (UK)	FT_3	0,013	0,038	0,2	2.410	2.482
Safrica (ML)	PP_4	0,075	0,225	1,2	2.410	2.482

It is now possible to calculate the decision variables at the manufacturers' side (using Equation 4.32);

The results are given in Table 5.14,

Table 5.14: Decision Variables at Manufacturer's side in Alternative Business Model

Manufacturers	Product	s_{mj}	Q_{mj}	t_{mj}	$LT_{h\text{-}m}$	t_c
Iran (SP)	CP_4	1.923	11.335	11,79	2,0	2640
Iran (FR)	CP_1	1.923	11.577	12,04	2,0	12
Iran (JP)	FT_2	48.077	131.797	5,48	2,0	20
Iran (ML)	PP_4	577	5.478	18,99	2,0	8568
Jordan (JP)	FT_2	28.846	100.225	10,42	3,0	20
Jordan (ML)	PP_4	346	4.166	36,11	3,0	8568
Jordan (SP)	CP_4	2.308	12.190	15,85	3,0	2640
Tanzania (ML)	PP_4	673	6.692	34,80	3,5	8568
Tanzania (JP)	FT_2	50.481	152.729	10,59	3,5	20
Tanzania (SP)	CP_4	4.038	18.576	16,10	3,5	2640
Turkey (FR)	CP_1	275	7.265	3,78	0,1	12
Turkey (AU)	CP_2	137	5.030	5,23	0,1	120
Turkey (US)	CP_3	27	2.298	11,95	0,1	11
Turkey (TR)	FT_1	5.495	73.973	1,92	0,1	52
Turkey (GE)	PP_1	41	2.431	8,43	0,1	8
Turkey (UK)	PP_2	14	1.357	14,12	0,1	14
Turkey (IT)	PP_3	14	1.403	14,60	0,1	714
Tunisia (TR)	FT_1	385	20.202	52,53	1,0	52
Tunisia (US)	FT_4	4.423	68.509	15,49	1,0	15
Tunisia (IT)	PP_3	58	2.969	51,46	1,0	714
Tunisia (SP)	CP_4	385	8.687	22,59	1,0	2640
Safrica (AU)	CP_2	1.538	9.464	24,61	4,0	120
Safrica (JP)	FT_2	11.538	60.274	20,89	4,0	20
Safrica (UK)	FT_3	7.692	49.213	25,59	4,0	25
Safrica (ML)	PP_4	231	3.234	56,06	4,0	8568

As different from the traditional model, the safety stock at the manufacturers' side is now derived using the policy of keeping a stock equal to of demand during transportation lead times from the supply hub to the manufacturers. Lead times are up-dated accordingly. Furthermore, as t_{mj}'s in alternative model change, the value of t_c changes, this is also reflected in Table 5.14.

Finally, the parameters related to the supply hub, Turkey are given in Table 5.15;

Table 5.15: Parameters related to Supply Hub

Hub	Supplier	Product	bh	r_h	K_{h_g}	g_{h1}	g_{h2}
Turkey	Austria (TR&SA)	CP_2	0,0036	0,0012	0,00	0,00	0,00
	France (TR&IR)	CP_1	0,0030	0,0012	0,00	0,00	0,00
	Germany (TR)	PP_1	0,0078	0,0012	0,00	0,00	0,00
	Italy (TR&TN)	PP_3	0,0078	0,0012	0,00	0,00	0,00
	Japan	FT_2	0,0009	0,0012	0,00	0,00	0,00
	Malaysia	PP_4	0,0078	0,0012	0,00	0,00	0,00
	Spain	CP_4	0,0036	0,0012	0,00	0,00	0,00
	Turkey (TR&TN)	FT_1	0,0009	0,0012	0,00	0,00	0,00
	UK (TR)	PP_2	0,0091	0,0012	0,00	0,00	0,00
	UK (SA)	FT_3	0,0009	0,0012	0,00	0,00	0,00
	USA (TR)	CP_3	0,0030	0,0012	0,00	0,00	0,00
	USA (TN)	FT_4	0,0009	0,0012	0,00	0,00	0,00

We take customs and agencies cost at the supply hub to be zero. This is due to the reasonable assumption that, the hub will be located either in a free zone or as a bonded warehouse in Turkey. In both situations, there are no customs and agencies costs associated with the hub.

In order to calculate the total inventory at supply hub side, it is first necessary to define the safety stock policy at supply hub. As stated earlier, suppliers do not keep safety stock at their premises in alternative business model. The safety stock level at the supply hub needs to cover two potential variations: potential fluctuations in manufacturers demand and the negative inventory occurring at hub side due to inconsistencies between incoming and outgoing inventories. To overcome the first risk, it is reasonable to carry a safety stock level that covers the demand during production plus transportation lead time of the related products. The latter variation is related to incompatibilities between incoming and outgoing inventories only at some specific periods. Even the difference between incoming and outgoing inventories over the cycle time t_o^1 is positive; we may observe negative inventory in some periods. Therefore, to avoid such situations, we can keep a stock that covers the minimum level of inventory detected during the cycle time t_o^1.

Considering those two factors, we can now define the safety stock level to be the maximum value of the two quantities based on the risks.

We use an example to demonstrate the steps of calculating the safety stock for a specific product. This is shown in Table 5.16. The safety stocks for the other products are computed similarly. The resulting safety stock levels are presented in Table 5.18.

Table 5.16: Safety Stock Calculation at Supply Hub

t_s' => 60 weeks	Weeks																													
Supplier : USA (TN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Q_d (from USA) in t_d weeks																				88.462										
Q_{mj} (to TN) in t_{mj} weeks															66.346															66.346
IN - OUT Inventory per week	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-66.346	-66.346	-66.346	-66.346	-66.346	22.115	22.115	22.115	22.115	22.115	22.115	22.115	22.115	22.115	22.115	-44.231

t_s' => 60 weeks	Weeks																													
Supplier : USA (TN)	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Q_d (from USA) in t_d weeks										88.462																				88.462
Q_{mj} (to TN) in t_{mj} weeks															66.346															66.346
IN - OUT Inventory per week	-44.231	-44.231	-44.231	-44.231	-44.231	-44.231	-44.231	-44.231	-44.231	44.231	44.231	44.231	44.231	44.231	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	-22.115	0

minimum negative inventory in 60 weeks	-66.346

After identifying the optimal values for decision variables for all parties, it is now possible to calculate the total inventory figures for the suppliers, supply hub and manufacturers using Equations 5.3, 6.4 and 7.2, respectively.

Table 5.17: Total Inventory per unit time at Supplier's side

Suppliers	Product	IN	OUT	IN-OUT	$s_{(a\ or\ h)}$	Total Inventory
Austria (TR&SA)	CP_2	81.975	66.489	15.486	0	15.486
France (TR&IR)	CP_1	18.872	3.484	15.389	0	15.389
Germany (TR)	PP_1	1.338	-2.206	3.544	0	3.544
Italy (TR&TN)	PP_3	54.995	52.683	2.312	0	2.312
Japan (SA&TZ&JR&IR)	FT_2	539.811	338.615	201.196	0	201.196
Malaysia (SA&TZ&JR&IR)	PP_4	2.801.419	2.794.357	7.062	0	7.062
Spain (TZ&TN&JR&IR)	CP_4	4.317.147	4.303.145	14.002	0	14.002
Turkey (TR&TN)	FT_1	1.032.374	938.000	94.374	0	94.374
UK (TR)	PP_2	750	-1.247	1.997	0	1.997
UK (SA)	FT_3	175.837	141.269	34.568	0	34.568
USA (TR)	CP_3	4.642	-2.681	7.323	0	7.323
USA (TN)	FT_4	44.592	-11.827	56.419	0	56.419

Inventory flow figures for the supply hub are shown in Table 5.18.

Table 5.18: Total Inventory per unit time at Supply Hub's side

Hub	Supplier	Product	IN	OUT	IN-OUT	$s_{(a\ or\ h)}$	Total Inventory
Turkey	Austria (TR&SA)	CP_2	551.105	558.137,81	-7.033,20	24.230,77	17.197,57
	France (TR&IR)	CP_1	38.099,08	42.501,88	-4.402,80	23.076,92	18.674,12
	Germany (TR)	PP_1	23.178,46	25.323,00	-2.144,54	6.346,15	4.201,62
	Italy (TR&TN)	PP_3	1.590.529,23	1.590.583,00	-53,77	3.923,08	3.869,30
	Japan	FT_2	1.357.846,15	1.306.333,59	51.512,57	326.419,06	377.931,63
	Malaysia	PP_4	13.998.664,62	13.995.599,17	3.065,44	9.307,69	12.373,14
	Spain	CP_4	30.195.452,31	30.182.298,45	13.153,85	11.538,46	24.692,32
	Turkey (TR&TN)	FT_1	2.958.000,00	2.982.912,36	-24.912,36	78.076,92	53.164,56
	UK (TR)	PP_2	24.330,00	25.571,33	-1.241,33	3.461,54	2.220,21
	UK (SA)	FT_3	646.076,92	648.470,25	-2.393,33	51.923,08	49.529,75
	USA (TR)	CP_3	68.184,15	73.947,37	-5.763,21	13.461,54	7.698,33
	USA (TN)	FT_4	87.692,31	98.437,82	-10.745,51	66.346,15	55.600,64

Manufacturer's inventory flow is given in Table 5.19 as follows;

Table 5.19: Total Inventory per unit time at Manufacturers' side

Manufacturers	Product	IN-OUT	s_{mj}	Total Inventory
Iran (SP)	CP_4	5.667	1.923	7.591
Iran (FR)	CP_1	5.789	1.923	7.712
Iran (JP)	FT_2	65.898	48.077	113.975
Iran (ML)	PP_4	2.739	577	3.316
Jordan (JP)	FT_2	50.113	28.846	78.959
Jordan (ML)	PP_4	2.083	346	2.429
Jordan (SP)	CP_4	6.095	2.308	8.403
Tanzania (ML)	PP_4	3.346	673	4.019
Tanzania (JP)	FT_2	76.365	50.481	126.845
Tanzania (SP)	CP_4	9.288	4.038	13.326
Turkey (FR)	CP_1	3.633	275	3.907
Turkey (AU)	CP_2	2.515	137	2.652
Turkey (US)	CP_3	1.149	27	1.176
Turkey (TR)	FT_1	36.987	5.495	42.481
Turkey (GE)	PP_1	1.215	41	1.257
Turkey (UK)	PP_2	679	14	692
Turkey (IT)	PP_3	702	14	715
Tunisia (TR)	FT_1	10.101	385	10.486
Tunisia (US)	FT_4	34.254	4.423	38.678
Tunisia (IT)	PP_3	1.484	58	1.542
Tunisia (SP)	CP_4	4.344	385	4.728
Safrica (AU)	CP_2	4.732	1.538	6.270
Safrica (JP)	FT_2	30.137	11.538	41.675
Safrica (UK)	FT_3	24.607	7.692	32.299
Safrica (ML)	PP_4	1.617	231	1.848

Given the optimal values for the decision variables and other related data, we are now in a position to calculate the total costs for the alternative business model. For this, we utilize Equations 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.13, 4.14, 4.15, 4.16, 4.17, 4.23, 4.24 and 4.25.

Table 5.20: Total Costs of Suppliers in Alternative Business Model

Suppliers	Product	Bs	Us	A_s	P_s	Z_s	TC_s
Austria (TR&SA)	CP_2	177	565,7	717,5	3.706	16	5.183
France (TR&IR)	CP_1	147	589,5	580	7.909	34	9.260
Germany (TR)	PP_1	87	134,1	130	794	3	1.149
Italy (TR&TN)	PP_3	57	107,0	59	423	2	647
Japan (SA&TZ&JR&IR)	FT_2	553	1.670,6	6.825	23.334	607	32.990
Malaysia (SA&TZ&JR&IR)	PP_4	173	336,4	688	1.798	8	3.003
Spain (TZ&TN&JR&IR)	CP_4	160	669,7	574	8.967	39	10.409
Turkey (TR&TN)	FT_1	130	425,6	216	17.753	462	18.986
UK (TR)	PP_2	57	73,0	53	266	1	450
UK (SA)	FT_3	95	242,6	110	917	23	1.387
USA (TR)	CP_3	70	260,0	81	536	2	949
USA (TN)	FT_4	155	323,1	471	2.075	53	3.076

Table 5.21: Total Costs of Supply Hub in Alternative Business Model

Hub	Supplier	Product	B_h	R_h	G_h	TC_h
Turkey	Austria (TR&SA)	CP_2	62,70	1,6	0,00	64
	France (TR&IR)	CP_1	56,74	3,3	0,00	60
	Germany (TR)	PP_1	32,83	0,3	0,00	33
	Italy (TR&TN)	PP_3	30,23	0,2	0,00	30
	Japan	FT_2	330,69	58,8	0,00	389
	Malaysia	PP_4	96,67	0,8	0,00	97
	Spain	CP_4	90,02	3,8	0,00	94
	Turkey (TR&TN)	FT_1	46,52	44,8	0,00	91
	UK (TR)	PP_2	20,24	0,1	0,00	20
	UK (SA)	FT_3	43,34	2,2	0,00	46
	USA (TR)	CP_3	23,39	0,2	0,00	24
	USA (TN)	FT_4	48,65	5,1	0,00	54

Table 5.22: Total Costs of Manufacturers in Alternative Business Model

Manufacturers	Product	B_{mj}	U_{mj}	A_{mj}	R_{mj}	G_{mj}	O_{mj}	TC_{mj}
Iran (SP)	CP_4	43	131,37	351,11	1	1.442	0,00014	1.969
Iran (FR)	CP_1	37	133,47	343,76	1	1.442	0,00012	1.957
Iran (JP)	FT_2	157	328,77	1.940	5	6.010	0,00007	8.440
Iran (ML)	PP_4	41	57,39	218	1	433	0,00019	749
Jordan (JP)	FT_2	109	227,77	1.157	2	2.404	0,00004	3.899
Jordan (ML)	PP_4	30	42,04	116	0	173	0,00010	361
Jordan (SP)	CP_4	48	145,43	389	1	1.154	0,00011	1.737
Tanzania (ML)	PP_4	49	69,56	280	0	288	0,00010	688
Tanzania (JP)	FT_2	174	365,90	2.705	3	3.606	0,00004	6.854
Tanzania (SP)	CP_4	76	230,65	997	1	1.731	0,00010	3.035
Turkey (FR)	CP_1	19	67,63	107	1	1.154	0,00037	1.348
Turkey (AU)	CP_2	15	45,90	77	1	577	0,00032	716
Turkey (US)	CP_3	6	20,36	25	0	288	0,00012	340
Turkey (TR)	FT_1	58	122,54	366	8	9.615	0,00021	10.170
Turkey (GE)	PP_1	15	21,75	48	1	173	0,00042	259
Turkey (UK)	PP_2	10	11,98	21	0	58	0,00030	101
Turkey (IT)	PP_3	9	12,38	21	0	58	0,00024	100
Tunisia (TR)	FT_1	14	30,25	81	0	96	0,00001	222
Tunisia (US)	FT_4	53	111,57	533	1	1.106	0,00003	1.805
Tunisia (IT)	PP_3	19	26,69	83	0	87	0,00007	215
Tunisia (SP)	CP_4	27	81,83	277	0	577	0,00007	963
Safrica (AU)	CP_2	36	108,53	305	0	577	0,00007	1.027
Safrica (JP)	FT_2	57	120,22	474	1	721	0,00002	1.374
Safrica (UK)	FT_3	44	93,17	293	0	481	0,00002	912
Safrica (ML)	PP_4	23	31,98	91	0	87	0,00006	232

Considering all above calculations, the total cost of the supply chain in alternative business model is calculated by Equation 4.31 as $137,964 per week.

