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A MODEL OF TOTAL LANDED COST FOR GLOBAL SUPPLY CHAIN MANAGEMENT

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Abstract

The recent economic trends has pushed companies to move their operations globally. One of the key decisions concerns the allocation of the final demand according to the available production facilities. To support this decision, the estimation of the total landed cost is suggested. The studies identified in literature limit their scopes in terms of products/markets and costs considered, while a wide perspective on the costs should be considered to reach a satisfactory solution. The purpose of the study is to build a comprehensive total landed cost model for the estimation of the costs related to tactical configurations (i.e. scenario analysis) in a case study

The research takes a constructive approach (Kasanen et al., 1993). Starting from the needs expressed by the managers of a case study, it aims to build a tool to answer to these needs and contribute to the literature on the topic. For the scope of the research, fourteen people throughout the organization were actively involved in the process for the collection of qualitative and quantitative data.

As result of the study, a model of the total landed cost for tactical planning is provided to the company. The model evaluates the effects of production allocation decisions on the following costs: transportation (inbound and outbound), customs, handling, inventory carrying costs, hidden costs and production costs. Its internal validity was tested and discussed with the future users of the application. As a result, it is shown that considering the total landed cost improves management's understanding of the profitability and robustness of their decisions. The validity and the limits of the approach are discussed. Finally, the study identifies new areas for future research.

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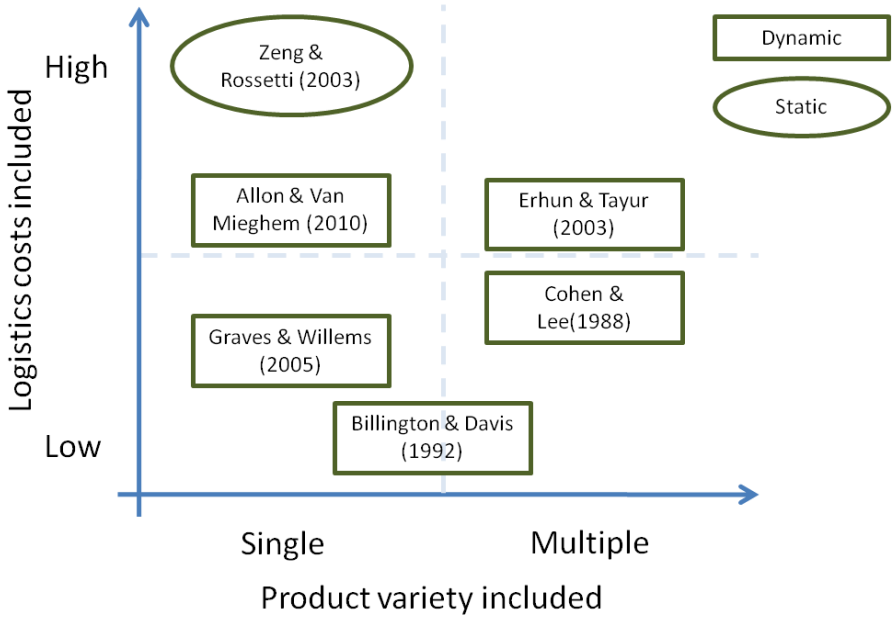
Sommario

Negli ultimi tre decenni, i trend economici hanno spinto le aziende a globalizzare la supply chain attraverso la delocalizzazione della produzione e lo spostamento della base fornitori verso il Far East. Negli ultimi anni, l'aumento dei costi del petrolio, l'apprezzamento della moneta Cinese e l'inflazione del costo dei fattori produttivi nei paesi in via di sviluppo sta portando alla revisione delle scelte di *offshoring*. In questo contesto, la disciplina di global supply chain management risulta avere un ruolo sempre più importante nel determinare i risultati delle aziende. I manager devono prendere decisioni a tre livelli diversi: strategico, tattico e operativo. Una delle scelte chiave che i manager devono affrontare a livello tattico è l'allocazione della domanda finale ai siti produttivi disponibili. Per valutare queste scelte, accademici e professionisti suggeriscono l'utilizzo di modelli di *Total Landed Cost*.

Gli studi identificati nella letteratura limitano il loro ambito in termini di mercati/ prodotti e costi considerati. L'obiettivo di questo studio è quindi lo sviluppo di un modello di *total landed cost* per la pianificazione tattica sulla base della stima dei costi generati dall'intera supply chain per un case study.



Classificazione letteratura su allocazione della produzione

Partendo dalle necessità espresse dal management dell'azienda considerata (chiamata Alpha in questo studio), lo scopo della ricerca è quello di fornire uno

strumento per migliorare le decisioni di allocazione della produzione nel caso di supply chain globale. Nell'ambito della ricerca, quattordici persone all'interno dell'azienda sono state attivamente coinvolte per la raccolta di dati quantitativi e qualitativi.

L'azienda considerata opera a livello global gestendo production plant in Estonia e Cina e servendo clienti in Europa, Cina e USA. Il management dell'azienda dispone di un modello per la valutazione dei costi di produzione. L'aumento dell'incidenza dei costi logistici rende importante considerare anche tali costi per la valutazione di decisioni di allocazione della produzione. Come risultato dello studio è stato sviluppato per l'azienda in esame un *software tool*. Il modello dei costi logistici proposto si basa sui principi dell' Activity Based Costing e integra il modello per la valutazione dei costi di produzione già in uso all'interno di Alpha. Complessivamente, il modello permette di valutare le decisioni tattiche di allocazione della produzione sulle seguenti voci di costo: trasporto (inbound e outbound), costi doganali, movimentazione materiali, costi delle scorte (di ciclo, di sicurezza e in transito), hidden costs (costi di qualità, fluttuazione dei tassi di cambio e incremento del capitale circolante) e costi di produzione. Date le caratteristiche del sistema produttivo di Alpha, l'orizzonte di pianificazione considerato è un anno. L'assenza di effetti di stagionalità permette di utilizzare un time bucket di un anno. Partendo dallo studio della struttura corrente della supply chain, i driver di costo sono stati identificati e legati alle voci di costo considerate. Nella tabella di seguito è mostrata la relazione esistente tra costi logistici e variabili decisionali:

	Driver direction	**Transportation**	**Inventory**	**Customs**	**Handling**
Shipment frequency (Outbound)	+	+	-	+	Not influenced
Production allocation	Offshoring	+	+	+	+ or -
Shipment frequency (Inbound)	+	+	-	+	Not influenced

La validità del modello è stata discussa con i futuri utilizzatori dello strumento di pianificazione. Il modello è testato sui dati storici e si stima un errore minore del 10%. Inoltre i dati generati dal modello rappresentano in modo appropriato la struttura dei costi dell'azienda. Considerato l'ambito di applicazione, l'accuratezza del modello è stata considerata adeguata da parte del management dell'azienda.

Per valutare i benefici legati alla stima del total landed cost, il modello è stato applicato ai dati di previsione della domanda, contribuendo a migliorare la comprensione del management sulla profittabilità dei prodotti. In particolare, permette di identificare i prodotti per cui la decisione di allocazione della produzione dovrebbe essere rivista.

Inoltre, il tool sviluppato permette di analizzare le decisioni tattiche sulla base di diversi scenari. Le decisioni di allocazione della produzione possono essere valutate al cambiare dei noli di trasporto, dei costi di mano d'opera, apprezzamento del RMB etc.etc. L'applicazione del modello permette quindi una migliore comprensione delle alternative a disposizione del management.

All'interno della ricerca, il modello valuta la decisione di allocazione della produzione per 7 prodotti. L'analisi effettuata considera tre possibili scenari: (1) *offshoring* della produzione, (2) produzione locale e (3) *nearshoring* di parte della produzione per aumentare flessibilità della supply chain. Nello studio viene mostrato come la valutazione del total landed cost permette di identificare alternative che altrimenti non sarebbero considerate dal management (l'alternativa 3 dal punto di vista dei costi di produzione non porterebbe a nessun vantaggio). Valutando la variazione dei fattori di incertezza è possibile comprendere meglio anche la robustezza della decisioni. Nel caso considerato l'apprezzamento dell' RMB e l'aumento dei costi di nolo aumenta fortemente i costi legati all'alternativa 2 (un aumento fino al 30% dei costi totali).

I limiti del modello considerato sono evidenziati all'interno della tesi. Inoltre, partendo da questo lavoro è possibile identificare possibili aree di ricerca futura. Infatti, il gap identificato all'interno della letteratura risulta essere solo parzialmente colmato. Come prossimo step potrebbe essere considerato lo sviluppo di un modello di ottimizzazione delle decisioni tattiche. Inoltre, per una migliore stima degli effetti

dell’incertezza sui costi totali, le variabili aleatorie dovrebbero essere modellate come tali e non come variabili statiche.

Chapter 1

1. Introduction

1.1 Background

This thesis is developed within a collaboration between Politecnico di Milano and Aalto University, School of science and technology. This study is a part of a broad research project named GlobeNet – Global operations network – run by the BIT research center. The GlobeNet project aims to identify the success factors and the designing rules in managing effectively global operations. It is sponsored by Tekes and by 10 global companies. This study is made in close collaboration with one of the ten companies, which in this study will be named "Alpha". In relation to the globalization of market economies, it is extremely important to understand the costs involved in the processes from sourcing to product delivering. Indeed, a better understanding of these expenses would allow the manager to get better information on the products profitability. Furthermore, it would support the choices of the managers on tactical planning.

1.2 Research problem

The recent economy trends pushed companies to move their operations globally (Pontradolfo & Okogbaa, 1999; Zeng and Rossetti, 2003; Christopher et Al., 2006; Bartlett et Al., 2008). The relocation of production facilities is increasing the distances between production plants and markets (Pontradolfo & Okogbaa, 1999; Zeng & Rossetti, 2003). Hence, the relevance of logistics costs in companies' profitability is rising (Kruger, 2002). The research has focused mostly on strategic decisions on supply chain design (Swaminathan & Tayur, 2004), while managing companies operating in the global environment requires taking decisions also at the tactical and operational levels (Schmidt & Wilhelm, 2000). To be successful in the current environment, it is important for the companies to coordinate the operations of their subsidiaries (Thomas & Griffin, 1996). One of the key decisions is about the

allocation of the final demand according to the possible production facilities (Allon & Van Mieghem, 2010). In this perspective, tactical decisions take a critical role in determining companies' performance.

Damme and Zon (1999) noticed that companies lack tools for tactical decision-making based on logistics cost information. In many companies, the focus is rather on manufacturing costs (Scully & Fawcett, 1993). However, the end-to-end costs should be considered in order to understand the implications of decisions on the all supply chain.

In the literature, there are very few works that propose techniques supporting tactical planning based on cost modeling (Comelli et Al., 2008). A study made by Erhun and Tayur (2003) shows the benefits of introducing the total landed cost as a tool for influencing managerial decisions. As far as my literature review goes, their research is one of the few studies that develops a total landed cost model for a real case and evaluates the benefits of its application. The model proposed by the authors is built to support the decisions at the operational level for an organization operating in the retail industry. Therefore, its application to a company operating in another environment for supporting tactical planning decisions would be of relevance for this research area.

Alpha is a Finnish company operating in the power supply systems industry, the global nature of its supply chain increases the complexities of decision-making. Furthermore, the high competition that the company is facing makes cost efficiency a requirement for enhancing profitability. For tactical planning purposes, the company is currently using a "cost of goods sold" model. It is through the forecasts of final demand and manufacturing expenses that the company's managers take decisions on production allocation. However, the model currently used does not give information about the impact of tactical decisions on logistics costs. As highlighted by the literature, the globalization of supply chain requires evaluating decisions on costs generated by sourcing, manufacturing and delivering processes (Goel et al.,2008). Therefore, Alpha's managers are calling for a tool that would integrate the information given by the "cost of goods sold" model to the information regarding logistics costs.

