

**COST BASED PERFORMANCE EVALUATION OF SUPPLY CHAIN
TYPES REGARDING DEMAND UNCERTAINTY: A PROPOSED
MATHEMATICAL MODEL**

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Programme : Management Engineering

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**TALEP BELİRSİZLİĞİNİ DİKKATE ALAN MALİYET TABANLI
TEDARİK ZİNCİRİ PERFORMANS DEĞERLENDİRMESİ: BİR
MATEMATİKSEL MODEL**

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FOREWORD

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ABBREVIATIONS

AMS	: Agile Manufacturing System
ASC	: Agile Supply Chain
ATO	: Assemble to Order
CI	: Confidence Interval
DFU	: Directions for Use
DSS	: Decision Support System
HSC	: Hybrid Supply Chain
ICT	: Information and Communication Technologies
JIT	: Just in Time
LSC	: Lean Supply Chain
MS	: Microsoft
MTO	: Make to Order
MTS	: Make to Stock
OP	: Operations Management
RDV	: Relative Demand Volatility
SA	: Sensitivity Analysis
SC	: Supply Chain
SCC	: Supply Chain Council
SCM	: Supply Chain Management
SME	: Small and medium enterprise
TC	: Total Cost
TPS	: Toyota Production System
TSC	: Traditional Supply Chain
VO	: Virtual Organization

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COST BASED PERFORMANCE EVALUATION OF SUPPLY CHAIN TYPES REGARDING DEMAND UNCERTAINTY: A PROPOSED MATHEMATICAL MODEL

SUMMARY

The competition is now on a different level and today's challenging environment asks for perfect players who are able to respond customer demands no matter how complicated they are to achieve. Delivering the right product to the consumer at the right time and at the right price is vital not only to achieve competitive success but also to survive in today's marketplace; therefore, competitive advantage lies through the supply chain. As a result of these emerging business challenges, supply chains are continuously being redefined and restructured; in fact, it is the supply chains that compete rather than the individual companies themselves, and the success or failure of supply chains is ultimately determined in the marketplace by the end consumer.

Furthermore, predicting demand distribution and variation is becoming much harder than ever as the demand moves from functional (standard) products to innovative (modern) products that seduce the customers emotionally. People have started to pay higher values to those appealing products, which pump profit margins up to new levels but with increasing marketability costs and shorter life cycles. On the other hand, there are still many products that cannot be evaluated emotionally, therefore having lower profit margins and stable demand characteristics.

When global competition and product trends are considered, selecting a supply chain structure suitable for the fluctuations in demand becomes vital. Therefore a general conceptual total cost model has been enhanced to answer which supply chain structure might be the most appropriate choice. Different supply chain combinations (some reflecting lean, agile or leagile SC characteristics) have been tested based on the degree of postponement and modularization under strategic scenarios; moreover, it has been shown that postponed structure is more appropriate for uncertain demand characteristics and higher service level preferences, while traditional structure performs better under stable demand. It has been seen that vertical integration is not the best choice under recent environment conditions; in fact, this explains why more and more companies are replacing vertical integration with vertical coordination and developing long-term arrangements with outside suppliers.

In short, the main focus of this research is to evaluate the cost based performance of certain supply chain types under different demand characteristics (generally for different kind of products) regarding demand uncertainty. A mathematical model, concerning specific characteristics of the supply chain types as parameters in the cost function has been proposed. It has been aimed to compare the cost effectiveness of every chain type individually, concerning service levels and the effects of demand fluctuation on the chain performance. Furthermore, a purpose-specific decision support system that helps the decision maker by simulating the effect of outbound postponement on a supply chain structure has been developed; what is more, a range of sensitivity analyses have been carried out through this system to achieve a better

understanding of the model parameters. Also, future research on the subject is recommended to widen the scope of the research regarding the key factors such as product life cycles, profit margins and transportation.

TALEP BELİRSİZLİĞİNİ DİKKATE ALAN MALİYET TABANLI TEDARİK ZİNCİRİ PERFORMANS DEĞERLENDİRMESİ: BİR MATEMATİKSEL MODEL

ÖZET

Rekabet artık farklı bir düzeydedir ve günümüzün rekabetçi ortamı, başarması ne kadar zor olursa olsun müşteri taleplerine cevap verebilecek mükemmel oyuncuları aramaktadır. Tüketicie doğru ürünü, doğru zamanda ve doğru fiyata ulaştırmak sadece rekabette başarıyı sağlamak için değil, aynı zamanda günümüz pazarında ayakta kalmak için de çok önemlidir; bundan dolayı, rekabet üstünlüğü tedarik zincirine bağlıdır. İş alanlarında ortaya çıkan bu yeni mücadeleler sonucunda tedarik zincirleri sürekli bir şekilde yeniden tanımlanmakta ve yeni baştan inşa edilmektedirler. Aslında, yarışma bireysel şirketlerin kendilerinden ziyade, tedarik zincirleri arasındadır ve tedarik zincirlerinin başarısı ya da başarısızlığı piyasada son tüketici tarafından belirlenmektedir.

Ayrıca, talep dağılımını ve varyasyonunu tahmin etme, talep işlevsel (standart) ürünlerden, tüketiciye duygusal yönden çekici gelen yenilikçi (modern) ürünlere kaydığı için gittikçe çok daha zor bir hal almaktadır. İnsanlar kar paylarını yeni seviyelere çıkaran, ama aynı zamanda da yüksek pazarlama maliyetlerine ve daha kısa yaşam döngüsüne sahip bu cazip ürünler için daha yüksek bedeller ödemeye başlamışlardır. Öte yandan, halen duygusal olarak değerlendirilmesi mümkün olmayan dolayısıyla daha düşük kar paylarına ve istikrarlı talep yapısına sahip birçok ürün bulunmaktadır.

Küresel rekabet ve ürün eğilimleri (trendleri) düşünüldüğünde, talep dalgalanmalarına uygun tedarik zinciri seçimi çok önemli olur. Bu yüzden genel bir kavramsal toplam maliyet modeli hangi tedarik zincirinin yapısının en uygun seçim olabileceği sorusunu cevaplandırabilmek için uyarlanmıştır. Farklı tedarik zinciri bileşimleri (bazıları yalın, çevik, yalın-çevik tedarik zinciri özelliklerini yansıtan) erteleme (postponement) ve modularizasyon derecesini temel alarak stratejik senaryolara göre test edilmiştir. Buna ilaveten, geleneksel yapı, sabit talep özellikleri altında daha iyi performans gösterirken, ertelenmiş (postponed) yapının belirsiz talep özellikleri ve daha yüksek hizmet seviyesi tercihleri için daha uygun olduğu gösterilmiştir. Günümüz koşulları altında dikey entegrasyonun en iyi tercih olmadığı görülmüştür; nitekim, bu durum gittikçe artan sayıda şirketin neden dikey entegrasyonu, dikey işbirliği ile değiştirmekte olduğunu ve dış tedarikçilerle neden uzun vadeli sözleşmeler yaptığını açıklamaktadır.

Kısaca, bu çalışmanın odak noktası, belirli tedarik zinciri türlerinin maliyet tabanlı performansını farklı talep özellikleri altında (çoğunlukla farklı ürünler için) ve talep belirsizliğini göz önünde bulundurarak değerlendirmektir. Tedarik zinciri türlerine özgü özellikleri maliyet fonksiyonunun parametreleri olarak barındıran bir matematiksel model önerilmiştir. Her bir tedarik zinciri çeşidinin maliyet etkinliğini, hizmet seviyesi ve talep dalgalanmalarının zincir performansı üzerindeki etkilerini göz önünde bulundurarak ayrı ayrı karşılaştırmak hedeflenmiştir. Bunun yanında, bir

tedarik zinciri yapısı üzerinde dağıtımdaki erteleme etkisini canlandırarak karar vericiye yardımcı olan amaca özel bir karar destek sistemi geliştirilmiştir. Ayrıca, model parametrelerini daha iyi kavramak için bu sistem aracılığıyla bir grup hassasiyet analizi gerçekleştirilmiştir. Bunlara ek olarak, yapılan araştırmanın kapsamını ürün yaşam döngüleri, kar payları ve nakliye gibi anahtar faktörleri dikkate alarak genişleten ilerki araştırmalar önerilmektedir.

1. INTRODUCTION

Supply chains have existed ever since people started trading; recently, interest on the subject is more than ever. In order to improve their performance and competitive advantage, businesses are paying increasing attention to supply chain operation and management (Kundu et al., 2008). With the effect of the globalization on the market economy, the competition has found a new focus between the supply chains (Fan et al., 2007); in fact, it is the supply chains that compete, not the individual companies anymore (Christopher, 1992, cited in Towill and Christopher, 2002). Moreover, the success or failure of supply chains is ultimately determined in the marketplace by the end consumer (Towill and Christopher, 2002). Therefore, organizations are facing increasing competition and challenges to get closer to their customers, reduce time to market, reduce costs, increase variety, improve quality, eliminate inventory, be right at first time, add innovations, improve reliability, and increase flexibility to their products and services. As a result of these emerging business challenges, supply chains are being redefined and restructured (Kundu et al., 2008).

Over the last two decades, there has been a steady convergence of the areas; operations management (OP), sourcing, and logistics into a single area commonly known as supply chain management (SCM). According to the SCM perspective, it is no longer satisfactory for companies to run these areas as loosely linked pockets of excellence. For this reason, businesses must also develop and manage the information flows, physical flows and relationships that link these areas together, also with upstream and downstream partners (Bozarth C.C. et al., 2009). Kundu et al. (2008) point out that operations not just for the efficiency of the individual firms in the supply chain but also for efficiency and effectiveness of the whole supply chain are increasingly becoming strategic postures. To achieve this, collaboration of supply chain partners with each other is essential, for example, by sharing risk and revenue, providing visibility throughout the supply chain, and appropriate supply chain operation strategies.

Supply chain seems to be a complicated system according to the majority of observers; in addition to this, as product life cycles shorten, product variety and customization levels increase and supply chain partners become more geographically dispersed, therefore managing the supply chain becomes an extremely challenging mission (Bozarth C.C. et al., 2009). Delivering the right product to the consumer at the right time, and at the right price is vital not only to achieve competitive success but also to survive in today's marketplace. Therefore, in order to achieve an optimal supply chain performance, it is an obligation to design supply chain as linked to business strategy, therefore, to the needs of the marketplace.

In short, the main focus of this thesis is to evaluate the cost based performance of certain supply chain types under different demand characteristics (generally for different kind of products) regarding demand uncertainty.

In the second chapter, from the literature review, the supply chain concept, its management and evolution throughout time, postponement and modularization decision in supply chain management and, finally, supply chain types will be highlighted.

Relationship of products and the supply chain will be discussed in the third chapter. Product types, demand patterns, trends, customer needs and competitive capabilities will be examined, also, product types will be aligned with the best fitting supply chain types.

In the fourth chapter, the framework of the mathematical model for supply chain performance evaluation regarding demand uncertainty will be built, and analytical formulation will be set up. The methodology& steps will be explained in depth; furthermore, a purpose-specific decision support system that helps the decision maker by simulating the effect of outbound postponement on a supply chain structure will be developed, and sensitivity analyses will be carried out through a number of strategic scenarios to achieve a better understanding of the framework. Finally, at the end of the chapter, findings are going to be stated.

In the last chapter, the conclusion will be made and final remarks will be expressed. Moreover, directions for future research will also be suggested within the context of this chapter.

2. SUPPLY CHAINS AND SUPPLY CHAIN MANAGEMENT

2.1 Supply Chain Concept

A supply chain can be defined with many proper but too generic terms such as integrating, connectivity, information exchange, communication, linkages, and logistics. However, one word definition of a supply chain should be simply “movement” as Plenert (2006) describes. Moreover, he extends this definition by defining three critical driving resources that define the success or failure of movement within the supply chain: materials, information, and money as demonstrated in Figure 2.1.

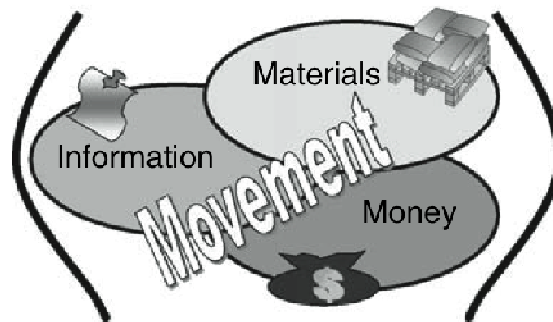


Figure 2.1 : The critical driving resources that define a supply chain

According to Stevens (1989), supply chain acts as a chain linking each element from customer and supplier through manufacturing and services; therefore, makes it possible to manage the flow of those three critical key resources to meet the business requirements.

The seamless flow of materials, money and information have equal importance in the chain, because a failure of one of them means a failure of all in an environment where various forces continuously interact with the overall supply chain (Figure 2.2). Thus, the main expertise is to sustain a flawless, well-performing machine while optimizing all the operational complexities of the supply chain under the effect of those external forces (Plenert, 2006).

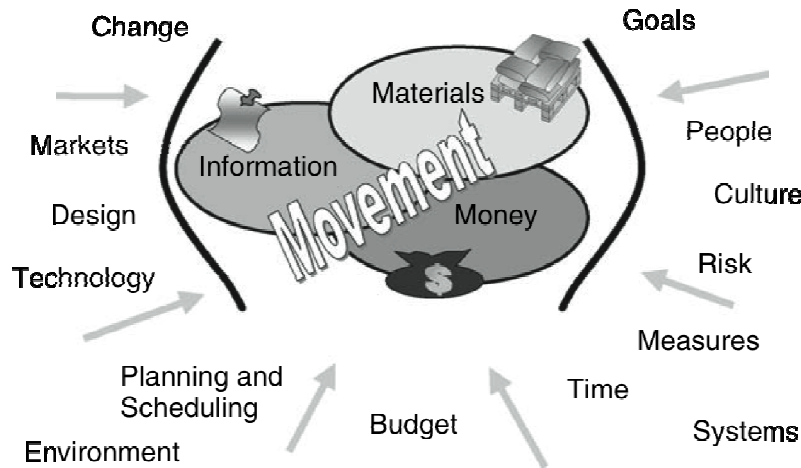


Figure 2.2 : The forces affecting the resources that define a supply chain

In early literature, supply chains were described as an umbrella of companies buffering the movement of materials between them while passing the products to each other in the direction of the customer with transportation and warehousing activities (Rivera et al., 2007). On the other hand, this description portrays just a limited part of the exchange and is not sufficient for the present supply chain definition.

Similarly, Eisler et al. (2007) note that the supply chain was only considered as a material transfer channel in the previous years. However, nowadays it is the main source of competitiveness and as Lancioni (2000) states it will be.

Sabri and Beamon (2000) define a supply chain as a set of facilities, supplies, customers, products and methods of controlling inventory, purchasing, and distribution. The chain links suppliers and customers, beginning with the production of raw material by a supplier, and ending with the consumption of a product by the customer. Besides, the flow of goods between a supplier and customer passes through several stages, and each stage may consist of many facilities in a supply chain.

According to Stevens (1989), a supply chain is a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via a feed-forward flow of materials and feedback flow of information.

Barton and Thomas (2009) have pointed out that in its most basic form, the supply chain is an extended network of suppliers, factories, warehouses, distribution centres,

and retailers through which raw materials are acquired, transformed, and delivered to customers.

Similarly, a supply chain is an integrated network of suppliers, manufacturing plants and distributing channels, which are organized to acquire raw materials, then to convert those raw materials to final products, and finally to distribute those products to customers (Mo et al., 2005).

Maropoulos et al. (2008) defined a supply chain as a set of more than three companies from supplier to customers, which could include factories, warehouses, retailers and end customers -depending on the complexity and the maturity of the chain-. Also, these companies are closely linked by upstream and downstream flows of materials, information, finances and services.

As a more comprehensive definition, a supply chain is composed of a complex sequence of processing stages, ranging from the supplies of raw materials, manufacturing of parts, components and assembling of end-products, to the delivery of finished products (Wu and Olson, 2008 cited in Huang and Qu, 2008). For each stage, multiple alternative supply options are naturally available to satisfy processing requirements (Huang and Keskar, 2007 cited in Huang and Qu, 2008). Thus, it is possible to represent a supply chain as a network with nodes that signify stages where many routes are available as supply options (Huang and Qu, 2008).

According to Wiendahl and Lutz (2002) cited in Maropoulos et al. (2008), the definition of supply chain was born as a consequence of the make-or-buy decision of enterprises, which has created large amounts of new flows and thus a direct requirement to manage these flows.

As a very wide concept, the scope of the supply chain is hard to define because of the common use of this term and its connection with the other areas such as logistics or purchasing (Larson and Halldorsson, 2002 cited in in Maropoulos et al., 2008). In fact, regarding the company perspective, the vision is expected to differ from one to another depending on different situations since the activities that make one company successful will probably not be functional for another, and obviously difficulties could appear when different companies work together (Menzer, 2001 cited in Maropoulos et al., 2008).

In short, the challenge is getting the right product, at the right price and at the right time; or simply, proper management of the supply chain, what has become vital for an organization (Fan et al., 2007). Likewise, Gunasekaran et al. (2001) have pointed out that enhancing the supply chain performance or in other words advancing into an efficient and effective supply chain needs supply chain management (SCM) to be assessed.

2.2 Supply Chain Management

According to Supply Chain Council (SCC) “the supply chain encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer”. Thus, supply chain management includes managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer.

Supply chain management (SCM) literature encompasses many different aspects such as management science (Lee, 2002), operations management (Lamming et al., 2000; Li and O'Brien, 2001), marketing (Canever et al., 2007), logistics (Christopher et al., 2006; Christopher et al., 2002; Pagh and Cooper, 1998) and purchasing (Cagliano et al., 2004; Giunipero and Brand, 1996; Harland, 1996). Briefly, SCM has been examined basically through two main perspectives in the literature; “purchasing and supply” and “transportation and logistics” (Tan, 2000). In case those two perspectives can be attached, SC embodies all the value-added activities on the value chain. Accordingly, SCM can make a significant importance in overall business planning process.

Also it is vital for firms to have a set of activities supporting each other with consistency (Porter, 1996) in accordance with the business strategy (Chopra and Meindl, 2004). A supply chain strategy developed according to the competitive advantage of a firm as well as its business strategy would provide the success.

In addition, it has been also noted that supply chains should be interpreted through the perspective of marketplace (Christopher and Towill, 2002; Mason-Jones et al., 2000b; Ayers, 1999). Today's marketplace is characterized with some new rules of competition. For example, competitive pressure forces more frequent product

modifications. Changeable customers needs and wants lead shorter product life cycles as well as the technology life cycles. High levels of variety and products' rapid growth increase business risk. All those changing conditions signify that forecast-based management is not viable any more. The new approach is forecasting for capacity, then executing against real demand. Accordingly, this requires more responsive supply chains.

During last decades, many organizations have adopted the lean thinking paradigm in their drive to optimize performance and improve competitive position. Lately, a new paradigm has been highlighted as an alternative to leanness. Despite the fact that many discussions took place proposing that those two paradigms can complete one after the other (Christopher and Towill, 2006; Towill and Christopher, 2002; Mason-Jones et al., 2000b; Childerhouse and Towill, 2000; Naylor et al., 1999). Hence, due to the need for a new approach to deal with changing needs and conditions of marketplace, a new aspect combining lean and agile paradigms has been brought front, which is called "leagile". This approach is known also as postponement of activities or mass customization. Its characteristics and categorization have been noted in the literature as well (Pagh and Cooper, 1998; Van Hoek et al., 1999).

Most of the companies have seen operational effectiveness as very important, especially after the success of Japanese companies by 1980s. Recently, it has been realized that supply chains are not satisfying enough as it is expected (Fisher, 1997). This situation can be a result of a lack of strategy (Porter, 1996). Operational effectiveness focus has been taking the place of strategy; hence, traditional supply chain aspect is not adequate to meet the requirements of sustainable success, in other words sustainable competitive advantage.

At the strategic level of SCM, the supply chain strategies establish and prioritize the objectives and means. Recently, empirical studies have pointed out the significance of supply chain strategy for business strategy as well as for competitiveness (i.e. competitive advantage) as well. However, the reality is that supply chain strategies are mostly inadequately articulated and defined (Schnetzler et al., 2007). Although the operations aspects of SCM have been examined for a long time, SCM strategy is a new concept. In fact, many researches need to be performed on methodologies for successful implementation of strategic SCM (Ross, 1998). Thus, it is necessary to

operate researches focused on the integration of SCM with company's marketing, financial, manufacturing, and logistics strategies.

The struggles in the marketplace led many academicians to propose particular supply chain processes based on different determinants. Table 2.1 exhibits some classifications and related determinants made by some academicians.

Table 2.1: Some Supply Chain Classifications in the Literature.

Academician(s)	Determinants	Classification
Fisher (1997)	Demand predictability	Physically efficient process
	Profit margin	Market responsive process
	Product variety	
	Product innovation	
	(customisation)	
	Product life cycle duration	
Pagh and Cooper (1998)	Market standards for lead-times	
	Demand uncertainty	Full speculation
	Product life cycle stage	Logistics postponement
	Product customisation	Manufacturing postponement
	Product variety	Full postponement
	Relative delivery time	
Naylor et al. (1999)	Delivery frequency	
	Product value	
	Stability of demand	Lean Agile Leagile
Lamming et al. (2000)	Product innovation	Innovative-unique and complex
	Product complexity	Innovative-unique and non-complex
	Product uniqueness	Functional and complex
		Functional and non-complex
Mason-Jones et al. (2000)	Demand uncertainty	Lean
	Product life cycle duration	Agile
	Marketplace characteristics	Leagile
Li and O'Brien (2001)	Product innovation	Physically efficient process
	Product variety	Physically responsive process
	Profit margin	Market responsive process
	Supply capabilities	Operational excellence
Morash (2001)	Competitive strategy	Customer closeness
	Demand characteristics	Lean
	Product characteristics	Agile
Christopher and Towill (2002)	Replenishment lead-time	
	Demand Predictability	Lean: Continuous Replenishment
	Demand Variability	Lean: Plan and Execute
Christopher et al. (2006)	Replenishment Lead Time	Agile: Quick Response
		Leagile: Postponement
		Physically Efficient Process
Wong et. al (2006)	Demand Variability	Physically Responsive Process
	Forecast Uncertainty	Market Responsive Process
	Contribution Margins	
	Time Window for Delivery	

To sum up, it is possible to say that the effective management of a supply chain is one of the key factors for the success of a company. During the last decade, therefore, supply chain management has gained huge interests from both academics

and industries. The key decision variable in the management of supply chain is how to utilize available resources (i.e., raw materials, processes, technology, capability, capital, and so on) at given economic and business environment, in order to enhance company's competitiveness in the market and to achieve maximum profit with maintaining high sustainability (**Chen, 2007**). Because, in a world where products are produced in a global production system and are sold in the global market place, the supply chain becomes major contributor to the corporate success. Indeed, the global competition is not based anymore on a challenge between manufacturing companies but mainly on a challenge between their supply chains, which consists in focusing on rapid response to customer needs at low costs.

2.2.1 SCM Challenges

Managing the supply chain is an intimidating daily challenge for the SC executives. The customers or stores have to be properly stocked and the deliveries have to be perfect order every time while balancing the need for low costs, proper inventory levels and maximum service. SCM is an integral component of the company's strategic direction and it should be planned to create and maintain competitive advantage. Furthermore, each chain is actually a series of buyers and sellers of products and services, which means that each link participant has his own objectives. These objectives are sometimes conflicting and can work against supply chain effectiveness. In addition to those, there are many more challenges that a company has to deal with such as growth in contract manufacturing, shifting to global manufacturing, unpredictable global demand, SC instability and increasing customer requirements, etc.

2.2.1.1 The Goal of SCM

The goal of the supply chain management can be defined as operating supply chain flows and assets so to maximize overall supply chain value. Supply chain value means the difference between the worth of the final product to the customer and supply chain costs of in filling the customer's request (Chopra and Meindl, 2004). In other words, it is the surplus of the supply chain, which is equal to:

= What the customer has paid – TC expended by supply chain in filling order

Value is correlated to supply chain profitability which is the difference between revenue generated from the customer and the overall cost across the supply chain. In fact, supply chain profitability is total profit to be shared across all stages of the supply chain. Hence, supply chain success should be measured by total supply chain profitability, not profits at an individual stage.

Traditionally logistics and supply chain management have been measured in terms transportation and inventory costs while the administration needed managing both. Traditionally firms have an inventory manager and a transportation manager. However, this view is very narrow and causes significant problems in the proper functioning of the supply chain.

As it is demonstrated in Table 2.2, logistics costs are a significant fraction of the total value of a product. The problem here is that this is a purely cost based view of the supply chain, which drives a firm to reduce logistics costs. This is an incomplete picture. By using effective logistics and supply chain strategies, it is possible to save big amounts and meet today's customer needs and wants. When responsiveness is needed, margins shall be high enough to compensate the responsiveness cost.

Table 2.2: Total value components of a product.

Costs as % of sales	Share
Profit	4%
Logistics Cost	21%
Marketing Cost	27%
Manufacturing Cost	48%

2.2.1.2 Problems Related to SCM

SCM's structure complexity (Figure 2.3) is its main problem since it encompasses whole business activities and the relationships between all firms within the chain. In this definition, logistics remains as a function of SCM, which copes with the delivery of products to the right place through the integration of transportation, customs clearance, storage etc.

In the literature, there are different approaches regarding supply chain complexity. Supply chains' structural complexity is related internally to integration between departments and levels within an organization and externally to informational, product and service transactions and relationships with other organizations involved in the supply chain. Supply chain complexity is associated with the level and variety

of interactions between and within the organizations. These interactions are defined by the business processes, which lead us to business rules.

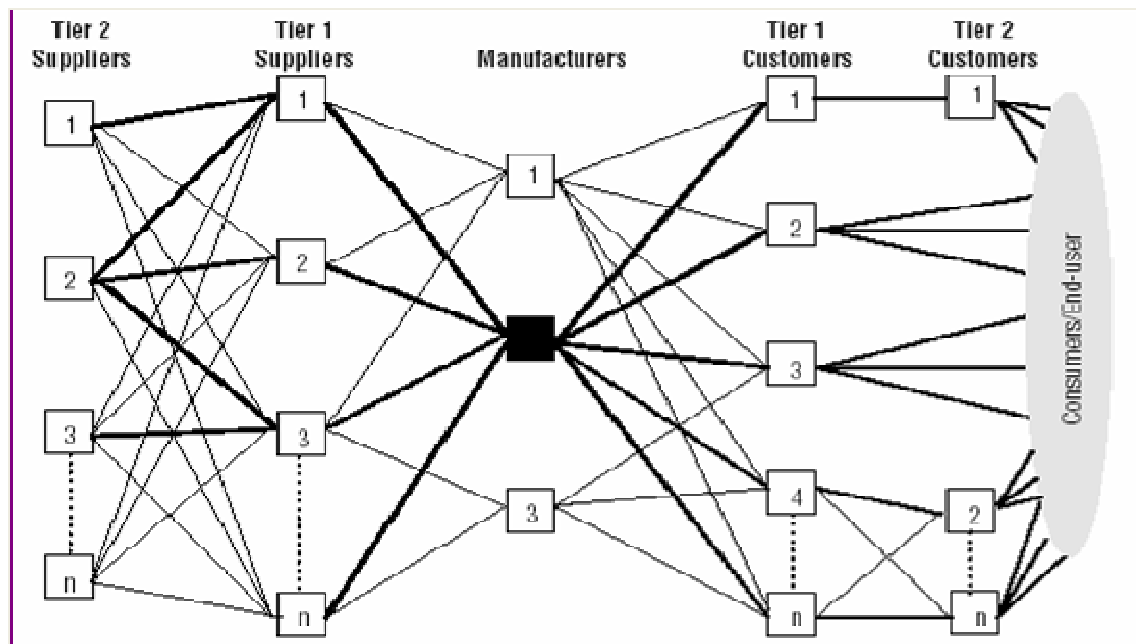


Figure 2.3 : Complex structure of supply chain.

The complexity within the chain causes deviations in the flow of materials and information throughout the chain. Accordingly, decreasing the complexity of the chain leads achieving cost reduction, improving performance and increasing flexibility. This phenomenon of variability magnification as we move from the customer to the producer in the supply chain is often referred to as the “bullwhip effect”. This effect signs synchronization lack among supply chain members. Even a slight change ripples backward in the form of magnified oscillations upstream, resembling the result of a flick of a bullwhip handle (Chase et al., 2001).

Due to the mismatch between the supply chain and demand patterns, inventory accumulates at various stages, whilst shortages and delays occur at others (Fisher, 1997; Mason-Jones et al., 2000b) as a result of bullwhip effect.

As a result, it is supposed to deal with the complexity of SC. These activities are proposed in the literature;

- Increasing integration and coordination throughout the chain
- Synchronization of demand, planning, manufacturing and supply processes
- Implementation of visibility
- Reduction of non value-added operations

- Upgrading automation
- Standardization of process and data
- Using decision support systems (DSS)

Firms should handle supplier selection and suggested selection criteria go parallel with the manufacturing performance and competitive priorities such as cost, quality, delivery and flexibility (Harland et al., 1999). According to traditional procurement strategies, “cost” is the criterion adopted in either local or global scale and it implies supplying materials at the lowest cost. However, many authors highlighted that other criteria (i.e. quality, delivery and flexibility) are equally or more important in most cases when supply has a direct impact on competitive performance, like in the case of innovative products (Cagliano et al., 2004).

Some other problems regarding SCM are about sharing the inventory throughout the chain, establishing a chain culture, proper information systems, and so on.

2.3 The Structure of Supply Chain

Supply chain structure includes activities related to facilities, transportation, inventory and information, which are described as supply chain drivers by Chopra and Meindl (2004). Supply chain structure, as well as the SC decisions, is affected by those activities.

Facilities signify the locations where the inventory is stored, assembled or fabricated (i.e. production sites and storage sites).

Inventory indicates the raw materials, work-in-process (WIP) and finished goods within a supply chain. They are determined by the inventory policies, which are chosen according to the supply chain priorities.

Transportation driver is moving inventory from one point to another in a supply chain. It is performed with respect to the combinations of transportation modes and the routes.

Finally, information driver refers to the data and analysis regarding inventory, transportation, and facilities throughout the supply chain.

2.3.1 Facilities

Essential functions formed by facilities decisions are summed up by Gattorna and Walters (1996) as;

- to create stockholding from which to service the needs of production and customers
- to act as an assurance against production failures
- to absorb the benefits of economic production runs
- to provide buffer stocks to meet fluctuating and uncertain sales demands
- to maximize the benefits of procurements economies
- to provide support for marketing and sales activities

Warehouse type mostly depends on product characteristics (i.e. special conditions to keep a breakable good), market demand volume and customer service requirements (Gattorna and Walters, 1996). Product characteristics especially determine the storage and handling methods. Rate of sale and sales volumes influence the methods used to process and progress orders. Customer service requirements affect lead time responses which in turn can affect the selection of materials handling equipment.