5.3. Comparison of Traditional and Alternative Business Models

The following section includes a comparison of the performances of the traditional and the alternative models, based on the preceding numeric analysis. We also identify the cost items that dominantly define the difference between the two models.

5.3.1. Comparison Analysis

Table 5.23 summarizes the total costs per unit time for each model. “Model 1” refers to “Traditional Business Model” whereas “Model 2” refers to “Alternative Business Model”. The unit time of the calculations is based on weeks. That is, Table 5.23 shows the total cost of each party per week based on each scenario.

Table 5.23: Comparison Analysis on Traditional and Alternative Business Models

Suppliers	Q_p	s_s	in-out	B_s	U_s	A_s	P_s	Z_s	R_s	G_s	O_s	TC_s
Model 1	201.133	420.154	561.179	3.720	4.587	0	68.476	0	-	-	-	**76.783**
Model 2	201.133	0	453.671	1.862	5.397	0	68.476	1.250	-	-	-	**76.986**
diff %	-	-100,00%	-19,16%	-49,93%	17,66%	-	0,00%	1,62%	-	-	-	0,26%

of the total

Manufacturers	Σ Q_{mj}	Σ s_{mj}	Σ (in-out)	Σ B_{mj}	Σ U_{mj}	Σ A_{mj}	Σ P_{mj}	Σ Z_{mj}	Σ R_{mj}	Σ G_{mj}	Σ O_{mj}	Σ TC_{mj}
Model 1	968.009	763.009	1.247.014	2.484	5.663	8.147	-	-	27	34.337	0,0021	**61.202**
Model 2	771.076	171.445	556.983	1.170	2.639	3.809	-	-	27	34.337	0,0033	**59.975**
diff %	-	-77,53%	-55,33%	-52,88%	-53,40%	-53,24%	-	-	0,00%	0,00%	61,30%	-2,01%

Hub	Q_d	s_h	in-out	B_h	U_h	A_h	P_h	Z_h	R_h	G_h	O_h	TC_h
Model 1	-	-	-	-	-	-	-	-	-	-	-	**0**
Model 2	752.992	618.111	9.042	882	-	-	-	-	121	0,0000	-	**1.003**
diff %	-	-	-	87,92%	-	-	-	-	12,08%	0,00%	-	-

of the total

of the total

SC	-	s_{sc}	in-out	B_{sc}	U_{sc}	A_{sc}	P_{sc}	Z_{sc}	R_{sc}	G_{sc}	O_{sc}	TC_{sc}
Model 1	-	1.183.163	1.808.193	6.204	10.250	18.692	68.476	0	27	34.337	0,0021	**137.986**
Model 2	-	789.556	1.019.695	3.915	8.036	21.801	68.476	1.250	149	34.337	0,0033	**137.964**
diff %	-	-33,27%	-43,61%	-36,90%	-21,60%	16,64%	0,00%	0,00%	442,79%	0,00%	61,30%	-0,02%

In Model 1, suppliers and manufacturers keep safety stock at their own sites. The level of the safety stock in this case is determined accordingly to the lead times which are remarkably long for each product. In Model 2, suppliers and manufacturers change safety stock policies. Suppliers do not keep safety stock at their site; instead they keep safety stocks at supply hub's premises, whereas manufacturers keep safety stocks based on the lead times, to the supply hub's premises. This is remarkably lower, since supply hub is located at a closer point both to suppliers and manufacturers. Hence, in Model 2, the amount of safety stock kept at the supplier's site is zero, there is still some level of safety stock kept at the manufacturers' site and remarkable amount is mainly kept at supply hub's site.

A comparison of the safety stock level for the overall supply chain results in a significant change in business model from the traditional one to the alternative. This also reduces the net inventory amount. That is the result of enhancing the supply chain structure by adding a hub at a closer stocking point to both the suppliers and manufacturers, affects inventory level for all products positively. For this particular case, we observe around 33% reduction in safety stock levels alone over the supply chain.

The demands of the manufacturers are the same for the two models. As the optimization analysis reveals, this implies that the optimal production quantities for the suppliers do not change either. On the other hand, manufacturers now consider lower the transportation costs from supply hub to manufacturers instead of considering higher transportation costs from suppliers to manufacturers in deciding on best order quantities (Q_{mj} values). This results in a reduction in the manufacturer order quantities in Model 2. This, in turn, means manufacturers now order more frequently, in smaller quantities, which increases the ordering costs of the manufacturers.

As a result of the decrease in safety stock levels and lower manufacturer order quantities, we have 44% reduction in net inventory level over the supply chain in Model 2 as compared to Model 1.

This is also reflected in the inventory holding costs by a 37% reduction. This reduction carries the effect, in part, of the introduction of a supply hub which makes it possible to store products at a lower cost than that of suppliers. We note that this is not a choice of parameters, rather a feasibility condition (Section 4.2.2)

On the other hand, the opportunity cost of suppliers' increase in Model 2 compared to Model 1, as suppliers tie up money to inventory kept at their own side plus to the inventory kept at supply hub. This coupled with the fact that manufacturers now have lower safety stock levels result in a reduction of the opportunity costs of manufacturers. In result, the opportunity cost over the supply chain reduces down by around 22%.

In both models, manufacturers bear the transportation costs. The inclusion of an intermediate transshipment point between suppliers and manufacturers in Model 2 increases the total number of shipments and the transportation costs.

The increase in transportation costs is about 17%, despite an additional discount of 25% is received on costs due to the consolidation of shipments.

Not surprisingly, the cost of production is the same for the two models since the production equals demand which is the same for both models. Model 2 includes as an additional cost for the supplier, the fixed cost of supply hub. Addition of a supply hub into the picture and increased number of shipments increases receiving cost in Model 2.

The customs and agencies costs do not change due to the fact that, the location of the supply hub in our case is in a free zone or a bonded warehouse. The agencies costs of receiving the products to the supply hub are assumed to be included in the fixed cost of supply hub as operating expense.

Some cost items in Model 2 have positive effect whereas some have negative effect with respect to Model 1. Overall, the total cost of the supply chain in Model 2 is around 0.02% lower than the total cost of the supply chain in Model 1. That is, the weekly cost of Model 2 is $137,964 and the weekly cost for Model 1 is $137,986.

Remarkable differences in total costs are observed in inventory holding cost, opportunity cost and transportation cost components. Model 2 has a higher transportation costs by 17%; the decrease (27%) in inventory carrying costs covers this increase over the supply chain.

At the suppliers' side, the cost of holding inventory decreases by 50%; however, the total cost increases by 0.26% in Model 2 with respect to Model 1. This is due to an increase in opportunity cost (18%) and additional supply hub cost (1.62% of the total).

At manufacturers' side, transportation costs increase (by 17%) due to the addition of the hub transportation cost; whereas the total cost decreases by 2.01%, as result of lower inventory carrying costs (by 53%) which covers the increased amount.

Thus, we have a decrease in manufacturers' costs, which covers the increase in suppliers' costs and the addition of hub costs.

In the light of the above analysis and results, we believe it can safely be stated that, for the multinational company, it is feasible to switch the business structure from Model 1 to Model 2 for its Middle East and Europe region.

Even though the cost advantage does not seem remarkable, operational ease and flexibility for all parties involved is worthwhile undertaking. Note also that the comparison we present is based on an idealized version of the current business model. In the event that the company chooses to change the business structure with respect to the alternative model, this is more likely to be possible by a joint agreement of all parties involved. Even though the multinational company is the dominating key company of the supply chain, any successful implementation requires the collaboration of the suppliers as well.

To this end, one tool the multinational company can utilize is to offer an appropriate level of additional costs suppliers incur due to the new supply chain design. One reasonable method of computing the markup level is dividing the total additional cost per week of the suppliers with the total number of units sold over the same period, thus, resulting in a flat price markup for all products.

This is shown in the next table;

Table 5.24: Calculation of Markup Rate

Suppliers	$d_{mj} * c_{mj}$
Austria (TR&SA)	40.384,62
France (TR&IR)	86.538,46
Germany (TR)	8.653,85
Italy (TR&TN)	4.615,38
Japan (SA&TZ&JR&IR)	254.807,69
Malaysia (SA&TZ&JR&IR)	19.615,38
Spain (TZ&TN&JR&IR)	98.076,92
Turkey (TR&TN)	194.230,77
UK (TR)	2.884,62
UK (SA)	9.615,38
USA (TR)	5.769,23
USA (TN)	22.115,38
Total	**747.307,69**

$TC_s^{II} - TC_s^{I}$	**203**
M_s	**0,027%**

This markup level can be applied as is to all suppliers in common. However, one may go with an individual analysis on the markup level for each supplier. This may result in no markup for some suppliers, even discounts on some suppliers whereas different amounts of markups for other suppliers.

In any case, the weighted average markup rate will be equal to the computed 0.027% which may be a guiding figure to the managers of the company.

5.3.2. Cash Flow Management

We now present an evaluation of the traditional and alternative models in terms of cash flows generated. This criterion is very important, especially for cases like our instance, where high amounts of cash are involved.

One can unquestionably argue that effective cash flow management is the one of the most important requirements for long term survival for any company. Having free cash available to use is equally valuable and promises high profits. In this sense, it can be safely stated that, any business model that ensures an acceptable level of profit/cost should be further supported with cash flow considerations. Ideally, the model would result in additional free cash flow, for instance, by freeing some money tied up in inventory.

We now review the free cash flow impact of the two models for the company that we analyze in the numeric study. We base the analysis on the relevant cost components as we do in the preceding parts of the thesis.

The analysis is based on a 5-year review period, as advised and practiced by the company managers to observe financial impacts of decisions. To facilitate the analysis, we convert weekly demand values into yearly figures and use the unit price information to generate the cash flows. We assume a yearly 7.5% cost of capital. With this information then, we can calculate the net present value figures.

Table 5.25: Comparison on Financial Statement of Traditional and Alternative Business Models

SUPPLIERS		Model 1 (Traditional Business Model)						Model 2 (Alternative Business Model)					
Costs		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Inventory Holding Cost		193.433	193.433	193.433	193.433	193.433	967.166	142.709	142.709	142.709	142.709	142.709	713.546
Transportation Cost		0	0	0	0	0	0	0	0	0	0	0	0
Receiving Cost		0	0	0	0	0	0	6.302	6.302	6.302	6.302	6.302	31.512
C&A Cost		0	0	0	0	0	0	0	0	0	0	0	0
Ordering Cost		0	0	0	0	0	0	0	0	0	0	0	0
Production Cost		3.560.778	3.560.778	3.560.778	3.560.778	3.560.778	17.803.889	3.560.778	3.560.778	3.560.778	3.560.778	3.560.778	17.803.889
Hub Cost		0	0	0	0	0	0	65.020	65.020	65.020	65.020	65.020	325.098
TOTAL COST		3.754.211	3.754.211	3.754.211	3.754.211	3.754.211	18.771.055	3.774.809	3.774.809	3.774.809	3.774.809	3.774.809	18.874.044
inventory in balance sheet		7.950.940						9.355.143					
cash flow		-11.705.151	-3.754.211	-3.754.211	-3.754.211	-3.754.211		-13.129.952	-3.774.809	-3.774.809	-3.774.809	-3.774.809	
Cost of Capital	7,5%												
NPV		**-22.585.329**						**-23.974.900**					
Difference in NPV (M 1 vs M 2)		**1.389.572**											

		Model 1 (Traditional Business Model)						Model 2 (Alternative Business Model)					
MANUFACTURERS													
Costs		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Inventory Holding Cost		129.165	129.165	129.165	129.165	129.165	645.824	60.857	60.857	60.857	60.857	60.857	304.283
Transportation Cost		971.965	971.965	971.965	971.965	971.965	4.859.824	1.133.670	1.133.670	1.133.670	1.133.670	1.133.670	5.668.349
Receiving Cost		1.423	1.423	1.423	1.423	1.423	7.117	1.423	1.423	1.423	1.423	1.423	7.117
C&A Cost		1.785.500	1.785.500	1.785.500	1.785.500	1.785.500	8.927.500	1.785.500	1.785.500	1.785.500	1.785.500	1.785.500	8.927.500
Ordering Cost		0	0	0	0	0	1	0	0	0	0	0	1
Production Cost		0	0	0	0	0	0	0	0	0	0	0	0
Hub Cost		0	0	0	0	0	0	0	0	0	0	0	0
TOTAL COST		2.888.053	2.888.053	2.888.053	2.888.053	2.888.053	14.440.266	2.981.450	2.981.450	2.981.450	2.981.450	2.981.450	14.907.250
inventory in balance sheet		9.815.631						4.574.532					
cash flow		-12.703.684	-2.888.053	-2.888.053	-2.888.053	-2.888.053		-7.555.982	-2.981.450	-2.981.450	-2.981.450	-2.981.450	
Cost of Capital	7,5%												
NPV		**-20.815.550**						**-16.317.982**					
Difference in NPV (M 1 vs M 2)		**-4.497.569**											

		Model 1 (Traditional Business Model)						Model 2 (Alternative Business Model)					
SUPPLY CHAIN													
Costs		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Inventory Holding Cost		322.598	322.598	322.598	322.598	322.598	1.612.990	203.566	203.566	203.566	203.566	203.566	1.017.829
Transportation Cost		971.965	971.965	971.965	971.965	971.965	4.859.824	1.133.670	1.133.670	1.133.670	1.133.670	1.133.670	5.668.349
Receiving Cost		1.423	1.423	1.423	1.423	1.423	7.117	7.726	7.726	7.726	7.726	7.726	38.628
C&A Cost		1.785.500	1.785.500	1.785.500	1.785.500	1.785.500	8.927.500	1.785.500	1.785.500	1.785.500	1.785.500	1.785.500	8.927.500
Ordering Cost		0	0	0	0	0	1	0	0	0	0	0	1
Production Cost		3.560.778	3.560.778	3.560.778	3.560.778	3.560.778	17.803.889	3.560.778	3.560.778	3.560.778	3.560.778	3.560.778	17.803.889
Hub Cost		0	0	0	0	0	0	65.020	65.020	65.020	65.020	65.020	325.098
TOTAL COST		6.642.264	6.642.264	6.642.264	6.642.264	6.642.264	33.211.321	6.756.259	6.756.259	6.756.259	6.756.259	6.756.259	33.781.294
inventory in balance sheet		17.766.571						13.929.675					
cash flow		-24.408.835	-6.642.264	-6.642.264	-6.642.264	-6.642.264		-20.685.933	-6.756.259	-6.756.259	-6.756.259	-6.756.259	
Cost of Capital	7,5%												
NPV		**-43.400.879**						**-40.292.882**					
Difference in NPV (M 1 vs M 2)		**-3.107.997**											

Table 5.25 summarizes the cash flow analysis through a financial statement summary of both models. Financial figures show a net present value (NPV) difference of $-1,389,572 between Model 1 and Model 2 whereas an incremental NPV of $+4,497,569. For manufacturers consolidated figures show an increased $+3,107,997 NPV for the overall supply chain for the planning horizon of 5 years.