Hence, the research question that will guide the study is:

How should the total landed cost be modeled in order to support the tactical decisions on how to run the operations in an efficient and effective way?

The focus of the model will be to provide a tool to support decision-making mainly for production allocation problems.

1.3 Goals of the research

In agreement with the research question, the study aims to:

1. Identify the variables that affect the total landed cost for production and delivering of products;
2. Develop a total landed cost model for the case study;
3. Assess the benefits of introducing a total landed cost model as a supportive tool in the tactical planning processes of the case study.

In building the model, the focus is on balancing the need of information for tactical decision-making with the costs of maintenance of the model itself. To limit the complexity of the tool, some costs were excluded. For instance the customer related costs, like shortage costs, are not considered.

1.4 Methods

In agreement with Kasanen et al. (1993), the research takes a constructive approach and aims to solve a managerial problem and contribute to the knowledge on the topic. In Figure 1-1, the elements characterizing the constructive approach are shown.

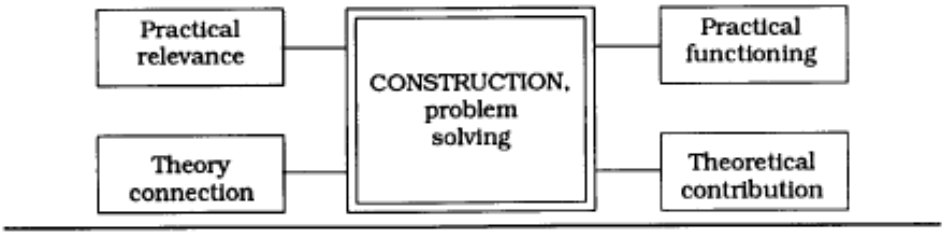


Figure 1-1 - Constructive approach (Kasanen et al., 1993)

Constructive research accepts subjectivity as a part of science. Studies following this approach can be based on qualitative or quantitative data and they normally take the form of case study (Kasanen et al., 1993). Hence in the work here reported, the real needs of Alpha management are considered. The research aims to find an innovative solution through the collection of qualitative and quantitative data.

The process for model development was structured in stages similar to the ones proposed by Shapiro (2001) for the execution of supply chain studies: 1)"Organize the study"; 2) "Collect the data"; 3) "Validate the data and model" and finally 4) "Analyze scenarios".

Organizing the study

The objective of the first stage was to define the decision-making situation in which the model should support the managers. This led to decisions regarding the basic characteristics of the model to be created. For this purpose the main users of the model, e.g. the logistics managers and the executive vice president of the operation, were interviewed.

Collecting the data

To balance the trade-off between accuracy and complexity of the model, it is necessary to collect information regarding the case study (Billington & Davis, 1992). Data regarding the current status of the supply chain and the characteristics of the environment in which Alpha is operating were collected. The information was collected through interviews (oral interviews and e-mails) with the employees working in the various departments of the organization, as following:

- Sales department (3 account managers and 1 customer support officer);

- Sourcing department (sourcing senior manager);
- Logistics department (logistics manager and logistics supervisor);
- Finance department (business controller and 3 accountants);
- Information technology (2 information systems specialists);
- Operations & sourcing (executive vice-president of the operations).

The aim of this stage was also to get an understanding of the information system structure and of the currently available data. This is a crucial stage for ensuring the accuracy of the model (Kosior & Strong, 2006) and limiting the need of new measures.

Validating the data and model

Based on the information collected in the interviews and on the literature studied, a *descriptive* model of the total landed cost of Alpha's supply chain was built. According to Shapiro (2001), a *descriptive* model aims to enhance the managers understanding of supply chains. This type of model corresponds adequately to the requirements expressed by Alpha managers. Indeed, they are looking for a model that would improve their comprehension of the supply chain costs. However, the model built does not propose algorithms for dynamic optimization.

For the development of the tactical planning model, five steps are proposed:

1. Setting the problem and defining the planning context of the decisions (i.e. planning horizon and time buckets) to be evaluated.
2. Creating a map of the supply chain topology and identifying the most significant costs.
3. Identifying the parameters that explain the costs and then classifying them in decision parameters and "external" ones.
4. Defining the relations between input variables and the costs identified in step 2.

5. Verifying the internal validity of the model through the evaluation of its accuracy and practical usefulness, as well as through its application to real cases.

Analyzing scenarios

The model was tested in order to demonstrate that the information given as output matches the real behavior of the supply chain. In doing this, the historical data were compared with the data generated by the model. Finally to show its usefulness, different scenarios are analyzed and presented.

1.5 Structure of the study

In agreement with the constructive approach, the research process is constituted by 6 stages (Kasanen et Al., 1993):

1. Finding a practical and significant problem which offers a research opportunity;
2. Gaining an overall understanding of the topic;
3. Finding an innovative solution for the problem;
4. Demonstrating the internal validity of the solution identified;
5. Showing the theoretical connections and the contribution to the subject;
6. Discuss the applicability of the solution in other contexts.

The structure of the thesis is aligned with the 6 stages listed above. In the first chapter the research problem and its relevance are presented. In the second and third chapters, the overall knowledge (theoretical and practical) gained for the scope of the study is presented through the literature review and the presentation of the basic characteristics of the supply chain studied. In chapter 4, the model developed is presented and validated. Finally in the 5th and 6th chapters, considerations about the theoretical contribution of the work and the external applicability of the solution are drawn. This structure shows the steps taken during the research in order to ensure that each of the elements presented in Figure 1-1 were considered. This is particularly important to ensure that a scientific approach of the problem is taken and to avoid reducing the project to a *consulting* work (Kasanen et Al., 1993).

Chapter 2

2. Global Supply Chain management

The globalization forces, the increasing importance of quality and time in competition and the environmental uncertainties are just some of the trends that can be considered responsible for the rising importance of supply chain management in the literature and in the corporate world (Mentzer et Al., 2001). The scope of this chapter is to present an overview of the literature already existing on global supply chain management and on management accounting. Given the scope of the study, the main focus of the literature review is on the strategic and tactical planning models already developed. In the review, their positive aspects and limits are discussed. The main categories of logistics costs identified by past researches are presented. The categorization presented will be used as a framework to develop the model for the case study. Finally, a brief overview of the literature on supply chain costs modeling is presented.

The research on supply chain management comprises a large number of studies. Hence, the number of different definitions on basic concepts, such as "supply chain" and "supply chain management", is innumerous. For the sake of clarity, the definitions created by Mentzer et Al. (2001) are accepted and stated below:

- Supply chain can be defined as: *"a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer"* (Mentzer et Al., 2001, Page. 4);

- Supply chain management can be defined as " *the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of*

the individual companies and the supply chain as a whole" (Mentzer et Al., 2001, page 18).

2.1 Globalization trend

The opportunity of getting access to *low-cost factors*, unique resources and new markets as well as the increasing cooperation among nations and the decreasing costs of international communication are pushing companies to move their operations globally (Pontradolfo & Okogbaa, 1999; Zeng and Rossetti, 2003; Christopher et Al., 2006; Bartlett et Al., 2008). Global competition puts pressure on companies toward choosing the best places in the world where they can perform their activities (Vidal & Goetschalckx, 2000). Due to the relocation of production facilities, the distances between production plants and markets are increasing. Therefore, the importance of the logistic costs is rising. At the same time, the access to low cost factors is decreasing the production costs (Pontradolfo & Okogbaa, 1999; Zeng & Rossetti, 2003). Consequently, the logistics costs are taking a significant role in determining the product total cost (Kruger, 2002) and companies' profitability.

Furthermore, the increasing competition that the most of the markets are experiencing is worsening the possible profit margins. So, getting a better understanding on profitability is becoming more and more critical for the decision makers within companies (Pontradolfo & Okogbaa, 1999; Giunipero & Eltantawy, 2004). The importance of this is also increased by cases of companies that have experienced the paradox of moving the production abroad to get the access to low-cost factors but ending up in high-costs supply chain outcomes (Christopher et Al. 2006). This paradox can be explained by the additional transportation costs and uncertainties involved in global operations (Scully & Fawcett, 1993).

To sum up, the challenges, arising from the global environment, are increasing the relevance of production and logistics operations management (Scully & Fawcett, 1993). Thus, the development of a tool supporting an effective and efficient management of global supply chains is in the interest of a large number of organizations.

2.2 Supply chain strategy

A broad part of the literature has focused its attention on defining frameworks and quantitative models to support the organizations in supply chain design (Meixell & Gargeya, 2005). It has been found that the most appropriate supply chain design depends on the characteristics of the products and the markets in which the various organizations are operating (Fisher, 1997; Lovell et Al., 2005). The companies' experiences in global operations have taught that product characteristics influence the efficacy and efficiency of off-shoring supply chain strategies (Christopher et Al. 2006). These findings have increased the awareness of researchers and practitioners that in supply chain design "one size does not fit all" (Lovell et Al., 2005).

In particular, Fisher (1997) categorizes the products in *Functional* and *Innovative* depending on their demand uncertainty, length of product life cycle, average stock-out rate, contribution margin, product variability and replenishment lead-time. The supply chain should be able to support the product characteristics. Therefore, for *functional* products, it is suggested to adopt *efficient* supply chain, and for *innovative* products a *responsive* supply chain is preferable (Fisher, 1997).

Lovell at al. (2005) has further developed the concepts introduced by Fisher (1997) through the introduction of the supply chain segmentation. Four categories of parameters influence the effectiveness and efficiency of the various supply chain designs: product factors, market factors, source factors, and geographic and commercial environment. The parameters are reduced to three through a trade-off analysis of the supply chain costs: throughput level, the demand variability of the products, and product value density. Given the broad variety of products and customers that companies have to deal with, the study suggests segmenting the supply chain strategies in order to fulfil adequately the different product and customer's requirements.

Christopher et al. (2006) identified three factors that should be considered in designing the supply chain strategies: products (standard or special), demand (stable or volatile), and replenishment lead-times (short or long). Moreover, given that normally the degree of innovation of the products depends on the demand stability, the first two factors can be merged. So the attention in designing the appropriate

supply chains should be given to the demand variability and lead times required by customers.

2.3 Strategic, tactical and operational level decisions

Even though, the literature has focused mostly on defining taxonomies and frameworks to support decisions on supply chain design, managing companies operating in the global environment is not only about taking strategic choices. (Pontradolfo & Okogbaa, 1999, Swaminathan & Tayur, 2004). Rather, managers need to take decisions at three levels: strategic, tactical and operational (Schmidt & Wilhelm, 2000). The tree types of decisions differ for their scope and the time frame on which they are evaluated. The three categories are broadly named in the literature and depending on the study, they may take different meanings. Hence, the objective of this paragraph is to clarify their definitions.

Decisions at the strategic level regard the design of the supply chain in terms of facilities locations, capacities and technologies to be employed. Generally, strategic choices deal with decisions that have to be evaluated in long term (from two to five years). The tactical decisions consider the product flows and the utilization levels of the different production plants. Finally, the operational decisions deal with assuring in-time deliveries and determining short-term scheduling (Schmidt & Wilhelm, 2000).