The fundamental reasons of warehouse facilities are:

- to reduce transportation costs
- to coordinate supply and demand
- to assist in the marketing process so as to provide customer service
- to assist in the production process

Marketing channels relate to the management of stocks and flows within the physical transfer of products between supplier, distributor and consumer. Intermediaries exist in order that the process of exchange can be made more efficient. Warehousing facilities and the role of intermediary are used as a part of service package.

The way in which the channel is structured is largely determined by where inventories should best be held in order to deliver to customer service specifications. This requires a combination of inventory and warehouse facilities to provide adequate availability, which refers to service levels, fulfil sorting function processes, and compensate channel intermediaries. Accordingly, the principles of postponement and speculation are developed to explain the process (Pagh and Cooper, 1998). Marketing channels are promoted by postponement of changes in the form and

identity of a product to the latest possible point in the marketing process, and inventory location to the latest possible point in time (Yang and Burns, 2003; Van Hoek et al., 1999).

For facilities decisions from a logistics perspective, manufacturing/operations strategy should be considered as well. From a marketing view, also available market-based opportunities should be considered (Gattorna and Walters, 1996):

- process structure/process life cycle stage (varies depending on lot size and product variety)
- demand characteristics (customer service expectations)
- product characteristics (different handling characteristics)

Likewise, decisions regarding capacity, operations strategy and warehousing methodology are made in consistency with each other, trading off responsiveness versus efficiency. As a summary of the facilities section, components of facilities and their corresponding decisions are shown below, in the Table 2.3.

Table 2.3: Components of facilities and related decisions

Components	Decisions
Location	Centralization versus Decentralization
Capacity	Efficiency, Flexibility
Manufacturing Methodology	Process Focused, Product Focused, Market Focused
Warehousing Methodology	Cross-Docking, SKU storage, Job Lot Storage

2.3.2 Inventory

SCM has a large impact on inventory levels throughout manufacturing and logistics systems. A coordinated effort to maximise inventory flows through the supply chain with inventory-holding points specifically tasked to respond customer service requirements is a widely accepted service objective to achieve (Chopra and Meindl, 2004).

Traditionally, inventory is not welcomed, but often they are essential aspects of manufacturing and supply activity. On the one hand, it acts as a buffer to failures in both external and internal supply systems and facilitates the achievement of effective customer service. However, holding of inventory is costly and mostly inefficient (Webster, 2002).

The strategic choices of inventory management decisions are summarized by Gattorna and Walters (1996) as;

- Who is the materials and component supplier to be?
- Who will hold the inventory, and where?
- How much inventory is required to be held?
- Where or with whom will the customer place orders; directly with the supplier or through an intermediary?
- How will orders be delivered, directly to the customer by an intermediary, or by a dedicated service company?

Three basic reasons of keeping an inventory can be counted as time, unpredictability and economies of scale impact. From supplier to user at every stage time delays present in the supply chain and each stage asks for maintaining a certain amount of inventory to use in this "lead time". Inventories are kept as buffers to meet "uncertainties in demand", supply and movements of goods. Ideal condition of "one unit at a time at a place where user needs it, when he needs it" principle tends to cause high costs in the means of logistics. So bulk buying, movement and storing brings in economies of scale, as well as inventory.

Inventory driver includes different types of decisions regarding different inventory types such as cycle inventory, safety inventory and seasonal inventory.

"Cycle inventory" indicates average inventory that builds up within the supply chain because a supply chain stage either produces or purchases in lots that are larger than those demanded by the customer (Chopra and Meindl, 2004). It results from the replenishment process and characterized by predictable demand and replenishment rates (Gattorna and Walters, 1996). No inventory would be needed other than this one in a certain world with a constant demand. Thus, cycle inventory is held primarily to take advantage of economies of scale in the supply chain.

"Safety inventory" signifies the inventory held in case demand exceeds sales expectations (Chopra and Meindl, 2004). It is held over and above the levels of cycle inventory because of uncertainties that occur in the demand pattern or lead-time. Hence, there is a proportion of the average inventory holding at any stockholding point which will be reserved to short-term variations in either demand or

replenishment lead time (Gattorna and Walters, 1996). This decision is made by comparing cost of losing sales and the cost of carrying too much inventory.

“Seasonal inventory” is the inventory built up to counter predictable variability in demand (Chopra and Meindl, 2004). It includes the accumulation of inventory prior to a season starts and this provides continuity of merchandise and economies of production for manufacturers. It is also held to process seasonally produced items when they are available and to hold inventories for consumption throughout the year. This may also maintain production capacity at more even levels together with maintaining stable levels of employment. It can be so as to take advantage of some quantity discounts if larger than average orders are placed (Gattorna and Walters, 1996). This decision is made by comparing the cost of carrying additional inventory and cost of flexible production.

Excessive inventory within a logistics pipeline would increase the overall working capital requirements of the pipeline and might put a very high cost burden on one or more partners (Christopher et al., 2006; Gattorna and Walters, 1996). More effective operation is occurred if the level of inventory throughout the logistics pipeline can be reduced.

The inventory type mix will vary among different businesses. Commodity and fashion items will have different inventory mixes due to the fact that they have different demand patterns.

The inventory decisions are summarized below in the Table 2.4 as components of inventory and their corresponding decisions.

Table 2.4: Components of inventory and related decisions

Components	Decisions
Cycle Inventory	Depends on lot size (quantity that a supply chain stage either produces or orders at a given time)
Safety Inventory	Cost of carrying too much inventory versus cost of losing sales
Seasonal Inventory	Cost of carrying additional inventory versus cost of flexible production

2.3.3 Transportation

Transportation is the moves of the product between stages within the supply chain. There are three basic factors to consider regarding transportation and they are;

operational factors, transport mode and channel strategy (Gattorna and Walters, 1996).

Operational factors consist of customer characteristics, environmental issues, product characteristics, company characteristics and philosophy. Transport mode is briefly influenced by load size, value, density, cost structures and competitive necessity. Channel strategy considerations are about the identification of available channels and the interfaces in each channel. So to make an appropriate transport selection decision, it is necessary to consider about the interface areas with other elements of the logistics system since transportation with facilities create time utility value in the supply chain. Additionally, transportation creates place utility value by delivering product to locations that are appropriate for customers (Gattorna and Walters, 1996). Moreover, the time and place utilities created by transportation are an important aspect of customer satisfaction. According to Gattorna and Walters (1996), there are a number of interface areas, and therefore decisions shared by transportation which should be explored by first identifying the areas of flexibility and inflexibility of the decisions but most importantly, that of the customer service objectives.

There are various modes of transportation such as air, truck, rail, ship, pipeline, electronic transportation, etc. According to the primary emphasis in business strategy, they are selected and/or combined. Besides, each mode varies in cost, speed, size of shipment, and flexibility. Most importantly, a comparison between the expenses of transportation modes and the cost of obsolesce and stock-out should be done before deciding which mode(s) to employ for the optimum result. In addition to this, route and network selection is also very much related to the responsiveness versus efficiency selection. Route refers to the path along which a product is shipped, while network is the collection of locations and routes.

The responsiveness is also affected by the *in-house* vs. *outsource* decision. An ideal supply chain shall capture the advantages of “make and buy” operations and avoid the risks of each as well. For instance, long-term supplier relations that are developed to provide stability are often severed when needs change. Because, predictability is desired, with no expense of creating inflexibility that prevents the ability to react to customer changes (Ketchen and Giunipero, 2004). In short, as largely discussed in the literature, “either out-sourcing or in-house manufacturing” is an important decision to make for all companies.

Customer communications, market coverage (level of flexibility, reliability and availability, and product characteristics), processing/manufacturing, pricing decisions, sourcing decisions, and customer service decisions are some of the major decisions influenced by transportation considerations

In brief, as well as the other drivers, transportation affects the level of responsiveness and efficiency of the supply chain (e.g. faster transportation allows greater responsiveness but lower efficiency within the SC). Moreover, as Chopra and Meindl (2004) state, inventory and transportation can be considered together in order to determine the right balance for the purpose of satisfying the customer needs.

2.3.4 Information

As well as many other subjects, the origins and the continuous development of the SCM concept are directly dependent on the capabilities of today's information and communication technologies (ICT). According to Ross (1988), SCM provides such a critical management and operational approach for competitive advantage because it is inherently linked with the networking power to be found in today's computerized information and communication systems.

Information leads a supply chain to become more efficient and more responsive at the same time; it reduces the need for a trade-off. While information technology is very important for supply chains, it is more important to find out which information is most valuable for the chain's value since relevant information available throughout the supply chain allows managers to make decisions that take into account all stages of the supply chain (Chopra and Meindl, 2004). The proper information allows performance to be optimized for the entire supply chain -not just for one stage- and leads to higher performance for each individual firm in the supply chain.

2.4 Postponement and Modularization Decision in SCM

In the literature much is written to generate insights into the relevance of the marketing, product or production characteristics such as implementation of postponement when sales fluctuate and product life cycles get shorter with high degree of customisation, commonality or modularity and decoupling of product process. Considering the application of postponement, there has to be some steps that can be postponed in order to create a point of postponement (sometimes called as

decoupling point). What is more, modular/standard design in product and production contributes to creating those points of postponement. For a successful postponement activity, product design may need to isolate the most variable portion of the functionality from other functions in order to be added last. Besides, moving the decoupling point closer to the end-user increases the efficiency and the effectiveness of the supply chain (Naylor et al., 1999).

2.4.1 Modularization

Starr (1965) initially introduced the concept of modularization in the literature with a product design approach where the product is assembled from a set of standardized constituent units (Ernst and Kamrad, 2000).

Modularity can take different forms in design and in production. Firstly, modularity in design refers to defining the design boundaries of a product and of its components; so that, design features and tasks avoid creating strong interdependencies among specific design of components (modules). A change made to one component does not require a change to other components in a fully modular architecture.

Secondly, modularity in production refers to designing the production process in order to make complicated products by designing and developing modules at different sites and then bringing them together to create a complete system. This type of modularity breaks down the whole production process into sub-processes that can be performed concurrently or in a different sequential order.

Ernst and Kamrad (2000) point out that as the level of modularization gets higher, outsourcing manufacturing or its constituent parts becomes easier; furthermore, modularization in product design is sometimes helpful for accelerating the new product development process.

2.4.2 Postponement

The postponement concept was initially discussed by Alderson (1950); as it was observed, products tend to become differentiated as they approach the point of purchase (Ernst and Kamrad, 2000). Furthermore, this differentiation improves the marketability but the manufacturability of the products becomes more complex. In other words, mass customisation (postponement) is the strategy where the key idea is to postpone the task of differentiating a product for a specific customer until the

latest possible point (Yang et al., 2004). Final customisation is postponed until customers specify the exact mix and match. According to Lampel and Mintzberg (1996), this allows a manufacturer to achieve the marketing benefits of customisation while reaping the cost benefits of standardised production in anticipation of future customer orders.

Zinn and Bowersox (1988); Lee and Billington (1992) cited in Ernst and Kamrad (2000) define different levels of postponement according to where in the supply chain the product is differentiated or customized and they summarized the options into two as time and form postponement. While form postponement refers to the delay in the final configuration of the product, time postponement refers to delays in product movement. In other words, postponement concept is about delaying activities as to the form and/or place of goods until the latest possible point in time when exact attributes of demand can be identified. Moreover, with constant changes such as volume change and variety change, it is a natural option for a company to seek opportunities for delaying some activities like the final processing or manufacturing of product to a time, as late as possible, and hence reduce the risk. Besides, postponement can also enhance the flexibility of a company to effectively meet the requirements of the growing product variety and quick response (Yang et al., 2004).

SC capabilities and value-added services to specific customer needs are tailored by customization. These distinct and responsive offerings represent specific solutions directed at what individual customers or segments want, rather than general solutions reflecting what the market wants (Morash, 2001). When the demand is unpredictable and lead-times are long, the ideal solution is to adopt the postponement concept. In classical meaning; “to carry strategic inventory in some generic form and assemble/configure/distribute as required when actual demand is encountered”. For example, Hewlett Packard follows this strategy for their range of DeskJet printers. They build a semi-finished product at their central facilities in North America and then ship it to four regional centres around the world that are run for them by third-party logistics service providers. At these centres the product is finally configured and delivered when actual customer orders are received (Christopher et al., 2006).

In the recent highly competitive environment, companies have to achieve agility in order to better respond to the rapidly changing customer-driven markets. With a high

degree of conformance to the customers' ultimate requirements, postponement has been identified as an important approach for contributing to the attainment of agility, through its contribution to the customisation of products and services, use of customer order information through the supply chain, and cross functional efforts (Van Hoek et al., 1999). Hence, companies should first consider every possible postponement opportunity along the supply chain and then balance the trade-off not from an individual player, but the whole supply chain. So, before establishing postponement strategies, companies need to identify and fully understand the marketplace requirements since its benefits vary with the competitive environment and there are certain conditions and situations where the implementation of postponement is more likely to succeed.

For instance, the degree of uncertainty is significant for selecting an appropriate postponement strategy. The strength of postponement lies in its capability of coping with those uncertainties inherent in dynamic and changing markets, which companies may have to accommodate in their business strategies (Yang et al., 2003). In easily predictable environments, companies would obviously gain little from postponement. On the other hand, postponement is favourable due to uncertainty about customer requirements and technical evolution in new product development. For example, the supply chain should respond quickly to the unpredictable demand to minimise stock-outs, forced markdowns, and obsolete inventory in innovative products (Fisher, 1997); therefore, it will be appropriate to postpone the final manufacturing and logistics operations (Pagh and Cooper, 1998).

According to Yang and Burns (2003), postponement fosters a new way of thinking about the supply chain and it has been identified as an important characteristic of modern and competitive supply chains (Van Hoek et al., 1999). Furthermore, postponement is a strategy to intentionally delay the execution of a task instead of starting it with incomplete or unreliable information input. At this stage, it is essential to anticipate the extent of the variability of those unpredictable items. The logic behind this is to delay commitment of the most uncertain items to a later time when these could be defined more efficiently in response to such possible major changes in customer needs, technologies and competitor's action. Once companies choose to target certain markets, the extent of product variability is clear and forecasting is easier at the generic level than at the level of the finished item. For

postponement to be successful further information such as information on local demands must be available in the delay period and postponement is valuable only if the information about the customers' needs can be captured quickly and accurately. However, Van Hoek et al. (1999) say that postponement does not necessarily rely on advanced IT and companies can combine postponement with simple information sharing to achieve low supply chain costs and high customer service level. Most importantly, companies have to understand how to tackle obstacles in the way to an effective adoption of postponement. Thus, even though now it is possible for companies to capture, validate, and forward information in real time, the players upstream in the supply chain may receive distorted information. While the latest techniques like the Internet, electronic data interchange (EDI) and point-of-sale system may improve the information flow by reducing the data collection errors and moving data quickly (Morash, 2001); in order to further enhance information flow towards postponement strategies, companies need to recognise the need for open communication, and manage the information whilst being willing to act as partners in the supply chain (Mason-Jones and Towill, 1999).

In short, companies implementing postponement may need to modify their postponement strategies over time, according to changes in the competitive environments, stages of product life cycle, technological advances and so on. Generally, the implementation of postponement leads to reducing economies of scale and increased cycle time, thus there is a need for integrating other related concepts/strategies into postponement, and supplementing rather than replacing each other.

2.4.2.1 Logistics Postponement

Generally, the central goal of companies that are implementing postponement is reducing logistics costs since postponement in logistics enables a company to keep its options open as to where inventory should be finally deployed. This greatly reduces the risk of wrong time and place utility of products, also decreases inventory levels across the supply chain while improving customer responsiveness.

Postponement is also involved in the repositioning of manufacturing activities in the distribution channel, not just limited to the relocation of inventories. This thinking depends on where in the process generic products should take on the form of specific

end products. Postponement may relocate final configuration from manufacturer plants closer to the end-use customer, allowing for rapid delivery of customised products and quick responsiveness to changes in display mixes. For example, packaging/labelling step (as one of the steps in differentiating generic goods for different brands and geographic markets) may be delayed until customer commitments are received and be better carried out by local based distributors before distribution and delivery to the customer. Moreover, it is viable to delay a product's variety, value, volume and weight increases through the implementation of postponement to save on inventory carrying and holding, assorting, stock-out and obsolescence costs (Pagh and Cooper, 1998; Van Hoek et al., 1999).

Furthermore, postponement is valuable when capacity is unresponsive (i.e. supplier lead times are long, production scheduling is inflexible, or manufacturing volumes are constrained). However, in many cases, postponement in logistics requires a fast and responsive transportation system and it can thus lead to a significant increase in transport cost. Its applications are also constrained by time windows specified by the market. Its maximum benefits are obtainable when the distribution is not only physical transportation, but also contains a product customisation component. Moreover, transshipment can be viewed as logistics postponement, because it delays the point of differentiation, which transforms a generic item (an item at any location) into a specific item (an item at a specific location). It can lead to cost reductions and improved services by enabling the sharing of stock among different locations, thereby reducing the inventory in the supply chain.

2.4.2.2 Manufacturing Postponement

The concept of manufacturing postponement maintains the product in a neutral and non-committed status as long as possible in the manufacturing process. As the inventory is gets more generic, its flexibility is becomes greater; meaning that the same components, modules or platforms can be embodied in a variety of end products. Thus, manufacturing postponement is one of the most beneficial strategic mechanisms to manage the risks associated with product variety and uncertain sales. In addition, since manufacturing postponement allows companies to operate with no finished inventory, companies may benefit from maintaining the bulk of their inventories in the cheaper and/or pre-customised form by delaying expensive operations and point of product differentiation.

The production of high-volume standard components and sub-assemblies is carried out wherever the greatest cost efficiencies can be achieved. Afterwards, these parts are distributed -consistent with demand- to transshipment centres close to the final assembly facility, which is generally close to the customer. At this point, they are sorted and consolidated for delivery to assembly lines. Last of all, final assembly is only undertaken in response to direct customer orders and consists of configuration to an individual specification (Webster, 2002).

Moreover, a company employing postponement strategies must consider product families and generations, and explore the commonality/modularity of products and processes as much as possible since using common components and processes from initial stages implies that the products assume their unique attributes as late as possible. Additionally, component commonality results in inventory pooling effects (e.g. lower inventory levels and reduced risk of obsolete inventories). However, introducing too much commonality (e.g. part standardisation which is easily perceived by the customer) can reduce product differentiation, leading to a cannibalisation effect.

Postponing manufacturing may also influence supplier relationships since manufacturing postponement means that customer orders will be fulfilled through production rather than through stockholding finished products. Hence, a reliable supplier network that can supply parts and services plays a key role in its application. The extensive use of manufacturing postponement leads the suppliers to take over part of the assembly factory, where they supply components directly into the final assembly line from their workshop adjacent to the factory (Van Hoek et al., 1999). Therefore, in manufacturing postponement, manufacturers may require distributors to take on additional responsibilities (due to the relocation of final manufacturing downstream to distributors/retailers). Also, manufacturers may need to foster and develop manufacturing capabilities (e.g. skills to assemble the products) within a particular distributor/retailer, since a company's success is partly tied to the strength of its weakest supply chain partner. However, in many industries like the automotive, aerospace and personal computer industries, many original equipment manufacturers share common distributors/retailers. The existence of common or overlapping distributors/retailers in different supply chains may limit the manufacturer's ability to invest in the related facilities and human training programs of distributors/retailers.

Because, any investment in the area will be automatically providing a free benefit for the manufacturers in other supply chains (competitors). Therefore, this competitive aspect sometimes complicates the effective employment of postponement strategies.

2.5 Supply Chain Types

While classifying the supply chain types, the research is grounded in the literature on lean and agile supply chains mainly (Table 2.5). These paradigms are integrated and classified to understand the correlation between different SC types and different product types that will be described later.

First of all, Ganeshan and Harrison (1995) cited in Vonderembse et al. (2008) deal with basics issues in SCM including a definition, strategic and operating issues, and four key decision areas: location, production, inventory, and transportation (distribution). They provide a brief literature review of supply chain modelling approaches, namely, network design methods, rough-cut methods, and simulation based methods.

Beamon (1998) focuses on supply chain design and analysis by providing a literature review on multi-stage supply chain modelling which involves four categories as deterministic, stochastic, economic, and simulation models. Supply chain performance measures, which are qualitative and quantitative as well as decision variables that impact supply chain modelling such as production and distribution scheduling, inventory levels, number of stages (echelons), distribution centres, plant product assignment, buyer/supplier relationships, product differentiation, and number of products held in inventory are also discussed by Beamon (1998). Groundwork in the following areas is laid for future research:

- Evaluating and developing supply chain performance measures
- Developing models and procedures to relate variables to the performance measures
- Considering issues relating to supply chain modelling
- Classifying supply chain systems to allow development of rules-of-thumb or general techniques to aid in the design and analysis of supply chains.

Table 2.5: Literature Review of SC Types (Vonderembse et al., 2008)

Author(s)	Areas researched and contributions made	Supports		
		Supply chains	Lean supply chains	Agile supply chains
Ganeshan and Harrison (1995)	Focused on the basics of SCM involving its definitions and strategies. Took into account 4 major decision areas: (1) location, (2) production, (3) inventory, (4) transportation. Provided a literature review on SC modeling approaches, namely, network design, rough-cut and simulation based methods.	*		
Beamon (1998)	Focused on SC design and analysis. Provided a literature review on multi-stage SC modeling. Focused on SC performance measures.	*		
Nolan (1999)	Defines 5 key characteristics in order to benefit from SCM systems, namely, implementation phases, senior level involvement, business process reengineering, collaboration and effective performance measures.	*		
Ragatz et al. (1996)	Focused on the integration of suppliers in new product development.		*	
Dowlatshahi (1996)	Developed and tested a model to study the early collaboration and interface of logistics and design activities. Model results in significant achievements for manufacturing enterprises.	*		*
Hoffman and Mehra (1996)	Studied the relationship between concurrent engineering and risk management. Resulted in substantial decrease in costs during the product development stages. Led to fewer efforts to responsiveness later in the product life cycle.			*
Gunasekaran (1999a, b)	Provided a conceptual model on AMSs. Reviewed the available literature on agile manufacturing.			*
Yusuf et al. (1999)	Provided information into the drivers, concepts and attributes of agile manufacturing. Provided tools and techniques required for a successful AMS, e.g., virtual organizations, quick response manufacturing, time-based competition, etc.			*
Sharifi and Zhang (1999)	Focused on an AMS and developed a conceptual model for achieving agility. Assumed that a LSC is a subset of an ASC.		*	*
Naylor et al. (1999)	Proposed the usage of the lean and agile concept with the aid of a decoupling point. Model highlights how the decoupling point satisfies different manufacturing types.		*	*

Moreover, Nolan (1999) makes a general classification of SCM systems and strategies that organizations should adopt to be successful and describes five characteristics that help managers to harvest all the benefits of the SCM approach. These characteristics are illustrated below as five steps that help in the effective implementation of a SCM system:

- Achievable implementation phases
- Senior level involvement

- Collaboration
- Business process and organizational design
- Effective performance measures.

Furthermore, some issues related to lean and agile supply chains are examined by Ragatz et al. (1996) cited in Vonderembse et al. (2008) parallel with the integration of suppliers with product development. Product development time gets shorter as organizations integrate their suppliers by involving them in product design and in some cases making them responsible for the design of components and systems. Additionally, relationships between customer and supplier as well as the most and least successful supplier integration efforts are analyzed in the paper.

Dowlatsahi (1996) cited in Vonderembse et al. (2008) concentrates on the early involvement of logistics in product design exploring areas where early collaboration and interfaces between logistics and design activities could result in major improvements for manufacturing enterprises.

What is more, the relationship between concurrent engineering and risk management is examined by Hoffman and Mehra (1996) cited in Vonderembse et al. (2008) concluding that concurrent engineering reduces risk because uncertainty decreases as everyone shares the same knowledge, speaks the same language, and works in a team environment. When a team approach is adopted during product development, this results in better planning, faster response to unanticipated changes from suppliers, and fewer changes late in the product development process when changes are more expensive; therefore, overall costs decline substantially.

Gunasekaran (1999a, b) reviews the available literature on agile manufacturing and the technologies that are essential to the adoption of agile manufacturing system (AMS). Besides, he provides a conceptual model of an AMS along four key dimensions as strategy, technology, systems, and people. He also contributes to a research that provides information into the drivers, concepts, and attributes of agile manufacturing. In the paper, Yusuf et al. (1999) provide information on the design and implementation of AMS, emphasizing the various tools and techniques that are fundamental for the success of AMS. The concepts such as virtual enterprise, computerized manufacturing control system, architecture for the development of manufacturing control systems, quick response manufacturing, time-based competition, rapid modelling capabilities, and object oriented modelling and

programming are highlighted in the research. It also overlooks the possible integration of a lean and agile supply chain as well as a design based on product characteristics. However, it works on the grounds that agile manufacturing is the only feasible solution to supply chain design.

Likewise, Sharifi and Zhang (1999) focus on the AMS by developing a conceptual model for achieving agility, with an assumption that a lean chain is a subset of an agile chain. The relationship between lean and agile supply chains is acknowledged and the possible integration of the two chains and, similarly, the benefits that can be derived from it are investigated.

Even though being informative, the aforementioned research studies do not completely describe the supply chain alternatives. Eventually, the combined use of a lean and agile supply chain is proposed by a model developed by Naylor et al. (1999), which is a basis for developing the hybrid (or leagile) supply chain (HSC). In order to meet the needs of the final customer, this research expands the alternatives through case studies and provides a framework for understanding the relationships among variety of approaches including concepts from lean and agile supply chain literature as well as traditional purchasing practices. In the rapidly changing business environment, organizations need a supply chain model that not only deals with operating constraints but with strategic and customer issues as well. Since the product is the core of the SC, there is no explanation for adopting a specific SC type unless it matches to the needs of the product and its customers.

Finally, an overview of traditional, lean, agile and hybrid (leagile) supply chains is provided in the following sections and illustrated in Table 2.6 and Table 2.7.

2.5.1 Traditional Supply Chains (TSC)

Faisal et al. (2006) defines the TSC as an integrated manufacturing process in which raw materials are manufactured into final products and then delivered to customers via distribution, retail, or both. The design, modelling, and analysis of the TSC had primarily focused on optimising the procurement of raw materials from suppliers and the distribution of products to customers (Beamon, 1998, 1999). Main target of this SC type is to achieve the lowest initial purchase prices with a supply assurance; moreover, as Spekman et al. (1998) state, its typical characteristics are: multiple partners, partner evaluations based on purchase price, cost-based information bases,

arms-length negotiations, formal short-term contracts and centralized purchasing. However, all these characteristics lead to some disadvantages such as forecast inaccuracies and slow response to the shifting market scenarios (Faisal et al., 2006).

2.5.2 Lean Supply Chains (LSC)

A lean supply chain employs continuous improvement efforts that focus on eliminating non-value steps or all waste, including time, to enable a level schedule to be established along the chain (Vonderembse et al., 2008; Naylor et al., 1999; Mason-Jones et al., 2000b). According to Ohno (1988) cited in Faisal et al. (2006), the origins of lean philosophy can be traced to the Toyota Production System (TPS). LSC enables the economic production of small quantities and enhance cost reduction, profitability, and manufacturing flexibility to some degree by encouraging the efforts to achieve internal manufacturing efficiencies and setup time reduction. Booth (1996) cited in Vonderembse et al. (2008) points out that internal flexibility is supplied by the short setup times, however, a LSC may lack external responsiveness to customer demands, which can require flexibility in product design, planning and scheduling, and distribution in addition to manufacturing. What is more, with the increasing rate of market change, the LSC approach has evolved into “multiple niche competition,” which is basically the production of any volume, blended with the capability to fulfil multiple market segments. Karlsson and Ahlstrom (1997) add that most of the lean principles are applicable to small and medium enterprises (SMEs) too. Besides, as Green et al. (1998) states, there exists a close synergy between the lean practices and environmental management, which has become an essential concern nowadays.

Recently, organizations have recognized that along with the added variety and responsiveness blend, they must stay flexible to future changes. With the shorter product life cycles and continuously evolving customer requirements, just being lean is not enough for the supply chain; it also has to respond to the market. When a successful combination is achieved, organizations move from concept to cash flow in a fraction of the time (Vonderembse et al., 2008).

2.5.3 Agile Supply Chains (ASC)

According to Duclos et al. (2003), appearance of a new business era symbolized by continuous and unpredictable changes with a focus on core competence and mass

customisation has forced companies to find flexible ways to encounter customer demand. As Christopher and Towill (2000) describe, agility is a business-wide ability that includes organisational structures, information systems, logistics processes and, especially, mindsets. Helo (2004) states that agile organisations maintain good productivity under pressure of uncertainty. Moreover, the objective in attaining agility is to set up a flawless supply chain in which all players think and act as one (Mason-Jones and Towill, 1999).

The agile supply chain (ASC) paradigm is an external perspective on flexibility that relates to the boundary between companies and markets. An ASC focuses on responding to unpredictable market changes and capitalizing on them through fast delivery and lead-time flexibility. New technologies, methods, tools, and techniques are deployed to resolve unforeseen troubles; and information systems, technologies as well as electronic data interchange capabilities are employed to move information faster and make better decisions. In order to push decision-making down the organization, more importance is given on organizational issues and people (knowledge systems and empowered employees). Furthermore, the systemic approach of ASC that integrates the business, enhances innovations across the company, and forms virtual organizations (VO) and production units based on customer requirements. In other words, a successful ASC is able to respond to rapidly changing and constantly fragmenting international markets by being dynamic, context-specific, growth-oriented, flexible across the organization, and driven by customer (Vonderembse et al., 2008; Faisal et al., 2006).

2.5.4 Leagile (Hybrid) Supply Chains (HSC)

Several researchers have been working on the concept of “leagile” lately (Naylor et al., 1999; van-Hoek, 2000; Mason-Jones et al., 2000b; Christopher and Towill, 2001). According to Mason-Jones et al. (2000) agility can be used downstream and leanness can be used upstream from a decoupling point in the supply chain where lean and agile approaches are combined for creating the optimum SC structure, therefore, providing cost effectiveness of the upstream chain and high service levels in a volatile marketplace in the downstream chain. Additionally, from a different perspective, Christopher and Towill (2001) suggest that lean and agile businesses can co-exist, even on the same site and with some limited rotation of personnel when the whole concept of leagility is properly understood.