The negative NPV at the suppliers' side is primarily due to higher inventory levels. The increase at the manufacturers' side is primarily due to carrying lower levels of inventory.

Financial figures suggest that the gain at the consolidated level is far positive and prominently advantageous for the supply chain overall. The negative figure at suppliers' side can be compensated, as mentioned earlier, for instance by adding an additional markup to the product's price or by some other compensation method. The result is valuable in that, it proves that in the long run, regardless of the compensating the suppliers' loss, applying the alternative business model promises free cash of $3,107,997 for the supply chain. The underlying drivers are the reduced level of inventories in alternative model.

5.3.3. The Decision

We provided a numeric analysis involving total cost figures and analyzed cash flow for both models. We conclude that even though the total costs for traditional business model and for alternative business model are very close, we can suggest the multinational company to redesign its business process with supply hubs in the Middle East and Europe region. The main motivation behind this decision would be the operational efficiency and flexibility that the alternative model provides plus the free cash generated primarily due to reduced inventory levels.

Beside other outcomes, this analysis underlines the importance of efficient and systematic inventory management, which as in this case, potentially enables the management to take a decision on changing the business model in the light of positive financial results.

We now provide additional analysis to measure the robustness of the decision and identify the breakeven points. This analysis will provide methods for posterior analysis for the decisions made regarding the supply chain and demonstrate the behavior of both models with respect to future projections.

5.3.4. Distribution of Costs Among Manufacturers

For the multinational company, the key criterion for deciding on the implementation of any business model depends on the benefits gained in total. Even though some of the manufacturers may face losses, the company is likely to go with the alternative model if the total gain is positive.

We provide such an analysis in Table 5.26. The table demonstrates the effect of each cost component for each product and on each individual manufacturer (The gains/losses are based on Model 2)

Table 5.26: Gain/Loss Analysis on Manufacturers' Side

		Bmj		Umj		Amj		Rmj		Gmj		Omj		TCmj				TCmj			
		M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2			M2	M1 vs M2		
Manufacturers	Product															As	As per mj		mj	dmj	% in ds
Iran (SP)	CP_4	77	43	232	131	603	351	1	1	1.442	1.442	0,00011	0,00014	2.355	1.969	574	169	2.138		962	0,29
Iran (FR)	CP_1	67	37	242	133	624	344	1	1	1.442	1.442	0,00009	0,00012	2.376	1.957	580	193	2.150		962	0,33
Iran (JP)	FT_2	438	157	919	329	3.961	1.940	5	5	6.010	6.010	0,00005	0,00007	11.331	8.440	6.825	3.219	11.660		24.038	0,47
Iran (ML)	PP_4	76	41	107	57	451	218	1	1	433	433	0,00013	0,00019	1.067	749	688	304	1.053	129	288	0,44
Jordan (JP)	FT_2	221	109	464	228	2.251	1.157	2	2	2.404	2.404	0,00003	0,00004	5.343	3.899	6.825	1.288	5.186		9.615	0,19
Jordan (ML)	PP_4	42	30	59	42	215	116	0	0	173	173	0,00008	0,00010	490	361	688	121	483		115	0,18
Jordan (SP)	CP_4	61	48	184	145	352	389	1	1	1.154	1.154	0,00011	0,00011	1.751	1.737	574	135	1.872	43	769	0,24
Tanzania (ML)	PP_4	58	49	82	70	388	280	0	0	288	288	0,00010	0,00010	817	688	688	202	890		192	0,29
Tanzania (JP)	FT_2	280	174	587	366	3.254	2.705	3	3	3.606	3.606	0,00004	0,00004	7.729	6.854	6.825	1.932	8.786		14.423	0,28
Tanzania (SP)	CP_4	117	76	353	231	1.011	997	1	1	1.731	1.731	0,00010	0,00010	3.213	3.035	574	202	3.238	-1.155	1.154	0,35
Turkey (FR)	CP_1	105	19	380	68	927	107	1	1	1.154	1.154	0,00014	0,00037	2.567	1.348	580	386	1.735		1.923	0,67
Turkey (AU)	CP_2	81	15	245	46	696	77	1	1	577	577	0,00010	0,00032	1.600	716	718	513	1.228		962	0,71
Turkey (US)	CP_3	26	6	94	20	146	25	0	0	288	288	0,00004	0,00012	554	340	81	81	421		192	1,00
Turkey (TR)	FT_1	299	58	628	123	366	366	8	8	9.615	9.615	0,00021	0,00021	10.915	10.170	216	214	10.383		38.462	0,99
Turkey (GE)	PP_1	55	15	78	22	214	48	1	1	173	173	0,00019	0,00042	522	259	130	130	389		288	1,00
Turkey (UK)	PP_2	33	10	40	12	96	21	0	0	58	58	0,00012	0,00030	228	101	53	53	154		96	1,00
Turkey (IT)	PP_3	24	9	34	12	72	21	0	0	58	58	0,00013	0,00024	189	100	59	37	137	2.128	96	0,63
Tunisia (TR)	FT_1	15	14	33	30	73	81	0	0	96	96	0,00001	0,00001	217	222	216	2	224		385	0,01
Tunisia (US)	FT_4	111	53	233	112	801	533	1	1	1.106	1.106	0,00002	0,00003	2.251	1.805	471	471	2.275		4.423	1,00
Tunisia (IT)	PP_3	25	19	35	27	98	83	0	0	87	87	0,00006	0,00007	245	215	59	22	237		58	0,38
Tunisia (SP)	CP_4	38	27	114	82	286	277	0	0	577	577	0,00007	0,00007	1.015	963	574	67	1.031	-39	385	0,12
Safrica (AU)	CP_2	53	36	159	109	392	305	0	0	577	577	0,00005	0,00007	1.180	1.027	718	205	1.232		385	0,29
Safrica (JP)	FT_2	86	57	180	120	764	474	1	1	721	721	0,00002	0,00002	1.752	1.374	6.825	386	1.760		2.885	0,06
Safrica (UK)	FT_3	67	44	141	93	542	293	0	0	481	481	0,00001	0,00002	1.231	912	110	110	1.022		1.923	1,00
Safrica (ML)	PP_4	29	23	40	32	108	91	0	0	87	87	0,00005	0,00006	264	232	688	61	293	122	58	0,09
TOTAL		2.484	1.170	5.663	2.639	18.692	11.298	27	27	34.337	34.337	0,00206	0,00332	61.202	49.472	36.335	10.503	59.975			

We allocate the total transportation cost related with shipments of a product from suppliers to the hub (A_s) and from hub to manufacturers based on the ratio of their share in the overall volume of that product.

The next table, Table 5.27, presents a similar analysis is carried out for the suppliers.

Table 5.27: Gain/Loss Analysis on Suppliers' Side

														HUB				
		Bs		Us		As		Ps		Zs		TCs		Bh	Rh	TCs+h		
		M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M2	M2	M2	M1 vs M2	ds
Austria (TR&SA)	CP_2	237	177	358	566	0	718	3.706	3.706	0	16	4.300	4.465	62,70	1,5533	4.529	-229	1.346
France (TR&IR)	CP_1	287	147	521	590	0	580	7.909	7.909	0	34	8.717	8.680	56,74	3,3284	8.740	-23	2.885
Germany (TR)	PP_1	99	87	70	134	0	130	794	794	0	3	964	1.019	32,83	0,3328	1.052	-89	288
Italy (TR&TN)	PP_3	93	57	65	107	0	59	423	423	0	2	581	588	30,23	0,1775	619	-38	154
Japan (SA&TZ&JR&IR)	FT_2	1.423	553	1.492	1.671	0	6.825	23.334	23.334	0	607	26.249	26.165	330,69	58,802	26.554	-305	50.962
Malaysia (SA&TZ&JR&IR)	PP_4	368	173	260	336	0	688	1.798	1.798	0	8	2.426	2.315	96,67	0,7544	2.413	13	654
Spain (TZ&TN&JR&IR)	CP_4	475	160	717	670	0	574	8.967	8.967	0	39	10.159	9.836	90,02	3,7722	9.930	229	3.269
Turkey (TR&TN)	FT_1	308	130	646	426	0	216	17.753	17.753	0	462	18.706	18.770	46,52	44,823	18.862	-155	38.846
UK (TR)	PP_2	60	57	36	73	0	53	266	266	0	1	362	397	20,24	0,1109	417	-55	96
UK (SA)	FT_3	134	95	141	243	0	110	917	917	0	23	1.191	1.277	43,34	2,219	1.323	-131	1.923
USA (TR)	CP_3	44	70	81	260	0	81	536	536	0	2	661	868	23,39	0,2219	891	-231	192
USA (TN)	FT_4	192	155	201	323	0	471	2.075	2.075	0	53	2.467	2.606	48,65	5,1036	2.660	-192	4.423
		3.720	1.862	4.587	5.397	0	10.503	68.476	68.476	0	1.250	76.783	76.986	882	121	77.990		

A combination of the two proceeding analysis may be used to calculate the total gain/loss of each manufacturer (in rows) and corresponding suppliers (in columns) with respect to Model 2.

This is presented in Table 5.28;

Table 5.28: Analysis showing Gain/Loss of Alternative Model for Individual Manufacturers

		M1 vs M2								
	mj (+)	s (-)								DIFF
İran	129	-8	-144	6	67					50
Jordan	43	-58	2	54						42
Tanzania	-1.155	-86	4	81						-1.157
Turkey	2.128	-164	-15	-89	-24	-154	-55	-231		1.398
Tunisia	-39	-14	27	-2	-192					-220
Safrica	122	-65	-17	1	-131					-91
										21

Accordingly, manufacturers in Tanzania, Tunisia and South Africa do not benefit from alternative model whereas manufacturer in Turkey has the highest benefit. Manufacturers, Iran and Jordan, benefit as well, but in smaller quantities.

The difference in total between the two models shows a gain by applying demonstrates benefits for Model 2 when manufacturers in the region are considered. When the multinational company is considered, this is supportive enough to apply the alternative model.

5.4. Parametric Analysis

The parametric analysis is carried out primarily by varying the selected parameters and observing the change in the optimal values of the decision variables and costs. We analyze the decision on the location of the supply hub by relaxing the limitation on the number of hubs. We also run the mathematical model for a set of different values for the rent cost per square meter of the supply hub. We then provide an analysis of the effect of changes in transportation discount rate. The decision on number and location of supply hub and on the markup level is tested further against varying demand rates. Next, we analyze the effect of capacity and technology parameters on total cost.

We finally develop an extension through an additional scenario. The supply chain structure in this scenario is similar to the one demonstrated in the preceding chapters. The basic difference that motivates the scenario to be analyzed is that the supplier in Turkey considered in the setting as an original product manufacturer is actually a hub warehouse. This hub is used for the products supplied from the supplier in Japan and serves to only the manufacturer in Turkey, rather than to the overall region.

5.4.1. Analysis 1: "Cost per Square Meter of Supply Hub"

With the decision of the location of a single hub, we take the cost per square meter per period to be \$3.5. We assume 2 pallets can be stored per square meter.

We now relax the single hub assumption and run the mathematical model using GAMS software for different values of number of hubs. For each value of the number of hubs from 1 to 5 and for the unrestricted case, we replicate the optimization for 7 values of the unit hub space cost.

The results are summarized in Table 5.29;

Table 5.29: Analysis on Different Costs per Square Meter of Supply Hub

	TOTAL COST_GAMS					
m^2 cost of Supply Hub	Gams_Optimal	Gams_1 Hub	Gams_2 Hubs	Gams_3 Hubs	Gams_4 Hubs	Gams_5 Hubs
2,0	2.994.130.840	3.043.311.200	2.994.130.840	3.022.323.020	3.061.165.840	3.101.697.480
2,5	3.013.552.250	3.052.599.700	3.013.552.250	3.055.254.980	3.103.808.500	3.154.473.050
3,0	3.032.973.650	3.061.888.200	3.032.973.650	3.088.186.920	3.146.451.150	3.207.248.600
as is	3.052.395.200	3.071.177.200	3.052.395.200	3.120.370.200	3.188.644.200	3.259.574.200
4,0	3.071.816.470	3.080.465.200	3.071.816.470	3.149.502.110	3.227.909.380	3.308.972.650
4,5	3.089.753.700	3.089.753.700	3.091.237.880	3.178.634.220	3.267.174.400	3.358.370.580
5,0	3.099.042.200	3.099.042.200	3.110.659.290	3.207.766.340	3.306.439.430	3.407.768.520

	LOCATION OF SUPPLY HUB					
m^2 cost of Supply Hub	Gams_Optimal	Gams_1 Hub	Gams_2 Hubs	Gams_3 Hubs	Gams_4 Hubs	Gams_5 Hubs
2,0	TR, DB	TR	TR, DB	TR, US, DB	TR, US, BL, DB	TR, US, BL, DB, SH
2,5	TR, DB	TR	TR, DB	TR, US, DB	TR, US, BL, DB	TR, US, BL, DB, SH
3,0	TR, DB	TR	TR, DB	TR, US, DB	TR, US, BL, DB	TR, US, BL, DB, SH
as is	TR, DB	TR	TR, DB	TR, BL, DB	TR, BL, DB, SH	TR, BL, SA, DB, SH
4,0	TR, DB	TR	TR, DB	TR, BL, DB	TR, BL, DB, SH	TR, BL, SA, DB, SH
4,5	TR	TR	TR, DB	TR, BL, DB	TR, BL, DB, SH	TR, BL, SA, DB, SH
5,0	TR	TR	TR, DB	TR, BL, DB	TR, BL, DB, SH	TR, BL, SA, DB, SH

As observed, for the base scenario with unit cost of $3.5, the optimal number of supply hubs is 2, with locations at Turkey and Dubai.