For the scope of this research, the supply chain decisions at the tactical level deal with the allocation of production, transportation of products (Comelli et Al, 2008), and the allocation of new products to the production plants. At the tactical level, the managers have to deal with both production and transportation. Their objective should be to minimize the overall costs spent in purchasing, producing and delivering the final products to the customers (Schmidt & Wilhelm, 2000) as well as to ensure that the expectations of the customers are fulfilled (Cohen & Lee, 1988, Christopher et Al., 2006).

At the operational level the decisions deal with daily production scheduling and the follow-up of job execution (Schmidt & Wilhelm, 2000). Even though, these issues are considered highly significant, they will not be considered in the following paragraphs as they are out from the scope of this research.

Currently there is a need of developing effective tactical planning tools (Swaminathan & Tayur, 2004). Indeed, the research on manufacturing strategy to be adopted on international manufacturing networks is quite scarce. The issues related to international manufacturing are normally reduced to factory-location and factory-design decisions (Shi & Gregory, 1998). Moreover, it has been found that companies invest more time in configuration decisions of the supply chain than in managing it. On the other hand, logistics activities result to be critical in enhancing the advantages related to global operations. Effective logistics planning is critical in optimizing the performance of the companies (Scully & Fawcett, 1993).

2.4 Supply chain planning

In order to take advantage of the globalization, it is important to coordinate the operations of the various subsidiaries (Thomas & Griffin, 1996). The current environment is calling for a transnational approach to global operations, where the strategy of the company has to be multi-local and global at the same time. Therefore, the tactical planning takes a critical role in determining the performance of companies.

When a company runs production in different locations one of the key planning decisions is on how to allocate the demand on the manufacturing sites (Allon & Van Mieghem, 2010). The objective of planning should be meeting the customers' requirements in the most efficient way (Cohen & Lee, 1988; Thomas & Griffin, 1996). Efficiency improvement is even more critical in industries in which the profits are shrinking due to the fierce competition (Erhun & Tayur, 2003). In many companies, the cost of goods sold and production related issues take the most of the attention in decision-making processes (Scully & Fawcett, 1993). For this reason, managers may lack of awareness on the relevance of logistics costs that are required to serve the various customers. Thus the development of a tactical planning tool, which evaluates the consequences of the decisions in terms of distribution costs, would support companies in improving their profitability (Damme & Zon, 1999) and building competitive advantage (Cohen & Lee, 1988).

Cohen and Lee (1988) work represents one of the key researches on tactical planning. The authors build a tool with the aim of evaluating the costs of the supply

chain in relation with the type of products produced, the structure of the supply chain and the type of markets in which the company is operating. The research aims to build a tool that would lead the management in reducing the overall supply chain costs. Therefore, it integrates in the same model the costs of the activities conducted in procurement, manufacturing, and delivery. However, the model is built on strong hypothesis on the transportation costs. Typically the freight rates are described by a non-linear function of the volume or weight transported. In contrast, the authors consider the freight rates as fixed to simplify their model. According to the authors, if the model were applied to a case where transportation costs are of primary importance, it would have been necessary to model them in a more accurate way.

Billington and Davis (1992) developed a cost model to support strategic and tactical decisions in a global supply chain for the Hewlett-Packard case. The approach is built on the hypothesis that the complexity of the problems analyzed does not allow computing optimal solutions. The aim of the model is to offer support to the management team rather than dictating decisions. Indeed, the authors recognized that for strategic and tactical decisions there are many issues that have to be considered qualitatively. So it is possible that the best solution is not the one that assumes the lowest costs in the model. In the technique developed by Billington and Davis (1992), the logistics costs are overly simplified. In fact only transportation and customs costs are considered. In contrast, other cost categories, such as the inventory holding costs, take a primary role in determining the total logistics costs (Zeng & Rossetti, 2003).

In their study, Zeng and Rossetti (2003) developed a technique to evaluate the logistics costs generated by the transportation modes available to the supply chain analyzed. The aim of the model is to compute the most economical way of transporting products on yearly basis. The approach does not consider the possibility of using a mix of transportation modes during the year. On the other hand, it is highly common among companies to switch transportation methods depending on the circumstances in which the transportations are organized (e.g., balancing air and sea shipments to hedge against demand uncertainty is an approach commonly and successfully used by companies, Graves and Willems, 2005).

Graves and Willems (2005) built a dynamic model to support supply chain configuration decisions in case of new product introductions. The aim of the authors (Graves & Willems, 2005) is to optimize the costs and the lead times required for the processes that go from sourcing to final delivery. The authors acknowledge that choosing the cheapest source for each stage of the supply chain may lead to suboptimal decisions. As a result, they constructed an optimization model that balances the "cost of goods sold" and the inventory holding costs generated by safety stock and pipeline inventories. The application of this approach improves the efficiency of the decisions on new codes' production allocation. On the other hand, the model proposed by the authors simplifies the nature of the logistics costs. In fact, their optimization model does not consider transportation and customs costs.

Recently Allon and Van Mieghem (2010) have developed a model to formulate the optimal production allocation. The research takes the form of a case study. The company considered by the authors runs two production plants, in China and in Mexico, and sells its products in North America. The model wants to optimize the production allocation of one code along the two production plants. The research demonstrates that the near shore production should be used to face demand uncertainty (so it should be used in a *responsive* way) and the offshore one to cover the expected level of demand. However as stated by the authors, the scope of the model is limited. Indeed, it considers a single product and single market configuration and it has to be expanded to more complex situations.

Finally Erhun & Tayur (2003) has developed an operational planning model for a company operating in the grocery retail industry. The model is built in order to support the management decisions on daily basis. The main objective of the model is to minimize the total costs through short-term planning. The positive impacts of the model are shown through pilot applications on a real case. In Table 2.1, a summary of articles presented in this paragraph is shown.

Table 2.1 Literature review on tactical planning models

Authors	Objectives	Costs	Simplification
Cohen and Lee (1988)	Evaluating supply chain costs for tactical planning	Procurement, manufacturing and delivery costs	Freight rates considered fixed, customs not considered
Billington and Davis (1992)	Cost model to support strategic and tactical decisions for the Hewlett-Packard case	Production, transportation and customs costs	Inventory holding costs are not evaluated
Zeng and Rossetti (2003)	Technique to compute the most economical way of transporting products on a yearly basis	Transportation, inventory holding, administration, customs, risk and damage, and handling and packaging costs	The production costs are not considered
Graves and Willems (2005)	Support supply chain configuration decisions in case of new product introductions	Production costs, inventory holding costs generated by safety stock and pipeline inventories	Transportation and customs costs are not included
Allon and Van Mieghem (2010)	Optimize the production allocation of one code along the two production plants	Production, inventory, transportation and customs costs	Single product and single market configuration.
Erhun and Tayur (2003)	Minimize the total costs through short-term planning (support operational decisions)	Transportation, inventory holding, purchasing and administration costs	Customs costs are not considered

2.5 Literature gap analysis

Based on the models described in the previous paragraph, the aim is to understand whether there is a gap in the supply chain planning literature or not. To support this analysis, the planning models presented in paragraph 2.4 are classified on four dimensions. In the first matrix shown below (Figure 2-1), the objective is to evaluate the scope of the model, whereas in the second one (Figure 2-2), the models are classified according to the planning horizon and their characteristics.

In Figure 2-1, the vertical axis ("Cost variety included") depicts the completeness of the model in terms of the cost categories considered, whereas the horizontal axis ("Product variety included") portrays the scope of the model in terms of product variety. In particular, it is interesting to consider whether the models are made for single products or if they consider multiple products for cost estimation. In the latter case, the models recognize the importance of taking a systemic perspective in order to evaluate the cost generated by one product.

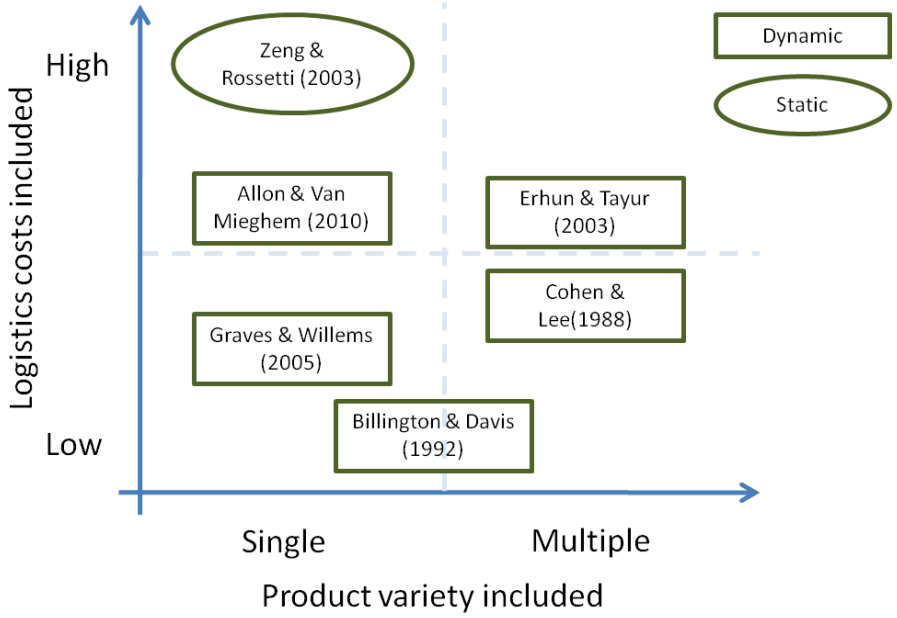


Figure 2-1 – Scopes of the model

In the top right corner of the matrix (Figure 2-1), a potential area for new research is identified. Looking at the matrix, the study made by Erhun and Tayur (2003) seems to fill the gap identified in the literature. In their model, the authors consider

explicitly the effects of shipments consolidation on the transportation cost. In addition, the authors (Erhun & Tayur, 2003) take into account a broad variety of expenses like holding, purchasing and administration costs. However, the model proposed by the authors (Erhun & Tayur, 2003) does not include the expenses related to international trade (customs costs and exchange rates fluctuation). In the second matrix (Figure 2-2), it is shown that the authors (Erhun & Tayur, 2003) consider a short term planning horizon (one day).

Cohen and Lee (1988) develop a model for middle term planning in a multiple-products configuration. In contrast, their approach simplifies the supply chain costs. Cohen and Lee (1988) consider as significant only the production and holding costs, whereas other authors (e.g. Zeng and Rossetti, 2003) have shown the importance of other expenses like transportation and customs costs. Finally, the focus of Graves and Willems (2005) and Billington and Davis (1992) is toward strategic decisions. In this case, decisions have to be evaluated in a long-term perspective.