Table 2.6: Traditional, lean, agile and leagile supply chains (Faisal et al., 2006)

Attributes	Traditional	Lean	Agile	Leagile (Hybrid)
Market demand	Unpredictable	Predictable	Volatile	Volatile and unpredictable
Product variety	Low	Low	High	Moderate
Product life cycle	Long	Long	Short	Short
Customer drivers	Cost	Cost	Lead time	Service level
Profit margin	Situational	Low	High	Moderate
Information enrichment	Very little	Desirable	Obligatory	Essential
Forecasting mechanism	Independent at each echelon	Algorithmic	Consultative	Both/either
Dominant costs	Both	Physical costs	Marketability costs	Both
Typical products	Standard products	Commodities	Highly Customized products	Customized products
Capacity to absorb supply chain risks	Moderate	Low	High	Moderate
Eliminate muda	Low priority	Essential	Desirable	Arbitrary
Quality	Market winner	Market qualifier	Market qualifier	Market qualifier
Cost	Market winner	Market winner	Market qualifier	Market winner
Network integration	Non existent	Desirable	Necessary	Obligatory
Virtual integration	Low priority	Desirable	Necessary	Obligatory
Information decoupling	Non existent	Advantageous	Necessary	Desirable
Postponement	Non existent	Not required	Necessary	Desirable
Product conception	Producer	Producer	Producer & customer	Producer & customer
Measurement of quality	Product defect rate	Product defect rate	Customer delight	Customer delight
Delivery penalties	Very few	Long term contractual	Loss of order	Loss of order

The leagile (or hybrid) supply chain makes it easier to realize mass customization by postponing product differentiation until final assembly as the lean or agile supply chain techniques are employed for component production with different characteristics (e.g. air bags would possibly be produced with a LSC while engine electronics might demand the innovation found in an ASC). Furthermore, understanding and satisfying customer requirements by being responsive, adaptable, and innovative can only be achieved by agility. According to Vonderembse et al. (2008), HSC implies to assemble-to-order products that have a relative forecast accuracy.

In brief, the competitive business environment requires matching the supply chain strategy with the product characteristics. Product characteristics may vary from commodities to highly customised products like fashion goods that imply the nature of the product. According to these characteristics and supply chain risk alleviation competency, Faisal et al. (2006) tries to suggest a suitable supply chain strategy in Figure 2.4.

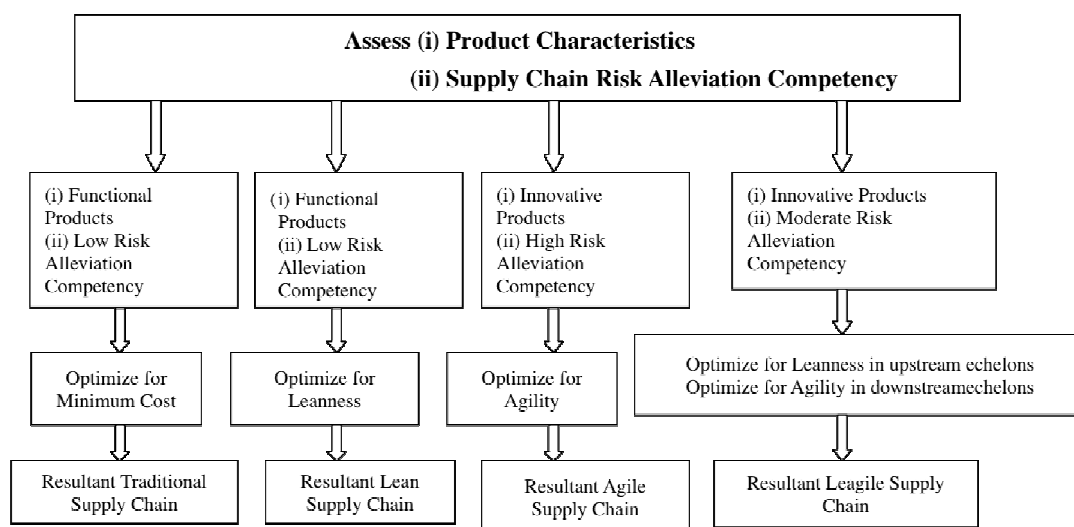


Figure 2.4 : Traditional, lean, agile and leagile supply chains – the linkages

As shown in the previous figure, lean supply chain is suitable when the nature of the product is commodity and risk alleviation competency is low; on the other hand, designing the SC with agile characteristics -where the chain can transform itself according to fast changing customer preferences- is the fitting choice when the product required is highly customised and risk alleviation competency of the supply chain is high. In addition, for a better level of understanding, supply chains are also

mapped on customer sensitivity and supply chain risk alleviation competency dimensions in Figure 2.5 (Faisal et al., 2006).

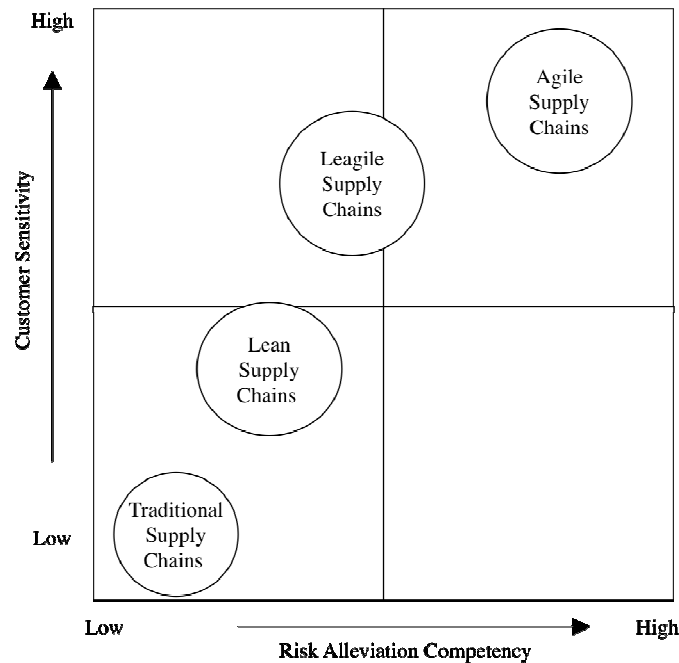


Figure 2.5 : Mapping supply chains on customer sensitivity and supply chain risk alleviation competency dimensions

Finally, a detailed comparison between lean, agile and leagile (hybrid) supply chains is made in Table 2.7 (Vonderembse et al., 2008).

Table 2.7: Differentiation between lean, agile and leagile supply chains

Category	Lean supply chain	Agile supply chain	Leagile (Hybrid) supply chain
Definition	A LSC employs continuous improvement to focus on the elimination of waste or non-value added steps in the supply chain. It is supported by the reduction of setup times to allow for the economic production of small quantities; thereby achieving cost reduction, flexibility and internal responsiveness. It does not have the ability to mass customize and be adaptable easily to future market requirements.	Agility relates to the interface between a company and the market. ASCs profit by responding to rapidly changing, continually fragmenting global markets by being dynamic and context-specific, aggressively changing, and growth oriented. They are driven by customer designed products and services.	A HSC generally involves "assemble to order" products where demand can be accurately forecasted. The supply chain helps to achieve some degree of customization by postponing product differentiation until final assembly. Lean or ASCs are utilized for component production. The agile part of the chain establishes an interface to understand and satisfy customer requirements by being responsive and innovative.
Purpose	Focus on cost reduction and flexibility for already available products. Employs a continuous improvement process to focus on the elimination of waste or non-value added activities across the chain. Primarily aims at cost cutting, flexibility and incremental improvements in products.	Understands customer requirements by interfacing with customers and market and being adaptable to future changes. Aims to produce in any volume and deliver to a wide variety of market niches simultaneously. Provides customized products at short lead times (responsiveness) by reducing the cost of variation.	Employ lean production methods manufacturing. Interfaces with the market to understand customer requirements. Achieve a degree of customization by postponing product differentiation until final assembly and adding innovative components to the existing products.

Table 2.7: Differentiation between lean, agile and leagile supply chains (continued)

Category	Lean supply chain	Agile supply chain	Leagile (Hybrid) supply chain
Approach to manufacturing	Advocates lean manufacturing techniques.	Advocates agile manufacturing techniques, which is an extension of lean manufacturing.	Employs lean and agile manufacturing techniques.
Integration	Integrate manufacturing, purchasing, quality and suppliers.	Integrates marketing, engineering, distribution and information systems.	Similar to the LSC at component level and follows an ASC at product level.
Production planning	Works on confirmed orders and reliable forecasts.	Has the ability to respond quickly to varying customer needs (mass customization).	Works on confirmed orders and reliable forecasts with some ability to achieve some produce variety.
Length of product life cycle	Standard products have relatively long life cycle times (42 years).	Innovative products have short life cycle times (3 months–1 year).	Involved the production of “assemble to order” products, which stay in the maturity phase of the life cycle for a long time.
Alliances	May participate in traditional alliances such as partnerships and joint ventures at the operating level.	Exploits a dynamic type of alliance known as a “virtual organization” that work on product design.	Along with traditional operating alliances, HSCs may utilize strategic alliances to respond to changing consumer requirements.
Markets	Serve only the current market segments.	Acquire new competencies, develop new product lines, and open up new markets.	Respond to customer requirements with innovative features in existing products. This enables the organization to capture a larger segment of that product market.
Organizational structure	Uses a static organizational structure with few levels in the hierarchy.	Create virtual organizations by creating alliances with partners that vary with different product offerings that change frequently.	Maintain an organization similar to a LSC. May create temporal relationships with partners to implement innovative features.
Approach to choosing suppliers	Supplier attributes involve low cost and high quality.	Supplier attributes involve speed, flexibility, and quality.	Supplier attributes involve low cost and high quality, along with the capability for speed and flexibility, as and when required.
Demand patterns	Demand can be accurately forecasted and average margin of forecasting error tends to be low, roughly 10%	Demand are unpredictable with forecasting errors exceeding 50%.	Similar to the LSC. The average product demand can be accurately forecasted. Component level forecasting may involve larger errors.
Inventory strategy	Generates high turns and minimizes inventory throughout the chain.	Make in response to customer demand.	Postpone product differentiation and minimize functional components inventory.
Lead time focus	Shorten lead-time as long as it does not increase cost.	Invest aggressively in ways to reduce lead times.	Similar to the LSC at component level (shorten lead-time but not at the expense of cost). At product level, to accommodate customer requirements.
Manufacturing focus	Maintain high average utilization rate.	Deploy excess buffer capacity to ensure that raw material/ components are available to manufacture the innovative products according to market requirements.	Combination of lean and ASC depending on comp.
Product design strategy	Maximize performance and minimize cost.	Design products to meet individual customer needs.	Use modular design in order to postpone product differentiation for as long as possible.
Human resources	Empowered individuals working in teams in their functional departments.	Involves decentralized decision-making. Empowered individuals working in cross-functional teams, which may be across company borders too.	Empowered individuals working in teams in their functional departments.

3. PRODUCTS AND SUPPLY CHAINS

3.1 Product Types

“Understanding the characteristics of the product is vital to design a supply chain that meets customer expectations” (Vonderembse, 2002 cited in Vonderembse et al., 2008). Three product types as standard, innovative, and hybrid are described and in this section.

3.1.1 Standard (Functional) Product

Standard products have long life cycles where designs change continuously and the market for standard products tends to be stable, so that demand can be forecasted correctly. Therefore, the product design and manufacturing processes can naturally be well-defined and predictable. High quality materials, just-in-time delivery, and quantity discounts comes by establishing long-term relationships with the suppliers (Vonderembse et al., 2008). Besides, especially in the mature phase of the product life cycle, cost minimization can be practiced very effectively with predictable demand patterns and consistent processes. As it will be described in depth later in this chapter, the best fitting SC type for the standard product is the LSC.

3.1.2 Innovative Product

Innovative products are significantly different from current products, and they often stand for a breakthrough in product concept and design. These new products require sophisticated design and/or manufacturing capabilities and they often persuade rising customer needs or in some cases needs that customers have yet to find out. Their high potentials to increase profits come from the price strategy since they are positioned into a premium price status; however, they generally have a shorter product life cycle than standard products. The competition is caused by the premium prices and once introduced and found to be successful, competitors quickly imitate innovative products. The product can become a standard product when demand grows and competitors appear, since cost and quality are the leading characteristics.

Therefore, the interaction with customers to spawn new ideas that drive a continual flow of new and enhanced products becomes essential for the original manufacturer (Vonderembse et al., 2008).

3.1.3 Hybrid Product

The hybrid product is a complex type of product, which involves a blend of standard and innovative components. Therefore, it requires a blend of SC types to manage the complexity of the demand, components and assembly. Hybrid products have a tendency to possess a long product life cycle with a certain level of improvement or periodical innovation that mostly take place at the module or component level. Furthermore, the connection with the final consumer is based on the concept of agility. What to manufacture inside the company and what to buy outsource is the critical decision for the manufacturer (Vonderembse et al., 2008).

Figure 3.1 illustrates the match between the supply chains and product characteristics. As seen, setting up an efficient supply chain is more appropriate for producing functional products where responsive supply chains -that are more flexible against customer demands- are required for the innovative products (Fisher, 1997).

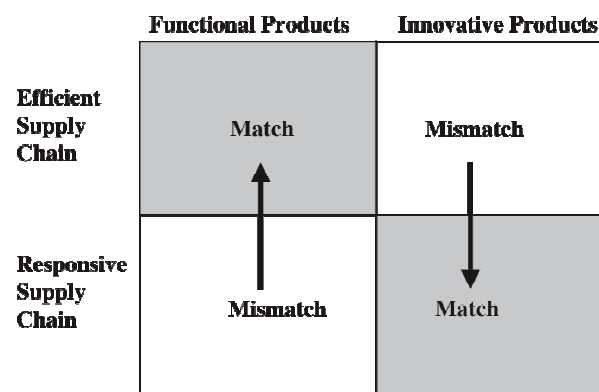


Figure 3.1 : Matching supply chains with product characteristics (Fisher, 1997)

3.2 Product Life Cycle

Unit sales for a product category over time are shown by the product life cycle, which is separated into four distinct stages: introduction, growth, maturity, and decline. “The shape of the sales curve reflects the notion that sales begin slowly during the introductory stage, then grow rapidly often reaching a peak relatively early in a product’s life. During the saturation or maturity phase, demand may grow

slowly for a long period of time before it begins to decrease” (Vonderembse et al., 2008). As the product advances along its life cycle this change there are other changes accompanying this change in competitive conditions, strategies, and performance. It is possible to describe the life cycle as a series of consistent propositions dealing with systematic changes in the marketplace.

As the first stage, the introduction stage involves the satisfaction of either a new need for an innovative product or an existing need for a standard product. For the new products, generally the competition comes from different products. Moreover, new products may have defects that should be dealt with as quickly as possible in order to avoid the pre-mature death.

Second stage is growth stage, which implies the product’s market approval and an increase in the organization’s market share. In this stage, demand begins to accelerate and the magnitude of the total market expands rapidly.

The competition boosts in the maturation stage when other organizations try to imitate the generic product with lower cost. Demand is generally determined by the alternatives or wearing out of the product and new family-formation rate.

In their last stage, products go through the decline stage as they lose attraction and sales decrease. The products become outdated, and new products substitute existing ones (Vonderembse et al., 2008).

Some important notes about the duration of product life cycle are listed below (Aitken et al., 2003):

- Short life cycles require rapid time to market.
- Short life cycles require short end-to-end pipelines to enable demand to be continuously replenished during the life cycle.
- Short life cycles require a demand chain to be able to ‘fast track’ product development, manufacturing and logistics to exploit ever-decreasing windows of opportunity.
- Replenishment lead times need to be matched to stage of the product life cycle, so to reduce lost sales and obsolescence risks.

3.3 Product Demand

Product demand structure, which can be highly uncertain and variable under the recent global marketplace conditions, becomes one of the most significant factors when making the supply chain decisions. According to Fisher (1997), a supply chain performs two distinct types of functions as a physical function and a market mediation function; however, as the latter function being less visible does not mean that it is less important since it ensures that the variety of products and services reaching the marketplace matches customers' expectations as fully as possible. High variety can be produced by any manufacturing system at a certain cost, but the vital issue is to produce high variety economically (Kundu et al., 2008).

Kundu et al. (2008) states that an effective supply chain should be efficient in terms of physical functions, and responsive in terms of market mediation functions. Different products have different demand characteristics, and as Fisher (1997) points out, innovative and functional products, which are going to be described later in this chapter, are two opposite extremes when classified to the nature of demand.

3.3.1 Demand Stability

A product that has a stable demand satisfies the basic needs of the consumers and demand for that product does not change much over time. Therefore, functional products with long life cycles have stable demands as their basic characteristics (Christopher et al., 2006; Mason-Jones et al., 2000b; Fisher, 1997). However this stability might trigger a fierce price competition, hence low profit margins. Functional products tend to have less product variety than innovative products, where variety is introduced due to the fashion-oriented nature of the product or the rapid introduction of new product options due to product technology advancements (Lee, 2002). On the other hand, innovative products are mostly characterized by lower volume, variable demand structure and shorter life cycle (Christopher et al., 2006). As mentioned before, this kind of products enable the company to achieve higher profit margins (Fisher, 1997). Conversely to the functional products, Chase et al. (2001) states that, imitators erode the competitive advantage and the life cycle of innovative products get shorter and companies are forced to continue innovations with these products.

3.3.2 Demand Predictability

Franks (2000) points out that a predictable demand pattern makes it possible to create a highly efficient SC network; however, for products with unpredictable demand, the supply chain network has to adjust itself to the new conditions and must be capable of responding to the demand as fast as possible.

Predictable demand can be described as inventory with “base flow” characteristics and is easily managed. However, seasonal demand products, which may be relatively easy to predict but which reflect high levels of demand in specific periods, are described as “wave flow” product characteristics (e.g. seasonal fashion wear). Additionally, “surge flow” products are the ones with highly unpredictable levels of demand and they are special products for which there is usually no repeat purchasing. Yet, a standard product, which is suddenly required, takes on surge characteristics as well.

As a result of unpredictable and volatile demand, responsiveness at supply is very much related to inventory policies. As much as inventory influences the responsiveness, it is the source of the high costs generated as well since more inventory causes greater responsiveness but greater cost. On the other hand, fewer inventories lead to lower cost but lower responsiveness. Depending on the competitive priorities determined through customer desire, overall trade-off between responsiveness and efficiency the inventory policies shall be determined. The demand characteristics of the target customer group play a very important role. The figure below (Figure 3.2) aligns levels of predictability with customer needs and suggests the supply chain focus.

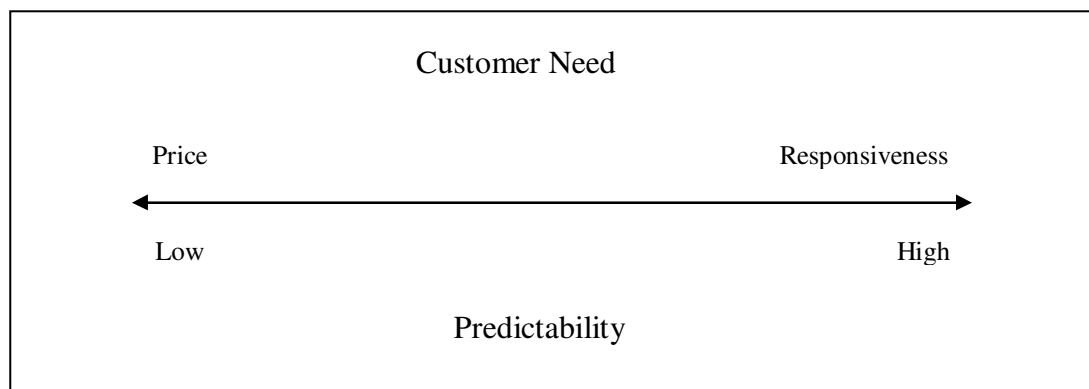


Figure 3.2 : Levels of predictability and corresponding supply chain focus

Christopher et al. (2006) states that functional products tend to have stable and predictable demand with long lifecycles. Innovative products, in contrast, generally have unpredictable demand with short lifecycles. The following framework (Figure 3.3) for supply chain design has been developed through the addition of replenishment lead-time as a critical driver of supply chain strategy (Christopher and Towill, 2002).

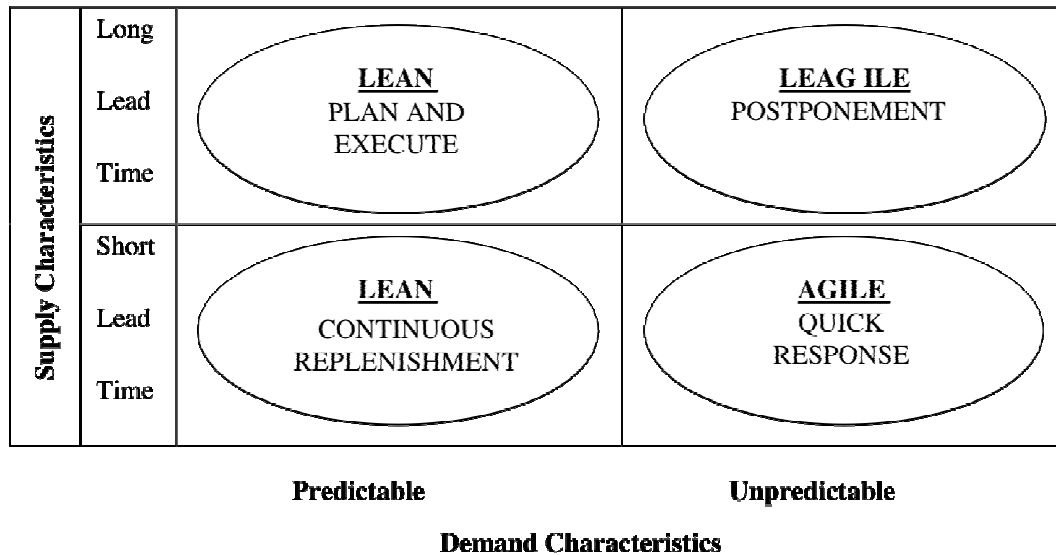


Figure 3.3 : Demand/supply characteristics that determine SC strategy

3.3.3 Aligning Product Delivery Strategies with Demand Characteristics

Companies seek supply chain operation strategies that enable them to gain the benefits of physical efficiency of mass production and the customer focus of mass customization. A key to gaining these benefits lies in the selection of appropriate decoupling points in the supply chain, which lie on the push-pull boundary. According to Kundu et al. (2008), placing the decoupling point wisely, or in other words, employing postponement tools properly on the point of product differentiation helps reducing supply chain risk and uncertainty.

Figure 3.4 (Hoekstra and Romme, 1992; cited in Naylor et al., 1999) presents the family of simplified supply chain structures with the decoupling point marked as a stock holding point. The manufacturers/assemblers represent one or more businesses in the supply chain. By varying the position of the decoupling point, Figure 3.4 highlights five common supply chain strategies as buy to order, make to order, assemble to order, make to stock, and ship to stock.

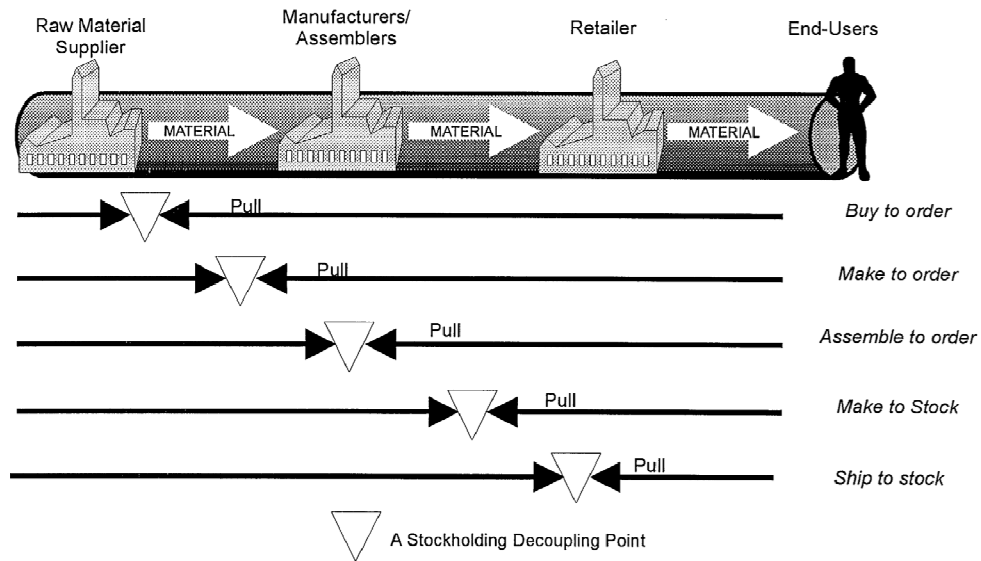


Figure 3.4 : Supply chain structures and the decoupling point

As Kundu et al. (2008) state, “The importance of product variety in relation to the selection of decoupling points lies in the fact that the way in which product variety is delivered has a strong impact on where, how, and when in the value chain, the product is customized”. Effects of the decoupling point on flow of material under unstable demand characteristics are shown below (Figure 3.5):

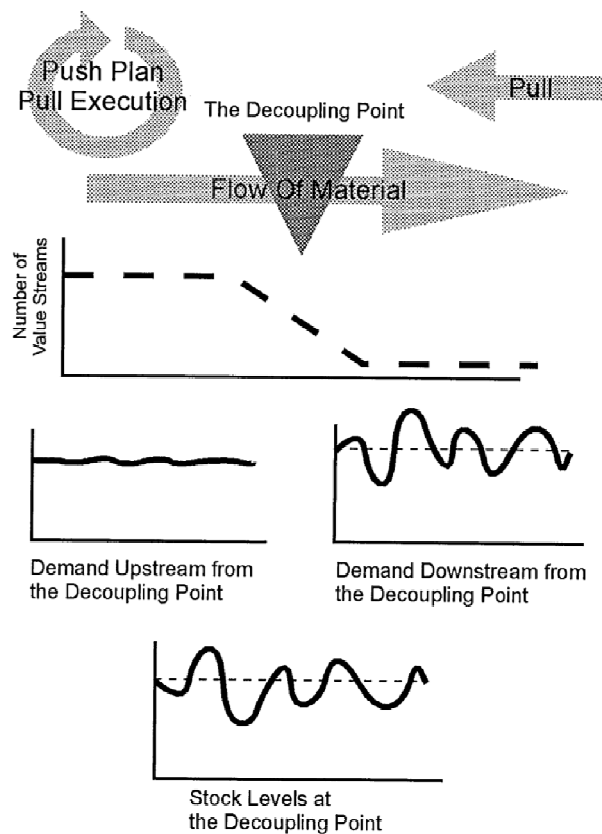


Figure 3.5 : Effects of the decoupling point (Naylor et al., 1999)

In addition to these, Olhager (2003) identifies the production to delivery lead time (P/D ratio) and the relative demand volatility (RDV) as two major factors affecting strategic positioning of the order penetration point (also known as customer order decoupling point). RDV is the standard deviation of the demand relative to the average demand. According to Kundu et al. (2008), the positioning of the push-pull boundary is an issue of evaluating the trade-offs between conflicting requirements i.e. balancing the cost to the customer with delivery lead time. A model for choosing the right product strategy by Olhager (2003) is shown below (Figure 3.6).

Relative Demand Volatility (RDV)	High	Make to Order (MTO)	Assemble to Order (ATO)
	Low	MTO (ATO) MTS	Make to Stock (MTS)
		P/D<1	P/D>1
		Production to delivery lead time ratio (P/D)	

Figure 3.6 : A model for choosing the right product strategy by Olhager (2003)

3.4 Trends and Demand Forecasts

Forecast uncertainty is the level of uncertainty when a demand forecast is evaluated. According to Fisher (1997), it is generally accepted as a consideration for supply chains because it influences investment risk directly by affecting the levels of obsolete inventory, lost sales and forced markdowns. As forecast uncertainty increases, the risks of lost sales and inventory obsolescence increase with it. Thus, forecast uncertainty is the main risk factor for making investment decisions on production and inventory. Wong et al. (2006) states that, generally, the unexpected customer trends, competition and supply uncertainty cause forecast errors.

Chopra and Meindl (2004) combines all of these attributes in a key measure suggesting that each customer need can be translated into the metric of “implied demand uncertainty”, which refers to the uncertainty that exists due to the portion of demand that the supply chain is required to meet. On the other hand, demand uncertainty is different than this definition. Whilst demand uncertainty is the

uncertainty of customer demand for a product, implied demand uncertainty is the resulting uncertainty for the supply chain given the portion of the demand the supply chain must handle and attributes the customer desires. For example, as a supply chain raises its service level so as to meet its customers' needs, and then it must be able to meet a higher percentage of actual demand. This forces the supply chain to be ready for rare surges in demand. Even though the underlying demand uncertainty of the product is the same, the implied demand uncertainty increases due to the increased service level. Therefore, implied demand uncertainty refers to "predictability" which has been emphasized by many academicians in their supply chain classifications such as Fisher (1997). Each attribute listed above has an effect on predictability of demand; thus, firms should understand the overall attributes of customer needs.

Fisher (1997) pointed out that attributes of demand are often correlated with product type and classified products as primarily "functional" and primarily "innovative" products with respect to those attributes such as product life cycle, product variety, and market standards for time window for delivery. Likewise, Christopher et al. (2006) stated that predictability will probably represent the product type too. In the literature, "functional" and "innovative" products are also called as "standard" or "commodity" products and "special" or "innovative/unique" respectively (Towill and Christopher, 2001; Morash, 2001; Lamming et al., 2000).

Last of all, according to Christopher and Towill (2002), predictability that implies the demand pattern has seen as a main sympathy when it comes to choose the right supply chain strategy since it affects the forecasting reliability. Moreover, where demand is stable it will generally be easier and proper to use forecast-based solutions, particularly where lead-times are long. In contrast, forecast-based management becomes less beneficial when demand is volatile. Therefore, the need in those situations is for agile supply chain strategies that imply end-to-end time compression or postponement of final product configuration.

3.5 Customer Needs and Competitive Capabilities

Today's marketplace is characterized by fierce global competition and for competitive advantage, getting the right product, at the right place, at the right time to the consumer is strongly required. Thus, within the marketplace, the success or failure of a supply chain is determined by the end user (Schnetzler et al., 2007). A

firm's ability to develop, manufacture and market attractive products is fundamental in the market economy. In competition with other firms it offers its products to customers and they make their choice among the offered products (Hörte and Ylinenpää, 1997). Therefore, the competitiveness of a firm could be described in terms of its ability to win orders on the market, in other words, its competitive capabilities.

One of the problems that companies recently face is the excess of supply over demand. Many approaches have been introduced in order to solve this problem such as just-in-time (JIT) concept. Before economies of scale have led to centralized distribution and manufacturing, which has lowered costs but at the same time also made the supply chain less flexible, the trend towards just-in-time and lean practices had led to a focus on efficiency rather than effectiveness. Consequently, the trend towards reducing costs has led to a globalization of supply chains, which is more complex and therefore more vulnerable. Accordingly, economies of scale have conducted centralized distribution and manufacturing, which has lowered costs but at the same time made the supply chain less flexible. Then, outsourcing non-core business activities in order to gain market competitiveness caused the loss of control of the supply chain when it may be most needed as the changing customer needs require more responsiveness.