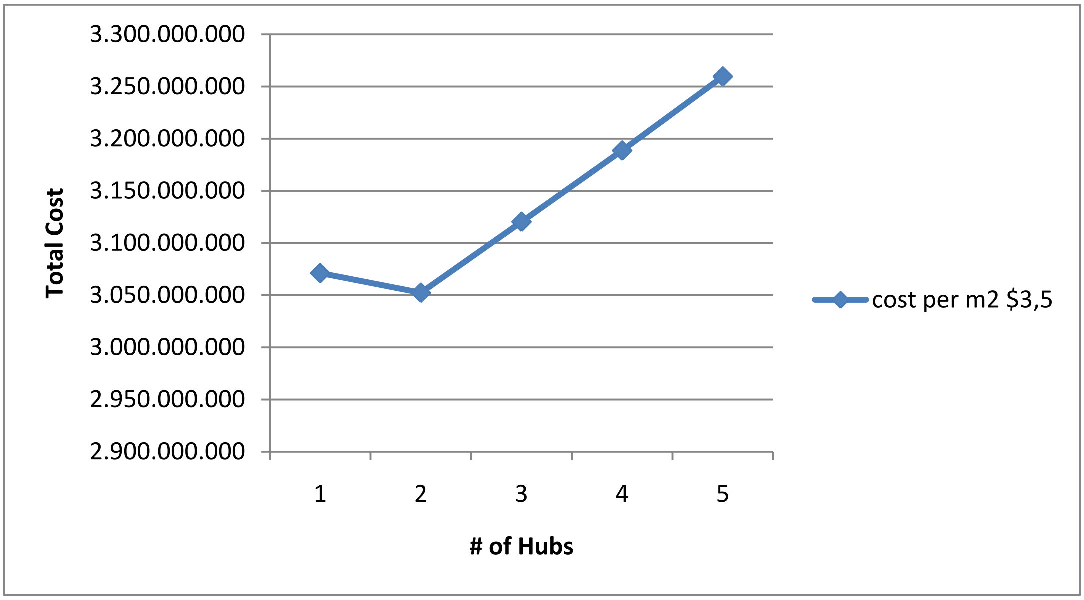

Figure 5.6: Optimal Total Cost vs. Number of Hubs

(with $3.5 cost per Square Meter per period)

Similarly, for unit costs of $4, $3, $2.5 and $2 costs per square meter of supply hub, the optimal number of supply hubs is still 2 with the same optimal locations: Turkey and Dubai.

This is shown in Figure 5.7.

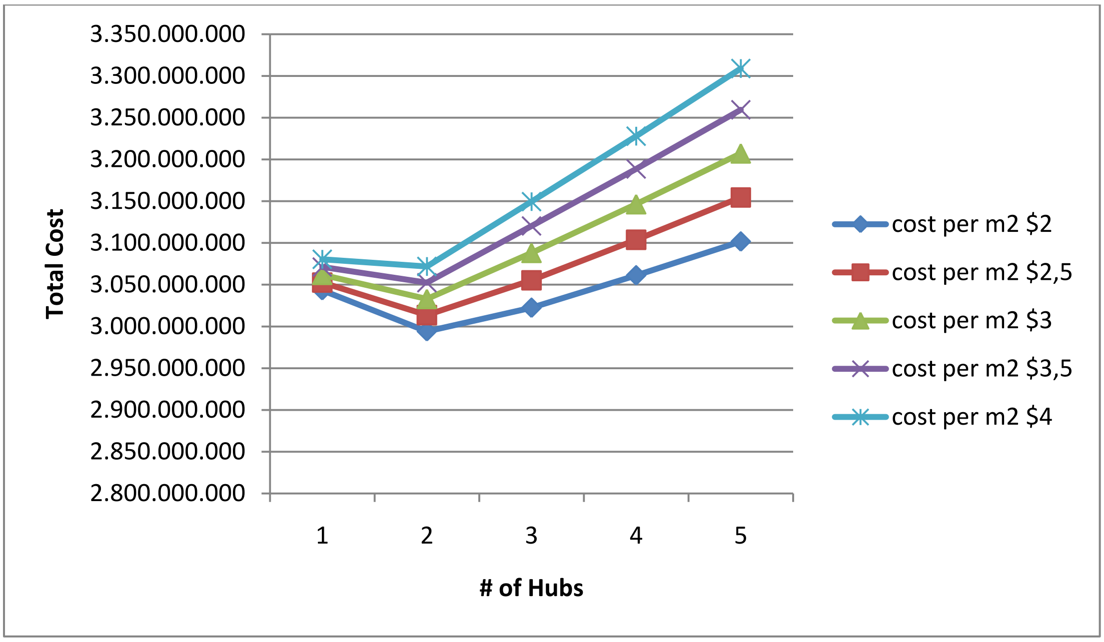

Figure 5.7: Optimal Total Cost vs. Number of Hubs

(various cost per square meter: ($4, $3.5, $3, $2.5, $2)

When we increase the cost per square meter of supply hub further to $4.5 and $5, the optimal number of supply hubs reduces to 1 with the proposed location Turkey. This is shown in Figure 5.8.

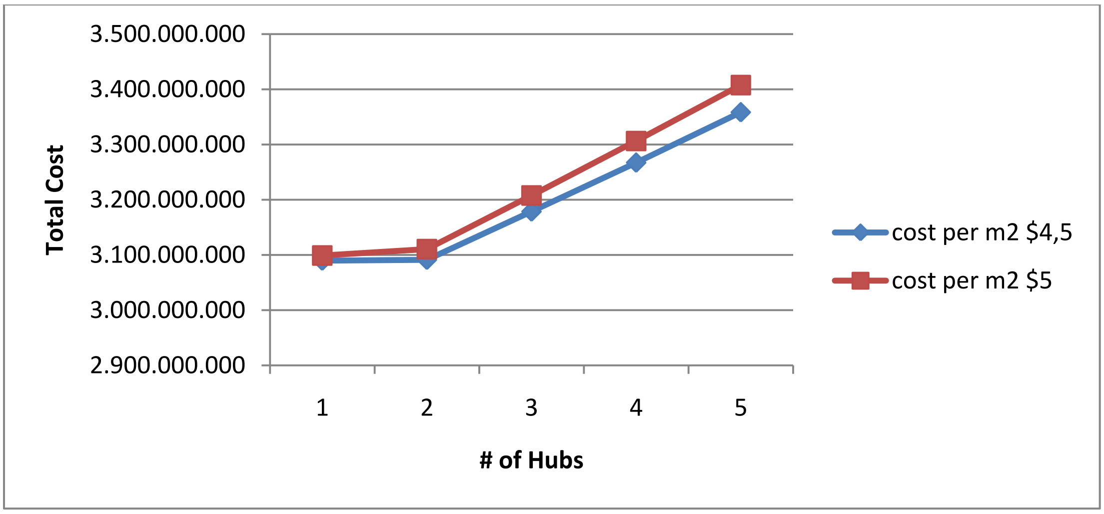

Figure 5.8: Optimal Total Cost vs. Number of Hubs

(various cost per square meter: ($5, $4.5)

Furthermore, if we limit the number of supply hubs to 1, we observe that the optimal location of the hub remains to be Turkey regardless of the cost per square meter of the hub. A similar result holds for the case with 2 hubs. For all unit hub space costs, the best hub locations are Turkey, Dubai.

When the cost per square meter is below \$3.5 (for \$3, \$2.5 and \$2) and in case we consider opening 3 hubs, the other hubs are proposed to be opened at USA and at Dubai. When the number of hubs is set to 4, for the same set of unit costs below \$3.5, the two locations remain the same, Turkey, Dubai, the other hub locations are now Belgium and Dubai. We need to add Shanghai as the fifth hub if we are to open 5 hubs.

For cost per square meter levels equal to or above \$3.5 (for \$3.5, \$4, \$4.5 and \$5): the second hub is proposed to be opened at Belgium; Dubai comes as the third hub location again. When the limitation is extended to 4 hubs, first three locations remain the same (Turkey, Belgium, Dubai), fourth location is now Shanghai. However, for 5 hubs, the hub locations are Turkey, Belgium, South Africa, Dubai and Shanghai.

This switch in locations at different unit costs number of supply hubs is basically due to the tradeoff between the volume attached to the hubs as well as the transportation costs of the routes. Therefore, as the limitation on the number of locations changes, the model proposes different hub locations for different levels of cost per square meter, depending on volumes and transportation costs.

The analysis clearly points to Turkey, the robust choice of the supply hub location, regardless of cost per square meter and the total number of hubs.

From another point of view, this also supports the company’s choice of considering a single supply hub. Based on the current figures and considering the rapidly changing business conditions, running operations through a single hub will be a decision that is justified under unexpected cost increases. This also supports operational constraints and of provides negotiation power towards third party contacts by attaching to a common location for all loads.

5.4.2. Analysis 2: "Optimal Number of Supply Hubs"

To theoretically prove the statement on the optimal number of hubs as stated in the previous subsection as 2, we relax the constraint in the mathematical model:

$$\sum_{n=1}^{N} Z_n = 1$$

Running the GAMS model, we have the optimal number of supply hub as 2, with proposed locations; Turkey and Dubai (see Table 5.30).

Table 5.30: Decision on Optimal Number and Location of Supply Hubs in GAMS

```
----     173 VARIABLE z.L  1 if supply hub h is opened and 0 otherwise

Turkey 1.000,     Dubai  1.000


----     173 VARIABLE s.L  the number of trucks for product k transported from i
                           to h

                           pp1         pp2         pp3         pp4         cp1

France  .Turkey                                                         33.000
Germany .Turkey          7.000
Italy   .Turkey                                  3.000
Malaysia.Dubai                                              15.000
UK      .Turkey                      3.000

               +           cp2         cp3         cp4         ft1         ft2

Austria .Turkey         17.000
Japan   .Dubai                                                         147.000
Spain   .Turkey                                 42.000
Turkey  .Turkey                                            112.000
USA     .Turkey                      2.000

               +           ft3         ft4

UK      .Turkey          6.000
USA     .Turkey                     13.000
```

Suppliers United Kingdom, United States of America, Turkey, Germany, Italy, Spain, Austria and France, are assigned to supply hub in Turkey. Malaysia and Japan are assigned to supply hub in Dubai.

Using this information, we up-date the transportation costs, that were listed earlier in Table 5.11 and 5.13 with the assumption of a single supply hub.

Table 5.31: Revised Transportation Costs based on the Optimal Number and Location of Supply Hubs

Suppliers	Product	a_{sf}	a_{sl}
Austria (TR&SA)	CP_2	2432,36	2505,3308
France (TR&IR)	CP_1	1011,5	1041,845
Germany (TR)	PP_1	1071	1103,13
Italy (TR&TN)	PP_3	856,8	882,504
Japan (SA&TZ&JR&IR)	FT_2	2601	2679,03
Malaysia (SA&TZ&JR&IR)	PP_4	2095,25	2158,1075
Spain (TZ&TN&JR&IR)	CP_4	773,5	796,705
Turkey (TR&TN)	FT_1	85	87,55
UK (TR)	PP_2	1088	1120,64
UK (SA)	FT_3	1088	1120,64
USA (TR)	CP_3	2125	2188,75
USA (TN)	FT_4	2125	2188,75

Manufacturers	Product	a_{hf}	a_{hl}
Iran (SP)	CP_4	1.300,00	1.339,00
Iran (FR)	CP_1	1.300,00	1.339,00
Iran (JP)	FT_2	475,00	489,25
Iran (ML)	PP_4	475,00	489,25
Jordan (JP)	FT_2	2.455,00	2.528,65
Jordan (ML)	PP_4	2.455,00	2.528,65
Jordan (SP)	CP_4	1.966,00	2.024,98
Tanzania (ML)	PP_4	2.910,00	2.997,30
Tanzania (JP)	FT_2	2.910,00	2.997,30
Tanzania (SP)	CP_4	3.150,00	3.244,50
Turkey (FR)	CP_1	100,00	103,00
Turkey (AU)	CP_2	100,00	103,00
Turkey (US)	CP_3	100,00	103,00
Turkey (TR)	FT_1	100,00	103,00
Turkey (GE)	PP_1	100,00	103,00
Turkey (UK)	PP_2	100,00	103,00
Turkey (IT)	PP_3	100,00	103,00
Tunisia (TR)	FT_1	2.000,00	2.060,00
Tunisia (US)	FT_4	2.000,00	2.060,00
Tunisia (IT)	PP_3	2.000,00	2.060,00
Tunisia (SP)	CP_4	2.000,00	2.060,00
Safrica (AU)	CP_2	2.410,00	2.482,30
Safrica (JP)	FT_2	2.296,00	2.364,88
Safrica (UK)	FT_3	2.410,00	2.482,30
Safrica (ML)	PP_4	2.296,00	2.364,88

In doing so, we take into consideration the fact that with two hubs; the company has smaller economies of scale and loses some negotiation power since part volume is now assigned to Dubai, instead of assigning all volumes to Turkey. Therefore, we take the level of discount the company receives on transportation costs to be 15% instead of 25% (what we previously had for consolidation of shipments through a single hub).

Resulting costs are summarized in Table 5.32.

For comparison purposes, we also include cost figures corresponding to 2 hubs and a 25% discount level.

Table 5.32: Analysis on Optimal Number and Location of Supply Hub

	TC _ 1 Hub	TC _ 2 Hubs %25 Discount	TC _ 2 Hubs %15 Discount	TC _ 1 Hub M1 vs M2	TC _ 2 Hubs %25 Discount M1 vs M2	TC _ 2 Hubs %15 Discount M1 vs M2
Model 1	137.986	137.986	137.986			
Model 2	137.964	136.258	137.575	-0,02%	-1,27%	-0,30%

The previous gains of 1.27% as a result of switching to Model 2 diminish with the introduction of a second supply hub. This is due to a reduction in the negotiation power of the company and thus higher transportation unit costs.

With an assumption of having a lower discount level of 15%, the net gain will go down to 0.30%. Even though this still supports 2 hubs, it can be stated that, the gain of 0.30% is unworthy to give up from the operational efficiency and ease, gained by working with a single hub. Therefore, it is advised here that, the multinational company may continue working with a single hub in terms of operational and management perspectives.

5.4.3. Analysis 3: "Discount on Transportation Cost"

Following the idea that the discount rate of 25% on the transportation rates may not always be realized as assumed, we do a numeric analysis by varying the discount rate within a set of values below and above 25%.

This analysis may refer to the case where different forwarding companies may offer different rates or the same company may offer different rates over time. We observe the effect of this change on total costs as well as the difference in costs of the two models. The analysis also points to a breakeven level of price discount beyond which the alternative business model is worthwhile undertaking.

This information on the breakeven level can well be used as a negotiation tool for the multinational company while discussing on the level of discounts.

With this intention, the model is run with different discount rates, starting from 0% (no discount) up to 45%.

The results are summarized in Table 5.33.

Table 5.33: Analysis on Different Discount Rates of Transportation Costs

Discount rate on Transportation Cost	$TC_{traditional}$	$TC_{alternative}$	TD vs ALT
0%	137.986	141.402	2,42%
5%	137.986	140.714	1,94%
10%	137.986	140.027	1,46%
15%	137.986	139.339	0,97%
20%	137.986	138.652	0,48%
as is	137.986	137.964	-0,02%
30%	137.986	137.277	-0,52%
35%	137.986	136.589	-1,02%
40%	137.986	135.902	-1,53%
45%	137.986	135.214	-2,05%

We can observe from the above table, that the break even discount rate which makes the alternative model better off in terms of total cost is somewhere between 20% and 25%.

Figure 5.9 shows a plot of the supply chain total cost against varying discount rates for the traditional and the alternative models.