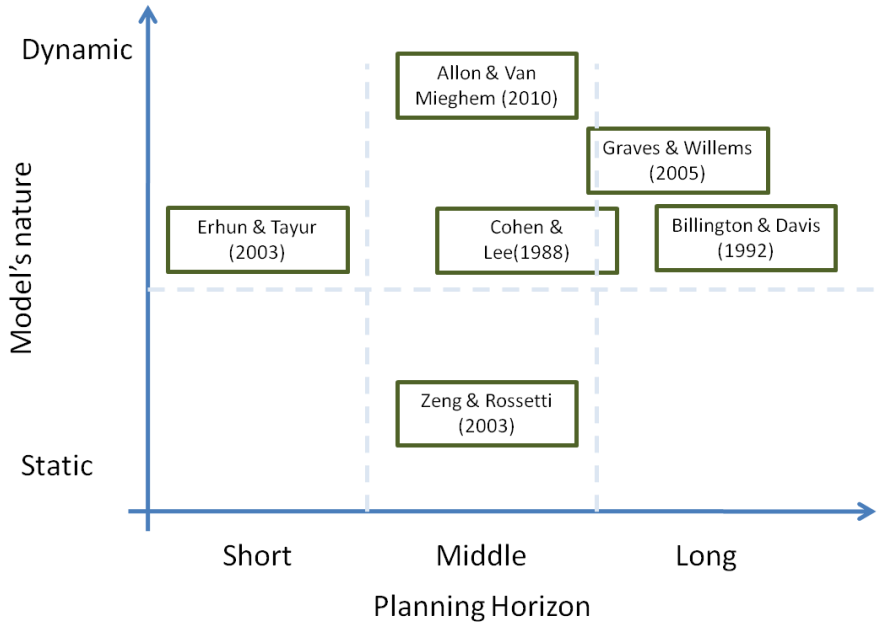


Figure 2-2 - Planning horizons and characteristics of the models

According to Shapiro (2001), the models presented can be categorized in: dynamic and static (descriptive). Based on the matrixes and on the discussion above, it is possible to argue that the dynamic approach requires simplifying the models in terms of costs or number of products considered . On the other hand, the static

approach, taken by Zeng and Rossetti (2003), allows modeling comprehensively the total landed cost.

As stated in Chapter 0, the aim of this research is to build a total landed cost model for tactical planning and production allocation decisions. Based on the discussion based on Figure 2-1and Figure 2-2, it is possible to say that this research might contribute to the current knowledge. Through the development of a planning model for middle-term decisions, it might integrate the results obtained by Erhun and Tayur (2003) and by Zeng and Rossetti (2003).

2.6 Modeling the total landed cost

Given the increasing importance of logistics costs in supply chain management (Kruger, 2002) in order to enhance an effective tactical planning and to optimize profitability, it is not possible to limit the cost analysis to production ("cost of goods sold"). In contrast, to optimize the efficiency and effectiveness of production allocation decisions, the estimation of the total landed cost is suggested (Goel et al. 2008, Allon & Van Mieghem, 2010). The total landed cost allows tactical decisions to be evaluated based on the cost information generated by sourcing, manufacturing and delivering processes. The benefits of applying a total landed cost model are recognized in literature and by practitioners (Georgia Tech, 2010). In fact, modeling the overall costs fosters collaboration among functional units (Erhun & Tayur, 2003).

However, the studies identified in literature limit their scopes in terms of products/markets and costs considered, while a wide perspective on the costs should be considered in order to reach a satisfactory solution. According to the study made by Erhun and Tayur (2003), the application of the total landed cost model to an organization operating in the retail industry has brought to significant results in optimizing the overall costs of the supply chain. Indeed, the model has helped the company in increasing the coordination of the organizational units. Modeling the overall costs of the supply chain has shown the trade-offs and the effects of the decisions of an individual organizational unit on the others (e.g. increase the purchases lot sizes to obtain discounts from the suppliers rises the inventory carrying costs). So, it has motivated the managers of the various units to focus on the overall

effects of their decisions and not only on the performance improvements of the singular departments.

2.6.1 Production costs

Mostly, research has focused its attention on production costs (Damme & Zon, 1999). In this category, the expenses related to the manufacturing activities are collected. Typically they are divided in direct and indirect costs. The direct costs include the expenses that are directly related to the production of singular unit, like direct materials and direct work. Indirect costs or overheads include the expenses related to manufacturing processes but that cannot be directly linked to the production of a singular unit. In their article, Cooper and Kaplan (1991) propose some examples of overheads, e.g. setups, material movements and plant management costs.

2.6.2 Logistics costs

According to Christopher (2005), one of main reasons explaining the difficulties of companies in taking a systemic perspective on logistics and distribution can be found in the lack of adequate cost information. When the logistics costs are considered, a total cost perspective should be taken. Indeed in logistics management, decisions have effects on multiple aspects of the overall supply chain (Lambert et al., 1998; Christohper, 2005). So the functional perspective on costs taken from conventional budgetary system is not adequate in evaluating the effects of logistics decisions. Furthermore, the logistics costs have to be evaluated in comparison with the existing logistics set-up. Thus, a decision should be evaluated on the basis of the differential costs that it generates (Christopher, 2005).

According to Zeng and Rossetti (2003), the logistics costs can be organized in six categories: transportation, inventory holding, administration, customs, risk and damage, and handling and packaging costs. The structure of the logistic costs is significantly differentiated depending on the different organizations considered. In particular, the product and supply chain characteristics influence their values in many ways. Generally the costs of transportation, inventories and documentation represent the most of the total logistic costs (around 90%) involved in international operations

(Scully & Fawcett, 1993). Therefore, when logistics is considered, a particular attention should be reserved to these costs.

In the following sections the cost categories identified by Zeng and Rossetti (2003) are listed and explained. This categorization is used as a framework to identify the main costs for the case study.

Transportation costs

Consolidation of orders and transportation modes have a primary role in determining the freight rates to be paid per product. Normally companies can use different means of transportation in order to reach different customers. In general, firms can use a mix of slow and fast means of transportation to cope with the demand and lead time uncertainties. For example, in case of delays in production, the company may choose to use faster means of transportation to meet customers' requirements on time. In other circumstances, the use of certain means of transportation can be forced by the nature of the products. In certain industries, customers' pressure for quick deliveries may require the only usage of faster means of transportation (for instance, shipment by air) (Zeng & Rossetti, 2003).

The choices taken on transportation do not affect only the transportation costs. Rather, they affect other aspects of the supply chain, such the inventory levels. Even though the literature has given little attention to the impacts of transportation decisions on the efficiency and effectiveness of the whole supply chain (Creazza et Al., 2010), to evaluate properly the consequences of tactical decisions these effects should be considered as well.

Inventory holding costs

In general, companies carry inventories in order to buffer against uncertainties (e.g. demand and lead-times variance) and to create economic efficiencies through consolidation of production and transportation orders (Swaminathan & Tayur, 2004). The consolidation of production and transportation makes possible to reduce setup costs, improve the utilization of means of transportation, and obtain discounts on the services offered by 3rd party logistics companies. The inventory holding costs normally represent one of the largest cost element among the logistics expenses

(Christopher, 2005). So, it should take a significant role in the decision-making and be carefully analyzed in the total landed cost calculation.

Based on the rationales motivating maintenance of stock in warehouses, it is possible to define three inventory categories (Vollmann 2005):

- Cycle stock, are kept in warehouse to fulfill in time the customers' requirements and minimize setups and transportation costs. The main challenge is normally to balance the trade-off between set-up and inventory holding costs (Stadtler & Kilger, 2005);
- Safety stock, are kept to buffer against uncertainties involved in supply chain activities, such as internal lead-times (transportation and production lead-times), unknown customer demand and uncertain suppliers' replenishment lead-times (Stadtler & Kilger, 2005);
- Stock in transit, are kept in the pipeline of the supply chain during the transportation lead-times.

The inventory holding costs consist of the cost of capital and the storage costs to maintain and protect the materials in the warehouses. The inventory related costs depend strongly on the lead-times and the uncertainties involved in the supply chain processes (Allon & Van Mieghem, 2010). So in case of cost estimation, the inventory holding costs depend on many factors and have to be evaluated at their expected values. For these reasons, the estimation of these costs complicates the computation of future logistic expenses. The risks of obsolescence and of price erosion have to be considered as well among the inventory holding costs. In particular, changes in product specifications or introduction of new products can make obsolete or reduce the value of the products kept in the warehouses.

To sum up, Christopher (2005) lists the costs that should be included in the inventory holding costs:

- Cost of capital, it evaluates the opportunity costs of the capital tied up in inventory instead of being used for other investments (Lalonde and Lambert, 1977). Normally the cost of capital is the most significant among the inventory holding costs;

- Storage and handling;
- Obsolescence, it is generated by material disposals and it is evaluated as the difference existing between the original costs and the salvage value (Lalonde and Lambert, 1977);
- Damage and deterioration;
- Pilferage/ shrinkage;
- Insurance;
- Management costs.

Administration costs

In this category, the costs of personnel involved in managing customer's orders and material purchasing are considered. The costs related to information exchange along the supply-chain are included as well.

Customs costs

In accordance with the policies of the countries, international trade may require the payment of taxes, duties and customs clearance. Even the costs of brokers, which may operate in behalf of the company, are taken into account.

Risk and damage costs

In this category, the costs related to the damages, losses, and stolen products are considered. Normally companies cover these risks through insurances. If the term "risk" were considered from a broader point of view, the logistics costs to be included in this category would be much higher. Indeed, many other costs can be related to operations uncertainty, e.g. costs of faster means of transportation used to face unexpected demand and the inventory holding costs of safety stock (Giunipero and Eltantawy, 2004). However, these costs are already taken into account in the other categories, so they are not repeated here.

Handling and packaging costs

Finally, at the various nodes of the supply chain, handling and packaging activities are performed. Their consumption of resources may take a significant role

in determining the efficiency of decisions on supply chain. Examples of the costs involved in this category are the expenses of collecting containers from the receiver warehouses and the material handling fees charged by transportation companies (Zeng & Rossetti, 2003).

2.6.3 Hidden costs

In addition to the costs listed above, Goel et al. (2008) has underlined the importance of considering the "hidden costs" to get a true picture of the landed costs. The authors has included in this category the following costs: *reworking errors*, *incremental financing* and, *exchange rate risk*. These costs take a significant role in determining the total costs in case of production offshoring. Indeed, the longer throughput time of the supply chain (time from sourcing to final delivery) stretches the *cash-to-cash* cycle. Moreover, operating with different currencies exposes the supply chain to the risks related with exchange rates.

Offshoring suppliers and production makes even more critical the quality problems. The long time elapsing from the start of the shipment till the delivery at the final destination increases strongly the costs related to a delivery of goods which do not respect the quality requirements. The long lead time incurring from the source to the final destination reduce the possibility of activating contingency plans (e.g. require a new shipment of goods) to avoid supply chain disruptions.

2.7 Supply chain costing

The objective of the research is to construct a total landed cost model. Hence in this paragraph, the main theories on supply chain costing are presented.

2.7.1 Activity based costing

In last two decades the activity-based costing approach has emerged among the other internal accounting techniques (Gupta & Galloway, 2003). Nowadays, this technique results to be well-known and widely accepted among practitioners and researchers (Schneeweiss, 1998). Given its broad acceptance and its suitability for this research, an adapted version of the activity-based costing is used for the tool built in this study. For this reason the literature review made for this research is focused mainly on this method. After a brief introduction of other accounting

methods for allocation and control of logistics expenses, the attention is shifted mainly to the activity-based costing technique.

Lin et al. (2001) list two accounting methods for supply chain costing: "total cost of ownership" and the "direct product profitability". The former approach focuses its attention on the total costs related to purchasing from a particular supplier. The latter approach focuses its attention on determining the profitability of specific products. Lambert et al. (1998) show other techniques to control the logistics costs, the most significant for the scope of this research is the "standard costs". In the approach suggested by Lambert et al. (1998), the objective is to calculate the logistics costs under the hypothesis that the company operates as planned. The planned operating levels are multiplied for cost indexes, which are identified through regression analysis and studies on historical data. The control system allows the company to estimate future costs and run variance analysis. Thus, it supports the evaluation of the operations efficiency compared with historical data.