Furthermore, Hill (2005) distinguishes between three types of criteria as qualifying, order-losing and order-winning. "Qualifiers" are those criteria that a firm must meet to have a customer consider it to be a possible supplier, while the "order-winners" are those criteria that win orders. Chase et al. (2001) describe order-winner as a criterion that differentiates the products or services of one firm from another. Depending on the situation, the order-winning criterion may be cost of the product (or price), product quality and reliability, or any other competitive dimensions. On the other hand, an order qualifier is a transmission criterion that permits a firm's products to even be considered as possible candidates for purchase. However, the roles of order winners and qualifiers are not stable. They change over time, they work in combinations, and they work in different ways on different markets and with different customers (Mason-Jones et al., 2000b; Hörte and Ylinenpää, 1997). In order to appeal the target customers and to succeed a superior performance, a better understanding of customer needs is required.

3.6 Relating Supply Chains with Product Types

Mainly, a lean SC (LSC) focuses on reducing lead-time, increasing efficiency, expanding manufacturing flexibility, and cutting cost. The LSC also focuses on continuous improvements (kaizen) while striving for these goals. Balancing the supply chain is the key that LSC uses to improve the product and the associated processes. A globally manufactured low cost item with highly predictable demand patterns and the possibility of a stable design over many years provided by the long product life cycle of the standard product enables the employment of a level schedule over the entire supply chain and over all the products' life cycle stages; therefore, offers cost minimization and profitability (Mason-Jones et al., 2000b). According to Vonderembse et al. (2008), this justifies the usage of a LSC for standard products. "In addition to providing cost minimization, the LSC is efficient and flexible, and it brings incremental improvements, permitting firms to constantly improve the quality of their products and keep their customers satisfied" (Vonderembse et al., 2008).

The first two stages of the product life cycle, introduction and growth, are the testing grounds to ensure that organizations are achieving customization and market adaptability for innovative products. Moreover, for innovative products to succeed, they should be producible in any volume, as per customer requirements. One of the strategic tools provided by ASC is a virtual organization (VO) that supports the usage of an ASC for the first two stages in the life of an innovative product. By providing concurrency of operations among the members of the VO, the agile company can rapidly deliver its innovative products in small quantities, on request. After the product has been firmly established, it transitions into the third stage of its life cycle which is maturity and in which the innovative product begins to take on the characteristics of a standard product. As price competition becomes very important, production becomes more standard like it is a part of the organizations' daily schedule, which by the time follows the LSC concept. In order to maximize their profits, organizations still need to deal with their customers and provide them not only the support that they need, but also launch new, enhanced versions of the existing product, therefore maintaining their customer base (Vonderembse et al., 2008).

Finally, hybrid products require the organization to blend a set of suppliers with a wide range of capabilities to handle the complexity (Choi and Hong, 2002); strategic

partnerships are established for the innovative and standard product combination. There is always the opportunity to introduce innovation into the hybrid products - especially when they are in the beginning of their life cycles-, therefore, hybrid products require HSC throughout their product life cycles.

As a summary of this section, SC classification regarding product type and product life cycle is demonstrated below, on the Table 3.1.

Table 3.1: SC classification based on product type and product life cycle
(Vonderembse et al., 2008)

Product Life Cycle	Product Type		
	Standard	Innovative	Hybrid
Introduction	Lean Supply Chain	Agile Supply Chain	Hybrid Supply Chain
Growth		Hybrid / Lean Supply Chain	
Maturity			
Decline			

4. EVALUATION OF SC COST PERFORMANCE REGARDING DEMAND UNCERTAINTY AND POSTPONEMENT: A PROPOSED MATHEMATICAL MODEL

4.1 Objective

The competition is now on a different level, and today's challenging environment asks for perfect players who are able to respond customer demands no matter how complicated they are to achieve. Besides, predicting demand distribution and variation is now becoming much harder than ever as the demand moves from functional (standard) products to innovative (modern) products that seduce the customers emotionally. While product life cycles shorten, and marketability costs arise; people start to pay higher values to those appealing products, which pumps profit margins up to new levels. On the other hand, there are still many products that can not be evaluated emotionally, though has lower profit margins and a stable demand.

In conclusion, the main objective of the study is to propose a supply chain total cost evaluation model –applicable for different supply chain structures- regarding demand uncertainty and postponement. Furthermore, developing a purpose-specific decision support system (Design is explained in Appendix C.) that helps the decision maker by simulating the effect of outbound postponement on a supply chain structure is aimed.

4.2 Methodology

First of all, the probability density function for a normal distribution is used to reflect the demand uncertainty while modelling the SC performance (under some assumptions).

Secondly, the notation of parameters and variables is introduced and a well-known total cost formulation -with respect to production quantity- regarding production costs, holding costs and backorder costs is referenced.

The next step aims embedding the demand uncertainty function into the general total cost function. In fact, this step is a cornerstone in the study where the differentiation between the concerning supply chain structures -or in some cases types- is formed. Moreover, critical conditions of optimal cost cases (for which proofs are given in Appendix A and B) are proposed.

Furthermore, a specific decision support system (DSS) interface that combines all the previous formulation and automatically calculates the results for the desired input parameters is developed. What is more, this interface is also intended for managers as a supportive tool in decision-making (whether to use inbound modularization/outbound postponement or not). So, in addition to simulating the effect of outbound postponement on a desired supply chain structure, the interface provides a better support and a wider perspective to the user via automated graphics that illustrate different combinations of modularization and postponement decisions visually.

Finally, an exemplary case, which is followed by strategically selected scenarios that are particularly fitted with some specific supply chain types, is given. Those scenarios include total costs calculations for different supply chain types under some assumptions and given values. In addition to this, sensitivity analyses are made for a better understanding of the analytical framework and its potentials.

4.3 Framework for Total Cost Analysis

In this section a conceptual framework for evaluating supply chain structures is presented. The framework captures the trade-offs faced by different supply chains through categorization into the two levels of inbound and outbound logistics. The inbound and outbound logistics is considered to encapsulate the degree of modularization and postponement. Therefore, inbound modularization is the element that captures the degree of outsourcing and the occupation of subcontractors for making the components. As mentioned before, a low inbound modularization stands for a vertically integrated supply chain; on the other hand, a high inbound modularization represents a supply chain with a high degree of horizontal integration that is highly decentralized which outsources the majority of the components from multiple suppliers (Ernst and Kamrad, 2000). Likewise, outbound postponement is the element that captures the amount of customization offered by the SC. Thus, a

supply chain that employs a high outbound postponement is basically organized around a make-to-order environment where customer demand triggers the completion of the final product. Conversely, an inventory of finished products is maintained to satisfy customer demand in a supply chain with a low outbound postponement, which characterizes a make-to-stock environment (Ernst and Kamrad, 2000).

The concepts of modularization and postponement are applicable to products involving a flow of discrete steps in the SC. In this study, -for simplicity- the logistics flow pattern is simplified into three distinct steps as manufacturing, assembly and packing.

- *Manufacturing*: The production of the component parts
- *Assembly*: Putting the different components together for creating the product
- *Packing (or packaging)*: Actual packaging and labelling of the final product to meet the customer demands.

In this simple perspective, the assembly step links inbound logistics with outbound logistics (or manufacturing to packaging) and this step acts as a separating buffer between those two. In the light of previous studies, the distinction among these steps is stated as follows: Ernst and Kamrad (2000) point out that the concept of postponing manufacturing is quite different from assembly and packaging; therefore, associate the manufacturing step with modularization and packaging step with postponement. The approach for the analytical section of this paper is based on this distinction; however, the refinement of the steps in the SC will be deferred to future research.

As demonstrated in the Figure 4.1, two main structures regarding their postponement status are examined in this study: The first structure is the traditional structure, which doesn't occupy any outbound postponement and the two markets mentioned for the model are served separately; on the other hand, second structure postpones packaging by fixing a decoupling point and uses this point as a buffer for demand uncertainty and variability. As mentioned before, postponing the packaging process reduces the fluctuations in demand (Mason-Jones et al., 2000a) and the bulk of savings increases. However, a higher fixed cost will be incurred because of two separate packaging processes.

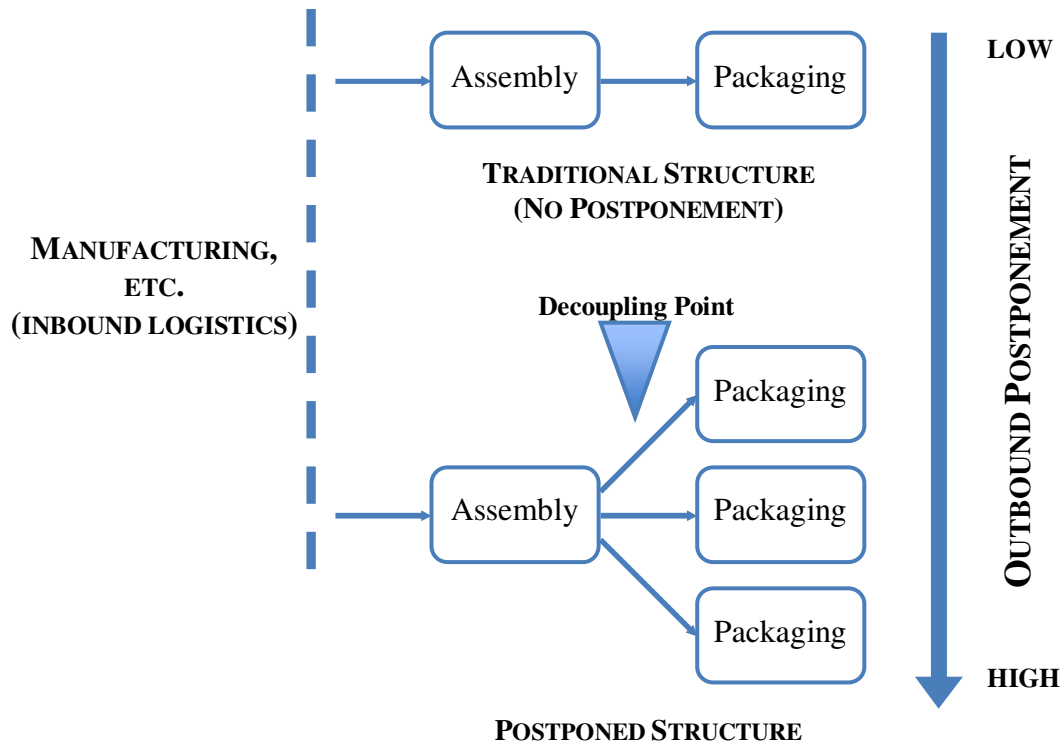


Figure 4.1 : Outbound Postponement

Manufacturing part will be associated with the inbound logistics where the product is made in the house or outsourced in standardized parts. Although, usage of modularization or a vertical structure before assembly is a matter of inbound logistics and the focus of the study is postponement and demand uncertainty; the framework is capable of connecting the inbound logistics with the overall results by adjusting to different fixed and variable cost combinations. Ernst and Kamrad (2000) categorize those structures in four main groups as *rigid*, *postponed*, *modularized*, and *flexible*, which are shown in Figure 4.2. The *rigid* structure represents the classical vertically integrated supply chain where the objective is to exploit economies of scale in production of large runs by maintaining large inventories of finished products. The opposite extreme of *rigid* structure is the *flexible* structure where many subcontractors are used to make the different components; here, the assembly of the final product is in response to a specific demand. In addition, economies due to the commonality effect are expected with respect to inventory. As Kundu et al. (2008) state, “risk pooling and reduction in lead time uncertainty are two major benefits of commonality that can lead to safety stock reduction”. The two other structures are called as intermediate structures. One of them is the *modularized* structure, which has multiple sources for the components, but no outbound postponement; the output

of the assembly process is the finished product itself. According to Tully (1995) this is probably the most typical supply chain structure for most industries (cited in Ernst and Kamrad, 2000). And last of all, the *postponed* structure that exploits economies of scale in the making of components while customizing the finished product to satisfy specific customer or market demand.

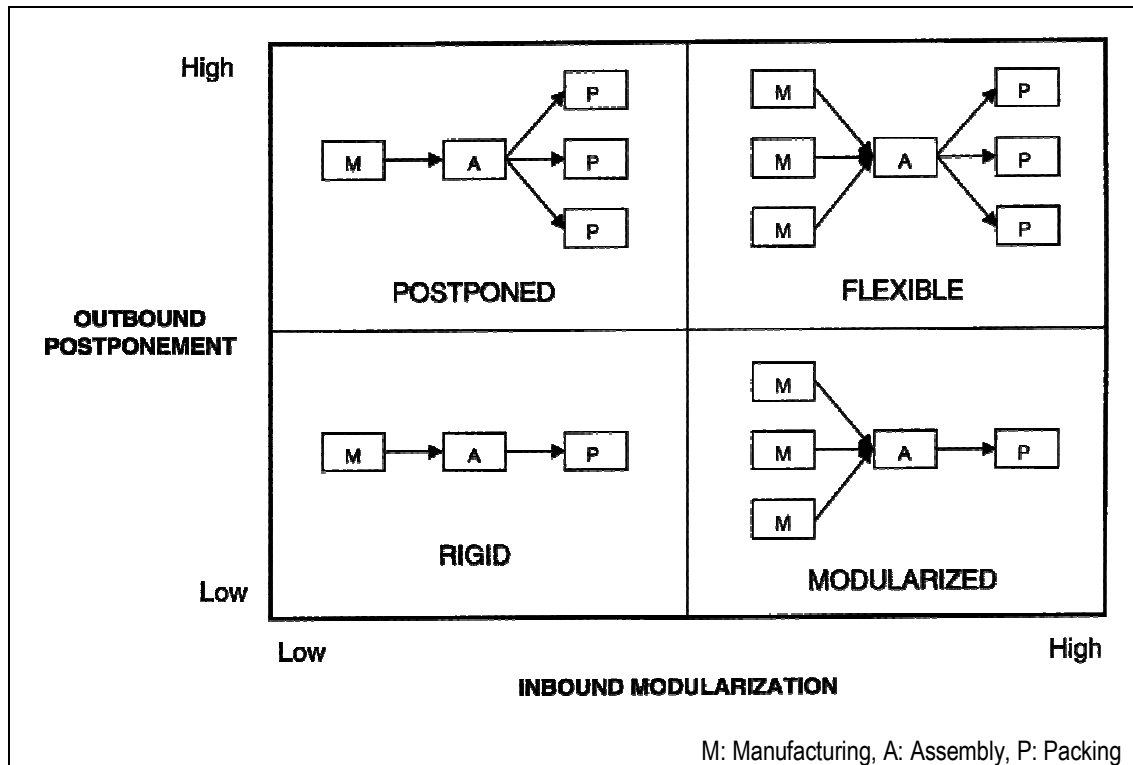


Figure 4.2 : Framework for supply chain structures

On this basis, it is probably not possible to intuitively decide what supply chain structure best suits the needs of a company. That also explains the necessity for an analytical evaluation of supply chain structures before deciding to employ them.

According to Ernst and Kamrad (2000), there is an explicit trade-off between cost and service levels that has to be accounted for or when companies increase the level of inbound modularization. For example, by using more modularized contracting, it becomes possible to significantly reduce the fixed costs involved, but with an increase in variable cost per unit, which happens to be the trade-off.

Moreover, for the postponement case the situation is reversed. By occupying a higher level of outbound postponement, companies may encounter an extra fixed cost because of maintaining multiple equipments for packaging and labelling (e.g., warehouse facilities with machines to label). On the other hand, the variable cost is

reduced because of centralized inventories, less risk associated with lower finished goods inventories, and/or bulk shipping from the plants. The combination of fixed and variable costs differ from one supply chain structure to another, and they will be elaborated upon in more detail while suggesting scenarios in the sensitivity analysis section.

4.4 Assumptions for the Framework

Due to the lack of exact information in some cases, qualified assumptions are required in order to investigate, clarify and explain the problem. Furthermore, current study is only concerned with development of a general framework upon which future work can be based. Therefore, the model has been conducted under several assumptions upon which further research is possible and encouraged. Without assumptions, the model would have been very complicated and hard to realize with high level of computational complexity; besides, the clarity and simplicity would have been compromised.

First of all, to focus discussion, a company that sells a product to two different markets with no demand correlation between them is considered. The only difference between the two market requirements is in the packaging since the labels (stickers on the package) come in different languages (e.g. a producer serving to the German and French market).

Secondly, order-up-to level inventory policy is used for simplicity in the model, which means no stock-outs happening since inventory is continuously replenished up-to the desired level. According to Solyalı and Süral (2008), this policy is one of the most basic inventory control policies and is often applied in practice.

Moreover, the flow of discrete steps in the SC is simplified into three. First of those three, manufacturing step is associated with the inbound logistics (modularization). Secondly, assembly step acts as the link between manufacturing and packaging (e.g. putting the pieces together after manufacturing); then, as the final step, packaging is related with outbound logistics (postponement) where the product is prepared for its final destination (e.g. in a postponed structure, the standard packaging process is handled in the point of assembly while specific adjustments for individual market demands are completed abroad). In addition to those, the second step, assembly is

not openly captured in the formulation (Equation (4.1)) since all the SC structures include it in a similar fashion.

Furthermore, the model includes the key costs of a supply chain in four main domains, which are fixed, variable, holding, and finally backorder costs, also, which will be explained thoroughly in the next section. Here, variable costs reflect the ones that would drop to zero as a consequence of eliminating the product; additionally, fixed costs are defined as those that do not change with quantity produced. What is more, holding and backorder costs are assumed the same under all SC structures and markets since they are a function of the finished goods inventory not the manufacturing method selected; therefore, have no direct impact on the analysis.

For simplicity reasons, transportation of products between the two markets is not possible since the products are already customized for the market and the product is assumed to be perishable but future work recommends a dynamic model where inventory is carried to the next period.

4.5 Analytical Formulation of the Total Cost Framework

The objective here is to derive structural findings that will allow the decision maker to illustrate comparative results for selecting one structure over another. For that, a simple analytical framework for evaluating various supply chains on a differential cost basis is provided. However, this evaluation is based on a general framework that gives just a general perspective on the outbound postponement and cost differentiation between the traditional and postponed structures. In addition to providing comparative results, the framework is fashioned to make it possible to coordinate a host of factors influencing operating costs with the expense of increased computational complexity.

With the generality approach, the framework is able to compute for various types and levels of postponement cases. In order to focus discussion, as mentioned before, a company that sells a product to two different markets with no demand correlation between them is considered while setting up the model. The only difference between those two market requirements is assumed to be in the packaging stage since different markets need different labelling (e.g. a producer serving to the German and French market).

Furthermore, the model includes the key costs of a supply chain in four main domains, which are fixed (F), variable (V), holding (H) and finally backorder (B) costs. The key costs are assigned as input parameters in the analytical model, by which easy adjustment to different cost combinations that are encountered in the market or, likewise, reflecting the accurate behaviour for different supply chain strategies became possible.

The first of two aforementioned main structures in this study is the *traditional* structure under which company makes two packaging runs - one for each market - based on the expected demand for each market and incurs a fixed cost and a variable cost for this action. On the other hand, under the *postponed* structure, the company postpones packaging by having separate labelling processes in each of the market locations (e.g. in Germany and France individually), which causes the company to encounter a fixed and a variable cost for each separate labelling process. As it was mentioned before, the bulk of savings from postponement should arise as a higher fixed cost is incurred by having two labelling processes as opposed to one.

Then again, since evaluating the performance of inbound logistics (suppliers, outsourcing, modularization, etc.) is not the main focus of this study, differentiation in this stage will be just sampled during the sensitivity analysis, in order to show the responsiveness and flexibility of the analytical model.

Finally, the following notation is introduced for the analytical framework, which is set forth for comparison purposes:

i	Index for the different supply chain structures Postponed (P), Traditional (T)
j	Index for the two markets A and B
F_i	Fixed cost under structure i
V_i	Variable cost under structure i
H	Holding cost per unit for the inventory of finished goods
B	Backorder cost per unit for demand not satisfied, where in most realistic applications $B \geq V_i$
S	The production quantity under each structure considered
q	Parameter for the sigma policy of the company ($q\sigma$ -for ex. 6σ)
k_j	Deviation parameter representing the deviation of production quantity from expected demand for market j (calculated as the percentage of <i>over/under production z-level</i> within the <i>sigma policy limit</i> : $k_j = z_j/q$)

z_j	Standard score (z-value) for the market j
σ_j	Standard deviation parameter for the market j
σ_j^2	Variance parameter for the market j
μ_j	Mean demand in market j
$f(x)$	Normal density function (Normal distribution function)
$f_s(x)$	Standard normal density function (Standard normal distribution)
$F(x)$	Normal cumulative distribution function
$F_s(x)$	Standard normal cumulative distribution function

In light of the above notation, the total cost under structure i is given by

$$TC_i(S) = F_i + V_i(S) + H \int_0^S (S - x) f(x) dx + B \int_S^\infty (x - S) f(x) dx. \quad (4.1)$$

As illustrated above, the first two terms in Equation (4.1) capture the fixed and variable cost of production and packaging cost. Since assembly process affects any structure in a similar fashion, it is not explicitly captured in the formulation. On the other hand, as mentioned by Zinn and Bowersox (1988) variable cost is thought to be dropping to zero as a consequence of eliminating the product (cited in Ernst and Kamrad 2000).

Furthermore, order-up-to level inventory policy is used for simplicity in the model, which means no stock-outs happening since inventory is continuously replenished up-to the desired level. According to Solyalı and Süral (2008), this policy is one of the most basic inventory control policies and is often applied in practice. So as to fulfill the model, holding and backorder costs are included as the other two terms of the Equation (4.1). H and B are assumed the same under all supply chain structures and for both markets. What is more, they are a function of the finished goods inventory, and a concern of the outbound logistics; so, logically, the manufacturing method selected has no effect on these terms. However, further research should explore different combinations of H and B cost components in a more detailed manner, especially if the market specifications vary in the means of inventory handling or stock-outs.

As the point of differentiation in the model, the production quantity S may be expressed in two ways depending on the level of outbound postponement. Firstly, if the outbound postponement is low (traditional structure), each market is treated independently since no demand correlation is assumed. Therefore, the production

quantity is a function of expected demand, and it can be expressed by the following equation:

$$S_T = \mu_A + z_A \sigma_A + \mu_B + z_B \sigma_B \quad (4.2)$$

As notified before, z_A and z_B values represent the standard scores (z-values) of the markets A and B, and they will be linked to the deviation parameters k_A and k_B with a ratio parameter further in this section. These parameters will characterize deviations from the mean demand and will be defined according to the strategic priorities of the company.

Secondly, if the outbound postponement is high (postponed structure), the company benefits from the commonality effect for the safety stock (Baker et al., 1986), resulting a consolidated expression of the deviation from the total mean demand for both markets. So the quantity to be produced under the postponed structure can be expressed as

$$S_P = \mu_A + \mu_B + \sqrt{z_A^2 \sigma_A^2 + z_B^2 \sigma_B^2}. \quad (4.3)$$

In the light of those expressions, in order to derivate the total cost function for different supply chain structures and to put the demand uncertainty into the equation, expected understock function is taken into account.

Assuming that demand is normally distributed ($g(x)$ denotes normal distribution function) with a mean μ and standard deviation σ ; when S units are ordered, an understock is shown with the following equation (Chopra and Meindl, 2004).

$$G(S) = \int_S^{\infty} (x - S) g(x) dx \quad (4.4)$$

With the intention of reflecting the dissimilar demand specifications of different structures and markets; $G_j(S_j)$ will be standing for the expected understock of market j in the traditional structure, while $G_P(S_P)$ will be indicating the understock for the whole postponed structure since the occupation of outbound postponement leads to commonality and creates a combined demand distribution with a different standard deviation. Similarly, $g_j(x)$ will be used to signify normal distribution function with a standard deviation of σ_j (std. dev. for the market j), as $g_P(x)$ will have a deviation of σ_P (std. dev. for the postponed structure).

While maintaining the assumptions, when Equation (4.2) and Equation (4.4) is substituted into Equation (4.1), the following equation is obtained for a supply chain structure with no postponement (also called as the traditional structure).

$$\begin{aligned}
TC_T(S_T) &= F_T + V_T(\mu_A + z_A \sigma_A + \mu_B + z_B \sigma_B) \\
&+ H(z_A \sigma_A + G_A(z_A \sigma_A) + z_B \sigma_B + G_B(z_B \sigma_B)) \\
&+ B(G_A(z_A \sigma_A) + G_B(z_B \sigma_B))
\end{aligned} \tag{4.5}$$

Likewise, for the supply chain structure with outbound postponement (postponed structure), the equation is formed by substituting Equations (4.3) and (4.4) into Equation (4.1).

$$\begin{aligned}
TC_P(S_P) &= F_P + V_P \left(\mu_A + \mu_B + \sqrt{z_A^2 \sigma_A^2 + z_B^2 \sigma_B^2} \right) \\
&+ H \left(\sqrt{z_A^2 \sigma_A^2 + z_B^2 \sigma_B^2} + G_P \left(\sqrt{z_A^2 \sigma_A^2 + z_B^2 \sigma_B^2} \right) \right) \\
&+ B G_P \left(\sqrt{z_A^2 \sigma_A^2 + z_B^2 \sigma_B^2} \right)
\end{aligned} \tag{4.6}$$

The standard deviation of the normal distribution function in $G_P(S_P)$ is calculated according to *Cramér's theorem* -which explains the standard deviation for the sum of two markets- since two markets are served from one safety stock (a.k.a. the effect of commonality). Thus, standard deviation for the demand distribution under the postponed structure will be

$$\sigma_P = \sqrt{\sigma_A^2 + \sigma_B^2}. \tag{4.7}$$

To simplify the equations, it is supposed that $z_B = \alpha z_A$ and $\sigma_B = \beta \sigma_A$ for $\alpha, \beta > 0$. Then S_T can be simplified as:

$$S_T = \mu_A + \mu_B + z_A \sigma_A (1 + \alpha \beta), \tag{4.8}$$

and when this equation is substituted into Equation (4.5), TC function of the traditional structure will be

$$\begin{aligned}
TC_T(S_T) &= F_T + V_T(\mu_A + \mu_B + z_A \sigma_A (1 + \alpha \beta)) \\
&+ H(z_A \sigma_A (1 + \alpha \beta) + G_A(z_A \sigma_A) + G_B(\alpha \beta z_A \sigma_A)) \\
&+ B(G_A(z_A \sigma_A) + G_B(\alpha \beta z_A \sigma_A)).
\end{aligned} \tag{4.9}$$

In addition to those, for the postponed structure, the production quantity can be written as,

$$S_p = \mu_A + \mu_B + z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}. \quad (4.10)$$

Thus, substituting this equation into the Equation (4.6), $TC_P(S_P)$ will be simplified as

$$\begin{aligned} & TC_P(S_P) \\ &= F_p + V_p \left(\mu_A + \mu_B + z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) \\ &+ H \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} + G_p \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) \right) \\ &+ B G_p \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) \end{aligned} \quad (4.11)$$

The following two equations are obtained from Equations (4.9) and (4.11) respectively. The critical conditions of total cost minimization cases under considered SC structures are indicated by those equations.

Under the traditional structure, z-level -for market A- (z_A) that minimizes the total cost, satisfies the following critical ratio condition.

$$(1 + \alpha\beta) \frac{B - V_T}{H + B} = F_{\sigma_A}(z_A \sigma_A) + \alpha\beta F_{\sigma_B}(\alpha\beta z_A \sigma_A) \quad (4.12)$$

And similarly, for the postponed structure, critical ratio condition is calculated as the following expression.

$$\frac{B - V_P}{H + B} = F_{\sigma_P} \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) \quad (4.13)$$

In all cases $B \geq V_i$ is assumed without any loss of generality, so positivity of the critical ratios are ensured; in other words, the critical ratios are never negative.

The proof is found in Appendix A.

While evaluating different combinations of supply chain structures, these critical ratios will still be valid regarding the postponement status. What is more, the differentiation of the manufacturing stage will be reflected to the model by adjusting to the appropriate fixed and variable cost combinations.

It is also important to note that, the deviation parameter k_j shows the percentage of over/under production within the limits that sigma policy covers (i.e. deviation level of 100% stands for the case that market is served with maximum over production and

no backorder is needed; conversely, the k_j value -100% stands for the case that market is served with minimum production quantity feasible, or in other words, with maximum under production where no inventory is held). Thus,

$$z_j = qk_j. \quad (4.14)$$

For example, 50% k_j value -with respect to the means of standard deviation and regarding a case that 5-sigma policy is used- would mean a possible demand variation up to $2.5z_j$ is covered by the buffer inventory (Normalized percentages with respect to production quantity will be mentioned in Appendix C under *Normaliser Add-in.*). It is clear that, a higher k_j value means a higher service level since the quality of the service is measured by the availability of the product when demanded by the consumer.

Additionally, as an outcome of the formulation, since the deviation parameter k_j can never be higher than 100% (or 1.00), z_j as well would never exceed the number value of the sigma policy (q) regarding the Equation (4.14).

4.5.1 Numerical Illustration of the Model

Modelling the demand uncertainty has come up with an increase in the computational complexity caused by the distribution and expected understock functions included in the formulation. Therefore, making the calculations on a computer turned into an obligation. As a result, all the numerical illustrations were handled by realizing the equations on Microsoft (MS) Excel. Afterwards, the MS Excel formulas were neatly merged in an Excel sheet in order to compose a decision support system interface, which is not only capable of evaluating the results for the given values, but is also able to provide a wider perspective to the user (manager) with a number of supportive tools and graphics.

4.5.1.1 Exemplary Case

Primarily, in this first case, all input parameters are considered equal for both structures (in further analysis they will be adjusted to fit to certain supply chain structures). By doing this, it is aimed to measure the effect of commonality under similar conditions. To illustrate the framework, the following set of case parameters are employed where

F_T, F_P	500 €
V_T, V_P	3 €/unit
H	1 €/unit
B	8 €/unit
μ_A, μ_B	100 units for markets A and B
σ_A^2	20 unit ²
σ_B^2	60 unit ²
α	1 (safety factor for market B is equal to the safety factor for market A)
q	5 (The company policy is set to 5σ)

By applying critical ratio conditions to the above case parameters the following Table 4.1 of summarized results is obtained:

Table 4.1: Optimal results of the exemplary case

Supply chain structure	Optimum k_A	Optimal units produced	Total Cost (EUR)
Traditional	2.794%	201.71	EUR 1,143.44
Postponed	2.794%	201.25	EUR 1,131.80

The optimum k_A values, optimal production quantity and minimized total costs of the structures are demonstrated on the Table where the optimal value of the deviation level k_A is the exact same under both structures. In fact, this is a lucky coincidence that gives an opportunity to evaluate the postponement effect precisely under the same service level decisions.

Most importantly, as an outcome of this incidental occasion, it is easily seen that the postponed structure was able to satisfy the same service level, with fewer units produced; hence, with a lower production cost faced. In order to prove this statement mathematically, a proposition is made in the following paragraph.