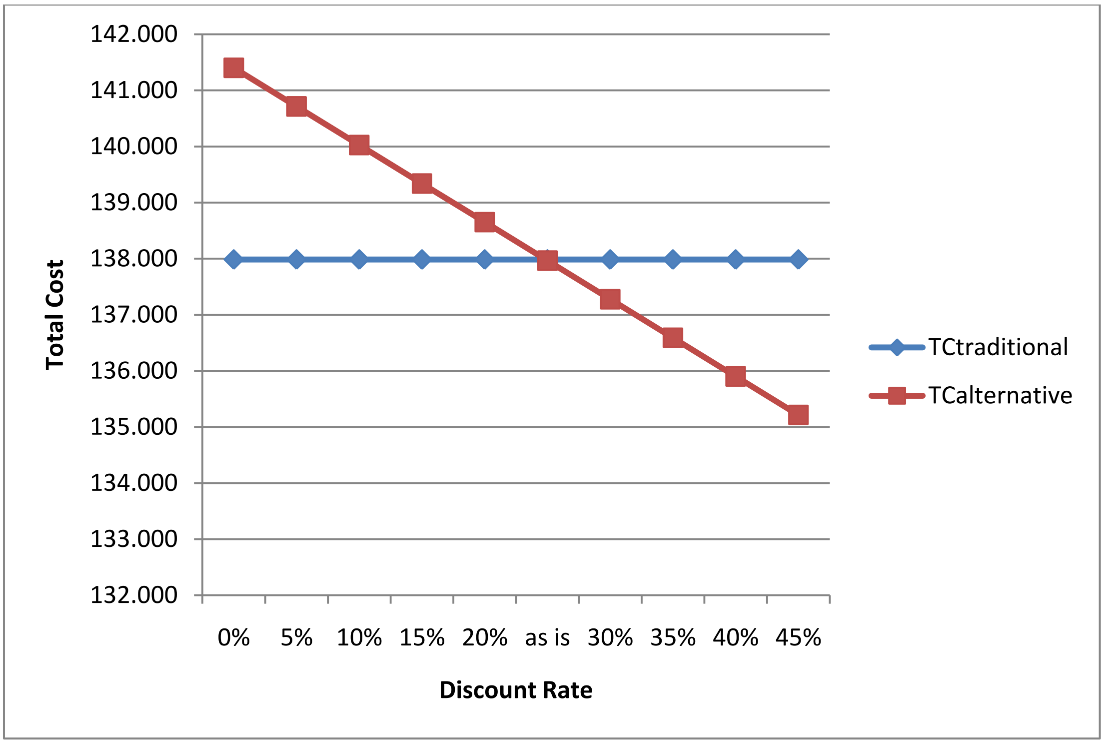

Figure 5.9: Effect of Different Discount Rates of Transportation Cost on Total Costs

The results also show that, at an appropriate level of discounts lower than the breakeven value, it may still be preferred to choose Model 2 where the cost of difference may be justified by additional benefits such as flexibility.

5.4.4. Analysis 4: "Effect of Variations in Demand"

The model and the numeric analysis in the thesis are developed with a set of demand data that is assumed to be constant. The decisions based on this data regarding the supply chain structure and long term decisions that have many further implications.

Therefore, we believe that a parametric analysis on the demand forecast data (that actually triggers and drives the whole system) will provide valuable results. We do this through the following analysis. We wish to note that each set of demand forecasts requires a repetition of all the calculations and rerun of the mathematical programming model.

Table 5.34 contains a summary of the changes in total cost for both models for different levels of demand variation. The table also includes a column showing the markup level to compensate the incremental cost of suppliers as a result of changing the business model.

Table 5.34: Analysis on Different Demand Rates

Variation in Demand	$TC_{traditional}$	$TC_{alternative}$	TD vs ALT	markup
(-) 50%	71.357	73.707	3,19%	0,66%
(-) 40%	84.882	86.691	2,09%	0,44%
(-) 30%	97.965	99.755	1,79%	0,29%
(-) 20%	111.768	112.378	0,54%	0,17%
(-) 10%	124.572	125.328	0,60%	0,09%
as is	**137.986**	**137.964**	**-0,02%**	**0,03%**
(+) 10%	150.948	150.556	-0,26%	-0,02%
(+) 20%	164.152	164.007	-0,09%	-0,05%
(+) 30%	177.135	176.686	-0,25%	-0,08%
(+) 40%	190.641	189.381	-0,67%	-0,11%
(+) 50%	203.577	202.052	-0,75%	-0,13%
(+) 60%	216.378	214.995	-0,64%	-0,14%
(+) 70%	229.905	227.859	-0,90%	-0,16%
(+) 80%	242.997	240.890	-0,87%	-0,17%
(+) 90%	256.383	253.550	-1,12%	-0,18%
(+) 100%	269.041	266.070	-1,12%	-0,18%

One can observe that a decrease in demand around 10% and above makes the traditional model more attractive cost wise. Besides, the positive effect of the alternative model on the total cost becomes stronger as demand increases.

It is interesting to note that the effect on the negative side is stronger than the positive effect of an increase in demand. For instance, 20% decrease in demand results in 0.54% higher costs for alternative model, whereas 20% increase in demand results in alternative model being only 0.09% better.

Figure 5.10 shows a plot of the required markup as a function of the level of change in the demand.

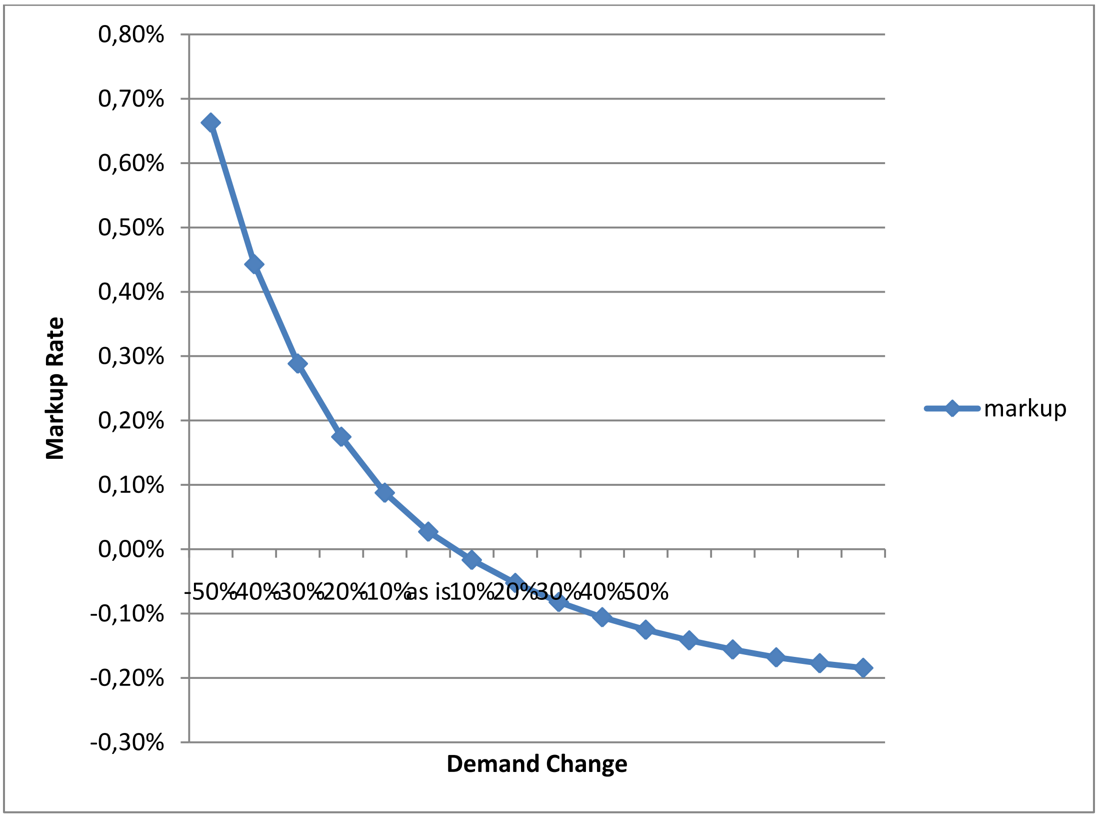

Figure 5.10: Effect of Different Demand Levels on Markup Rates

Table 5.35 demonstrates the optimal number of hubs as demand is varied.

Table 5.35: Effect of Different Demand Levels on the Decision of Number and Location of Supply Hubs

Variation in Demand	# of hubs	optimal location
-50%	1	TR
-40%	1	TR
-30%	1	TR
-20%	2	TR-DB
-10%	2	TR-DB
as is	**2**	**TR-DB**
10%	2	TR-DB
20%	2	TR-DB
30%	2	TR-DB
40%	2	TR-DB
50%	2	TR-DB

The optimal number of supply hubs does not change for a demand level between 80% - 150% of the initial values. When demand drops down by more than -20%, the optimal number of supply hubs turns out to be 1.

Regardless of the demand level, the optimal location is Turkey when we need a single hub and Turkey and Dubai when we need two hubs.

5.4.5. Analysis 5: "Review of Capacity and Technology"

A review of the current capacity and technology of the suppliers may provide additional insights from a strategic point of view. Such an analysis may guide in deciding for capacity expansion and downsizing decisions concerning the suppliers.

With this intention, we carry out a numeric analysis using different rates of production for suppliers.

Table 5.36 shows different production rates for the suppliers both with downsizing scenario and with extension scenarios.

Table 5.37 and 5.38 show the total costs based on varying production rate scenarios for the traditional and alternative business models.

Whenever the scenario requires a production capacity below the demand rate, that scenario becomes infeasible (recall feasibility condition of Equation 3.26) and is left out of consideration.

Table 5.36: Different Production Rates of the Suppliers

				r_p value																			
SUPPLIERS	d_s	r_p	d_s / r_p	0,0-0,20%	-0,20%	-0,30%	-0,40%	-0,50%	-0,60%	-0,70%	-0,80%	-0,90%	1%	1,10%	1,20%	1,30%	1,40%	1,50%	1,60%	1,70%	1,80%	1,90%
Austria (TR&SA)	1.346	9.000	0,15	1.350	1.800	2.700	3.600	4.500	5.400	6.300	7.200	8.100	9.000	9.900	10.800	11.700	12.600	13.500	14.400	15.300	16.200	17.100
France (TR&IR)	2.885	8.500	0,34	2.890	1.700	2.550	3.400	4.250	5.100	5.950	6.800	7.650	8.500	9.350	10.200	11.050	11.900	12.750	13.600	14.450	15.300	16.150
Germany (TR)	288	1.500	0,19	300	300	450	600	750	900	1.050	1.200	1.350	1.500	1.650	1.800	1.950	2.100	2.250	2.400	2.550	2.700	2.850
Italy (TR&TN)	154	500	0,31	155	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950
Japan (SA&TZ&JR&IR)	50.962	200.000	0,25	52.000	40.000	60.000	80.000	100.000	120.000	140.000	160.000	180.000	200.000	220.000	240.000	260.000	280.000	300.000	320.000	340.000	360.000	380.000
Malaysia (SA&TZ&JR&IR)	654	2.500	0,26	675	500	750	1.000	1.250	1.500	1.750	2.000	2.250	2.500	2.750	3.000	3.250	3.500	3.750	4.000	4.250	4.500	4.750
Spain (TZ&TN&JR&IR)	3.269	10.000	0,33	3.300	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000	11.000	12.000	13.000	14.000	15.000	16.000	17.000	18.000	19.000
Turkey (TR&TN)	38.846	120.000	0,32	39.600	24.000	36.000	48.000	60.000	72.000	84.000	96.000	108.000	120.000	132.000	144.000	156.000	168.000	180.000	192.000	204.000	216.000	228.000
UK (TR)	96	800	0,12	96	160	240	320	400	480	560	640	720	800	880	960	1.040	1.120	1.200	1.280	1.360	1.440	1.520
UK (SA)	1.923	250.000	0,01	2.500	50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000	250.000	275.000	300.000	325.000	350.000	375.000	400.000	425.000	450.000	475.000
USA (TR)	192	6.000	0,03	240	1.200	1.800	2.400	3.000	3.600	4.200	4.800	5.400	6.000	6.600	7.200	7.800	8.400	9.000	9.600	10.200	10.800	11.400
USA (TN)	4.423	250.000	0,02	5.000	50.000	75.000	100.000	125.000	150.000	175.000	200.000	225.000	250.000	275.000	300.000	325.000	350.000	375.000	400.000	425.000	450.000	475.000

Table 5.37: Analysis on the Effect of Different Production Rates on Total Costs in Traditional Business Model

	Total Costs based on changing r_p values _ Traditional Model																		
SUPPLIERS	$TC_{0,00}$-$TC_{0,10}$	$TC_{0,2}$	$TC_{0,3}$	$TC_{0,4}$	$TC_{0,5}$	$TC_{0,6}$	$TC_{0,7}$	$TC_{0,8}$	$TC_{0,9}$	TC_{1}	$TC_{1,1}$	$TC_{1,2}$	$TC_{1,3}$	$TC_{1,4}$	$TC_{1,5}$	$TC_{1,6}$	$TC_{1,7}$	$TC_{1,8}$	$TC_{1,9}$
Austria (TR&SA)	4.235	4.269	4.284	4.291	4.294	4.296	4.298	4.299	4.300	4.300	4.301	4.301	4.302	4.302	4.302	4.303	4.303	4.303	4.303
France (TR&IR)				8.674	8.692	8.701	8.707	8.712	8.715	8.717	8.719	8.721	8.722	8.723	8.724	8.725	8.726	8.726	8.727
Germany (TR)		951	958	960	962	962	963	963	963	964	964	964	964	964	964	964	964	964	964
Italy (TR&TN)				578	579	580	580	581	581	581	581	581	581	581	581	581	581	581	581
Japan (SA&TZ&JR&IR)			26.062	26.146	26.185	26.208	26.223	26.234	26.243	26.249	26.254	26.259	26.262	26.265	26.268	26.270	26.272	26.274	26.276
Malaysia (SA&TZ&JR&IR)			2.409	2.417	2.420	2.422	2.423	2.424	2.425	2.426	2.426	2.426	2.427	2.427	2.427	2.427	2.428	2.428	2.428
Spain (TZ&TN&JR&IR)				10.110	10.130	10.141	10.148	10.152	10.156	10.159	10.161	10.163	10.164	10.165	10.167	10.168	10.168	10.169	10.170
Turkey (TR&TN)				18.617	18.653	18.673	18.686	18.695	18.701	18.706	18.710	18.714	18.717	18.719	18.721	18.723	18.724	18.726	18.727
UK (TR)	357	360	361	362	362	362	362	362	362	362	362	362	362	362	362	362	362	363	363
UK (SA)	1.147	1.190	1.191	1.191	1.191	1.191	1.191	1.191	1.191	1.191	1.192	1.192	1.192	1.192	1.192	1.192	1.192	1.192	1.192
USA (TR)	648	659	660	660	660	660	660	660	661	661	661	661	661	661	661	661	661	661	661
USA (TN)	2.383	2.463	2.465	2.465	2.466	2.466	2.467	2.467	2.467	2.467	2.467	2.467	2.468	2.468	2.468	2.468	2.468	2.468	2.468
MANUFACTURERS																			
Iran (SP)				2.399	2.376	2.367	2.362	2.359	2.356	2.355	2.354	2.353	2.352	2.351	2.350	2.350	2.349	2.349	2.349
Iran (FR)				2.426	2.398	2.388	2.383	2.380	2.377	2.376	2.374	2.373	2.372	2.372	2.371	2.371	2.370	2.370	2.369
Iran (JP)			11.598	11.439	11.392	11.369	11.354	11.344	11.337	11.331	11.327	11.324	11.321	11.318	11.316	11.314	11.313	11.311	11.310
Iran (ML)			1.089	1.076	1.072	1.070	1.069	1.068	1.068	1.067	1.067	1.067	1.066	1.066	1.066	1.066	1.066	1.066	1.066
Jordan (JP)			5.449	5.385	5.367	5.357	5.352	5.348	5.345	5.343	5.341	5.339	5.338	5.337	5.336	5.336	5.335	5.335	5.334
Jordan (ML)			499	493	492	491	490	490	490	490	490	489	489	489	489	489	489	489	489
Jordan (SP)				1.787	1.768	1.761	1.757	1.755	1.753	1.751	1.750	1.750	1.749	1.748	1.748	1.747	1.747	1.747	1.747
Tanzania (ML)			831	822	820	819	818	817	817	817	816	816	816	816	816	816	816	816	816
Tanzania (JP)			7.889	7.793	7.766	7.751	7.743	7.737	7.732	7.729	7.727	7.724	7.723	7.721	7.720	7.719	7.718	7.717	7.716
Tanzania (SP)				3.266	3.238	3.227	3.221	3.218	3.215	3.213	3.211	3.210	3.209	3.208	3.208	3.207	3.206	3.206	3.206
Turkey (FR)				2.667	2.611	2.592	2.581	2.575	2.570	2.567	2.564	2.562	2.560	2.559	2.558	2.557	2.556	2.555	2.554
Turkey (AU)	2.397	1.657	1.624	1.614	1.609	1.606	1.604	1.602	1.601	1.600	1.600	1.599	1.599	1.598	1.598	1.598	1.597	1.597	1.597
Turkey (US)	587	557	556	555	555	555	555	554	554	554	554	554	554	554	554	554	554	554	554
Turkey (TR)				11.250	11.075	11.007	10.970	10.945	10.928	10.915	10.905	10.897	10.891	10.885	10.881	10.877	10.873	10.870	10.868
Turkey (GE)		579	532	527	525	524	523	523	522	522	522	521	521	521	521	521	521	521	520
Turkey (UK)	245	232	230	229	229	229	228	228	228	228	228	228	228	228	228	228	228	228	228
Turkey (IT)				193	191	190	189	189	189	189	189	189	188	188	188	188	188	188	188
Tunisia (TR)				220	218	218	217	217	217	217	217	217	217	217	216	216	216	216	216
Tunisia (US)	2.505	2.259	2.256	2.254	2.253	2.253	2.252	2.252	2.252	2.251	2.251	2.251	2.251	2.251	2.251	2.251	2.251	2.251	2.251
Tunisia (IT)				247	246	246	245	245	245	245	245	245	245	245	245	245	245	245	245
Tunisia (SP)				1.032	1.023	1.019	1.017	1.016	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.013	1.012	1.012	1.012
Safrica (AU)	1.499	1.203	1.190	1.186	1.184	1.183	1.182	1.181	1.181	1.180	1.180	1.180	1.180	1.180	1.179	1.179	1.179	1.179	1.179
Safrica (JP)			1.784	1.765	1.759	1.756	1.755	1.753	1.753	1.752	1.751	1.751	1.751	1.750	1.750	1.750	1.750	1.749	1.749
Safrica (UK)	1.335	1.233	1.233	1.232	1.232	1.232	1.232	1.231	1.231	1.231	1.231	1.231	1.231	1.231	1.231	1.231	1.231	1.231	1.231
Safrica (ML)			268	266	265	265	264	264	264	264	264	264	264	264	264	264	264	264	264