The activity-based costing allows identifying accurately the real costs of doing business with a business unit or a customer as well as commercializing a product (Cooper and Kaplan, 1991, Lin et Al., 2001). Indeed, through the allocation of the overhead costs on the basis of consumption of activities, it is able to represent the real consumption of resources more accurately than the traditional accounting systems. Traditional accounting systems allocate overhead costs on volume-based drivers, which do not grasp the differences in resource consumption of different cost objects (Lin et Al., 2001). The activity-based costing method proposes to allocate the overhead costs on the activities performed in the various departments. Then, the costs of the activities are distributed on the basis of the activities consumed by the cost objects (e.g., products, customers and business units) (Kaplan & Cooper, 1998). The use of this technique has improved the understanding on how resources are consumed within organizations (Cooper and Kaplan, 1991). Therefore, it has brought many benefits in decision-making situations. The activity-based costing technique can be considered one of the most common supporting tools discussed by the literature for improving supply chain management and firms' performance (Askarany et Al., 2009). In fact, its introduction led to many performance improvements, such

as increasing effectiveness and efficiency of companies and providing a better understanding of customer and product profitability (Askarany et Al., 2009).

Even though the number of applications of the activity-based costing to production costs is large, the same cannot be affirmed for its applications on logistics costs. Indeed, researchers and practitioners have focused their attention mostly on manufacturing activities (Damme & Zon, 1999). Damme and Zon (1999) noticed that managers lack tools for evaluating logistics decisions on the basis of cost information.

According to the literature review, the research made by Lin et al. (2001) is one of the few studies applying the activity-based costing method to logistics costs. The authors suggest a framework for the application of activity-based accounting technique to logistics costs. For the construction of the accounting model, it is critical to analyze the processes involved in the execution of logistics (Damme & Zon, 1999; Lin et al. 2001).

2.7.2 Supply chain costing for planning support

To evaluate decisions in supply chain management, it is necessary to consider its effects on the future total landed cost. The high uncertainties involved in global operations call for accounting models that enhance better understanding of the effects of uncertainties on the costs. Thus, it is not enough to build accounting models for the allocation of historical costs to cost objects (Askarany et al., 2009). Managers need models that allow them testing the future effects of decisions before they are put in practice (Salafatinos, 1996). In particular, planning models that show the cause-effect relationships between costs and decisions are of primary importance in improving decision-making (Lin et Al., 2001; Askarany et al., 2009). Even though the study made by Singer and Donoso (2008) is limited to the production activities, they demonstrate that activity-based costing approach can be used for cost estimation. Similarly, Salafatinos (1996) proposes to expand the scope of activity-based costing technique for the evaluation of decision profitability.

When planning models are built, it is necessary to define the existing relations between overhead costs and tactical planning decisions (Schneeweiss, 1998). Thus, the following scheme is proposed for cost estimation (Schneeweiss, 1998, page 278):

"Amount of output → Required Activities → Required resources → Incurred overhead costs". In this approach, the direction of the process is opposite to the one used for the allocation of historical costs. The accounting models normally consider the incurred overhead costs and allocate them on the actual cost objects. In contrast in the planning models, given the amount of cost objects planned a certain amount of overhead costs are projected to incur in the future.

Finally in contrast with Singer & Donoso (2008) and Salafatinos (1996), Schneeweiss (1998) shows the limitations of the activity-based costing technique when it is employed for planning purposes. The author shows that for portfolio, make or buy or outsourcing decisions, other approaches result to be more accurate. However, it is recognized that for tactical planning the activity-based costing approach may be accurate enough. The application of the activity-based costing can be considered a necessary first step for companies that aim to get the access to more sophisticated planning models. In fact, its application requires companies to collect data and information that are prerequisites for the employment of advanced planning models (Schneeweiss, 1998).

Chapter 3

3. Case description

Since the total landed cost is to be modeled, it is necessary to understand the purchasing, manufacturing and delivering processes executed in the supply chain (Damme & Zon, 1999; Lin et al. 2001). According to Zeng and Rossetti (2003), each business is characterized by different costs. To provide a usable planning tool to Alpha, it is important to balance the existing trade-off between accuracy and complexity of the model (Billington & Davis, 1992). The first step is then to understand how the processes are executed in the case study to identify the significant costs. This paragraph shows the competitive environment of the case study and the characteristics of its supply chain.

3.1 Overview of the market

Alpha operates in the B2B business and its main customers are Telecom, Industrial and Healthcare industries. Aside from the stand-alone products, the company offers also customized solution and maintenance services for its customers. Alpha is a Finnish enterprise, while it has established operations even outside the home country. Alpha is present with its facilities in Finland, Estonia, China, Sweden and United States. During 2009 the number employees was 550 and the net sales 64.062 k€.

The market for power supply systems is characterized by fierce competition. Consequently, the available profit margins are decreasing. The company has also to deal with high demand uncertainty, which increases the complexities for an efficient operations management. The down term that has hit the world economy since 2008 has induced the suppliers in engaging in divestment activities. These strategies are now showing their effects in generating component shortage and unbalanced demand

and supply. As a result of this phenomenon, the purchasing price of the inbound components is increasing. The costs of direct materials represent 80% of the cost of goods sold of Alpha products. Hence, the tough situation of the supply market is undermining Alpha profitability.

In the industry where Alpha is operating, the focus of competition is mainly on cost leadership so cost efficiency is a critical requirement for competitiveness. At the same time, high product mix and volume flexibility have to be maintained to answer to the uncertain final demand. In these circumstances, Alpha management would like to have a decision-making tool that allows evaluating the effects of the decisions on the overall costs of the supply chain. The development of a total landed cost model, which integrates the data obtained from the "cost of goods sold" model currently in use with information on logistics costs, is consequently required.

3.2 Supply chain configuration

The aim of this paragraph is to describe the network currently used by the case study to serve the final customers. In Figure 3-1, a diagram representing the available solutions for purchasing (global and local suppliers) and delivering (local and global transportation to customers and consignment deposits) are shown.

Alpha runs two productions plants in Estonia and China. The company has sales office located in China, Finland and USA. Furthermore, with the collaboration of third-party logistics partners, it runs consignment deposits in Sweden, Estonia and China. Most of the suppliers are located in Estonia and China whereas for components with particular quality requirements or characterized by significant differences in purchasing price Alpha recurs to global sourcing. For the Chinese production plant 4% of the value of the components is bought globally while in the Estonian case 13% of the value of the materials is sourced outside the European Union.

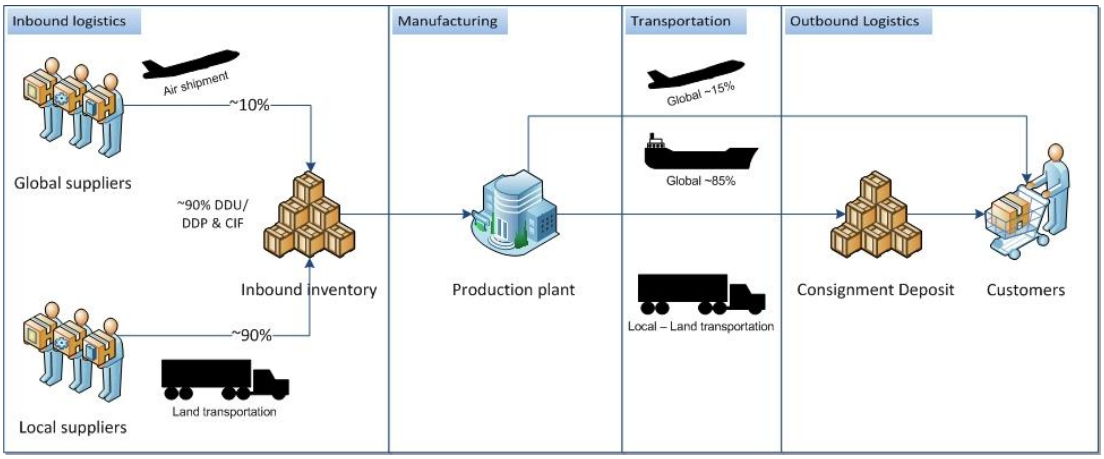


Figure 3-1 - Supply chain map

Even though the production plants adopt the same processes and technologies for their operations, their performances differ strongly. It is estimated that the production in China is 20% cheaper than in Estonia. The difference is explained by the current exchange rates and the differences in the costs of the production factors. On the inbound side, the replenishment lead-time of the suppliers differs strongly for the two production plants: on average the suppliers of the Estonian production plant replenishes three times faster than in the Chinese case.

Depending on the products considered, the production planning process might follow different logics: make-to-order (MTO), assembly-to-order (ATO), and ship-to-order (STO). For the first two logics, the processes that lead the company to fulfill the customers' orders are the same. The orders received are added to the production schedule. When the production is finalized, the orders are delivered to the customers. The make-to-order and assembly-to-order logics differ only for the presence of critical components. In cases where products contain critical components (long replenishment lead-times or high uncertainties related to their sourcing), the company hedges against the risk of shortage of components through safety stock.

For the products managed through ship-to-order logic, the company agrees with the customers on minimum and maximum days-of-supply to be kept in the warehouses. These boundaries are the result of the negotiation process between Alpha and the buyer. The buyer normally pushes for high availability and Alpha to keep the inventories at low levels. For these products the company offers "vendor managed inventory" services. In some cases, Alpha has agreed with the customers to

open local deposits in proximities of the customers' production plants in order to shorten the delivery lead times and increase the service level. The consignment deposits are managed by third-party logistics companies. Depending on the case, the company has agreed with the customers on how to share the handling expenses at the local deposits. In all the deposits, Alpha owns the products until their consumption.

For the demand planning process, the organization requires the customers to provide twelve months consumption forecasts. These data are then analyzed and adapted by the sales function, which is responsible to provide the final forecasts to the operations. Customers do not have any liability on the forecasts provided. Hence, the reliability of the data received differs greatly customer-by-customer. The final outcome of the demand planning process is used for capacity and supply planning. In case of ship-to-order logic, the forecasts are also used for production and transportation scheduling.

The supply planning is mainly automatic. Indeed, the call-off process is run mainly by the MRP system. Manual operations are required for the introduction of new components or in case of critical situations, e.g. when the information system detects risks of component shortage. According to purchasing volumes and values, the components are classified in ABC categories. Different MRP replenishment parameters (e.g. the planning horizon) are assigned to different categories. On the basis of the consumption forecasts, the batch sizes of the orders are determined. In most of the cases, the complexity of the supply market requires to use physical and time buffers in order to avoid shortage of components. For this purpose, the purchase orders are anticipated a period of time before the real need on the production lines.

For the components characterized by stable consumption and short delivery lead-times, material replenishment is managed with Kanban logic or consignment stock. In case of consignment stock, the materials are stored in Alpha inbound warehouse but they become Alpha property only when they are used in production. In case of Kanban replenishment logic, the functioning parameters, such as number of cards and card size, are agreed with the suppliers. Even in this case, the information necessary for sourcing management is recorded in the information system. Therefore, most of the activities for the call-off process are automatically executed by the information system.

Based on the Incoterms 2000, Alpha has negotiated different contract terms with suppliers and customers. Alpha is responsible for arranging and carrying the transportation costs for part of the inbound components as well as for part of the final products. In these cases, third party logistics companies execute the transportation. In fact, the complexities related to international trade make impossible for the company to organize the transportation by itself (Scully & Fawcett, 1993). The company uses normally a global partner to organize transportations. However depending on the circumstances, the company may resort to "occasional agreements" with other suppliers in order to get better freight rates.

In Figure 3-2, the share of the contract terms used in inbound logistics in both production plants is shown. The percentages are calculated on the value of the total purchases. The DDU/DDP and CIF contracts cover more than 90% percent of the purchases in both cases. This means that for the 90% of the components purchased, the suppliers organize completely or partially the transportation to the Alpha facilities.