Theoretically, for a given deviation parameter k_A , the total cost for the postponed structure is lower than the total cost for the traditional structure if the following condition holds:

$$TC_P(S_P) \leq TC_T(S_T) \Leftrightarrow F_P - F_T \leq V_T(S_T) - V_P(S_P) - K, \quad (4.15)$$

where

$$K = H z_A \sigma_A \left(\sqrt{1 + \alpha^2 \beta^2} - (1 + \alpha \beta) \right) + (H + B) \left(G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right). \quad (4.16)$$

It is straightforward to verify that K is always smaller than zero ($K < 0$), and the proof for the inequality can be found in Appendix B. Moreover, a comprehensive graphical proof of this exemplary case will be given in the next section.

Testing Equations (4.15) and (4.16) for the given input values by using the acquired k_A values of the cost minimization cases will lead to the following results:

$$0 \leq 1.38 - K$$

$$K = - \text{EUR } 10.27$$

Therefore, $TC_P(S_P) \leq TC_T(S_T)$ status is approved.

In sum, the exemplary case was an introduction to the analytical framework modelled, and only basic output parameters were illustrated in this section. Further combinations of inputs will be demonstrated as case studies -in a more detailed approach- by the help of the interface modelled in MS Excel.

4.5.1.2 A Decision Support System for Postponement Decision in a SC

As mentioned before, the framework was also fashioned to coordinate a host of factors influencing operating costs while providing comparative results, but with the expense of increased computational complexity. So, after developing the analytical formulation of the framework, the model was tested through different combinations of cases by composing it virtually on Microsoft Excel. Since recent technological advances gives the opportunity to handle many complex calculations in the blink of an eye, computational complexity is not a problem anymore, of course, as long as the model is correctly set up in the virtual environment.

Firstly, a very primitive version of the recent *MS Excel Interface* was built in order to deal with the basic calculations for several exemplary cases. Then the second step was rearranging its components neatly into a simple interface with the intention of entitling publicity to the interface. In fact, the purpose was to provide a helpful tool that is easy to use by any user; also, on which the input parameters can be easily adjusted.

However, after a number of steps, the interface evolved into a *Managerial Decision Support System* with advanced inputs, outputs, sensitivity analysis, and finally graphics that are automatically, precisely, and immediately updated as soon as any change in the input parameters is sensed.

The interface is explained in Appendix C with the directions for use and screenshots. Additionally, MS Excel document is found in the CD that is securely housed in a pocket on the inside of the back cover.

Last of all, before exemplifying and evaluating different cases in the next section, the basic outputs for the first case (exemplary case) will be illustrated here together with the graphical proof of the aforementioned total cost proposition. Below, the - automated- results of the DSS interface are demonstrated with partial screenshots from output frames of the interface (Figure 4.3 - 4.6):

Cost Minimization (Optimal Levels Calculated to Minimize Cost)		
	Traditional Structure	Postponed Structure
Deviation Param. for Market A (kA)	2.79%	2.79%
Deviation Param. for Market B (kB)	2.79%	2.79%
Total Prod. Quantity	201.71	201.25
Total Cost	EUR 1,143.44	EUR 1,131.80

Figure 4.3 : Cost minimization case output parameters

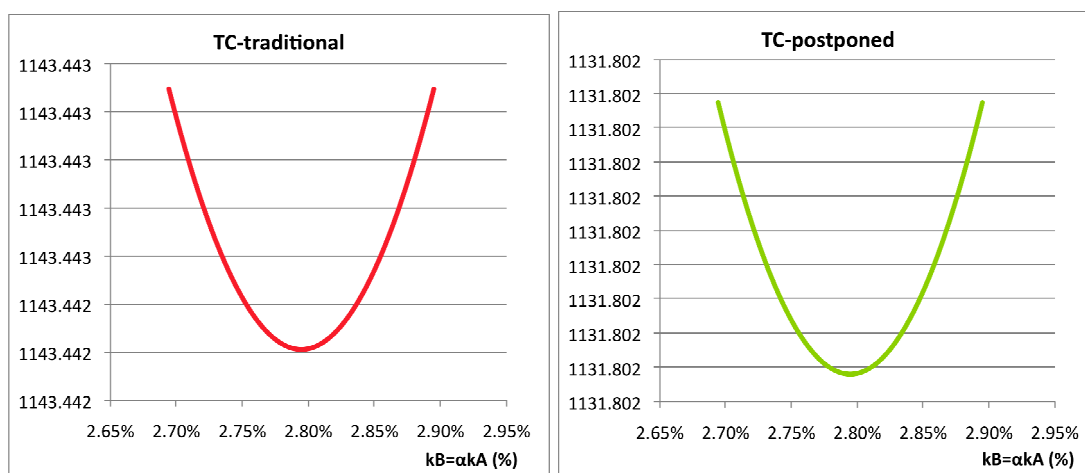


Figure 4.4 : Absolute minimums of the TC functions

Figure 4.5 is the partial screenshot from the output frame of the interface that illustrates the most significant cost minimization case parameters. It basically corresponds to the information that Table 4.1 demonstrates.

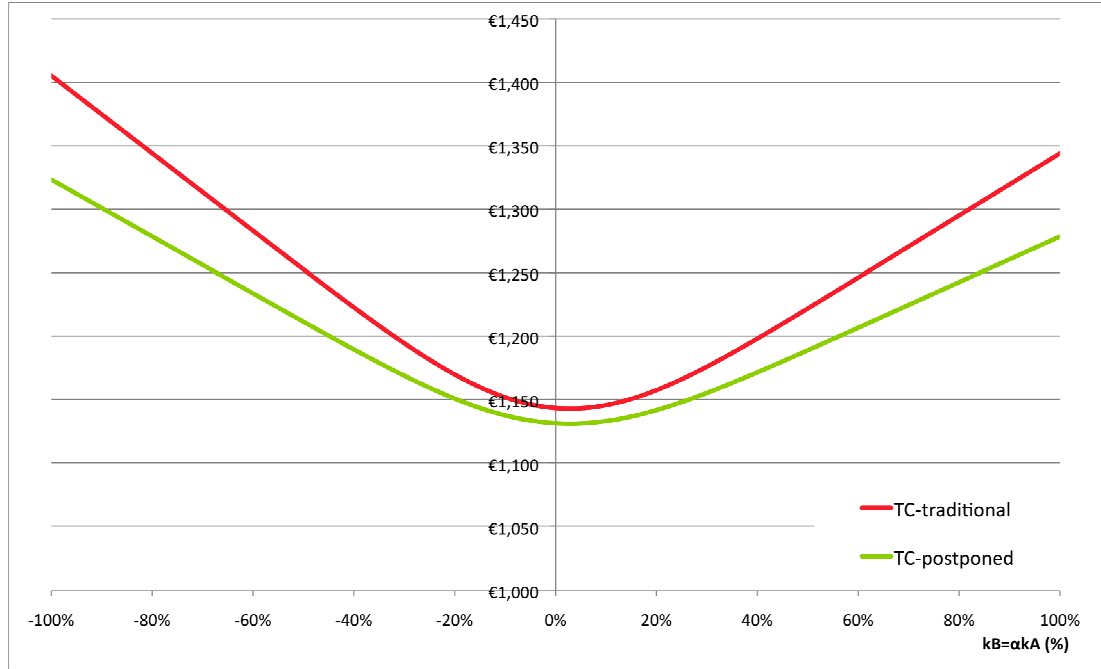


Figure 4.5 : Total Cost (TC) – k_B Graph

The graph demonstrated in the Figure 4.5 traces the result of the TC function while all other inputs are fixed but the deviation parameter k_B representing the deviation of production quantity from expected demand for market B is changing. In this case, $k_B = k_A$, since $k_B = \alpha k_A$ and $\alpha = 1$.

In fact, the graphs in Figure 4.4 and Figure 4.5 are proofs for all the propositions that are made so far, as

- it proves that both functions are convex in the given interval (Figure 4.5),
- the critical ratio conditions are able to locate the minimums properly (Figure 4.4),
- and the total cost of the postponed structure never exceeds the total cost of the traditional structure for the input parameters of the corresponding case (equal input values for both structures) (Figure 4.5).

Finally, Figure 4.6 validates that K is always < 0 no matter what the k_B value is; in addition to this, the difference between the total cost of the postponed structure and the traditional structure with respect to the deviation parameter (k_B) is traced on the same figure.

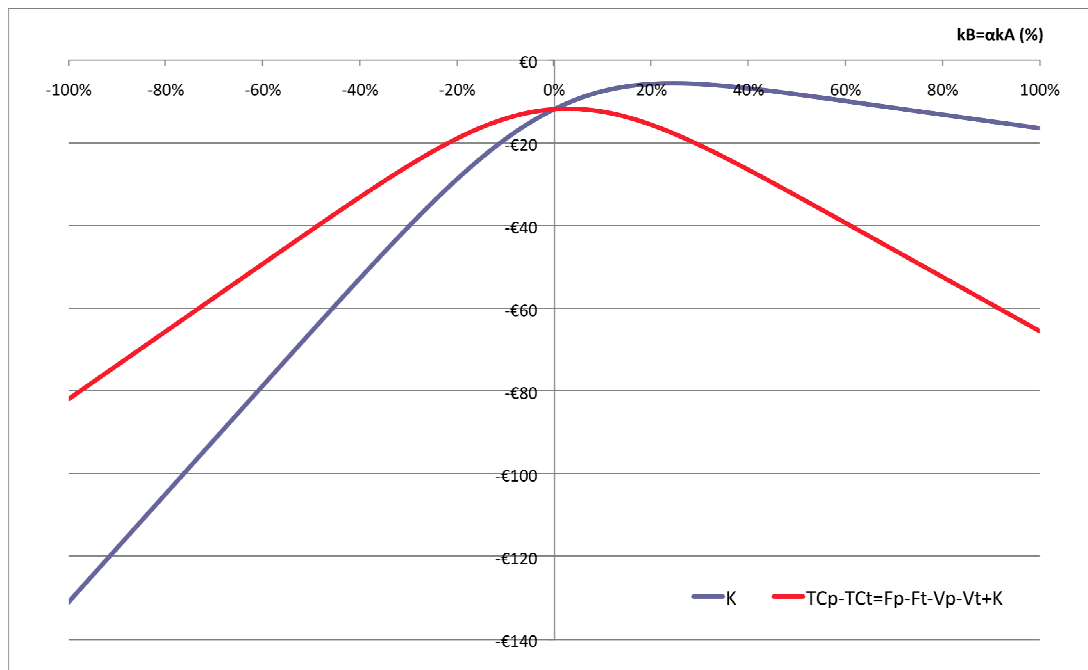


Figure 4.6 : $K < 0$, $\Delta TC - k_B$ Graph

4.6 Sensitivity Analysis

Saltelli et al. (2008) describe a sensitivity analysis (SA) as the study of how the variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model.

Therefore, according to this explanation, the developed DSS Interface provides the right tools for sensitivity analysis. In fact, as it was mentioned before, this interface has been formed step by step; what is more, integrating sensitivity analysis tool was a cornerstone for the computerized framework. Frankly speaking, it was where the interface evolved to be a Decision Support System.

The DSS Interface supports sensitivity analysis for the Total Cost function and its components with respect to

- standard deviation parameter (σ) for measuring the effects of market uncertainty
- deviation parameter (k) for evaluating over/under production alternatives as they correspond to different service levels.

Besides, the sensitivity analyses are shown not just by numbers but also with the graphics that bring an ease of understanding to the case with visual support. As any

other pieces of the interface, these graphics are immediately updated as soon as new inputs are entered.

The DSS interface aims to measure the behaviour of supply chain structures by simulating scenarios virtually before the product goes into the market; therefore, it is a supportive tool for the managers to understand the risks and make their critical decisions. Furthermore, thinking of the current environment specifications, it is certainly helpful to be able to capture the effects of fluctuating demand.

In brief, the interface is designed to link different service levels and outbound postponement with demand uncertainty by employing distribution functions that combine probability with statistics. Consequently the sensitivity analyses in the DSS interface are also set up regarding these factors. Moreover, the design of the interface makes it possible to run the sensitivity analysis with other inputs than σ and k ; however, for simplicity, they are not built in the interface since they would not have any direct correlation with the main objective that this study targets.

Below, with the help of the DSS interface, different combinations of input parameters will be studied and the results will be commented through graphics and sensitivity analyses. Finally, overall findings will be summarized at the end of the section.

4.6.1 Numerical Cases

Different combinations of input parameters will be tested via the DSS interface; in addition to this, first case input values are taken as the point of origin and the differentiation will be carried out with some changes over them.

Table 4.2 demonstrates the appropriate scenarios regarding postponement decision and inbound modularization (e.g. outsourcing). ΔF and ΔV are the differences on the cost parameters caused by the postponement or modularization decisions. Moreover, ΔF and ΔV define any two positive numbers and their magnitude can be specific to each case. On the other hand employment of those parameters is an assumption that is used as a way of simplifying the comparison among other supply chain structures and further research should explore the range and variability of these parameters in depth.

The Scenarios are tested under the shift of other parameters as variance of the demand, desired priority ratios for the markets, sigma qualifier, and finally backorder and holding costs.

Table 4.2: Scenarios regarding outbound postponement and inbound modularization

Scenario No.	Traditional Structure with no Outbound Postponement		Postponed Structure	
	Fixed Cost	Variable Cost	Fixed Cost	Variable Cost
Base Case	F	V	F	V
Scenario 1	F	V	$F + \Delta F$	$V - \Delta V$
Scenario 2	$F - \Delta F$	$V + \Delta V$	F	V
Scenario 3	$F - \Delta F$	V	F	$V - \Delta V$

(F: € 500, ΔF : € 250, V: € 3 per Unit, ΔV : € 1 per Unit)

As mentioned before, Ernst and Kamrad (2000) states that employing outbound postponement increases fixed costs with an advantage of increased bulk savings from a reduction in the variability of demand. Inversely, fixed costs are lower and variable costs are higher when the companies subcontract the manufacturing step (utilization of inbound modularization) in standardized pieces. Of course further research should study the behaviour of these parameters more accurately since assumptions are used for illustrative purposes.

The scenarios signify a set of decisions taken for inbound modularization and outbound postponement. It is important to highlight that the only difference between the postponed and traditional structure is the level of outbound postponement. Any inbound logistics decision taken, is related to both of them. For example, in scenario 2, subcontracting is employed for the manufacturing process, and this condition applies to both structures with no regard to what their postponement status is.

First of all, base case assumes that both case parameters are similar even if the second structure employs postponement for packing. Under normal conditions, postponement effect should have created an impact that increases the fixed costs ($+ \Delta F$) while decreasing the variable costs ($- \Delta V$) because of the aforementioned savings. In fact, the main reason to example this particular case was to prove that the postponed structure always results in lower costs under same input values with the traditional structure. However, base case can also mean that packaging activity is subcontracted under the postponed structure; so the increase in fixed cost (because of the postponement decision) is compensated by the decrease that outsourcing

provides. Likewise, the same rule applies in the other direction for the variable cost parameter. Yet again, further research should explore the range and variability of these parameters under different strategies in a more comprehensive approach.

Secondly, scenario 1 analyses the former case with no subcontracting employed in packaging while scenario 2 uses subcontracting in manufacturing process. Furthermore, with the assumptions that are given above, it is straightforward to verify the differentiations in fixed and variable cost parameters for both cases.

As the last scenario, third one assumes that the competition in the market is fierce and subcontractors charge the company only in bargain levels. Hence, the fixed cost parameter decreases by ΔF , but the variable cost parameter does not increase because of the pressure that competitive rivalry puts on subcontractors.

By combining Table 4.2 with Figure 4.2, another perspective on the scenarios is demonstrated in the Table 4.3.

Table 4.3: Aligning scenarios with SC structures

Scenario No.	Traditional Structure with no Outbound Postponement		Postponed Structure	
	Cost Characteristics	SC Structure	Cost Characteristics	SC Structure
Base Case	F V	Rigid	F V	Postponed (Packing step is outsourced)
Scenario 1	F V	Rigid	F+ ΔF V- ΔV	Postponed
Scenario 2	F- ΔF V+ ΔV	Modularized	F V	Flexible
Scenario 3	F- ΔF V	Modularized (Competition between subcontractors)	F V- ΔV	Flexible (Competition between subcontractors)

The optimal results of the scenarios are demonstrated on the Table 4.4. These results are calculated with the input values that are assigned by applying the assumptions on Table 4.2 to the exemplary case input parameters.

No direct comparison can be made among the scenarios since the optimal k values are computed individually for each case. Evaluation of TC performance regarding demand uncertainty is also not possible through these outputs; sensitivity analysis regarding the demand uncertainty (standard deviation) will be used for that purpose.

Table 4.4: Optimum results of the scenarios for the exemplary case input parameters

Scenario No.	Traditional Structure with no Outbound Postponement			Postponed Structure			
	Deviation from μ_j		Total units produced	Total cost (€)	Dev. from total μ (k_p)	Total units produced	Total cost (€)
	k_A	k_B					
Base Case	2.79%	2.79%	201.71	1,143.44	2.79%	201.25	1,131.80
Scenario 1	2.79%	2.79%	201.71	1,143.44	8.61%	203.85	1,179.27
Scenario 2	-2.79%	-2.79%	198.29	1,093.44	2.79%	201.25	1,131.80
Scenario 3	2.79%	2.79%	201.71	893.44	8.61%	203.85	929.27

(H:1, B:8, μ_A, μ_B :100, σ_A^2 :20, σ_B^2 :60, α :1)

Moreover, when direct comparison is required, graphical tools that capture the whole over/under production spectrum should be examined. On the other hand, some important points should be expressed through Table 4.5 and Figure 4.8.

- Under the same input values and when both markets are served with an identical over/under production level ($k_A=k_B$), total cost of the postponed structure is lower than the total cost of the traditional structure. Besides, under the postponed structure, the same service level as the other structure can be achieved by producing less. (Base Case)
- Between four main structures, under the case parameters used here, the most cost effective option is the *modularized* structure, but with lower service levels (since lower k values point to a lower service level). This structure is followed by the flexible structure, which has resulted with the same service level as the rigid structure but with a lower cost. Finally, the highest service level is achieved by the postponed structure accompanied by the highest cost. (Scenario 1, 2)
- When there is fierce competition between the subcontractors, outsourcing becomes very profitable as seen on Scenario 3.

In order to compare different supply chain structures accurately, the deviation parameter k should be fixed at a value, and output should be compared. What is more, as a helpful tool of the interface, graphical support of the DSS system allows side-by-side comparisons by capturing the whole range of k level (whole range of over/under production); the tool and graphic output will be illustrated later in this section.

For all those cases, the company policy is set to 5σ since it covers 99,9999713% of the demand curve. Its effect on the numerical results of the scenarios can be measured, but it is not necessary and it would have no effect on the optimum units produced or optimum costs evaluated under the concerning input combinations (for higher total cost values, the effect of the sigma policy would probably become visible.). Increasing the value of sigma policy (q) will result with a proportional alternation in the optimum k values since they are percentage measures of z -levels covered within the sigma policy limits. It is also important to state it again that the deviation parameter k is proportional with z -value; in other words, they are not defined in production units. This choice was made for simplicity; but support for the user is given with an add-in embedded into the DSS interface on the main window. Outputs of this add-in (called *Normaliser*) are demonstrated below on the Table 4.5.

Table 4.5: Normalised k values of optimum levels

Scenario No.	Normalised k values of the traditional structure		Normalised k values of the postponed structure
	Market A (k_A)	Market B (k_B)	Overall
Base Case	11.09%	11.09%	11.09%
Scenario 1	11.09%	11.09%	33.32%
Scenario 2	-11.09%	-11.09%	11.09%
Scenario 3	11.09%	11.09%	33.32%

The next analysis is a basic sensitivity anal. regarding the α value, which prioritizes Market B over Market A as it increases. The results are given on the Table 4.6.

Table 4.6: Optimum results of the scenarios for α sensitivity

Scenario No.	Traditional Structure with no Outbound Postponement					Postponed Structure		
	α	k_A	k_B	Total units produced (S_T)	Total cost (€)	Overall k value	Total units produced (S_P)	Total cost (€)
Base Case	1	2.79%	2.79%	201.71	1,143.44	2.79%	201.25	1,131.80
	2	1.57%	3.15%	201.57	1,143.48	2.79%	201.25	1,131.80
	3	1.04%	3.13%	201.45	1,143.51	2.79%	201.25	1,131.80
Scenario 1	1	2.79%	2.79%	201.71	1,143.44	8.61%	203.85	1,179.27
	2	1.57%	3.15%	201.57	1,143.48	8.61%	203.85	1,179.27
	3	1.04%	3.13%	201.45	1,143.51	8.61%	203.85	1,179.27
Scenario 2	1	-2.79%	-2.79%	198.29	1,093.44	2.79%	201.25	1,131.80
	2	-3.64%	-1.82%	198.48	1,093.49	2.79%	201.25	1,131.80
	3	-3.70%	-1.23%	198.69	1,093.54	2.79%	201.25	1,131.80
Scenario 3	1	2.79%	2.79%	201.71	893.44	8.61%	203.85	929.27
	2	1.57%	3.15%	201.57	893.48	8.61%	203.85	929.27
	3	1.04%	3.13%	201.45	893.51	8.61%	203.85	929.27

(H:1, B:8, μ_A :100, σ_A^2 :20, σ_B^2 :60)

As a limitation of the model, when an optimum k value results negative, the α rule is valid in the opposite way and Market A is α times prioritized over Market B. In order to find the accurate results, α value should be replaced with $1/\alpha$ just for this case. Of course, the model is always accurate when $\alpha=1$.

As demonstrated above, traditional structure is more sensitive to changes in the α value than the postponed structure, which happens to stay unaffected.

Holding and Backorder Cost combinations are also tested on scenario 1 (with $\alpha=3$) since it would be enough to understand the effects of Holding and Backorder components. Below Table 4.7 shows the differentiation made.

Table 4.7: Holding – Backorder Cost combinations

Combination No.	Holding Cost	Backorder Cost
Combination 1	H	$B - \Delta B$
Exemplary Case	H	B
Combination 2	H	$B + \Delta B$
Combination 3	$H - \Delta H$	$B - \Delta B$
Combination 4	$H - \Delta H$	B
Combination 5	$H - \Delta H$	$B + \Delta B$
Combination 6	$H + \Delta H$	$B - \Delta B$
Combination 7	$H + \Delta H$	B
Combination 8	$H + \Delta H$	$B + \Delta B$

H: 1, ΔH : 0.5, B: 8, ΔB : 2 (€ per Unit)

And the results are shown on the following table (Table 4.8).

Table 4.8: Optimum results for Holding – Backorder Cost combinations

Scenario No. 1	Traditional Structure with no Outbound Postponement				Postponed Structure		
Parameter Combination Set	k_A	k_B	Total units produced (S_T)	Total cost (€)	Overall k value	Total units produced (S_P)	Total cost (€)
Combination 1	-4.78%	-1.59%	198.32	1,133.70	3.60%	201.61	1,174.58
Exemplary Case	1.04%	3.13%	201.45	1,143.51	8.61%	203.85	1,179.27
Combination 2	2.62%	7.85%	203.62	1,150.93	12.09%	205.41	1,182.69
Combination 3	-2.56%	-0.85%	199.10	1,131.57	5.87%	202.62	1,172.22
Combination 4	1.67%	5.01%	202.31	1,140.57	10.83%	204.84	1,176.20
Combination 5	3.24%	9.71%	204.49	1,147.33	14.25%	206.37	1,179.07
Combination 6	-6.74%	-2.25%	197.62	1,135.67	1.67%	200.75	1,176.67
Combination 7	0.49%	1.48%	200.68	1,146.22	6.72%	203.01	1,182.04
Combination 8	2.07%	6.20%	202.86	1,154.28	10.24%	204.58	1,186.00

(μ_A, μ_B :100, σ_A^2 :20, σ_B^2 :60, α :3 (1/3 for negative k_j))

It is straightforward to verify that as Holding (H) and Backorder (B) cost components arise, total cost increases. Some other outcomes of the analysis is listed below:

- (1) As H increases (while B is constant), production quantity (S) decreases.
- (2) As B increases (while H is constant), production quantity (S) increases.
- (3) Combination 3 and Combination 8 signifies the situations where H and B affect the production quantity in the opposite direction. Comparing those situations with the Exemplary Case results demonstrates the dominant cost component for the concerning component differentiations. For example, in this case, the dominant differentiation is ΔB since both comparisons of the combinations confirm the outcome (2).

4.6.2 Total Cost Sensitivity Graphs

It is possible to perform unlimited sensitivity analyses with the ease that DSS Interface provides to the user. Moreover, under the previous assumptions, there are two kinds of analyses that this interface especially focuses on. These are: sensitivity graphics of total cost functions with respect to over/under production levels, and sensitivity graphics of total cost functions with respect to standard deviation parameters.

4.6.2.1 Sensitivity Graphs with respect to Over/Under Production Level (k_B)

Firstly, sensitivity analysis with respect to the deviation parameter k_B is illustrated by four figures respectively, representing the four scenarios (Figure 4.7 - 4.10). Priority ratio is 3 ($\alpha=3$).

These figures are derivatives of Figure 4.5 for which remarks were stated before. As already described, the graphs trace the result of the TC function while all other inputs are constant but the deviation parameter k_B is changing. The value of k_B is shown on the axis as the percentage of the z-levels covered regarding the company policy.

As proved before with the inequality (4.15), also shown in the Figure 4.5, total cost of the postponed structure never exceeds the total cost of the traditional structure when the input parameters are equal (Figure 4.7).

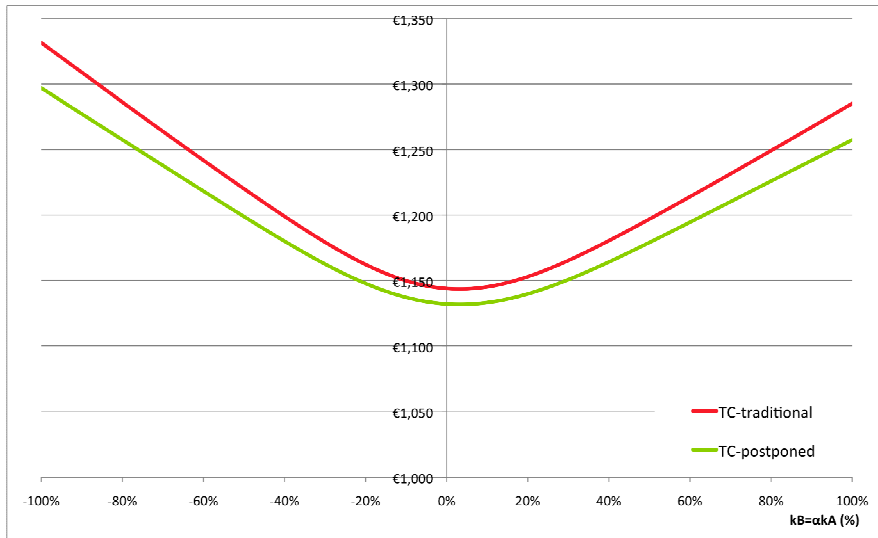


Figure 4.7 : Sensitivity analysis graph with respect to k_B (Base Case)

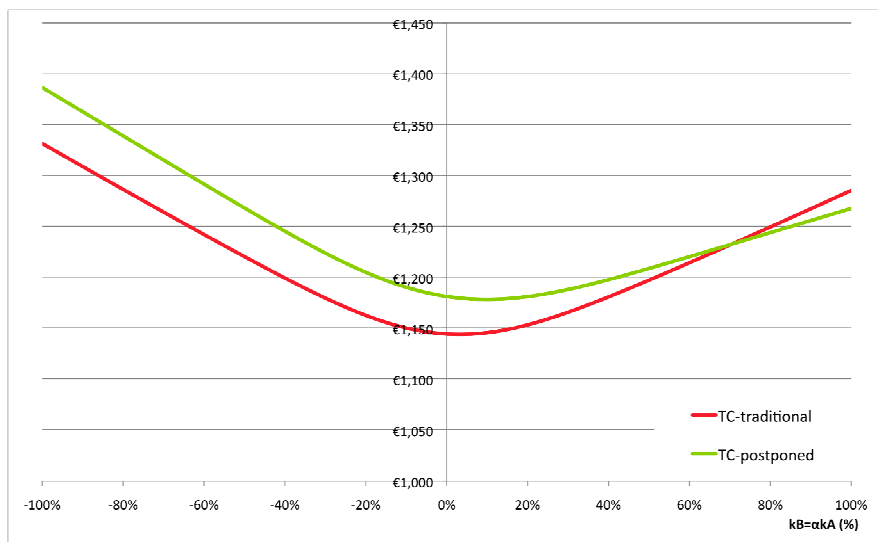


Figure 4.8 : Sensitivity analysis graph with respect to k_B (Scenario 1)

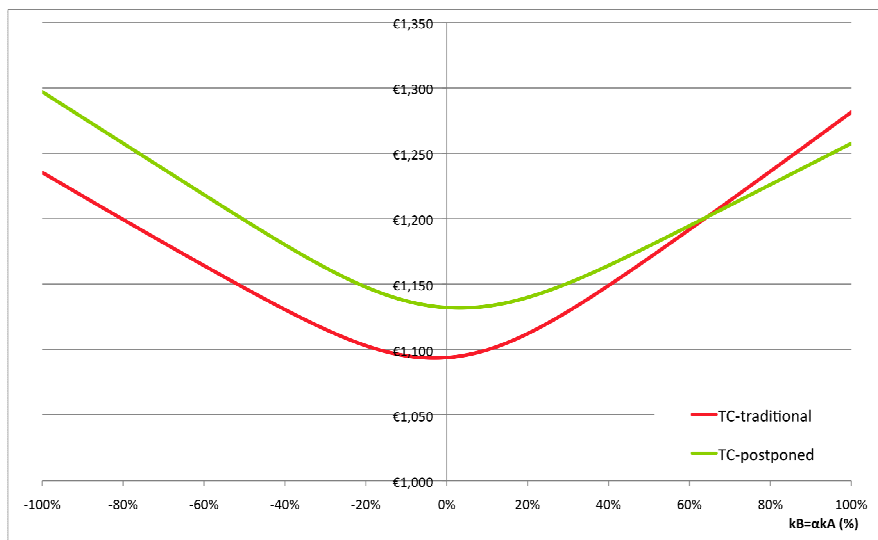


Figure 4.9 : Sensitivity analysis graph with respect to k_B (Scenario 2)

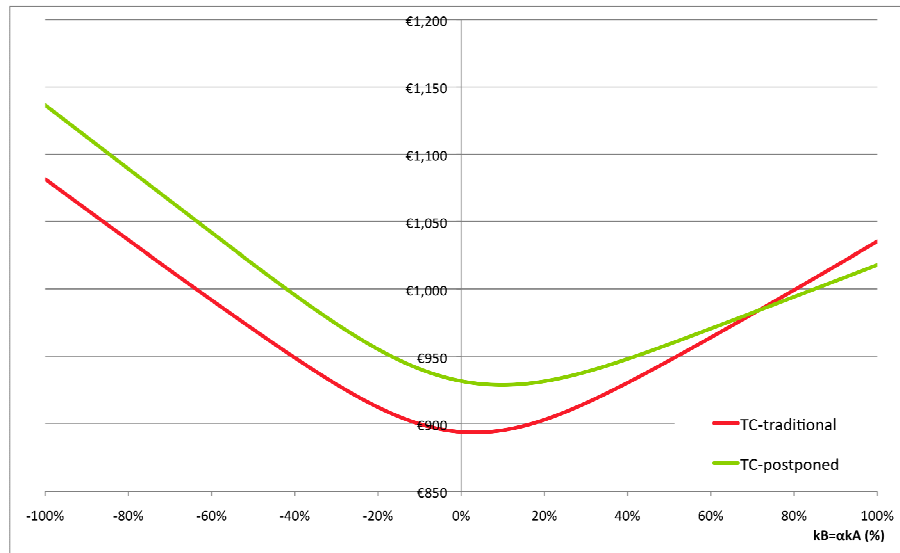


Figure 4.10 : Sensitivity analysis graph with respect to k_B (Scenario 3)

Previous three graphics show that postponed structure gains cost advantage when a company prefers to over produce, in other words, to work with higher service levels. This outcome was expected since higher service levels are satisfied with lower production quantity when postponement is employed; besides, as the variable costs decrease, the bulk savings increase from a reduction in the variability of demand.