Table 5.38: Analysis on the Effect of Different Production Rates on Total Costs in Alternative Business Model

				Total Costs based on changing r_p values _ Alternative Model																		
SUPPLIERS				$TC_{0,00\text{-}TC0,20}$	$TC_{0,2}$	$TC_{0,3}$	$TC_{0,4}$	$TC_{0,5}$	$TC_{0,6}$	$TC_{0,7}$	$TC_{0,8}$	$TC_{0,9}$	TC_{1}	$TC_{1,1}$	$TC_{1,2}$	$TC_{1,3}$	$TC_{1,4}$	$TC_{1,5}$	$TC_{1,6}$	$TC_{1,7}$	$TC_{1,8}$	$TC_{1,9}$
Austria (TR&SA)				5.590	5.151	5.167	5.173	5.176	5.178	5.180	5.181	5.182	5.183	5.183	5.184	5.184	5.184	5.185	5.185	5.185	5.185	5.186
France (TR&IR)							9.216	9.234	9.244	9.250	9.254	9.257	9.260	9.261	9.263	9.264	9.266	9.266	9.267	9.268	9.269	9.269
Germany (TR)					1.137	1.144	1.146	1.147	1.148	1.148	1.149	1.149	1.149	1.149	1.150	1.150	1.150	1.150	1.150	1.150	1.150	1.150
Italy (TR&TN)							644	645	646	646	647	647	647	647	647	647	647	647	647	647	648	648
Japan (SA&TZ&JR&IR)						33.184	33.041	33.013	33.002	32.996	32.993	32.991	32.990	32.989	32.988	32.987	32.987	32.987	32.986	32.986	32.986	32.986
Malaysia (SA&TZ&JR&IR)						2.987	2.994	2.998	3.000	3.001	3.002	3.003	3.003	3.004	3.004	3.005	3.005	3.005	3.005	3.006	3.006	3.006
Spain (TZ&TN&JR&IR)							10.416	10.381	10.391	10.398	10.403	10.407	10.409	10.412	10.413	10.415	10.416	10.417	10.418	10.419	10.420	10.420
Turkey (TR&TN)							18.979	18.933	18.953	18.966	18.974	18.981	18.986	18.990	18.994	18.996	18.999	19.001	19.003	19.004	19.006	19.007
UK (TR)				445	448	449	449	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
UK (SA)				1.343	1.386	1.386	1.386	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387	1.387
USA (TR)				937	947	948	948	948	948	949	949	949	949	949	949	949	949	949	949	949	949	949
USA (TN)				3.050	3.072	3.074	3.075	3.075	3.076	3.076	3.076	3.076	3.076	3.076	3.077	3.077	3.077	3.077	3.077	3.077	3.077	3.077
MANUFACTURERS																						
Iran (SP)				1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969	1.969
Iran (FR)				1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957
Iran (JP)				8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440	8.440
Iran (ML)				749	749	749	749	749	749	749	749	749	749	749	749	749	749	749	749	749	749	749
Jordan (JP)				3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899	3.899
Jordan (ML)				361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361
Jordan (SP)				1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737	1.737
Tanzania (ML)				688	688	688	688	688	688	688	688	688	688	688	688	688	688	688	688	688	688	688
Tanzania (JP)				6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854	6.854
Tanzania (SP)				3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035	3.035
Turkey (FR)				1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348	1.348
Turkey (AU)				716	716	716	716	716	716	716	716	716	716	716	716	716	716	716	716	716	716	716
Turkey (US)				340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340
Turkey (TR)				10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170	10.170
Turkey (GE)				259	259	259	259	259	259	259	259	259	259	259	259	259	259	259	259	259	259	259
Turkey (UK)				101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101
Turkey (IT)				100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Tunisia (TR)				222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222	222
Tunisia (US)				1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805	1.805
Tunisia (IT)				215	215	215	215	215	215	215	215	215	215	215	215	215	215	215	215	215	215	215
Tunisia (SP)				963	963	963	963	963	963	963	963	963	963	963	963	963	963	963	963	963	963	963
Safrica (AU)				1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027	1.027
Safrica (JP)				1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374	1.374
Safrica (UK)				912	912	912	912	912	912	912	912	912	912	912	912	912	912	912	912	912	912	912
Safrica (ML)				232	232	232	232	232	232	232	232	232	232	232	232	232	232	232	232	232	232	232

The results are in line with the findings of the similar discussion in Chapter 3, Section 3.2.2, that was summarized in Figure 3.11.

Increasing the production rate first causes a steep increase in the total cost of the suppliers, however after some point, investing in technology and increasing production speed results in a much smoother total cost curve.

Figure 5.11 and 5.12 demonstrate these effects for various suppliers.

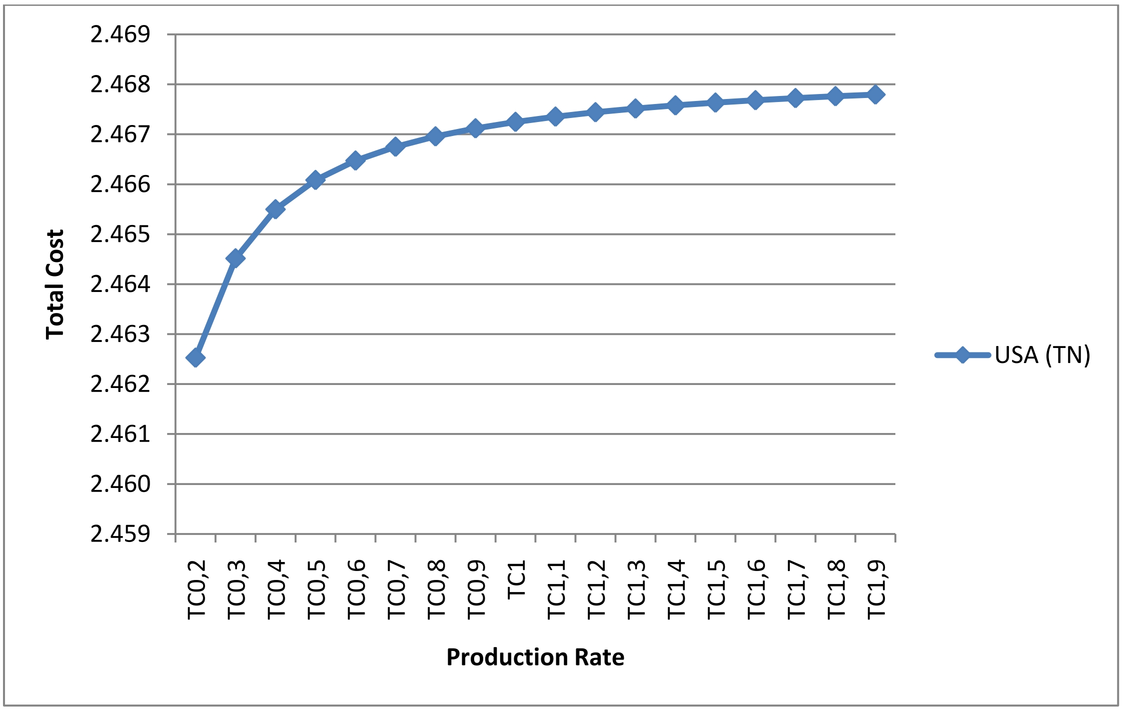

Figure 5.11: Total Cost Behavior of the Supplier in USA based on Different Rates of Production in Traditional Model

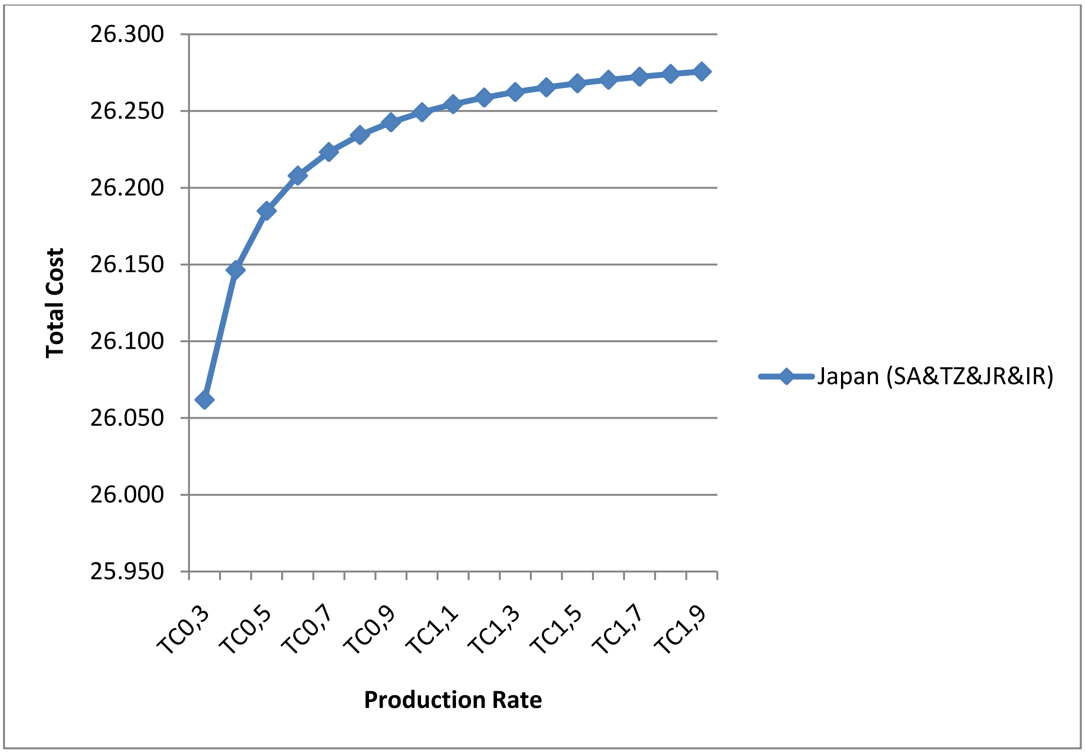

Figure 5.12: Total Cost Behavior of the Supplier in Japan based on Different Rates of Production in Traditional Model

Based on this analysis, current production rate and capacity of the suppliers can be evaluated and any capacity downsizing or extension decisions can be questioned with regard to its impact to the total costs.

On the manufacturers' side, the impact of capacity increase or decrease on total cost is observed with a converse effect as compared to the suppliers. This makes sense since a capacity increase on the supplier side decreases the length of production run, hence the lead time associated with suppliers.

In such a situation, manufacturers may prefer to keep less safety stock and reduce their costs. Similar behavior is expected both for traditional and alternative business models.

Figures 5.13 and 5.14 provide examples to the phenomenon.