When Alpha resorts to global sourcing, the transportations are mainly executed through air shipments (see Figure 3-1). In fact the high value density of the components makes profitable the use of fast means of transportation.

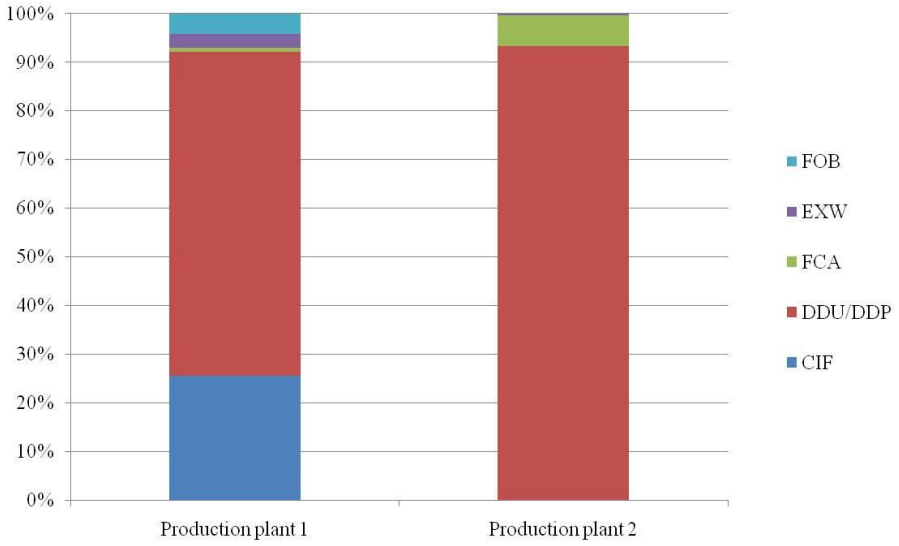


Figure 3-2 – Contract terms with suppliers

In outbound logistics, Alpha has to arrange and pay the transportation for 20% of the sales. The transportations under Alpha responsibility are directed to Sweden, Finland, China and Estonia. They can be categorized in local and global shipments. For the local shipments (e.g. the transportation from Estonia to Sweden) the only mean of transportation available is truck. For global routes (e.g from China to Estonia), sea or air shipments can be selected. In making this choice, the company aims to optimize the existing trade-off between transportation lead-time and freight rates. The general policy adopted by the company consists in using sea shipments (characterized by long lead times and low freight rates) to cover the expected demand and the air shipments (characterized by short lead time and high freight rates) to increase the flexibility of the logistics network.

3.2.1 Description of the production processes

In the two production plants run by Alpha, the production processes used are the same (Figure 3-3). Thus, the existing cost differences are related to differences in wage levels, component prices and exchange rates. The production process is not highly automated. Rather, most of the activities are executed manually, for instance the assembly and test processes. This makes significant the tacit knowledge to gain to execute efficiently the production activities. In agreement with Grant (1996), this knowledge is difficult and costly to transmit and it is mainly transmitted through

observation and practice. For this reason, the introduction of a new worker or a new product requires time and costs before the process is running in the most efficient way. Furthermore, different products are normally allocated to the different production plants. Therefore, it is not suitable in the short-term run to switch the venue of product manufacturing.

In this perspective, tactical decisions regarding production allocation result to be critical in determining the results of the company. Indeed, this decision is difficult to be changed in the short term. The company considers two production allocation strategies. The most commonly used is to dedicate the production of a particular code to only one facility, i.e. Estonia or China. On the other hand, the production can be shared across the two facilities, i.e. Estonia and China. The latter solution is rarely used at the moment. In fact sharing the production volumes decreases the slope of the "experience curve" (Johnson et Al., 2008, page: 123) and it makes this solution less efficient.

Given the characteristics of the process, the maximum capacity results to be flexible. Indeed, the low automation characterizing the production processes allows the production capacity to be increased through overtime work. Moreover, the capacity of the machines used (e.g. the SMD production line) is higher than the capacity currently consumed. For these reasons the production capacity is not considered as constraining factor in Alpha. So the managers do not have to deal with capacity allocation and mix optimization problems.

Finally, the manufacturing process supports the production on ca. 350 codes that require ca. 11000 components in inbound for their assembly. For this reason, the management of sourcing results to be critical to ensure the correct functioning of the operations.

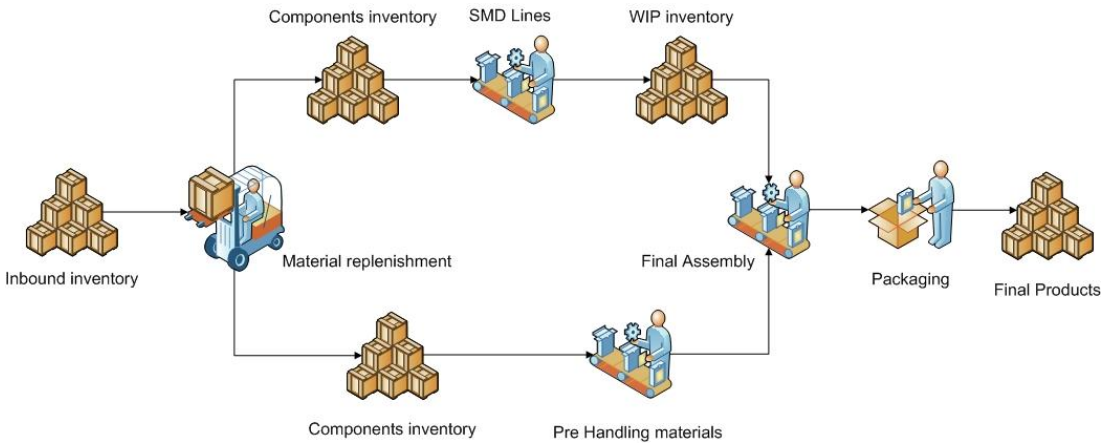


Figure 3-3 - Alpha manufacturing process

3.3 Structure of the costs

For the purpose of the study, the relative importance of the costs generated by the supply chain should be considered. In Figure 3-4, the data collected from the "accounting and finance" department on the fiscal year 2009 are presented. The cost of goods sold cover on average the 96% of the total landed cost. The company is already running a model for budgeting and evaluating the effects of decisions on the production costs. For this reason, the modeling attention is on the logistics costs.

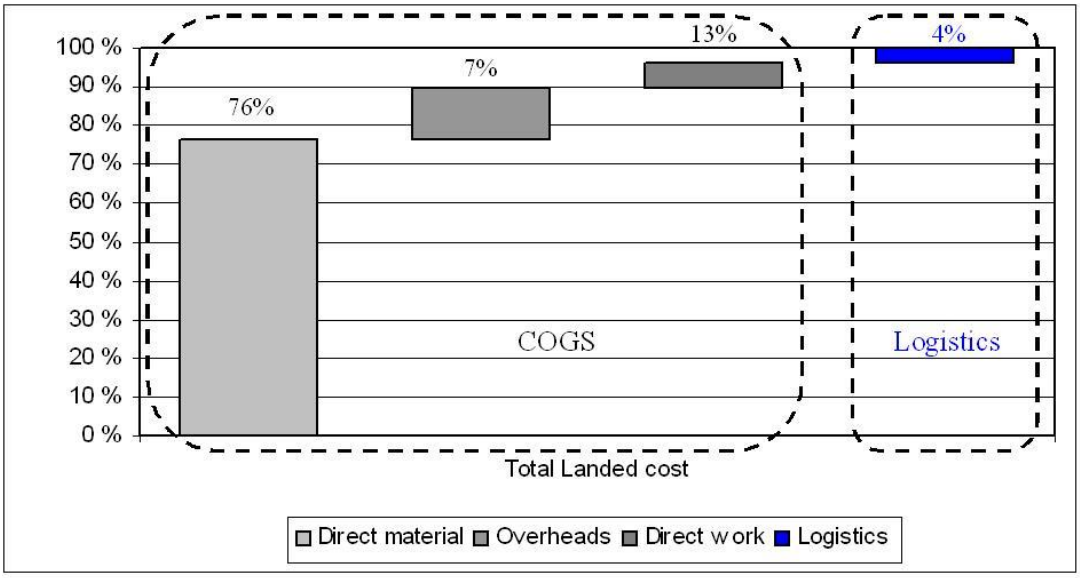


Figure 3-4 - Composition of the total landed cost [Fiscal year 2009]

Chapter 4

4. Total landed cost model

As explained in the previous chapters, the focus of modeling is on the logistics costs. They are integrated with the output data provided in the "cost of goods sold" model in use by the case study. In this chapter, the process that led to the model construction is presented. The various costs identified by the literature are analyzed and the design decisions taken during the modeling process are shown. Finally, the internal validity and the accuracy of the model are discussed thoroughly.

The structure of the chapter follows the steps that were taken during the design of the tool constructed. The chapter is divided in the following paragraphs:

1. Set the problem and define the planning context of the decisions;
2. Create a map of the supply chain costs;
3. Identify and classify the cost drivers;
4. Define the relations between input variables and the costs;
5. Validate the model.

In Appendix 1, the structure of the software developed to run the model is briefly presented through diagrams.

4.1 Set the problem

4.1.1 Planning horizon

The objective of the model is to provide support in global supply chain management, which means to develop a tool for supporting the planning activities that Alpha has to execute to enhance the benefits of global operations (Scully & Fawcett, 1993). Depending on the decisions supported, different aspects of the supply chain system should be emphasized. In this research, the decisions that the

management wants to evaluate are at the tactical level. The significant managerial decisions to be evaluated by the model emerged during the interviews, some examples are: to switch the production allocation, to determine the production venue for new products, and to start manufacturing common codes in the two production plants. The efficiency of the decisions considered depends on uncertain factors like the transportation freight rates, customers' behavior and exchange rates fluctuation. Therefore, managers are interested in a tool that would allow them to evaluate the effects of external uncertainty on the alternatives analyzed.

In order to evaluate such decisions, it is necessary to decide on an adequate time frame. The time frame selected should consider the minimum period of time during which the decisions evaluated cannot be changed. Consideration of a longer planning period would not add any pertinent information to help the decision-making process and would decrease the accuracy of the input data. As mentioned in paragraph 3.2.1, the characteristics of the production process do not allow changes in decisions regarding production allocation in the short term. A one-year planning horizon was considered as adequate. Nevertheless, the model can be easily adapted for shorter planning horizons (for example 6 months). The data collected did not show seasonal factors during the time frame of the model. Thus, the time bucket of the model is one year. The presence of seasonal effects on the input variables would require modeling separately the different periods. Subsequently the different periods should be merged in order to get the complete estimation of the total landed cost.

4.1.2 Model characteristics

This model follows Billington and Davis (1992) approach. According to the authors, three characteristics should be respected in creating a decision-making model. Firstly, the model should allow scenario analysis. Secondly, it should be based on the already existing data within the organization, because the collection of additional data would add unaffordable costs to the project. Thirdly, the model should be based on spreadsheet software. The usage of this type of software makes it efficient to communicate data to managers. Therefore, the model makes use of such characteristics.