In addition to these, while evaluating the decision of outsourcing, postponement or both, these scenario graphics happen to be informative guides since they reflect specific market characteristics on the model regarding postponement and modularization decisions.

As mentioned before, flexibility of the model design provides support for testing effects of any kind of input via DSS Interface. Therefore, scenario 1 will be tested for the different variance values of demand for Market A. Variance will respectively take the values 20 unit² (demonstrated with the Figure 4.8), 80 unit² and 160 unit² as illustrated with the Figures 4.11 and 4.12. Variance of Market B is always 60 unit², and $\alpha=3$ as in the previous cases.

Figures 4.8, 4.11 and 4.12 show that postponed structure is indeed more capable of handling demand uncertainty. Thus, as the variance of demand for Market A increases, the traditional structure starts to lose its cost advantage against the postponed structure up to lower k_B values. This result can be easily traced from the graphs by observing the movement of the intersection point between the two structures.

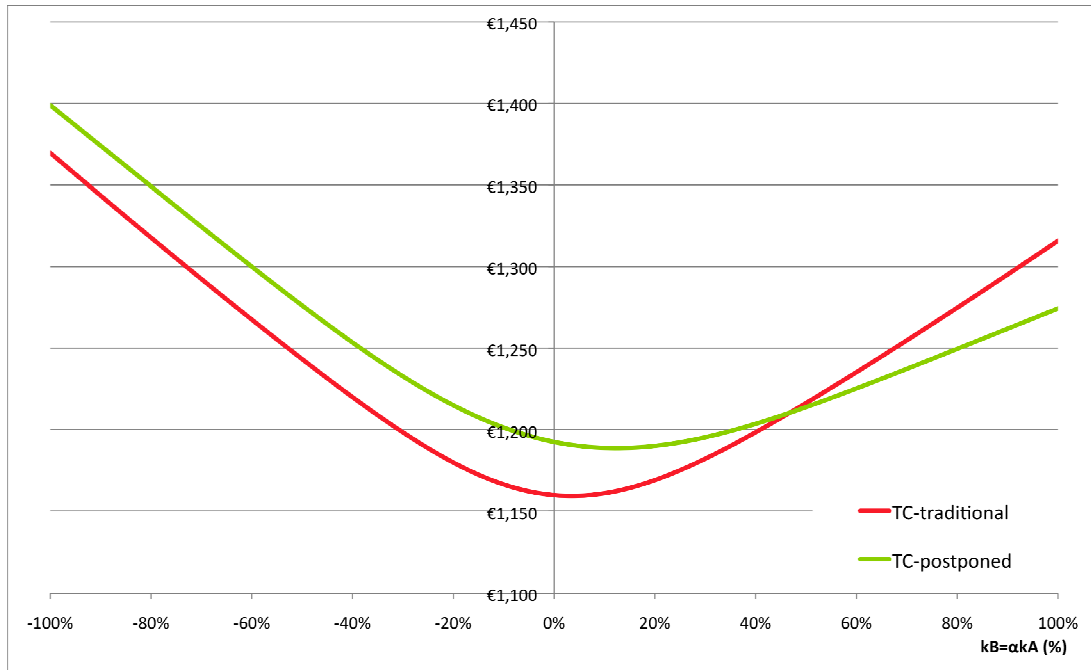


Figure 4.11 : TC Sensitivity graph with respect to k_B (Scenario 1, $\sigma_A^2=80$)

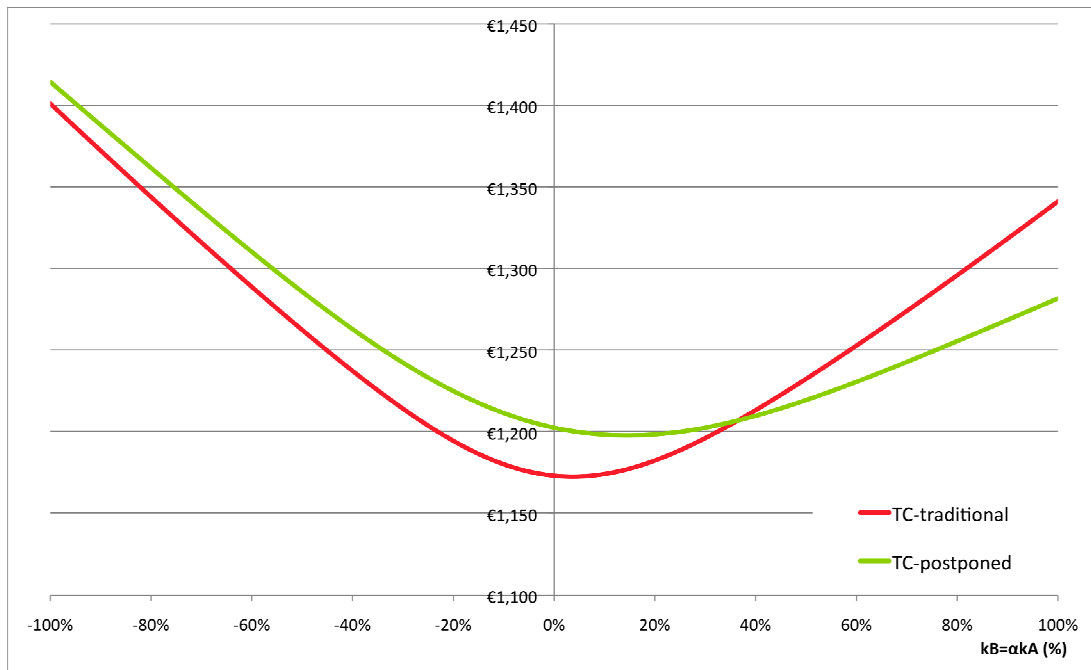


Figure 4.12 : TC Sensitivity graph with respect to k_B (Scenario 1, $\sigma_A^2=160$)

4.6.2.2 Sensitivity Graphs with respect to Standard Dev. Parameter (σ_A)

As it is clearly understood, employing postponement in a SC has a significant benefit as variance of demand increases; or, in other words, as demand becomes more uncertain. In addition to other analysis, the approach is also examined in depth via

another sensitivity analysis tool that is included in the content of the DSS Interface design. The concerning tool is another sensitivity graph that traces the result of the Total Cost function as standard deviations increase. It starts from zero fluctuation and rises to an uncertain demand characteristic. Standard deviations of the market demands are assumed to be proportional and they have a ratio of β ($\sigma_B = \beta\sigma_A$).

The following figures represent the variance sensitivity of aforementioned scenarios (Figure 4.13 - 4.16). ($\alpha = 3$, $k_A = 1.04$, $\beta = 1.732$)

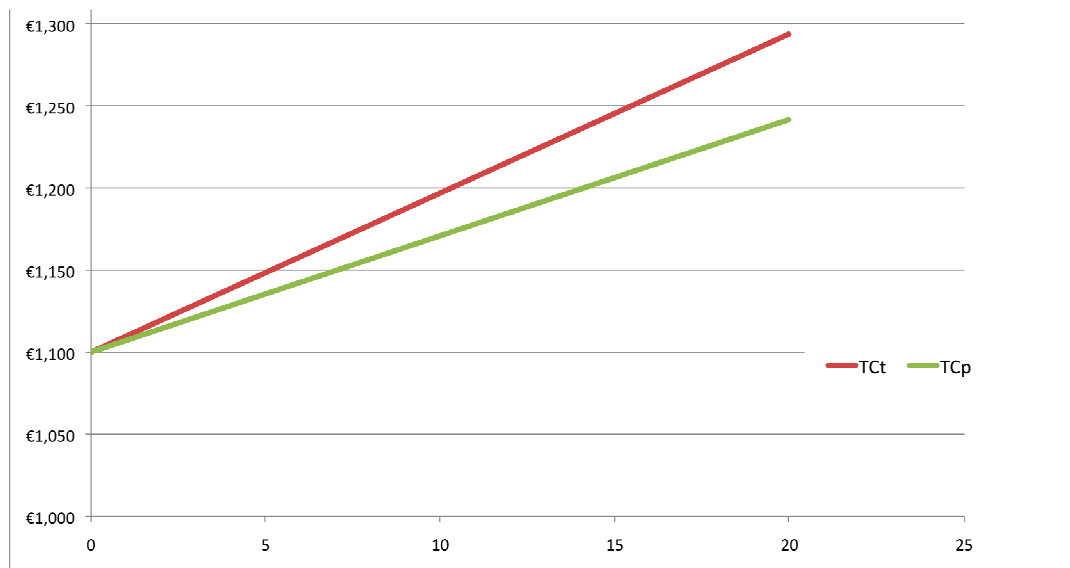


Figure 4.13 : Sensitivity analysis graph with respect to σ_A (Base Case Scenario)

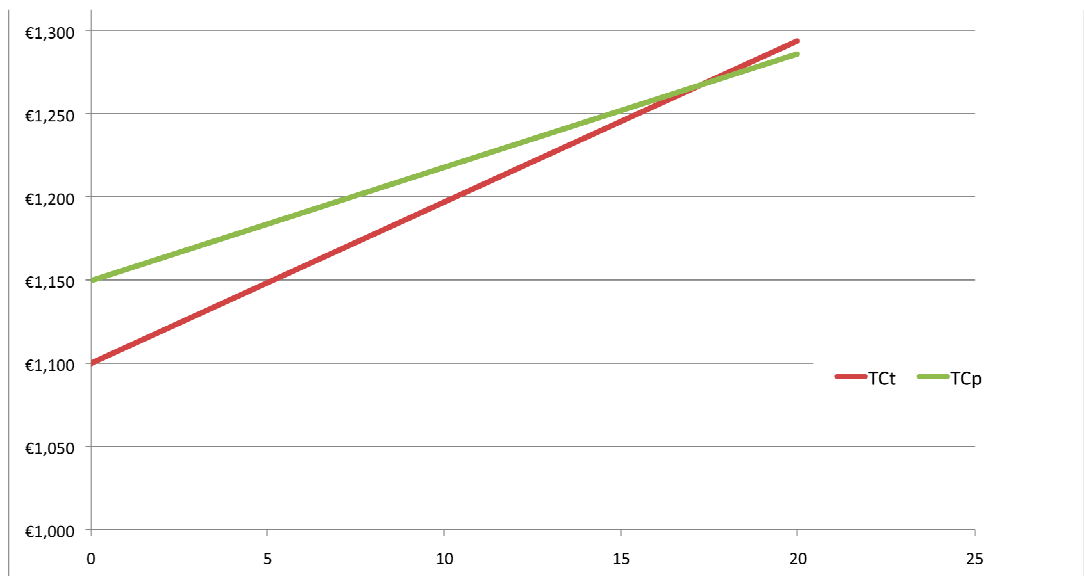


Figure 4.14 : Sensitivity analysis graph with respect to σ_A (Scenario 1)

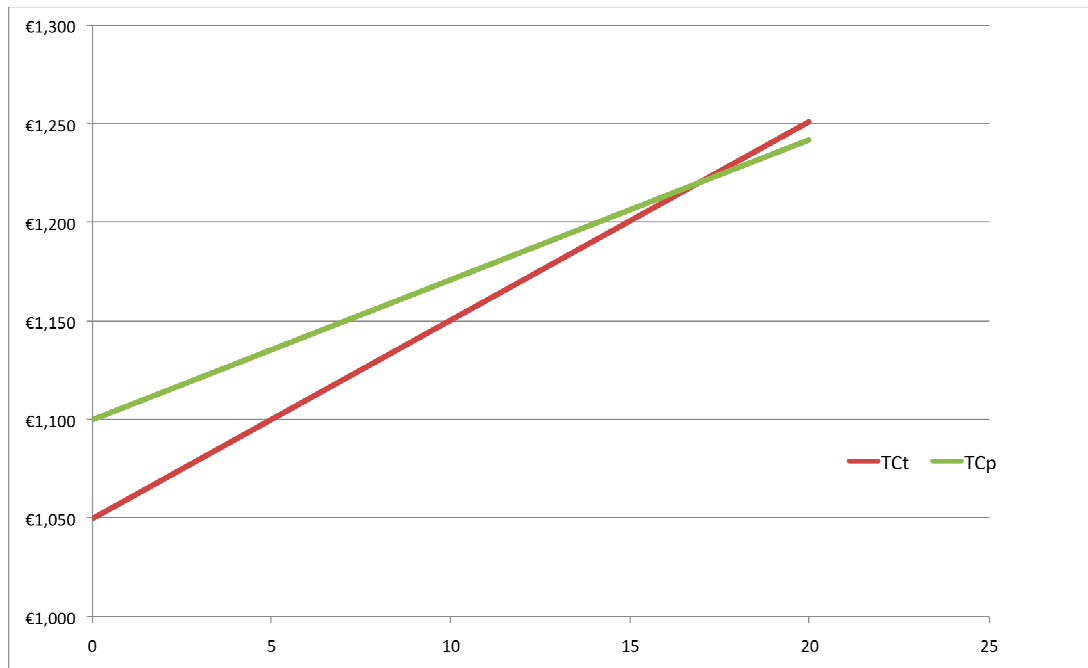


Figure 4.15 : Sensitivity analysis graph with respect to σ_A (Scenario 2)

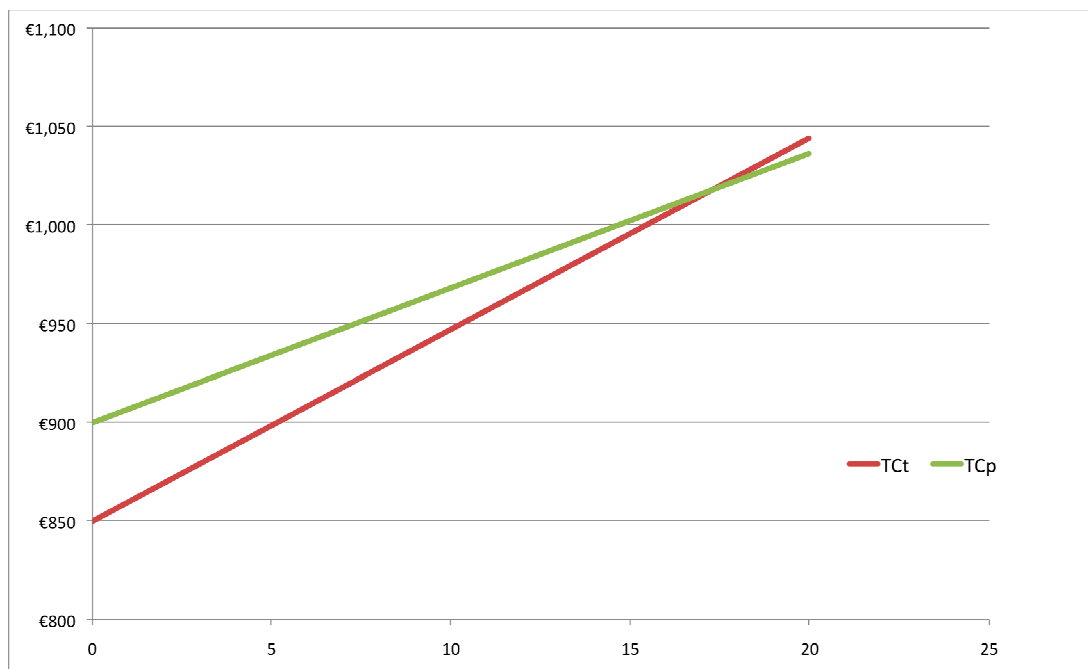


Figure 4.16 : Sensitivity analysis graph with respect to σ_A (Scenario 3)

These four graphics illustrate it clearly that postponed structure is more appropriate for uncertain demand characteristics; in contrast, traditional structure has a better performance under stable demand.

Intersection of the TC_T and TC_P functions simply indicate the point where structure costs are equal under the exact same input values. Furthermore, it is possible to suggest a general rule regarding the intersection point (if there is one), such as:

- Traditional structure, for the standard deviation (σ_A) values less than the σ value corresponding to the intersection point;
- Postponed structure, for standard deviation (σ_A) values higher than the σ value corresponding to the intersection point

should be preferred for a more cost efficient supply chain structure.

Deviation parameter k_A is taken as a constant parameter when drawing sensitivity analysis graphs for measuring the effect of demand uncertainty. As a further study, scenario 1 will be tested for the different k_A values. While $\alpha = 3$, k_A will respectively take the values 1.04% (demonstrated in the Figure 4.14), 5.2% and 26% as shown with the Figures 4.17 and 4.18. Since $\alpha = 3$, $k_B = 3 k_A$.

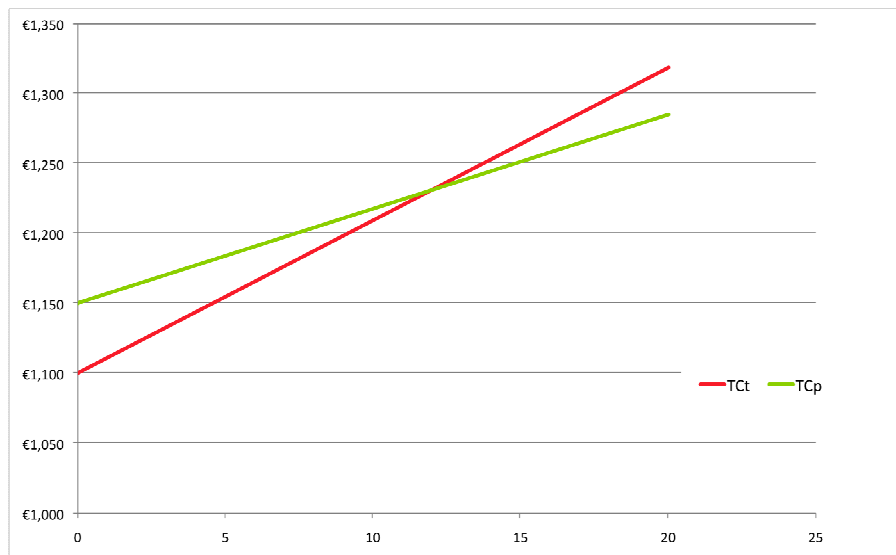


Figure 4.17 : Sensitivity analysis graph with respect to σ_A (Scenario 1, $k_A = 0.052$)

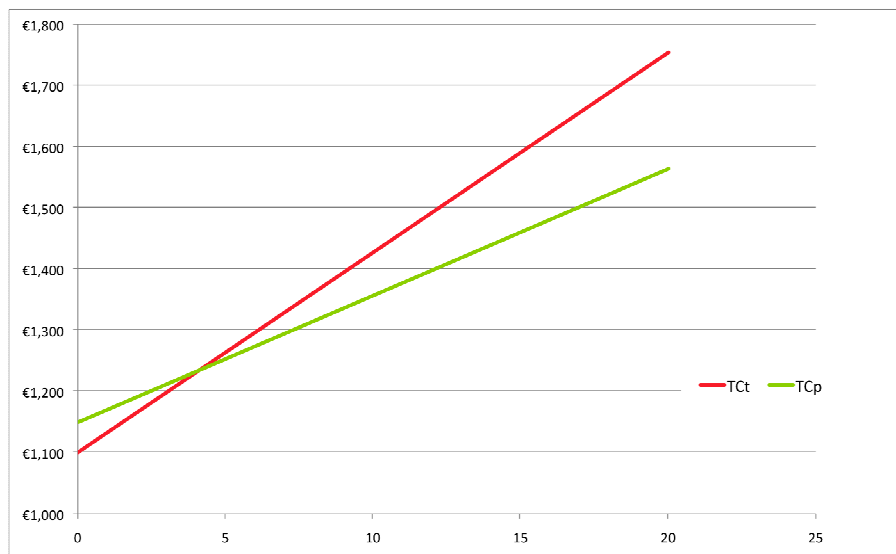


Figure 4.18 : Sensitivity analysis graph with respect to σ_A (Scenario 1, $k_A = 0.26$)

Comparison of the Figures 4.14, 4.17 and 4.18 show that for the higher service level requirements and as the demand gets uncertain, postponed structure becomes the one to be employed for the cost advantage. Conversely, as deviation parameter k_A increases, the intersection point shifts to lower values of standard deviation, which means the cost effective area of traditional structure gets smaller.

4.6.3 Findings of Sensitivity Analysis

The most important outcome of the sensitivity analysis section is that Total Cost - demand uncertainty connection is successfully acknowledged and illustrated by various graphics and table charts. Secondly, the analytical model proved itself several times by locating the expected results correctly and providing a high level of understanding on the SC cost behaviour. Moreover, the DSS interface for postponement decision was tested and enhanced as simulations were carried out. It is seen that, the graphics that the interface provides to the user play a very critical role in decision making since they include the trends of the functions under given parameters and selected variables. It is common sense that just plain numbers -for one case only- are not enough for creating enough understanding and perspective on the behaviour of a SC when the problem is quite complex; therefore, the DSS Interface gives the opportunity to generate simulations from the given parameters by employing mathematical and visual tools.

Sensitivity analyses were carried out in two categories under the appropriate scenarios that were created for simulating possible market characteristics. The first category is numerical analysis under which optimum results (over/under production level, production quantity, total cost) are calculated -for all eight cases signified by four scenarios-, alpha sensitivity is tested, and finally the effects of the alternation in Holding and Backorder cost parameters are measured. The latter category is graphical analysis, which consists of *Sensitivity Graphs with respect to Over/Under Production Level (k_B)*, and *Sensitivity Graphs with respect to Standard Deviation Parameter (σ_A)*. These graphs trace the result of the TC function while all other inputs are constant but the k_B or respectively σ_A is changing. The results obtained from the sensitivity analyses are summarized below:

- Under the same input values and when both markets are served with an identical over/under production percentage, total cost of the postponed

structure is always lower than the total cost of the traditional structure since the same service level can be achieved by producing less.

- When there is fierce competition between the subcontractors, outsourcing becomes very profitable
- An Increase in H decreases the production quantity (S); and, in contrast, an increase in B adds to the production quantity (S).
- The postponed structure gains cost advantage when the company prefers working with higher service levels.
- While the postponed structure is more appropriate for uncertain demand characteristics, traditional structure has a better performance under stable demand.

Flexibility of the model design provides support for testing effects of any kind of input via DSS Interface. For example, by fixing the demand variance to a constant level, the sensitivity graphs with respect to the over/under production parameter can be drawn; reciprocally, variance sensitivity is traced under a constant deviation parameter (k) representing a constant percentage of over/under production level within the feasible limits.

5. CONCLUSION AND FINAL REMARKS

Competition in the global business environment has forced companies to view the entire supply chain in an integrative manner. It is no longer adequate to optimize the manufacturing function without linking it to the distribution function or vice-versa. Consumers are more informed, more demanding and less loyal. The concepts of outsourcing and postponement allow companies to combine economies of scale and scope through the integration of product and process design.

In this study, thinking of the global competition, it is aimed to achieve a correlation between the fluctuations in demand and supply chain structure. Therefore a conceptual framework was updated to answer what supply chain structure is the most appropriate choice. Based on the degree of postponement different supply chain combinations were tested. Those analyses confirmed that vertical integration is not the best choice under recent environment conditions. In fact, more and more companies are replacing vertical integration with vertical coordination and developing long-term arrangements with outside suppliers.

The analytical framework in this study, though simple in its structure, provides a way to initiate the decision process. And a helpful tool for managerial decision-making was designed in MS Excel with the same simplicity. However, besides being very simple and functioning under some assumptions, the Decision Support System (DSS) Interface is very capable of pointing out some very valuable information.

The study performed by Ernst and Kamrad (2000) is the base for this research. The general cost model and four main supply chain structures as *Rigid*, *Postponed*, *Modularized*, and *Flexible* are referenced to this source. Differentiation from the main article had started by modifying the TC model; afterwards, appropriate scenarios were created for possible market characteristics, and the scenarios were tested with the help of the aforementioned MS Excel Interface, which is designed as a decision support system for the managers.

Recently, many companies are achieving significant competitive advantage by the way they configure and manage their supply chain structures. Thus, future research on this subject -but especially on the points that are not investigated in depth and which are briefed by making assumptions- should be carried out to form a much more precise model with an extensive context. Different combinations of service levels, H and B cost components should be explored in a more detailed manner, especially if the market specifications vary in the means of inventory handling or stock-outs. Also the differentiation parameters that are used to define the scenarios (ΔF and ΔV) are any two positive numbers and their magnitude can be specific to each case. Employment of those parameters is an assumption that is used as a way of simplifying the comparison among other supply chain structures and further research should explore the range and variability for these parameters in depth.

The study basically investigates the effects of postponement and many other parameters on a supply chain; in fact, this work can also be carried out for many other areas; i.e. for evaluating the profitable way of managing the storage points or warehouses (e.g. whether to serve from one main storage point or to separate it).

Last but not the least, the studied stationary model can be enhanced to a dynamic model by adding periodic inventory parameters where the inventory of a period (day, week, month) is carried to the next cycle. As S_T and S_P parameters define the - periodic- production quantities, the inventory of the previous periods can be subtracted from these values. Likewise, cases where transportation between the markets is possible can be studied. After providing a better total cost model, the decision support system interface can also be updated with a user-friendly approach to attain generality and ease. Moreover given the shortening in product life cycles, some analysis of different demand patterns for various products and markets would be definitely useful and an interesting direction for future research.

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APPENDICES

APPENDIX A: The Proof of Critical Ratios

APPENDIX B: The Proof of the Total Cost Proposition

APPENDIX C: DSS Interface

APPENDIX A: The Proof of Critical Ratios

To locate the absolute minimum point of convex functions the first derivatives are used as the second derivatives are employed for finding if a function is concave or convex.

Here in the aforementioned model, the service level parameter (z_A) that minimizes the total cost function is searched.

First of all, Leibniz's rule is used to determine the derivative of the expected understock function (Equation (4.4)). According to Leibniz's rule:

$$\frac{d}{dy} \int_{a_1(y)}^{a_2(y)} h(x, y) dx = \int_{a_1(y)}^{a_2(y)} [\partial h(x, y) / \partial y] dx + h(a_2(y), y) a_2'(y) - h(a_1(y), y) a_1'(y). \quad (\text{A.1})$$

Thus the derivative of Equation (4.4) will be:

$$\begin{aligned} \frac{d}{dS} \int_S^\infty (x - S) g(x) dx &= \int_S^\infty [\partial (x - S) g(x) / \partial S] dx + [(\infty - S) g(\infty)] 0 - [(S - S) g(S)] 1 \\ &= \int_S^\infty -g(x) dx + 0 - 0 \\ &= -[G(\infty) - G(S)] \\ &= G(S) - 1 = F(S) - 1 \end{aligned} \quad (\text{A.2})$$

Similarly,

$$\frac{d}{dz_A} G_A(z_A \sigma_A) = \sigma_A (G_A(z_A \sigma_A) - 1) = \sigma_A (F_{\sigma_A}(z_A \sigma_A) - 1), \quad (\text{A.3})$$

$$\frac{d}{dz_A} G_B(\alpha \beta z_A \sigma_A) = \alpha \beta \sigma_A (G_B(\alpha \beta z_A \sigma_A) - 1) = \alpha \beta \sigma_A (F_{\sigma_B}(\alpha \beta z_A \sigma_A) - 1), \quad (\text{A.4})$$

$$\begin{aligned} \frac{d}{dz_A} G_P(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) &= \sigma_A \sqrt{1 + \alpha^2 \beta^2} (G_P(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1) \\ &= \sigma_A \sqrt{1 + \alpha^2 \beta^2} (F_{\sigma_P}(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1) \end{aligned} \quad (\text{A.5})$$

As mentioned before the minimum point should satisfy,

$$\frac{d}{dz_A} TC_T(S_T) = 0, \quad (\text{A.6})$$

therefore the first derivative of Equation (4.9) will be determined and equalled to zero in order to satisfy this condition.

$$\begin{aligned} & 0 + V_T (\sigma_A (1 + \alpha\beta)) \\ & + H \sigma_A \left((1 + \alpha\beta) + F_{\sigma_A} (z_A \sigma_A) - 1 + \alpha\beta (F_{\sigma_B} (\alpha\beta z_A \sigma_A) - 1) \right) \\ & + B \sigma_A (F_{\sigma_A} (z_A \sigma_A) - 1 + \alpha\beta F_{\sigma_B} (\alpha\beta z_A \sigma_A) - \alpha\beta) = 0 \\ \\ & V_T (1 + \alpha\beta) + H (1 + \alpha\beta) + H (F_{\sigma_A} (z_A \sigma_A) + \alpha\beta F_{\sigma_B} (\alpha\beta z_A \sigma_A)) - H (1 + \alpha\beta) \\ & + B (F_{\sigma_A} (z_A \sigma_A) + \alpha\beta F_{\sigma_B} (\alpha\beta z_A \sigma_A)) - B (1 + \alpha\beta) = 0 \\ \\ & (H + B) (F_{\sigma_A} (z_A \sigma_A) + \alpha\beta F_{\sigma_B} (\alpha\beta z_A \sigma_A)) = (B - V_T) (1 + \alpha\beta) \end{aligned}$$

And finally the critical ratio condition for *traditional* structure is found as:

$$(1 + \alpha\beta) \frac{B - V_T}{H + B} = F_{\sigma_A} (z_A \sigma_A) + \alpha\beta F_{\sigma_B} (\alpha\beta z_A \sigma_A). \quad (\text{A.7})$$

Secondly, for the postponed structure the critical ratio condition will be found similarly by the use of Equation (4.11) instead of Equation (4.9):

$$\begin{aligned} & \frac{d}{dz_A} TC_P(S_P) = 0, \\ \\ & 0 = 0 + V_P \sigma_A \sqrt{1 + \alpha^2 \beta^2} \\ & + H \sigma_A \left(\sqrt{1 + \alpha^2 \beta^2} + \sqrt{1 + \alpha^2 \beta^2} \left(F_{\sigma_P} (z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1 \right) \right), \\ & + B \sigma_A \sqrt{1 + \alpha^2 \beta^2} \left(F_{\sigma_P} (z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1 \right) \\ \\ & V_P + H \left(1 + \left(F_{\sigma_P} (z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1 \right) \right) + B \left(F_{\sigma_P} (z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1 \right) = 0, \\ \\ & V_P + H + \left(F_{\sigma_P} (z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) - 1 \right) (H + B) = 0, \end{aligned}$$

$$\left(F_{\sigma_p} \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) \right) (H + B) = (B - V_p),$$

and finally the critical ratio condition for *postponed* structure is

$$\frac{B - V_p}{H + B} = F_{\sigma_p} \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right). \quad (\text{A.8})$$

After calculating the critical ratio conditions, second derivatives of TC functions with respect to z_A have to be determined to prove that the functions are convex and the points that satisfy the critical conditions are absolute minimums.