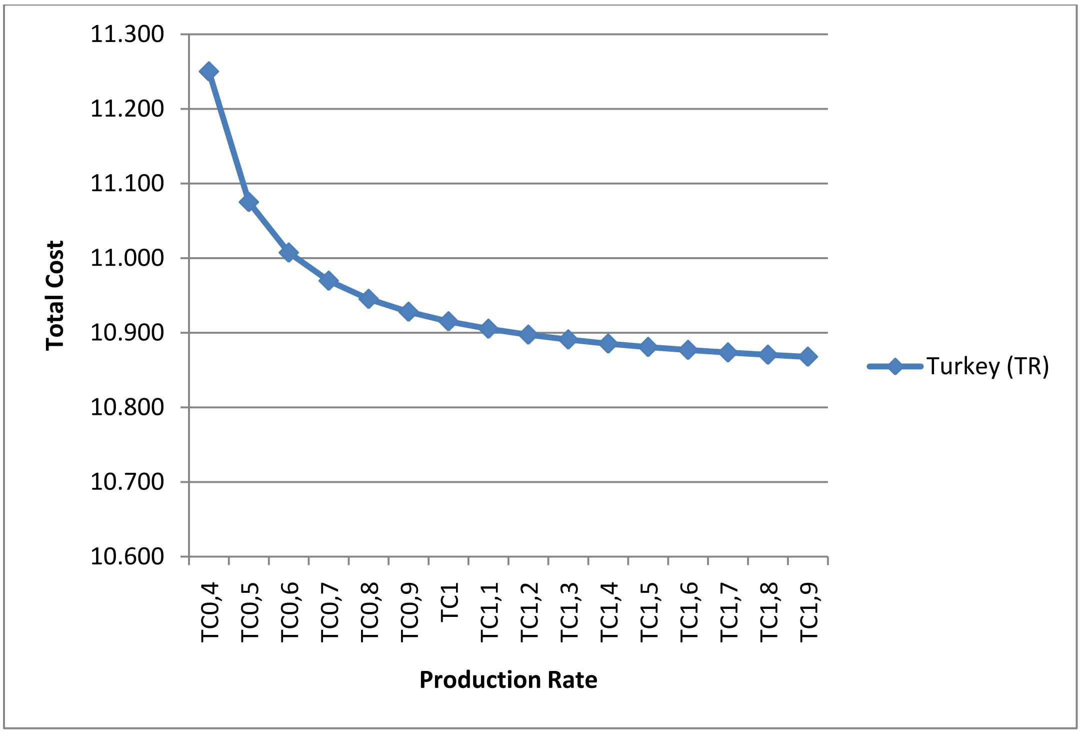

Figure 5.13: Total Cost Behavior of the Manufacturer in Turkey based on Different Rates of Production in Traditional Model

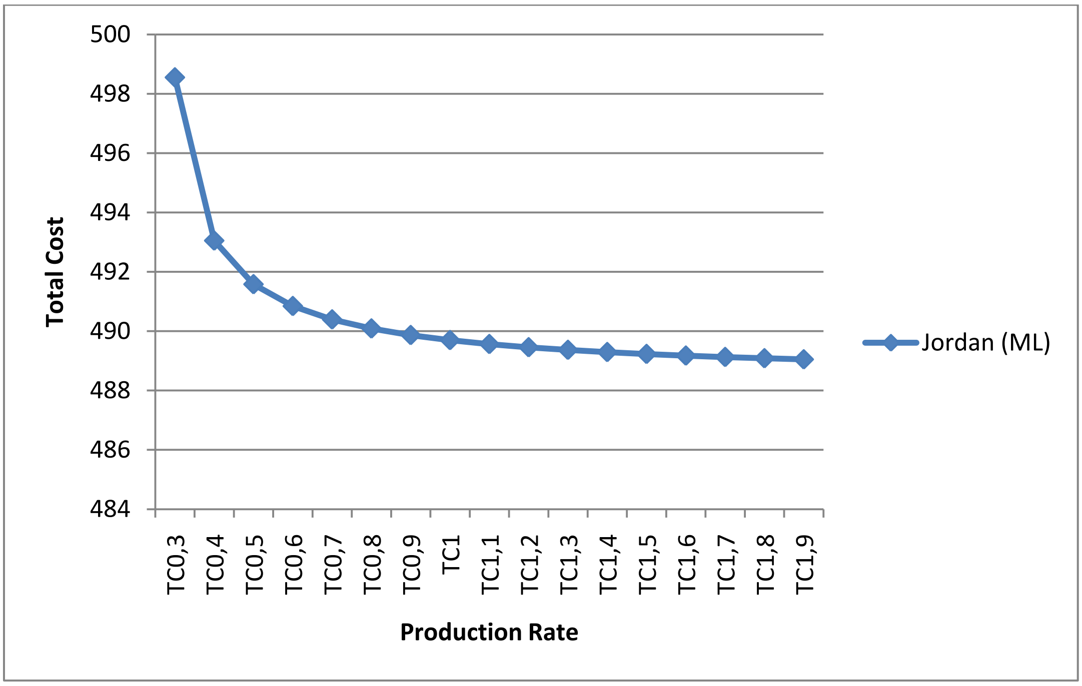

Figure 5.14: Total Cost Behavior of the Manufacturer in Jordan based on Different Rates of Production in Traditional Model

The rate of reduction in the total cost of the manufacturer, however, is not uniform. To some extent, the increase at the production rate of the suppliers causes a higher reduction rate in the total cost of the manufacturers beyond some value the effect of the increase on manufacturers' cost is negligible.

Referring to Table 5.38, we observe that, the effect of changing the production rate of suppliers on the total cost of suppliers in alternative business model demonstrates varying behaviors. For instance, as shown by Figure 5.15, increasing the production rate of supplier in Japan reduces down the total cost of the suppliers.

However, we can see from Figure 5.16 that increasing the production rate of the supplier in USA increases the total cost of the suppliers.

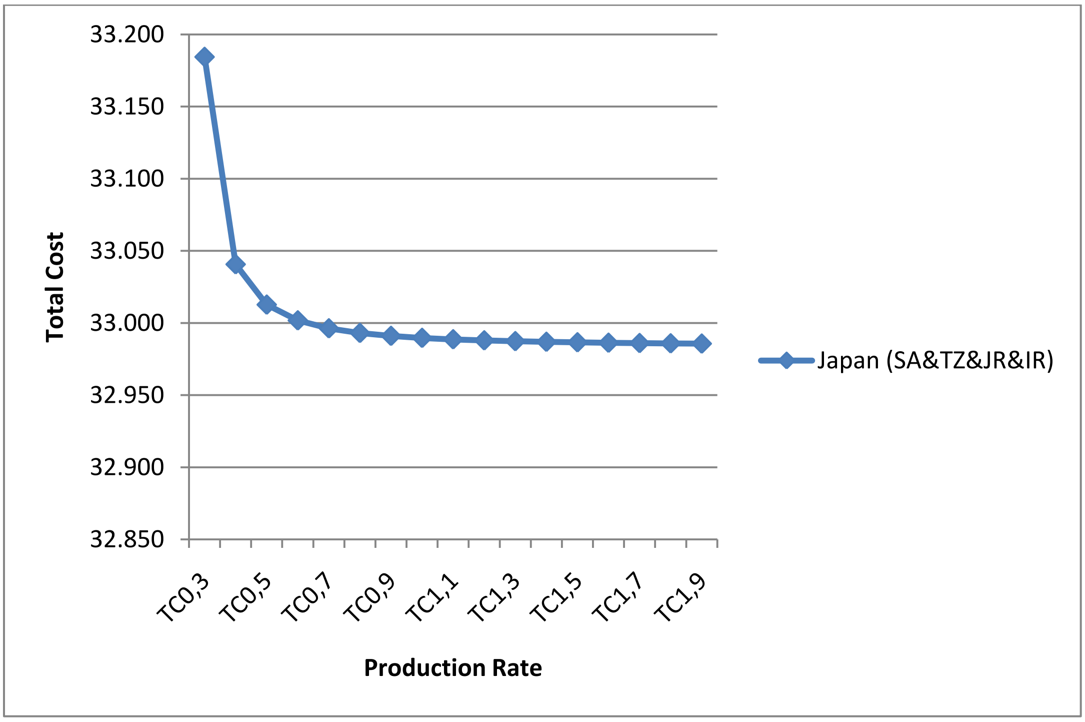

Figure 5.15: Total Cost Behavior of the Supplier in Japan based on Different Rates of Production in Alternative Model

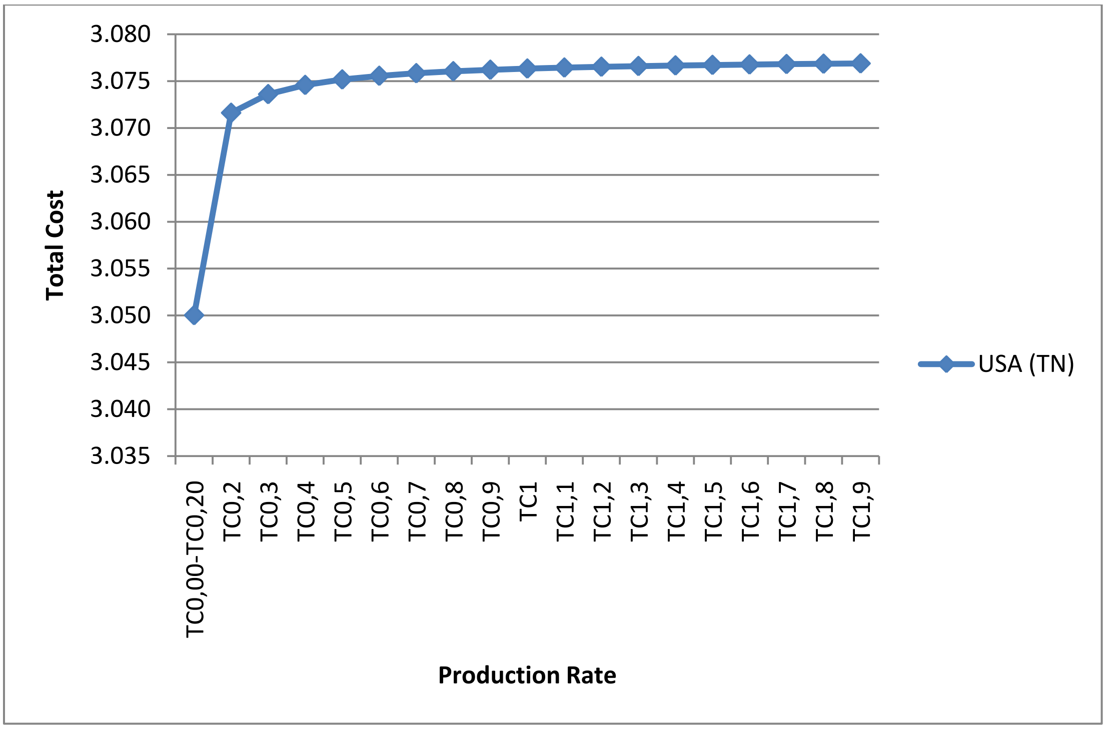

Figure 5.16: Total Cost Behavior of the Supplier in USA based on Different Rates of Production in Alternative Model

To provide an insight on this varying behavior, we take a closer look at the costs of the two suppliers: one in Japan and the other in USA.

The analysis is presented in Table 5.39.

Table 5.39: Effect of Different Production Rates on Costs

rp	1								
Costs	Bs	Us	As	Ps	Zs	TCs	hub safety	hub inventory	supplier
Japan (SA&TZ&JR&IR)	553	1.671	6.825	23.334	607	32.990	326.419	51.513	15.486
USA (TN)	155	323	471	2.075	53	3.076	66.346	-10.746	56.419

rp	2								
Costs	Bs	Us	As	Ps	Zs	TCs	hub safety	hub inventory	supplier
Japan (SA&TZ&JR&IR)	560	1.646	6.825	23.348	607	32.986	315.311	51.513	15.538
USA (TN)	155	323	471	2.075	53	3.077	66.346	-10.746	56.470

rp	3								
Costs	Bs	Us	As	Ps	Zs	TCs	hub safety	hub inventory	supplier
Japan (SA&TZ&JR&IR)	562	1.638	6.825	23.353	607	32.985	311.981	51.513	15.554
USA (TN)	155	323	471	2.075	53	3.077	66.346	-10.746	56.487

Now observe that, as production rate increases, both suppliers have higher inventory holding costs and production costs; inventory level of hub, transportation costs and fixed cost of supply hub do not change. For the product supplied from supplier in Japan, it is possible to keep lower inventory. The product supplied from USA needs the same safety stock level as before.

Hence, with increasing production speeds, the total cost of the supplier in Japan decreases in dominating the effect of reduced safety stock levels, whereas the total cost of USA supplier increases as a result of higher inventories kept for a longer time.

Therefore, it can be stated that, the key difference conflicting behaviors of total costs for different suppliers is mainly due to the safety stock policy of the supply hub. Since the safety stock policy of the supply hub is defined as keeping the maximum of “demand per lead time” or “inventory to ensure a positive in/out flow at supply hub”, the maximum may or may not change with changing production rate.

Referring to Table 5.37, we may also note that, in alternative business model, changes in suppliers’ production rates do not affect costs of manufacturers, since there exists an intermediate warehouse which decouples the suppliers and manufacturers.

5.4.6. Analysis 6: "Scenario analysis for the supplier in Turkey"

Discussions with the company managers reveal that the company is already working with a supply hub, but exclusively, for one of its products. This product is FT2, supplied from Japan to manufacturers in Turkey, Tunisia, South Africa and Tanzania. For manufacturers in Turkey and Tunisia, a warehouse in Turkey is used as a supply hub. That is, the supplier in Japan sends the products to the hub in Turkey; delivery to manufacturers in Turkey and Tunisia are made from the hub. The supplier ships products to manufacturers in South Africa and Tanzania directly.

At this point, we ask the question of what the best supply chain structure would be if we relaxed the necessity of sending FT2 from Japan to Turkey and Tunisia plants through the supply hub in Turkey.

That is, we relax the previously made allocation and let the model decide on the optimal distribution structure for the supplier in Japan.

We do this by an up-date of demands. That is, we move the demand from the supply hub in Turkey back to its original source; the supplier in Japan. We then re-compute the optimal values Q_p, t_p, t_s, Q_d, t_d, t_o and t_o^1 for the supplier. This modification also implies the necessity of recalculation of the total hub space requirement, thus the fixed cost of supply hub is revised accordingly. Finally, we update the required safety stock level in supply hub for product, FT2.

Table 5.40 demonstrates the revised values.

Table 5.40: Revised Values at Suppliers based on the Scenario Analysis

Suppliers	Product	d_s	Q_p	t_p	t_s	t_o	Q_d	t_d	Z_s	$t_{o'}$	safety for hub
Austria (TR&SA)	CP_2	1.346	2.835	0,32	2,11	120	28.560,00	21,22	**19,22**	840	24.230,8
France (TR&IR)	CP_1	2.885	4.737	0,56	1,64	12	27.648,00	9,58	**41,19**	36	23.076,9
Germany (TR)	PP_1	288	456	0,30	1,58	8	6.720,00	23,30	**4,12**	184	6.346,2
Italy (TR&TN)	PP_3	154	208	0,42	1,35	714	4.480,00	29,12	**2,20**	20.706	3.923,1
Japan (SA&TZ&JR&IR&TR&TN)	FT_2	89.808	125.116	0,63	1,39	260	342.000,00	3,81	**1.282,28**	780	595.028,1
Malaysia (SA&TZ&JR&IR)	PP_4	654	927	0,37	1,42	8568	13.440,00	20,56	**9,34**	42.840	9.307,7
Spain (TZ&TN&JR&IR)	CP_4	3.269	5.236	0,52	1,60	2640	24.480,00	7,49	**46,68**	18.480	11.538,5
UK (TR)	PP_2	96	176	0,22	1,83	14	3.840,00	39,94	**1,37**	546	3.461,5
UK (SA)	FT_3	1.923	15.253	0,06	7,93	175	54.000,00	28,08	**27,46**	700	51.923,1
USA (TR)	CP_3	192	849	0,14	4,41	44	13.824,00	71,88	**2,75**	781	13.461,5
USA (TN)	FT_4	4.423	23.249	0,09	5,26	15	90.000,00	20,35	**63,15**	60	66.346,2

On manufacturers' side, we assign the demands of the manufacturers in Tunisia and Turkey to the supplier in Japan back from the hub in Turkey.