Following the categorization made by Shapiro (2001), the current model is "descriptive" and it does not propose "dynamic" optimization. As discussed in paragraph 2.5, this approach allows modelling comprehensively the supply chain costs. The complexity of the decisions considered and the influence of uncertain factors require the managers' judgements for decision-making. Therefore, the model does not want to dictate optimal solutions. Rather, it is intended as a supporting tool in decisions-making. For this purpose, the model represents the causal relationship between decisions and cost as well as allows the evaluation of the effects of uncertainty. The quality of an optimization model is affected by the "garbage-in, garbage-out" problem (Shapiro, 2001). The usage of the data already measured within the organization as well as the usage of spreadsheet software requires taking simplified assumptions in representing the real processes. In running the model it is necessary to estimate future input variables, like the final demand and the average exchange rates. So in case of dynamic optimization, the optimal solutions suggested could mislead the managers in their decision-making. Rather, the necessity of comparing "manually" various solutions leads the managers toward a better understanding of the model functioning and subsequently the understanding of the consequences of their choices. Finally, the creation of an optimization model would complicate critically the problem, as it would require the usage of more advanced software, what in its turn would compromise the simplicity and easiness of operations of the model, which are considered key factors for its internal validity (Kasanen, 1993).

4.1.3 The scope of the model

The total landed cost model is applied to the 350 products sold to twelve groups of customers. The minimum part of the system to be considered to get a reliable cost estimation should be defined. In this case, since transportation are not merged across customers, it is required to consider at least all the products sold to one customer on a particular route (for example all the products sold to the customer *c*, that are produced in China and sent to Europe).

According to the focus of the research, decisions regarding the costs to be included and excluded from the model are made. This is critical to balance the accuracy of the model with its complexity. In particular, considering the

characteristics of the case study, it is decided to exclude the *shortage costs* (Stevenson, 2002, page: 556) or "customer related" costs from the scope of this research. The static approach of the model does not allow to evaluate them. Furthermore, according to the Alpha managers, the quality of the relation with customers is not influenced by the occurrence of occasional shortage of products or delivery delays and they do not result in loss of sales opportunity. The main customers are involved in long-term relations with Alpha. The competitive advantage offered by the company is based on the flexibility in product development and cost competitiveness. Alpha plans the production following make-to-order and assembly-to-order logic for more that 90% of the total sales. The characteristics of the production processes and the high production capacity make unlikely delays in production. Nevertheless, in case of delays the sale of the products is just postponed. From the interviews with the sales department, it emerged that Alpha has to pay fees for late deliveries or shortage of products only in few cases. The sales managers explained that normally customers do not require the payment of these fees. For these reasons, the shortage costs identified by Stevenson (2002) do not take a critical role for the case considered.

To sum up, Table 4.1 lists the characteristics of the model presented in the discussion above.

Table 4.1 – Classification of the model

Planning horizon	Reversibility period of the tactical decisions (1 year)
Characteristics of the model	Descriptive model (optimization is not required and it could be misleading, not feasible or compromising the simplicity of the model)
Cost variety included	Logistics costs and production costs. The shortage costs are excluded.
Product variety included	Multiple products - define the minimum portion of products that should be considered to ensure accuracy

4.2 Map of the costs

In this stage the costs generated by the supply chain activities are identified and mapped. In Figure 4-1, the significant costs identified are located in the current supply chain setup. The map is the final result of the modeling stage described in this paragraph.

Since the aim of the model is to support tactical decisions, the basic structure of the supply chain is considered as given during the development of the model. Depending on the agreements established by Alpha with customers and suppliers, the responsibilities in the logistics processes are distributed to the various players. In accordance with the requirements of the managers, the scope of the model is only limited to the costs under Alpha's responsibility.

Following the categorization made by Zeng and Rossetti (2003), two of the six cost categories are discarded. Indeed, *the risk and damage costs* are covered by an annual insurance contract that the finance department signs with counterparty. Under the hypothesis that the supply chain structure remains the same, the insurance cost can be considered as fixed. Hence, this cost is not influenced by tactical decisions and it can be excluded from the total landed cost calculation. The *administration costs* are not considered as well. Indeed on the supply side, they are already included in the "cost of goods sold" model, and on the demand side each customer has been assigned to a sales person. So even in this case, these costs do not depend from tactical decisions taken by the managers of the operations.

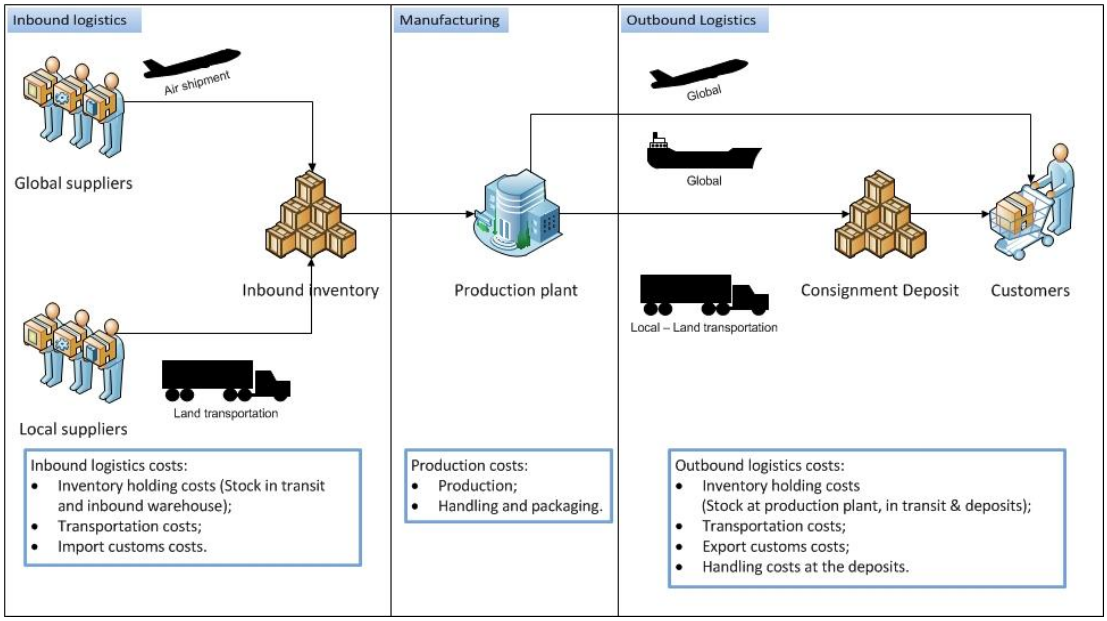


Figure 4-1 – Map of the costs

To understand the relative importance of the costs included in the model, the data on the real logistics expenses are collected for the fiscal years 2008, 2009 and 2010 until the end of June (Figure 4-2).

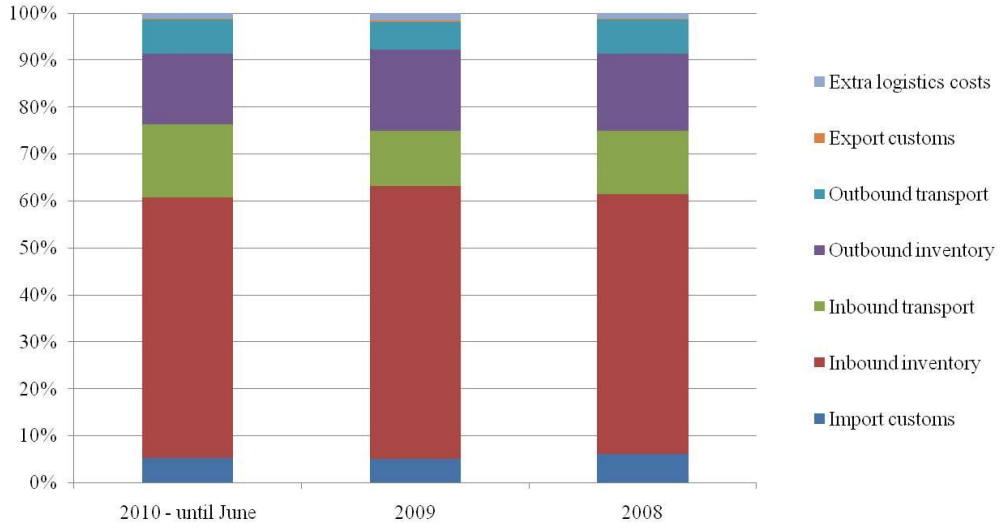


Figure 4-2 – Historical data on logistics costs

As it is shown in Figure 4-2, the cost structure represents well the complexities involved in managing Alpha supply chain. The inbound activities explain more than 70% of the logistics costs. In particular, the most of the logistics expenses are explained by the inventory holding costs at the inbound inventories. On the other

hand, the customs costs for outbound products result to be small. In fact, the products commercialized by Alpha are not subjected to duties.

From Figure 4-2, the relevance of the inbound transportation costs is clear. Currently, the purchasing price of the inbound material is evaluated at the landed cost, which in addition to the purchasing price includes also the transportation expenses. The inbound transportation costs are already accounted in the "cost of goods sold" model in use in the company. Moreover, from the interviews, it emerged that the inbound transportation costs are not influenced by the planning variables available to the managers. In fact, the choice regarding the usage of global or local suppliers results to be quite straightforward. For example, when the production is made in Europe, components like surge protectors and printed circuit boards are sourced from Chinese suppliers. The component high value density and the cheap prices offered by Chinese suppliers make profitable the transportation of goods. Similar considerations can be made for components bought in Europe and used for the Chinese production. In this case, global sourcing is necessary for components that require specific know-how or particular quality requirements. Moreover Alpha does not have the planning capability and the size for consolidating the orders coming from suppliers located in the same countries. So, the transportation costs associated to the components can be considered independent by the decisions taken on production allocation. Even though the choice regarding where to locate the production affects the inbound transportation costs (production in Europe requires to purchase a bigger share of the value of the bill of materials in China than vice versa), this difference can be well captured by the differences in purchasing prices. For these reasons, there would not be any advantage in separating these costs from the "cost of goods sold" calculation.

In the same manner, the inbound handling and packaging costs are included in the cost of goods sold (Figure 4-1). So, they are not considered in the total landed cost calculation either. In the following paragraphs, a deeper analysis of the remaining logistics costs and their drivers is made.

4.2.1 Inbound logistics costs

In this paragraph, the logistics costs generated by sourcing processes are considered. The aim of the paragraph is to define the most significant costs and define the basic drivers that explain them.

Inventory holding costs

The inventory holding costs depend mainly on the holding costs per unit and the average level of inventories kept in the warehouses. The average level of inventory depends on the replenishment logic used for the components. Depending on the three possible replenishment logics in use (traditional MRP-based replenishment; Kanban or consignment stock), the level of the stock of a particular component is determined by different parameters.

As presented in the literature review, Christopher (2005) proposes six different categories of costs to be included in the holding costs. The costs of *storage and handling* are already included in the "cost of goods sold" calculation. Additionally the *damage and deterioration, pilferage and shrinkage* as well as *insurance* costs are covered by the insurance that was mentioned in paragraph 4.2. These costs should be excluded from the analysis in order to ensure the coherence of the model. Therefore, the inventory holding costs are determined by the cost of capital and the obsolescence cost. In addition to these, even the price erosion cost is evaluated. The relevance of this expenditure emerged during the interviews. In the industry in which Alpha is operating, the components lose on average 15% of their value during a year. Thus, maintaining the components within the processes of the company generates an opportunity cost. This cost can be evaluated by the value loss that a component experiences during the time elapsing from its purchase to the sale of the product including the component itself.

The three costs considered can be expressed as percentage of the component price. In fact, the cost of capital is the minimum rate of return required for new investments (La Londe & Lambert, 1977). The obsolescence cost indicates the probability for a component to become obsolete. Finally, the price erosion cost can be expressed as the percentage reduction of the component value. To sum up, the significant variables that drive the average level of stock kept in inventory are: the

replenishment parameters used in the MRP system, the amount of components consumed, the size of kanban cards and the number of cards and finally the suppliers' delivery lead-times and the contract terms agreed with them.