The second fundamental theorem of Calculus will be used for calculating the derivatives of integrals. According to this theorem:

$$\frac{d}{dx} \int_a^x f(t) dt = f(x) \quad (\text{A.9})$$

when $f(t)$ is continuous on $[a, x]$.

Since there is the variable z_A in the lower boundaries of the integrals, chain rule has to be applied before using the second fundamental theorem of calculus to be able to calculate the derivative of the integrals.

In calculus, the chain rule is a formula for the derivative of the composite of two functions. In intuitive terms, if a variable (y) depends on a second variable (u), which in turn depends on a third variable (x), then the rate of change of y with respect to x can be computed as the rate of change of y with respect to u multiplied by the rate of change of u with respect to x . Schematically,

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}. \quad (\text{A.10})$$

As calculated before, the first derivative of the TC_T function is below:

$$\begin{aligned} \frac{d}{dz_A} TC_T(S_T) &= (V_T + H) \sigma_A (1 + \alpha \beta) \\ &+ (H + B) \left(\int_{z_A \sigma_A}^{\infty} -\sigma_A g_A(x) dx + \int_{\alpha \beta z_A \sigma_A}^{\infty} -\alpha \beta \sigma_A g_B(x) dx \right). \end{aligned} \quad (\text{A.11})$$

This equation will be arranged -for ease of application- in the subsequent expressions:

$$\begin{aligned} \frac{d}{dz_A} TC_T(S_T) &= (V_T + H)\sigma_A(1 + \alpha\beta) \\ &+ (H + B)\sigma_A \left(\int_0^\infty -g_A(x)dx + \int_{z_A\sigma_A}^0 -g_A(x)dx + \alpha\beta \int_0^\infty -g_B(x)dx + \alpha\beta \int_{\alpha\beta z_A\sigma_A}^0 -g_B(x)dx \right) \end{aligned}$$

$$\begin{aligned} \frac{d}{dz_A} TC_T(S_T) &= (V_T + H)\sigma_A(1 + \alpha\beta) \\ &+ (H + B)\sigma_A \left(-0.5 + \int_0^{z_A\sigma_A} g_A(x)dx - 0.5\alpha\beta + \alpha\beta \int_0^{\alpha\beta z_A\sigma_A} g_B(x)dx \right) \end{aligned}$$

Finally, regarding the second fundamental theorem of Calculus and the chain rule, the second derivative of TC_T function with respect to z_A can be calculated.

$$\frac{d^2}{dz_A^2} TC_T(S_T) = (H + B)\sigma_A \left(\frac{d}{dz_A} \int_0^{z_A\sigma_A} g_A(x)dx + \alpha\beta \frac{d}{dz_A} \int_0^{\alpha\beta z_A\sigma_A} g_B(x)dx \right)$$

It then follows that,

$$\begin{aligned} u &= z_A\sigma_A, \frac{du}{dz_A} = \sigma_A \\ v &= \alpha\beta z_A\sigma_A, \frac{dv}{dz_A} = \alpha\beta\sigma_A \\ \frac{d^2}{dz_A^2} TC_T(S_T) &= (H + B)\sigma_A \left(\frac{d}{dz_A} \int_0^u g_A(x)dx + \alpha\beta \frac{d}{dz_A} \int_0^v g_B(x)dx \right), \\ &= (H + B)\sigma_A (g_A(u)u' + \alpha\beta g_B(v)v') \\ &= (H + B)\sigma_A (g_A(z_A\sigma_A)\sigma_A + \alpha\beta g_B(\alpha\beta z_A\sigma_A)\alpha\beta\sigma_A) \end{aligned}$$

until the equation below is obtained:

$$\frac{d^2}{dz_A^2} TC_T(S_T) = (H + B)\sigma_A^2 (g_A(z_A\sigma_A) + \alpha^2\beta^2 g_B(\alpha\beta z_A\sigma_A)), \quad (\text{A.12})$$

which is always positive since the normal distribution function never gets negative values. Therefore, TC_T function is convex, meaning the z_A parameter that satisfies the critical ratio condition belongs to the *cost minimization case*.

In a similar manner, the second derivative of TC_P function with respect to z_A is determined:

$$\frac{d}{dz_A} TC_P(S_P) = (V_P + H)\sigma_A \sqrt{1 + \alpha^2\beta^2} + (H + B) \int_{z_A\sigma_A \sqrt{1 + \alpha^2\beta^2}}^\infty -\sigma_A \sqrt{1 + \alpha^2\beta^2} g_P(x)dx \quad (\text{A.13})$$

By arranging the terms,

$$\begin{aligned}
\frac{d}{dz_A} TC_P(S_P) &= (V_P + H)\sigma_A \sqrt{1 + \alpha^2 \beta^2} \\
&+ (H + B)\sigma_A \sqrt{1 + \alpha^2 \beta^2} \left(\int_0^\infty -g_P(x) dx + \int_{z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}}^0 -g_P(x) dx \right) \\
&= \sigma_A \sqrt{1 + \alpha^2 \beta^2} \left((V_P + H) + (H + B) \left(-0.5 + \int_0^{z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}} g_P(x) dx \right) \right)
\end{aligned}$$

Once more regarding the second fundamental theorem of Calculus and the chain rule, the second derivative of TC_P function with respect to z_A will be calculated.

$$\frac{d^2}{dz_A^2} TC_P(S_P) = (H + B)\sigma_A \sqrt{1 + \alpha^2 \beta^2} \frac{d}{dz_A} \int_0^{z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}} g_P(x) dx$$

It then follows that,

$$\begin{aligned}
u &= z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}, \frac{du}{dz_A} = \sigma_A \sqrt{1 + \alpha^2 \beta^2} \\
\frac{d^2}{dz_A^2} TC_P(S_P) &= (H + B)\sigma_A \sqrt{1 + \alpha^2 \beta^2} g_P(u) u' \\
&= (H + B)\sigma_A \sqrt{1 + \alpha^2 \beta^2} g_P(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}) \sigma_A \sqrt{1 + \alpha^2 \beta^2}
\end{aligned}$$

The following equation is obtained:

$$\frac{d^2}{dz_A^2} TC_P(S_P) = (H + B)\sigma_A^2 (1 + \alpha^2 \beta^2) g_P(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2}), \quad (\text{A.14})$$

which is always positive since the normal distribution function $g(x)$ never gets negative values. Consequently, TC_P function as well is convex, and the z_A parameter that satisfies the critical ratio condition corresponds to the absolute minimum of the total cost function.

APPENDIX B: The Proof of the Total Cost Proposition

Taking the difference between Eq. (4.11) and Eq. (4.9) and rearranging the terms we obtain

$$\begin{aligned}
& TC_P(S_P) - TC_T(S_T) \\
&= F_P - F_T + V_P(S_P) - V_T(S_T) \\
&+ H \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} + G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - z_A \sigma_A (1 + \alpha \beta) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right) \\
&+ B \left(G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right) \\
&= F_P - F_T + V_P(S_P) - V_T(S_T) \\
&+ H z_A \sigma_A \left(\sqrt{1 + \alpha^2 \beta^2} - (1 + \alpha \beta) \right) \\
&+ (H + B) \left(G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right)
\end{aligned} \tag{B.1}$$

Since $TC_P(S_P) \leq TC_T(S_T)$ is the proposition, it then follows that

$$\begin{aligned}
& TC_P(S_P) - TC_T(S_T) \leq 0 \\
& F_P - F_T + V_P(S_P) - V_T(S_T) \\
&+ H z_A \sigma_A \left(\sqrt{1 + \alpha^2 \beta^2} - (1 + \alpha \beta) \right) \\
&+ (H + B) \left(G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right) \leq 0
\end{aligned}$$

$$\begin{aligned}
& F_P - F_T \leq V_T(S_T) - V_P(S_P) \\
& - H z_A \sigma_A \left(\sqrt{1 + \alpha^2 \beta^2} - (1 + \alpha \beta) \right) \\
& - (H + B) \left(G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right)
\end{aligned}$$

Therefore,

$$F_P - F_T \leq V_T(S_T) - V_P(S_P) - K \tag{B.2}$$

$$\begin{aligned}
& K = H z_A \sigma_A \left(\sqrt{1 + \alpha^2 \beta^2} - (1 + \alpha \beta) \right) \\
& + (H + B) \left(G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) - G_A(z_A \sigma_A) - G_B(\alpha \beta z_A \sigma_A) \right)
\end{aligned} \tag{B.3}$$

Besides, at this point, it is possible to prove that K is always < 0 , since

$$\sqrt{1 + \alpha^2 \beta^2} = \sqrt{(1 + \alpha\beta)^2 - 2\alpha\beta} \rightarrow \sqrt{1 + \alpha^2 \beta^2} \leq (1 + \alpha\beta), \text{ and}$$

$$G_P \left(z_A \sigma_A \sqrt{1 + \alpha^2 \beta^2} \right) \leq G_A(z_A \sigma_A) + G_B(\alpha \beta z_A \sigma_A) \quad (\text{B.4})$$

where $G(x)$ is always positive and a decreasing function.

APPENDIX C: DSS Interface

The DSS Interface is thought to be a supportive tool for managerial decisions. It is designed as layers of *MS Excel* sheets that provide inputs, outputs, and sensitivity analysis with visually enhanced graphics. The main window of the interface is built on the first sheet and consists of the numerical input and output cells. As soon as any combination of input values are entered or updated; the interface automatically evaluates the output parameters, updates the main screen values, and precisely sketches the graphics in their corresponding chart sheets.

Moreover, input field and output fields are all designed in a way that is easy to use and understand. Most of the labels are illustrative, and few confusing points are explained by inserting comments to necessary cells.

Below, the pieces of the main screen are explored step by step; afterwards, overall appearance is revealed. Directions for use (DFU) are given under each piece of screenshot when it is necessary.

First of all, main output frame of DSS is illustrated in Figure C.1. This frame is especially selected to be the first one for a better understanding of input frame descriptions, which is the focus of the next step.

OUTPUT					
Under Desired Over/Under Production Levels			Cost Minimization (Optimal Levels Calculated to Minimize Cost)		
	Market A	Market B		Traditional Structure	Postponed Structure
Deviation of Prod. Quantity from μ (k)	10.00%	15.00%	Deviation Param. for Market A (kA)	1.69%	2.89%
	Traditional Structure	Postponed Structure	Deviation Param. for Market B (kB)	3.38%	5.79%
Total Prod. Quantity	266.20	261.62	Total Prod. Quantity	253.27	254.14
Total Cost	EUR 1,353.60	EUR 1,374.64	Total Cost	EUR 1,342.77	EUR 1,369.55

Figure C.1 : Main Output Frame of DSS

The main output frame gives the overall results in a very simplistic way. On this field, the results are grouped under two titles as *Output Under Desired Over/Under Production Levels* and *Output of the Cost Minimization Case*:

The first group is placed on the left-hand side of the frame as it is shown on Figure C.1, and includes the results of total production quantity and total cost for both structures regarding user assigned over/under production deviation parameters (k), which are also shown on the same side to prevent complications.

Secondly, the latter group illustrates the cost minimization case results, for which the over/under production deviation parameters (k) are evaluated automatically within the DSS Interface to fit the cost minimization conditions.

In addition to those, there are two more pieces of output frames that include advanced results for both cases mentioned above. These frames (Figure C.3, Figure C.4) will be illustrated just after the input frame (Figure C.2).

INPUT					
Common Cost Parameters	Traditional Structure	Postponed Structure	Demand Parameters for Markets	Market A	Market B
Fixed Cost	EUR 500.00	EUR 630.00	Mean Demand (μ)	100	150
Variable Cost (per unit)	EUR 3.00	EUR 2.70	Variance of Demand (σ^2) (Uncertainty)	180	160
Backorder C. (per unit)	EUR 8.00				
Hoding Cost (per unit)	EUR 1.00		Desired Dev. of Prod. Quantity from μ (k)	10.00%	15.00%
Priority Ratio (α)(Market B/A)		2.00	Desired β (σ_B/σ_A)		3
INPUT - Advanced Parameters					
Sigma qualifier of business		5 σ			

Figure C.2 : Input frame of DSS

There are three kind of calculations carried out with the values above:

- Total Cost calculations under desired over/under production deviation parameters (k),
- Total Cost calculations of the cost minimization case
- Total Cost sensitivity analysis with respect to standard deviation (σ)

While all these kinds utilize many common parameters such as mean demands, fixed, costs, etc., there are a few variables that make the differentiation.

- Desired deviation of production quantity from expected (mean) demand (k) for Market A and Market B gives the possibility to assign the any over/under production level to any market individually. Understandably, this parameter is occupied for the TC calculations under desired over/under production levels.
- Priority Ratio (α) is -as explained before while making the analytical formulation- the ratio between the over/under production deviation parameters of Market B to Market A (k_B/k_A). This variable is utilized in TC minimization case.
- Desired β is the ratio between the standard deviations of again Market B to Market A, and utilized in TC sensitivity analysis. Besides it can be automated by assigning the function “=H13” to its corresponding cell. This function will allocate the value of β from the values of variance input.
- And Variance of Demand is used in all cases except TC sensitivity analysis.

Common cost parameters (fixed, variable, holding, backorder), sigma qualifier of business and mean demand are standard in any kind of calculation.

The following Figure C.3 demonstrates the advanced output frame of total cost calculations under the user controlled over/under production levels; and, Figure C.4 demonstrates the advanced output frame of total cost calculations under the optimal over/under production levels for cost minimization case. Priority ratio is especially emphasized in both fields since it is the only different parameter between those two evaluations. Moreover, cost components are individually shown in currency and ratios to give a better perspective of the cost components.

OUTPUT - Advanced Evaluation Under Desired Production Levels					
Desired Priority Ratio of markets (Market B/Market A)		Traditional Structure			Postponed Structure
1.5		Market A	Market B	Markets in Total	Markets in Total
Standard Deviation of Demand Distribution (σ)		13.41640786	12.64911064		18.43908891
Deviation of Production Quan. from Mean (Estimated) Demand as z-level		0.5	0.75		0.630126038
Cost Components	Fixed	EUR 500.00			EUR 630.00
	Variable	EUR 320.12	EUR 478.46	EUR 798.59	EUR 706.37
	Holding	EUR 9.36	EUR 11.15	EUR 20.51	EUR 14.58
	Backorder	EUR 21.23	EUR 13.27	EUR 34.50	EUR 23.68
	V+H+B	EUR 350.72	EUR 502.88	EUR 853.60	EUR 744.64
Cost Components in Ratios	Fixed	36.94%			45.83%
	Variable	23.65%	35.35%	59.00%	51.39%
	Holding	0.69%	0.82%	1.52%	1.06%
	Backorder	1.57%	0.98%	2.55%	1.72%
	V+H+B	25.91%	37.15%	63.06%	54.17%

Figure C.3 : Advanced Output frame of DSS for desired production levels

OUTPUT - Advanced Evaluation of Optimal Solution					
Priority Ratio (α)	Current β (σ_B/σ_A)	Traditional Structure			Postponed Structure
2	0.94281	Market A	Market B	Markets in Total	Markets in Total
Standard Deviation of Demand Distribution (σ)		13.41640786	12.64911064		18.43908891
Deviation of Production Quan. from Mean (Estimated Demand as z-level)		0.084560234	0.169120469		0.224687715
Cost Components	Fixed	EUR 500.00			EUR 630.00
	Variable	EUR 303.40	EUR 456.42	EUR 759.82	EUR 686.19
	Holding	EUR 5.94	EUR 6.19	EUR 12.13	EUR 9.61
	Backorder	EUR 38.43	EUR 32.39	EUR 70.82	EUR 43.76
	V+H+B	EUR 347.78	EUR 494.99	EUR 842.77	EUR 739.55
Cost Components in Ratios	Fixed	37.24%			46.00%
	Variable	22.60%	33.99%	56.59%	50.10%
	Holding	0.44%	0.46%	0.90%	0.70%
	Backorder	2.86%	2.41%	5.27%	3.19%
	V+H+B	25.90%	36.86%	62.76%	54.00%

Figure C.4 : Advanced Output frame of DSS for cost minimization case

There are also eight pie charts (Figure C.5, Figure C.6) on the main window of DSS Interface that gives a high level of understanding of cost components and their contribution to overall TC.

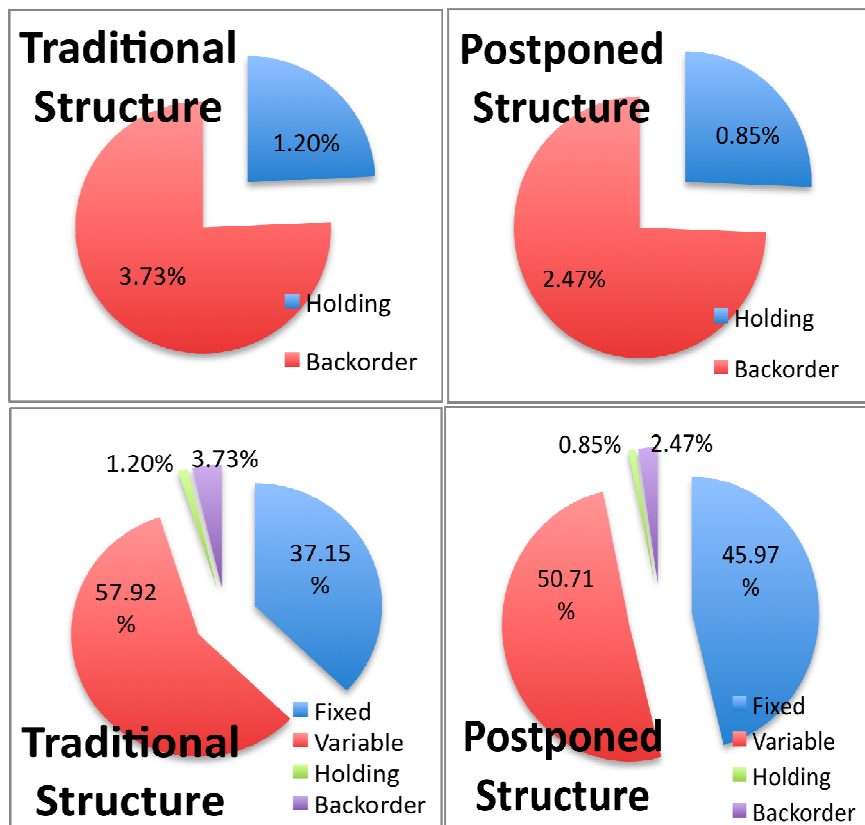


Figure C.5 : Pie Charts of cost components under desired service levels

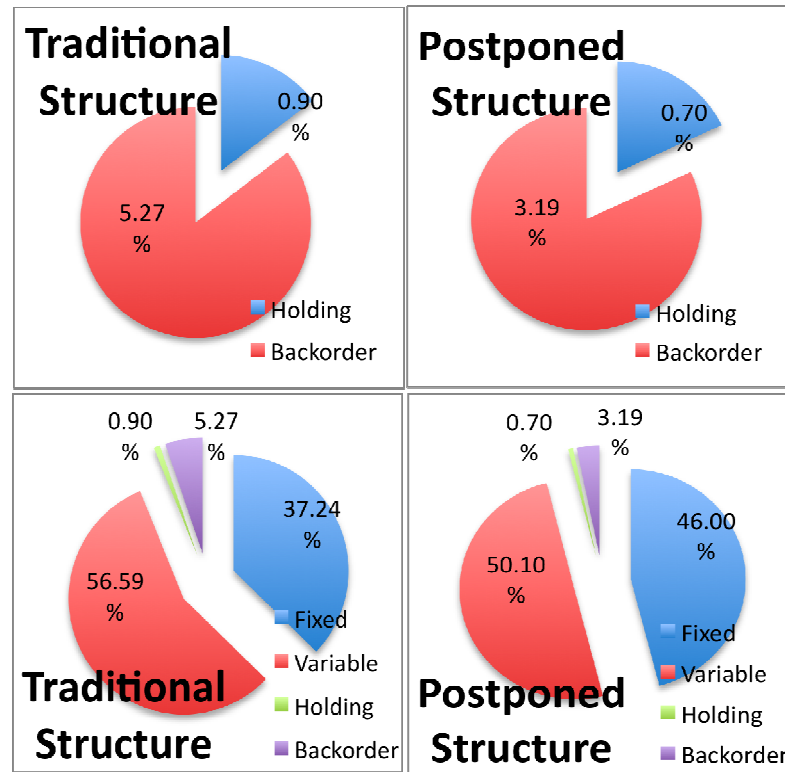


Figure C.6 : Pie Charts of cost components for the cost minimization case

Another advanced evaluation field on the main window of the DSS interface is demonstrated in the Figure C.7. This part is mainly designed to give the status of intersections between the total cost results (where the total costs are equal during the sensitivity analysis with respect to service levels or standard deviations) of the traditional and postponed structures. Here in this piece, the differences between the optimal Total Costs are continuously screened as well, and the optimal overall deviation parameter of postponed structure, which does not exist in the main output frame, is shown.

Evaluated Deviation Param. (k) of Postponed Structure in Cost Minimization Case:		Output-TCProp(optimal case)		2nd Intersection point of curves(if available)
		TCp(opt)-TCt(opt)		
		EUR 26.78		
4.49%		Intersection point of curves(if available)		
Adjusted into level of :				
Market A	Market B	kA	19.69%	-23.86%
2.89%	5.79%	TC	EUR 1,413.84	EUR 1,488.15
		kB	39.37%	-47.73%
TC-σ SENSITIVITY Analysis regarding desired parameters		Intersection Point w.r.t. σA		σA^2
		14.0211597		196.5929194
				σB^2
				1769.33627

Figure C.7 : Advanced Output frame of DSS for intersection points

Following Figure C.8 is a screenshot of the main window of DSS Interface.

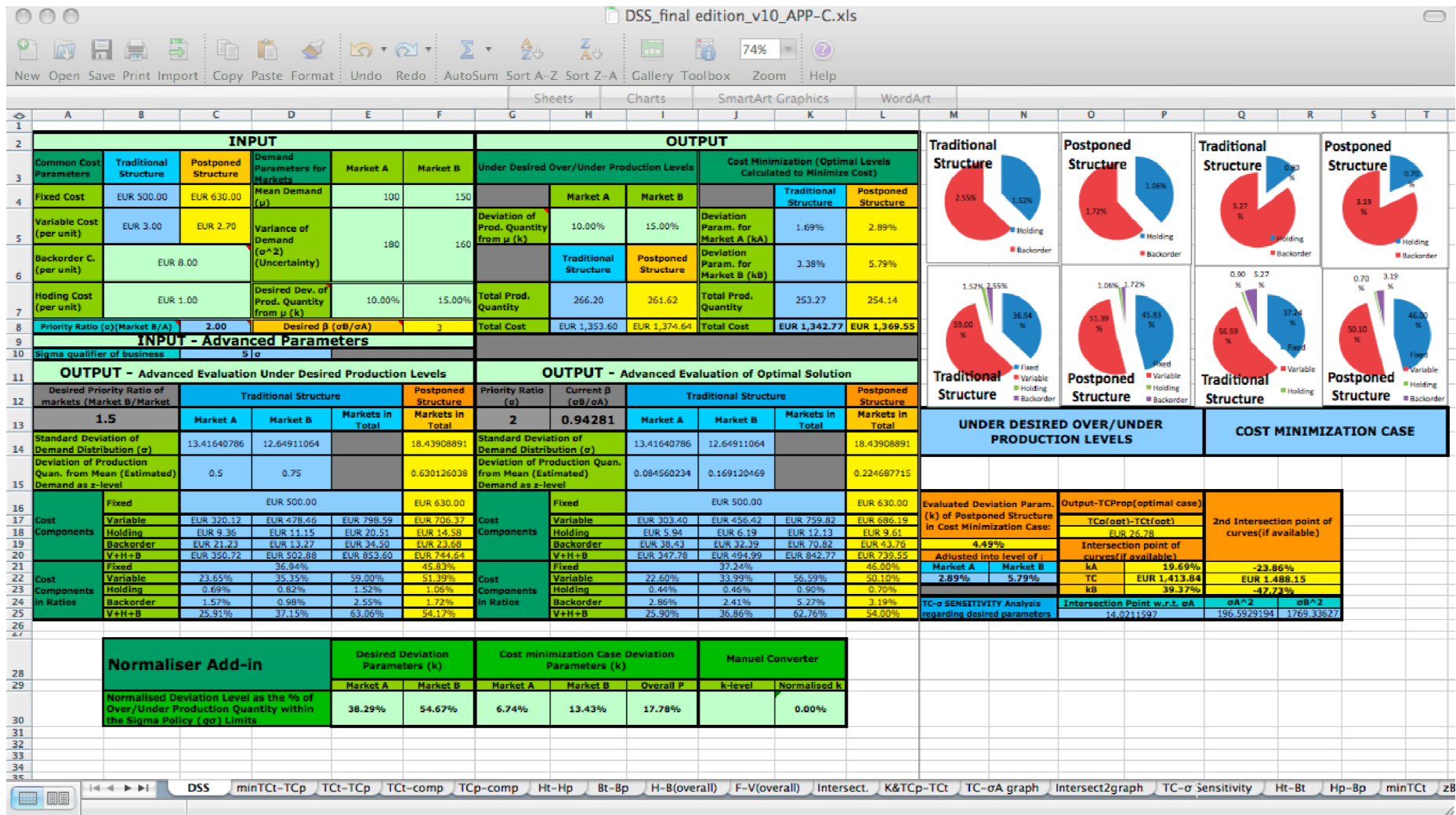


Figure C.8 : The main window of the DSS Interface

And finally the last piece on the main window of the DSS interface is the Normaliser Add-in (Figure C.9). This piece aims to convert the k values (that are proportional to z-values) to unit scale. The converted value will show how many percent of the fluctuation (in production units) is covered by the buffer stock. The choice was made for simplicity; but support for the users is given with this add-in embedded into the main window of the DSS Interface.

Normaliser Add-in	Desired Deviation Parameters (k)		Cost minimization Case Deviation Parameters (k)			Manuel Converter	
	Market A	Market B	Market A	Market B	Overall P	k-level	Normalised k
Normalised Deviation Level as the % of Over/Under Production Quantity within the Sigma Policy ($q\sigma$) Limits	38.29%	54.67%	6.74%	13.43%	17.78%		0.00%

Figure C.9 : *Normaliser* Add-in of DSS Interface

As it is viewed on the bottom of the main window of the DSS Interface, this MS Excel document is consisted of several sheets. In fact it was already stated that the main window is using the first sheet of the document. The other sheets are chart sheets that include graphics, and excel sheets where the formulation of the framework is made and all evaluations are carried out. Following figures are some screenshots from these sheets.

Second sheet, -labelled as minTCt-TCp- includes a number of graphics, which focus on the absolute minimums of the TC functions regarding both types of SC structures. (Figure C.10)

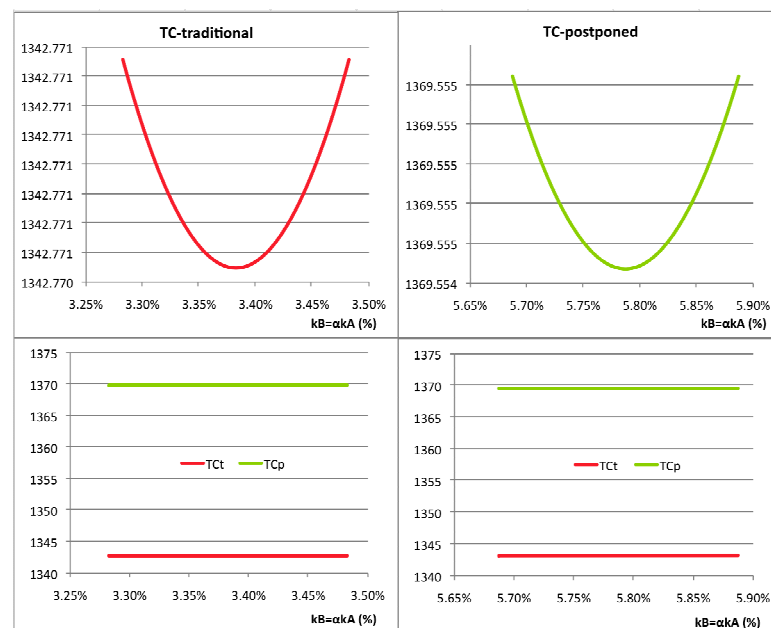


Figure C.10 : TC function graphs focused around optimum points in cost min. case

Besides, bar charts that compare the optimum point results are also found on this sheet. These bar charts are a different way of demonstrating the cost components that are shown with pie charts in the main window. The reason why both charts are presented in the interface is that it needs to be ergonomic for anyone -since every people have a different way of understanding-. Bar charts are shown below in the Figures C.11 and C.12.