Similarly, optimal values for Q_{mj} and t_{mj} as well as safety stock levels are re-calculated for both manufacturers.

Table 5.41 shows the data;

Table 5.41: Revised Values at Manufacturers based on the Scenario Analysis

Manufacturers	Product	s_{mj}	Q_{mj}	t_{mj}
Iran (JP)	FT_2	48.077	131.797	5,48
Jordan (JP)	FT_2	28.846	100.225	10,42
Tanzania (JP)	FT_2	50.481	152.729	10,59
Turkey (JP)	FT_2	5.495	73.973	1,92
Tunisia (JP)	FT_2	385	20.202	52,53
Safrica (JP)	FT_2	11.538	60.274	20,89

The computation of the total costs with respect to this scenario shows that the alternative model has cost advantage of 1.82% over the traditional model.

The results are summarized in Table 5.42.

Table 5.42: Comparison Analysis on Traditional and Alternative Business Models based on the Scenario

	Total Cost	
Model 1	146.358	
Model 2	143.738	-1,82%

	NPV difference	
Model 1	-46.554.274	
Model 2	-41.859.627	-4.694.647

Markup rate	**0,0143%**

The incremental Net Present Value worth of the alternative model increases to $4,694,647 whereas the markup rate reduces down to 0.01%.

Hence, the improvement in total cost brought by the implementation of the alternative model becomes more evident through assigning the product FT2 to its original supplier.

5.4.7. Evaluation of the Decision

Having completed the numeric analysis that also includes the parametric study; we conclude that alternative business model can be safely applied in the Middle East and Europe region of the multinational company. The region will gain flexibility as well as operational ease and efficiency while generating a smaller total cost and improving service levels in the supply chain. Besides, uncertainty situations will be better covered with the postponement of allocations to manufacturers' demand and the aggregate inventory kept at the supply hubs will provide risk pooling.

The net present worth analysis further shows the potential incremental gain of $3 million free cash in consolidated levels. Structuring the business model through a single hub in Turkey is a well-supported approach.

CHAPTER VI

CONCLUSION AND FURTHER RESEARCH

Companies acting in the international platform face the pressure of fierce competition and increasing costs due to the enlarged supply chains. This necessitates the reevaluation of the business model for these multinational companies. The motivation of improving the supply chain network designs of globally operating multinational companies forms the basis of the thesis. The operations of these companies are undermined by long distanced suppliers providing expensive and high volume products.

For an identification of the problem and a clear assessment of the scope, we carried out an extensive literature review on the subject. The review process included broadest perspective, supply chain network design, and the more focused areas of integration, coordination, collaboration and cooperation within supply chains. This study also contains a review of studies related with inventory management systems. These studies have guided the ideas for the alternative supply chain network design, as analyzed in the thesis, to work properly in the business strategy of the multinational companies.

The main purpose of the study was to develop a decision support tool which helps multinational companies to review their current business models and assess whether a redesign in the supply chain network improves their performance metrics.

The redesign alternative is based over the consideration of supply hubs in the supply chain network in one of the regions of the multinational company. The specifics of the study were determined based on the background issues triggering the need for business model development of most of the multinational companies, such as improving the procurement process of long distanced suppliers providing high-priced and high-volume products. The model scope, therefore, considers such a setting and choice of products.

The methods followed in the research follows an analytical outline of the cost structures of all parties in supply chains for different business models. We then numerically supported the findings by adopting the mathematical model into a real life case. The decomposition process and real data verification process is noteworthy valuable in terms of forming the baseline of the study in a manageable framework as well as ensuring the validity and practical applicability of the results.

The thesis includes detailed explanations of the business flows in traditional and alternative model. The traditional business model established on the flow of individual supply of products by the manufacturers from the suppliers whereas the alternative business model is build up on a flow of consolidated supply of products through supply hubs. The cost structures and mathematical representation of the costs, both for the traditional business model of the multinational companies and for the alternative business model, are developed and initial findings for the proper implementation of the mathematical model in both business models are outlined. Besides, the model for determining the optimal number and location of supply hubs is modeled by a mathematical programming formulation, which is then solved to optimality using the GAMS optimization software.

When all details and decisions for the two models are identified, a comparison analysis is carried out. Since the company structure poses specific considerations and data, the developed model needs to be solved for each specific company and for each specific scenario. Accordingly, the decision on which business model to apply needs to be made through an evaluation of each company on its own.

We further carried out numeric analysis in order to provide insights and to test the robustness of the decision given.

To conclude, we believe that, the model developed in the thesis can properly be used for assessing the current supply chain network design of a multinational company as well as evaluating the decisions on redesigning the supply chain network of the multinational company through consolidating regional requirements.

It is shown that for the multinational company under consideration, the alternative model which is structured through supply hubs benefits the supply chain in common more than the traditional business model and conditions for benefiting all parties involved can be properly identified as well. The total cost of the alternative business model can be less than the traditional business model and alternative business model provide operational efficiency and ease for the regional supply chain as well as better cash flow management for the supply chain. We also discussed that it will improve service levels throughout the supply chain and provide risk pooling.

The findings in the thesis refer to the problems of the components of physical distribution system like physical flow and handling of products towards channel institutions. Business strategy is developed on channels of distribution with a specific emphasis on business models with the use of supply hubs, their costs and the ownership of products, with an aim of improving service levels on the downstream activities.

In term of further research, we believe that extending the study to uncertainty assumption may extend the applicability of the model for better use in practical assessments. Furthermore, generating more discussions on safety stocks, for instance including into GAMS formulation, may provide valuable insights. Extensions to the cases with probabilistic analysis of demand data can add value, especially in terms of relaxing the limitations on product groupings. Methods for better allocation of hub costs can be developed to evident the benefits better, generated at that side. Simultaneous decisions can be reworked for different scenarios, for instance, first on hub location, then on lot sizing. Developing the approach on parametric analysis would also provide further insights to validate the robustness of the decision. Another research area can be to extend the decision support tool with a user interface.

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APPENDIX

Appendix - A. GAMS Model for Hub Location Problem

SETS

i suppliers / Austria, France, Germany, Italy, Japan, Malaysia, Spain, Turkey, UK, USA /

h Supply Hub / USA, Brazil, Belgium, Turkey, SAfrica, Dubai, Shanghai /

j production plants / Iran, Jordan, SAfrica, Tanzania, Turkey, Tunisia /

k products / pp1,pp2,pp3,pp4,cp1,cp2,cp3,cp4,ft1,ft2,ft3,ft4 /

;

table c1t(i,h) truck costs from supplier i to hub h

	USA	Brazil	Belgium	Turkey	SAfrica	Dubai	Shanghai
Austria	3710	5325.6	2450	2861.6	3950	2970	2247
France	2310	5015	1050	1190	4956	2405	1480
Germany	2310	4920	1050	1260	3625	2445	1520
Italy	2618	4160	2575	1008	3750	2775	1500
Japan	1865	5970	4550	3200	4770	3060	1036
Malaysia	2165	5225	3960	3100	3975	2465	1036
Spain	1771	3440	2145	910	3910	2355	1465
Turkey	2100	1650	735	100	2600	1650	1450
UK	2078	1705	1340	1280	4631	1785	1455
USA	100	1463	1966	2500	4486	1932	1765

table c2t(h,j) truck costs from hub h to production plant j

	Iran	Jordan	SAfrica	Tanzania	Turkey	Tunisia
USA	1932	1932	4486	4486	2500	2878
Brazil	2478	4260	1530	5885	3800	3550

Belgium	2184	3490	2710	4670	1190	2845
Turkey	1300	1966	2410	3150	100	2000
SAfrica	3285.8	4410	100	3100	3310	4225
Dubai	475	2455	2296	2910	2601	3320
Shanghai	2765	4595	3330	4545	3400	4475

table st(i,k) total supply of supplier i for product k in trucks

	pp1	pp2	pp3	pp4	cp1	cp2	cp3	cp4	ft1	ft2	ft3	ft4
Austria	0	0	0	0	0	17	0	0	0	0	0	0
France	0	0	0	0	33	0	0	0	0	0	0	0
Germany	7	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	4	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	147	0	0
Malaysia	0	0	0	15	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	42	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	112	0	0	0
UK	0	3	0	0	0	0	0	0	0	0	6	0
USA	0	0	0	0	0	0	2	0	0	0	0	13

table dt(j,k) total demand of production plant j for product k in trucks

	pp1	pp2	pp3	pp4	cp1	cp2	cp3	cp4	ft1	ft2	ft3	ft4
Iran	0	0	0	7	11	0	0	12	0	69	0	0
Jordan	0	0	0	3	0	0	0	10	0	28	0	0
SAfrica	0	0	0	1	0	5	0	0	0	8	6	0
Tanzania	0	0	0	4	0	0	0	15	0	42	0	0
Turkey	7	3	2	0	22	12	2	0	111	0	0	0
Tunisia	0	0	1	0	0	0	0	5	1	0	0	13

table vc(i,j,k) customs and agencies cost per unit for product k supplided by supplier i to manufacturer j

	pp1	pp2	pp3	pp4	cp1	cp2	cp3	cp4	ft1	ft2	ft3	ft4
Austria.SAfrica	0	0	0	0	0	1.5	0	0	0	0	0	0
Austria.Turkey	0	0	0	0	0	0.6	0	0	0	0	0	0
France.Iran	0	0	0	0	1.5	0	0	0	0	0	0	0
France.Turkey	0	0	0	0	0.6	0	0	0	0	0	0	0
Germany.Turkey	0.6	0	0	0	0	0	0	0	0	0	0	0
Italy.Turkey	0	0	0.6	0	0	0	0	0	0	0	0	0
Italy.Tunisia	0	0	1.5	0	0	0	0	0	0	0	0	0
Japan.Iran	0	0	0	0	0	0	0	0	0	0.25	0	0
Japan.Jordan	0	0	0	0	0	0	0	0	0	0.25	0	0
Japan.SAfrica	0	0	0	0	0	0	0	0	0	0.25	0	0
Japan.Tanzania	0	0	0	0	0	0	0	0	0	0.25	0	0
Malaysia.Iran	0	0	0	1.5	0	0	0	0	0	0	0	0
Malaysia.Jordan	0	0	0	1.5	0	0	0	0	0	0	0	0
Malaysia.SAfrica	0	0	0	1.5	0	0	0	0	0	0	0	0
Malaysia.Tanzania	0	0	0	1.5	0	0	0	0	0	0	0	0
Spain.Iran	0	0	0	0	0	0	0	1.5	0	0	0	0
Spain.Jordan	0	0	0	0	0	0	0	1.5	0	0	0	0
Spain.Tanzania	0	0	0	0	0	0	0	1.5	0	0	0	0
Spain.Tunisia	0	0	0	0	0	0	0	1.5	0	0	0	0
Turkey.Turkey	0	0	0	0	0	0	0	0	0.25	0	0	0
Turkey.Tunisia	0	0	0	0	0	0	0	0	0.25	0	0	0
UK.SAfrica	0	0	0	0	0	0	0	0	0	0	0.25	0
UK.Turkey	0	0.6	0	0	0	0	0	0	0	0	0	0
USA.Turkey	0	0	0	0	0	0	1.5	0	0	0	0	0
USA.Tunisia	0	0	0	0	0	0	0	0	0	0	0	0.25

table qty(i,j,k) total supply of supplier i to manufacturer j for product k in units

	pp1	pp2	pp3	pp4	cp1	cp2	cp3	cp4	ft1	ft2	ft3	ft4
Austria.SAfrica	0	0	0	0	0	20000	0	0	0	0	0	0
Austria.Turkey	0	0	0	0	0	50000	0	0	0	0	0	0
France.Iran	0	0	0	0	5 0000	0	0	0	0	0	0	0
France.Turkey	0	0	0	0	100000	0	0	0	0	0	0	0
Germany.Turkey	15000	0	0	0	0	0	0	0	0	0	0	0
Italy.Turkey	0	0	5000	0	0	0	0	0	0	0	0	0
Italy.Tunisia	0	0	3000	0	0	0	0	0	0	0	0	0
Japan.Iran	0	0	0	0	0	0	0	0	0	1250000	0	0
Japan.Jordan	0	0	0	0	0	0	0	0	0	500000	0	0
Japan.SAfrica	0	0	0	0	0	0	0	0	0	150000	0	0
Japan.Tanzania	0	0	0	0	0	0	0	0	0	750000	0	0
Malaysia.Iran	0	0	0	15000	0	0	0	0	0	0	0	0
Malaysia.Jordan	0	0	0	6000	0	0	0	0	0	0	0	0
Malaysia.SAfrica	0	0	0	3000	0	0	0	0	0	0	0	0
Malaysia.Tanzania	0	0	0	10000	0	0	0	0	0	0	0	0
Spain.Iran	0	0	0	0	0	0	0	50000	0	0	0	0
Spain.Jordan	0	0	0	0	0	0	0	40000	0	0	0	0
Spain.Tanzania	0	0	0	0	0	0	0	60000	0	0	0	0
Spain.Tunisia	0	0	0	0	0	0	0	20000	0	0	0	0
Turkey.Turkey	0	0	0	0	0	0	0	0	2000000	0	0	0
Turkey.Tunisia	0	0	0	0	0	0	0	0	20000	0	0	0
UK.SAfrica	0	0	0	0	0	0	0	0	0	0	100000	0
UK.Turkey	0	5000	0	0	0	0	0	0	0	0	0	0
USA.Turkey	0	0	0	0	0	0	10000	0	0	0	0	0
USA.Tunisia	0	0	0	0	0	0	0	0	0	0	0	230000

```
parameter f(h) fixed cost of opening supply hub h

/

USA        94574

Brazil     94574

Belgium    67975

Turkey     65020

SAfrica    70930

Dubai      70930

Shanghai   70930

/


VARIABLES

tc objective function value


positive variable

s(i,h,k) the number of trucks for product k transported from i to h

p(h,j,k) the number of trucks for product k transported from h to j


BINARY VARIABLES

z(h)    1 if supply hub h is opened and 0 otherwise

x(i,h,k) 1 if supplier i is assigned to hub h and 0 otherwise


EQUATIONS

OBJECTIVE   minimize the total cost

c1

c2

c3

c4

c5
```

```
c6
c7
;

OBJECTIVE    ..
tc=e=sum((i,h,k),s(i,h,k)*c1t(i,h))+sum((h,j,k),p(h,j,k)*c2t(h,j))+sum(h,f(h)*z(h))+sum((i,j,k),(vc
(i,j,k)*qty(i,j,k)));
c1 (i,k)     .. sum((h),s(i,h,k))=l=st(i,k);
c2 (j,k)     .. sum((h),p(h,j,k))=g=dt(j,k);
c3 (h,k)     .. sum((i),s(i,h,k))=e=sum((j),p(h,j,k));
c4 (h)       .. 100000*z(h)=g=sum((i,k),s(i,h,k));
c5 (i,h,k)   .. s(i,h,k)=l=100000000*x(i,h,k);
c6 (i,k)     .. sum((h),x(i,h,k))=e=1;
c7           .. sum((h),z(h))=e=1;

MODEL Hub /ALL/;
option optcr=0;
option optca=0;
SOLVE Hub USING MIP minimizing tc;
display tc.l,z.l,s.l,p.l,x.l
```