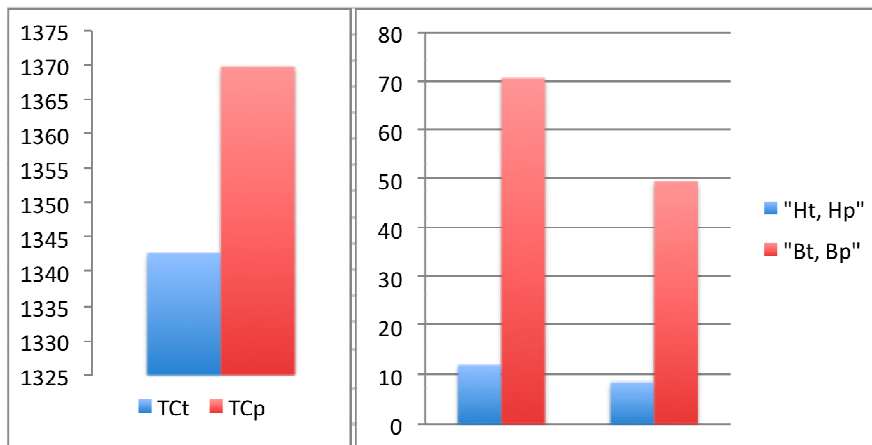


Figure C.11 : Cost minimization case - Bar charts (Evaluated at the optimum service level of traditional structure)

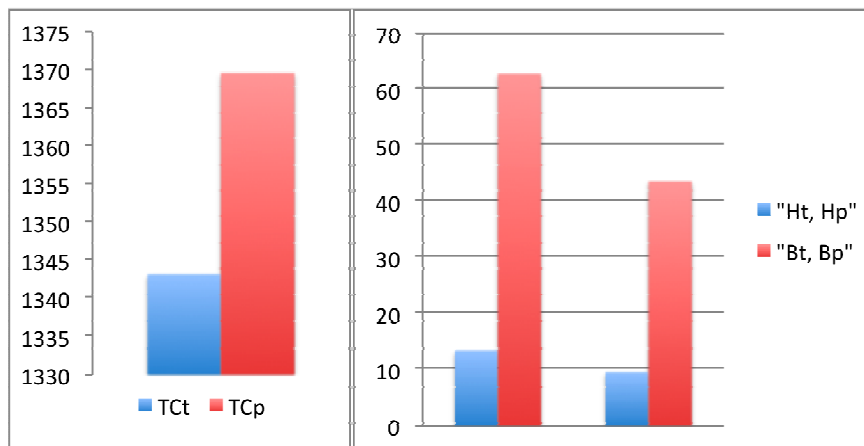


Figure C.12 : Cost minimization case - Bar charts (Evaluated at the optimum service level of postponed structure)

Third sheet -labelled as TCt-TCp- is a chart sheet, which holds a graph that the sensitivity analysis of TC functions with respect to k_B (full range of over/under production) is made. This sheet is one of the most important graphs for a manager when taking the service level (over/under production) and postponement decision since it shows the behaviour of both structures in a very wide perspective.

Furthermore, any changes in the input parameters will immediately show up here and their effects on TC can be easily observed. It is possible to say that the framework is a basic simulation of a virtual marketplace with all the flexibility provided by the interface to the user. The sensitivity analysis of the TC functions with respect to k_B is illustrated in the Figure C.13.

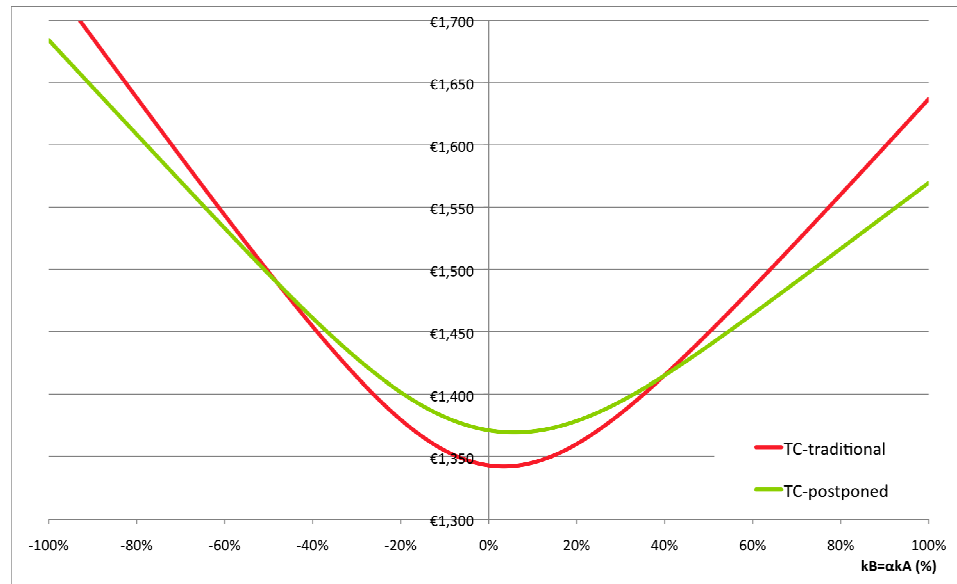


Figure C.13 : Sensitivity analysis of the TC functions with respect to k_B

Placed on the 4th and 5th sheets of the DSS interface, Figure C.14 and Figure C.15 points up to the sensitivity of the total cost components of supply chain with respect to k_B .

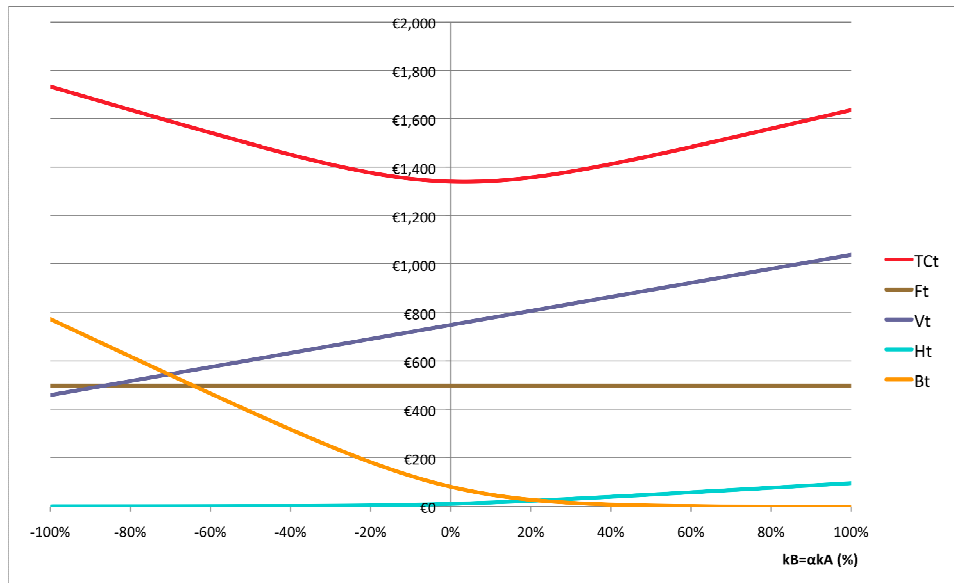


Figure C.14 : Sensitivity analysis of the TC components with respect to k_B
(Traditional Structure)

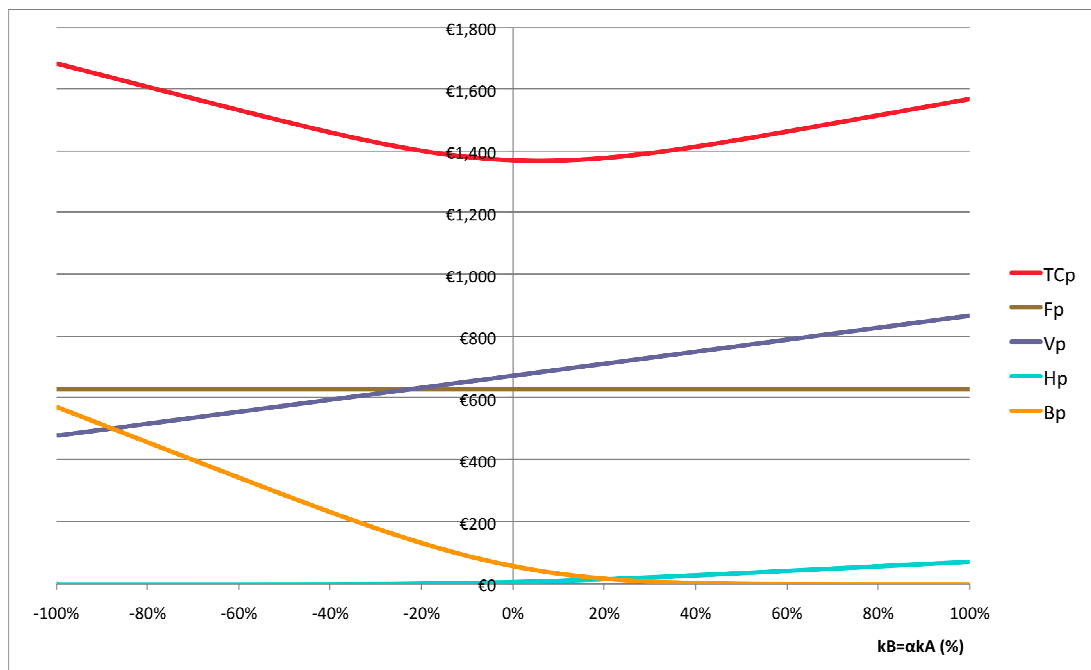


Figure C.15 : Sensitivity analysis of the TC components with respect to k_B
(Postponed Structure)

The TC components shown in the figures are overall fixed, variable, holding and backorder costs. Following four sheets of the DSS interface is a focused approach to the total cost components of the traditional and postponed structures. Firstly, the holding costs, then the backorder costs are compared individually in depth. Their

overall is demonstrated in the next sheet and finally the fixed and variable cost comparison is given place afterwards (Figures C.16 - C.19).

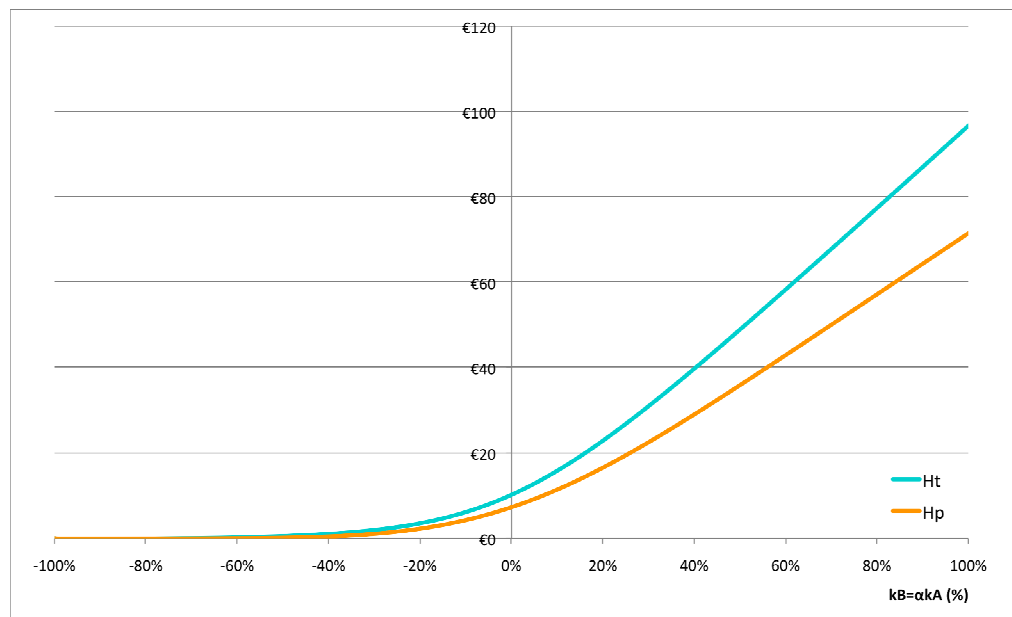


Figure C.16 : Sensitivity analysis of the Holding costs with respect to k_B

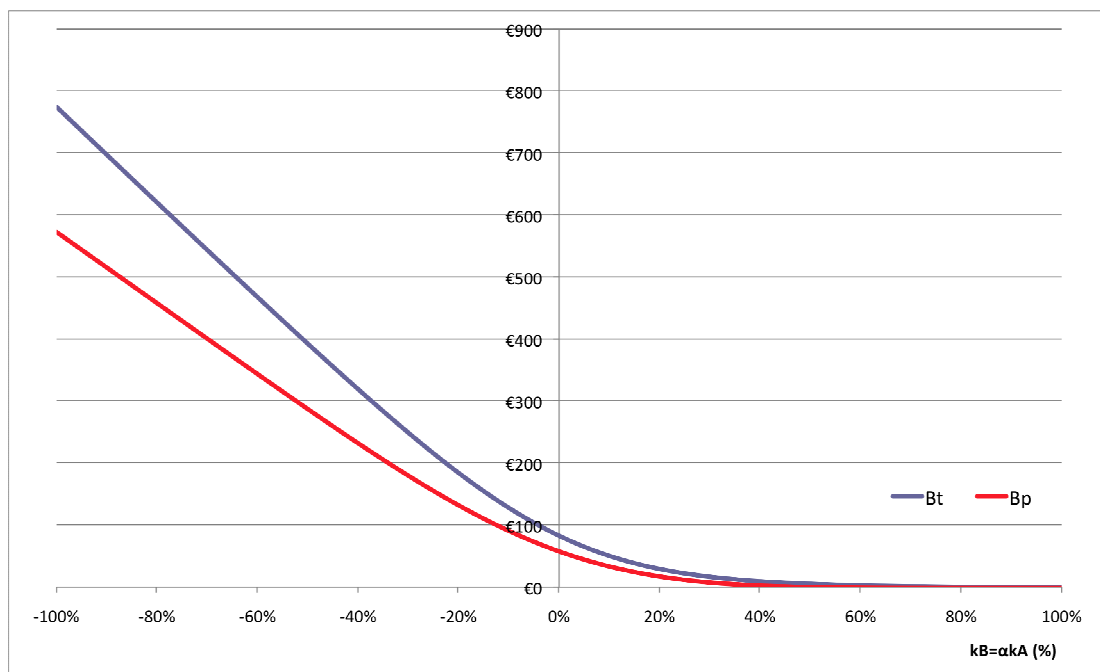


Figure C.17 : Sensitivity analysis of the Backorder costs with respect to k_B

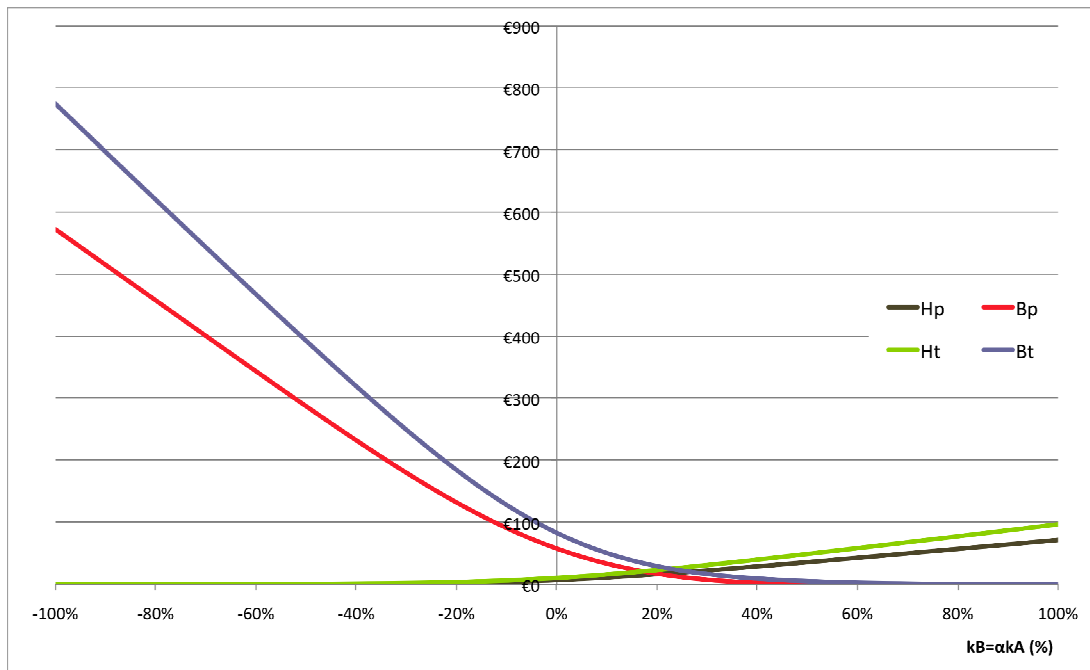


Figure C.18 : Sensitivity analysis of the Holding and Backorder costs with respect to k_B

Holding and Backorder cost graphics for the structures individually are also found in the context of the interface; however, Figure C.18 already demonstrates them here, and they will not be shown in this section. As stated before for the bar charts, these graphs are also present in the interface just for ergonomic reasons.

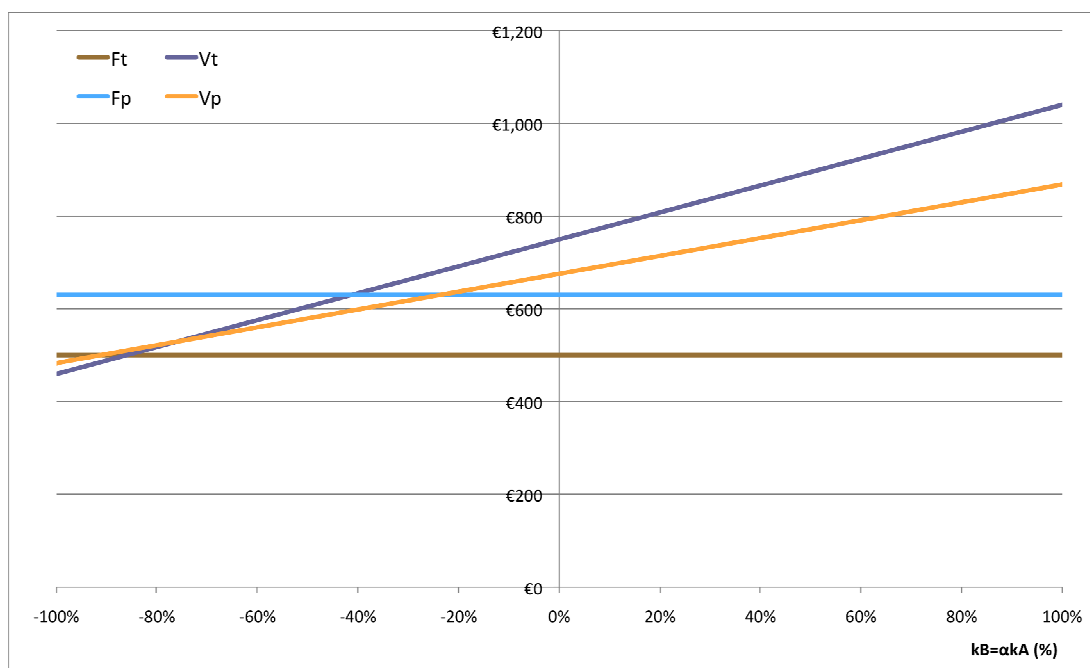


Figure C.19 : Sensitivity analysis of the Fixed and Variable Costs with respect to k_B

Furthermore, intersection(s) between the total cost results (where the total costs of traditional and postponed structures are equal during the sensitivity analysis with respect to service levels) are sketched if available. Rarely, two intersections are possible as shown in the Figures C.20 and C.21.

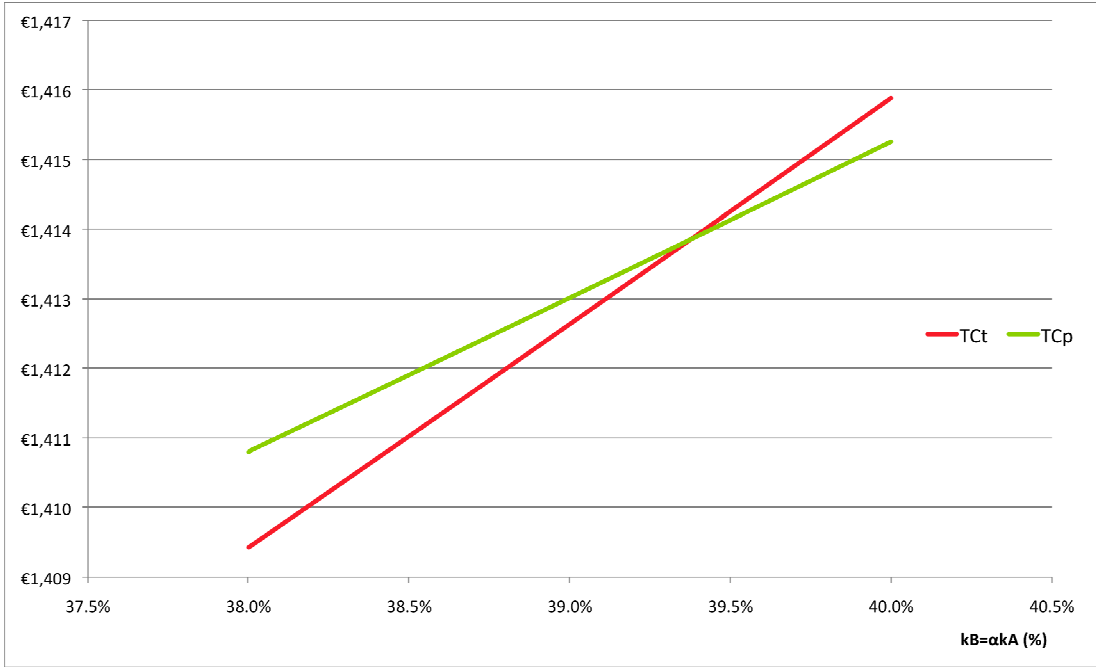


Figure C.20 : Intersection point (1) analysis with respect to k_B

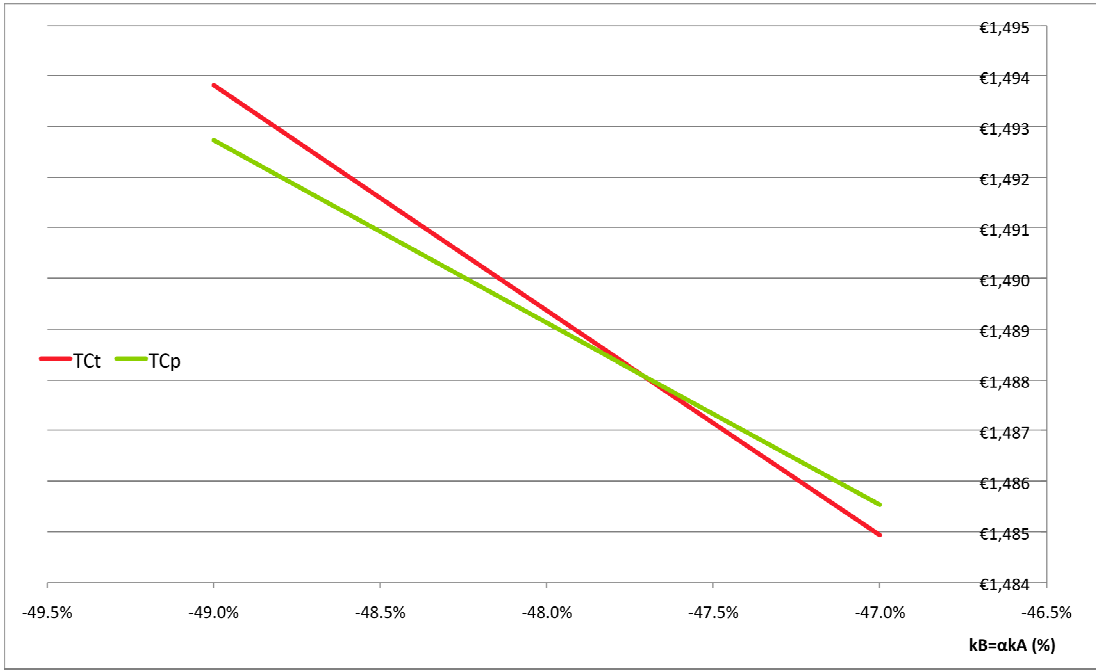


Figure C.21 : Intersection point (2) analysis with respect to k_B

Total Cost difference proposition and the “K” parameter are also modelled by DSS as demonstrated in the Figure C.22.



Figure C.22 : ΔTC_i proposition and the “K” parameter with respect to k_B

Last of all, another important set of graphics is provided by DSS interface on the sheet called “TC- σ_A graph” and “TC- σ Sensitivity”. Especially “TC- σ_A graph” is also one of the most important chart sheets for a manager when taking the over/under production and postponement decisions regarding the fluctuations in the marketplace. It illustrates the sensitivity of TC functions against demand uncertainty and variability by assigning the standard deviation parameters as variables while evaluating the results. That is why the DSS asks for the β ratio as an input parameter in the main window. When this ratio is entered σ_A , σ_B and σ_P has a mathematical connection and the graph can be sketched with respect to any standard deviation value. For the interface σ_A is chosen to be the axis parameter. Sensitivity analysis of the TC functions with respect to σ_A is shown below in the Figure C.23. This analysis can also be called to be simulating demand uncertainty or fluctuations in demand virtually.

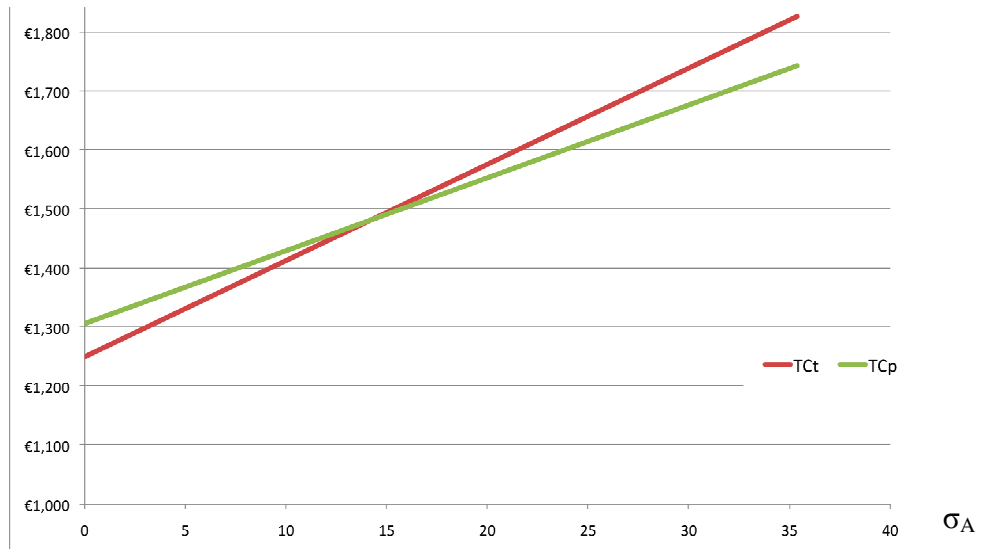


Figure C.23 : Sensitivity analysis of the TC functions with respect to σ_A

“TC- σ Sensitivity” sheet of the DSS interface includes graphics that highlight the sensitivity of the total cost components individually with respect to fluctuations in demand. (Figure C.24, Figure C.25).

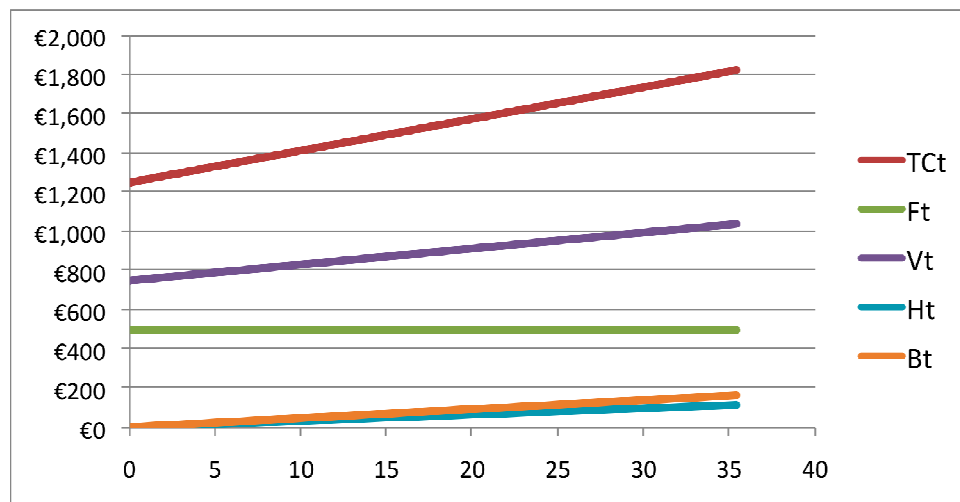


Figure C.24 : Sensitivity analysis of the TC components with respect to σ_A
(Traditional Structure)

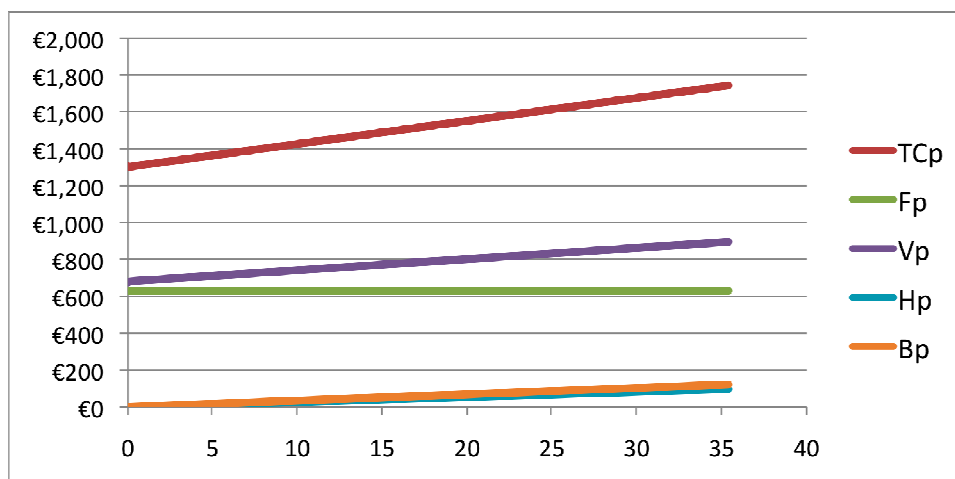


Figure C.25 : Sensitivity analysis of the TC components with respect to σ_A
(Postponed Structure)

Moreover, TC difference proposition and the “K” parameter are modelled for this case as well and placed into this sheet. (Figure C.26)

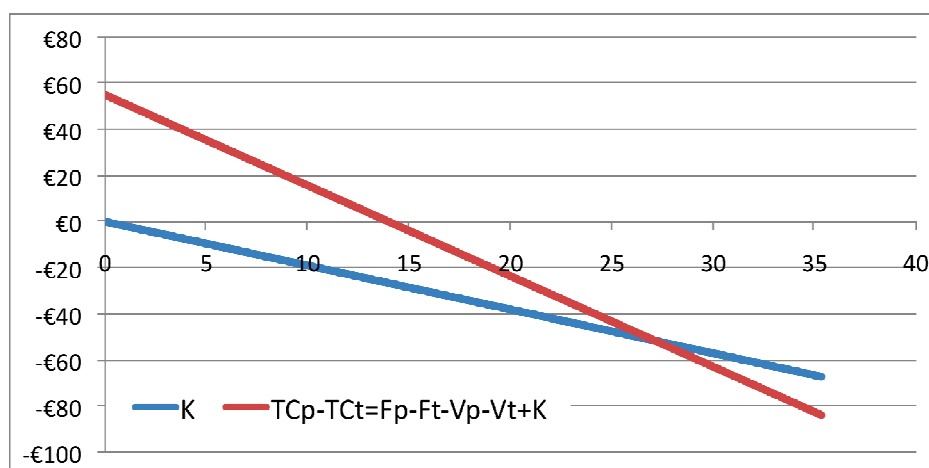


Figure C.26 : ΔTC_i proposition and the “K” parameter with respect to σ_A

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