Customs costs

Depending on the policies of the countries, imports of components can require the payment of duties and customs clearance fees. In accordance with the contract terms, the customs costs can be shared among the players or associated to only one of them. Normally Alpha is responsible for the payment of the import duties.

The components are categorized in bonded and non-bonded. In the former case the components are exported again after the production is finalized, in the latter they remain in the country. The duties have to be paid only for non-bonded components. The taxes charged vary for different materials. In general, electronic materials are free of charge. On the other hand, components like plastics and chemicals require paying on average duties equal to 10% of the value of the goods imported.

The customs clearance costs are related to fees that Alpha needs to pay for invoice handling in international trade. In the current case, the customs clearance costs are included in the calculation of the inbound freight costs and thus in the purchasing price of the materials. As the inbound transportation costs, they are considered in the model through the inclusion of data on the cost of goods sold of the products.

4.2.2 Outbound logistics costs

In this paragraph, the outbound logistics costs are evaluated. The responsibility for the outbound logistics costs is shared between Alpha and the customers in accordance with the contract terms.

Transportation costs

The transportation costs are considered in the total landed cost model only when they are under Alpha's responsibility. Depending on the various routes, different means of transportation may be available. The choice about the available transportation modes is made at the strategic level. In fact, these decisions affect the logistics system for a long period of time. Since the focus of the research is on tactical decisions, the transportation modes available are considered as taken.

Therefore for each route, the available transportation modes are clearly defined. For local routes, the transportation by truck is the only one available. On the contrary for global routes, the company balances the usage of sea and air shipments in order to optimize the trade-off between transportation costs and responsiveness of the supply chain. In order to model the transportation costs, it is necessary to consider freight rates, physical characteristics of the products (volume and weight), number of shipments during the year, and amount of products to be transported on various routes.

The estimation of the freight rates results to be challenging. Typically they depend on many factors, such as: route covered, means of transportation used, amount of goods transported per shipment (expressed in volume or weight depending on the type of transportation), and logistics company offering the transportation service. Furthermore, the freight rates are driven also from factors that are out of control of the organization like: oil price, macroeconomic situation, and global balance of the logistics network of the partners (e.g. in different seasons of the year the freight rates fluctuate depending on the level of usage of the logistics network of the transportation companies). The freight rates are fluctuating in the short term and operational decisions are influenced strongly by their fluctuations. For the scope of the model, it is necessary to define a standard situation in which the average freight rates can be estimated for tactical planning.

Inventory holding costs

The holding costs depend on the average amount of stock kept in the system and the inventory holding costs per unit. Before considering how to define the average level of stock, the inventory holding costs per product are discussed. Following the same approach used for the inbound holding costs, the six costs categories proposed by Christopher (2005) are considered. Even for outbound products, the *storage and handling* costs as well as the *management costs* at the production plants are already considered in the "cost of goods sold" model. On the other hand, the *storage and handling* costs at the local deposits are considered in the outbound *handling and packaging costs*. The final products are insured, the insurance covers the *damage and deterioration* and *pilferage/ shrinkage* costs. Hence, these expenses can be left out from the analysis.

Therefore, among the categories proposed by Christopher (2005), only the *costs of capital* and *obsolescence* are significant for the analysis. In addition to the six cost categories, the price erosion cost is considered as well. Indeed, it may represent a significant cost in case of a systematic reduction of the prices. However, data on the evolution of the product price in the past four years has shown that the price erosion is not significant for Alpha products. As for the inbound logistics, the inventory holding costs can be expressed as percentage of the product value. Under the hypothesis that the product prices are higher than the manufacturing costs, the value of the products can be expressed by the cost of goods sold.

Following the framework proposed by Vollmann (2005), inventory can be categorized in: cycle stock, safety stock and stock in transit. To be able to evaluate the impact of tactical decisions on the inventory holding costs, it is necessary to define the parameters and variables that influence the average level of stock kept in the logistics system. The average level of stock has to be modelled in different ways depending on the type of inventory considered. The cycle stock depend mainly on the final demand and the production lead-times. The stock in transit depend on the total volume transported and the transportation lead-times. Finally, the level of safety stock is mainly correlated to the uncertainty that the supply chain has to face. In this context, the demand and lead-times (e.g. transportation lead-times) are considered the main sources of uncertainty.

Customs costs

As in the inbound logistics, the trade policies established by different countries may require the payment of customs costs for exports. The type of products commercialized by Alpha does not require the payment of export duties. In contrast, the customs clearance costs to be paid on the exports may be significant in evaluating the efficiency of tactical decisions. The customs clearance fee to be paid per invoice is related to the number of lines contained in it and not from the value of goods exported. Hence, when the amount of products per invoice is low, the customs clearance costs may take a significant role in determining the profitability of the products. The production venue affects the customs clearance fees to be paid so in certain cases these costs may take a significant role in determining the best production allocation for profit optimization. For this reason, even though their

absolute value is of secondary importance, it is decided to include the customs clearance costs in the total landed cost model.

Handling and packaging costs

The costs generated by packaging and handling activities should be considered in this category. In Alpha accounting system, the packaging and handling costs generated at the production plants are already recorded in the "cost of goods sold" model. So, the only expenses to be considered are the one at the local deposits.

To calculate the costs generated by handling activities, it is necessary to consider the activities and the processes performed at the local deposits. In Figure 4-3, a sketch of the activities performed at the deposits is presented.

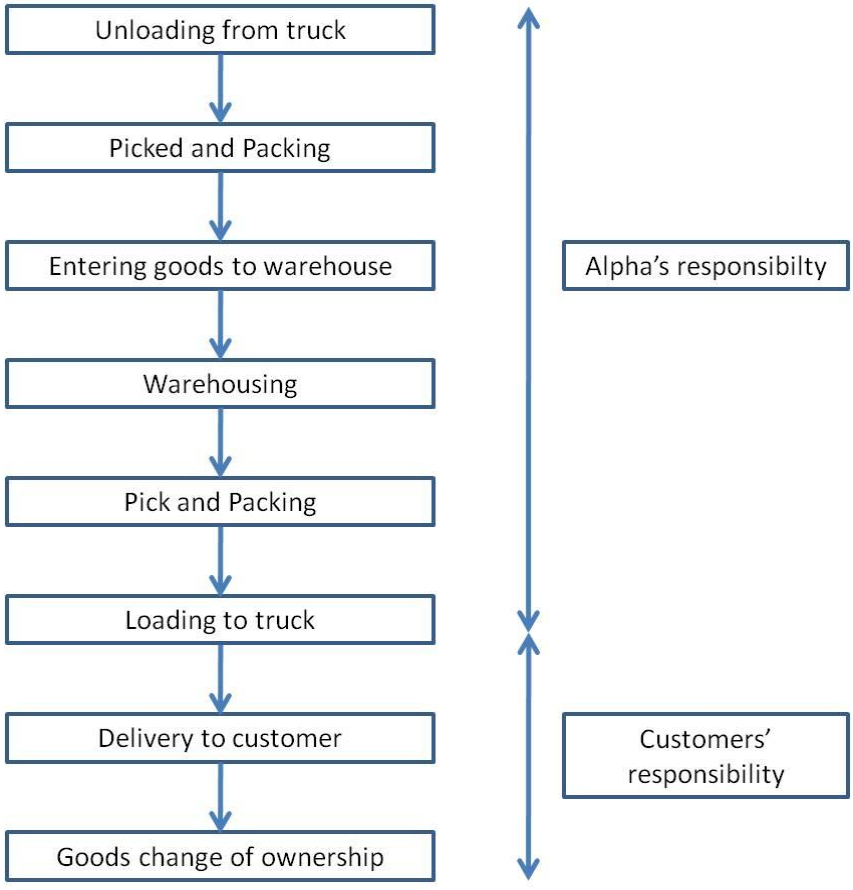


Figure 4-3 – Processes at the local deposits

The division of the responsibility between customers and Alpha is clearly stated in the contracts established for the management of the consignment deposits. This allows allocating the handling costs properly. As stated previously, the ownership of

the goods is shifted only when the products are delivered to the customers' production plants.

4.2.3 Hidden costs

According to the article written by Goel et al. (2008), the hidden costs described in the literature review should be included in the total landed cost model. During the interview with Alpha operations and logistics managers, it emerged that Chinese production plan and the Estonian did not show any difference in terms of quality. Therefore, the costs related to *reworking errors* were excluded from the analysis.

On the other hand, the costs linked to *incremental financing* and *exchange rate risk* take a significant role in the case study. Based on the data collected, it is estimated a supply chain throughput time toward the European market of 88 days for the Chinese production plant against 34 days for the Estonian one (the lead time includes the activities from the order of the inbound material until the final delivery at the local hub). The strong difference among the production plants has a significant impact on the stock in transit in the system and it requires *incremental financing* in case of production offshoring in China. The two production plants finance their activities with different currencies (Chinese RMB and Estonian EEK) and Alpha economic results are expressed in Euro. Therefore, the company is exposed to exchange rate risk and its profitability depend on the exchange rates.

4.3 Cost drivers

To summarize the considerations made in the previous paragraph, the drivers of the costs considered are collected in Table 4.2. The categorization allows getting a better understanding of the data to be collected from the information system.

The drivers listed in the table are valid for both inbound and outbound logistics. The consumption of the inbound materials can be directly connected to the demand of products through the bills of materials.

Table 4.2 – Matrix costs and drivers

Drivers	Transportation	Inventory	Customs	Handling
Final demand	x	x	x	x
Logistics network (production plants, hubs, suppliers location)	x	x	x	x
Exchange rates	x	x	x	x
Production allocation	x	x	x	x
Shipment frequency (Outbound)	x	x	x	x
Product packaging (volume, weight)	x			x
Freight rates (transportation mode)	x			
Cost of capital		X		
Demand variability		x		
Bill of materials value erosion		x		
Product value		x	x	
Process lead times (production, transportation)		x		
Contract terms	x	x		
Shipment frequency (Inbound)	x	x	x	x
"Harmonized system" codes			x	
Country policies			x	

The "shipment frequency" and the "transportation mode" take a significant role in determining the final results of the model. As the production allocation, the number of shipments and the mix of means of transportation are considered as a decision variable. Depending on these variables, the freight and the inventory carrying costs are defined.

To get a better understanding on which analyses the model should support, it is useful to categorize the drivers of the costs. They can be divided in the drivers under the control of the management, "decision parameters", and the drivers that are partially or completely outside the control of the organization.

Table 4.3 - Decision parameters

Strategic parameters	Transportation modes Logistics network (production plants, hubs, suppliers location)
Tactical parameters	Shipment frequency (Outbound) Production allocation (current and new products) Shipment frequency (Inbound)
Negotiable parameters	Product packaging Contracts terms

In Table 4.3, the "decision parameters" are further divided on the basis of their planning horizons (strategic and tactical planning decisions). It is significant to make this classification to define clearly the focus of the model, which in this research results to be on tactical decisions. Therefore, the model is built to support the comparison of alternative configurations of the tactical parameters, whereas modification of the strategic variables would require upgrading the model.

Based on the parameters identified, the table below (Table 4.4) shows the existing relation between decisions variables and the logistics costs considered. The decision on the shipment frequency (Inbound and Outbound) requires to balance the trade-off between the transportation cost and the inventory holding cost. On the one hand increasing the shipment frequency allows reducing cycle and safety stock. On the other hand, it decreases the volumes shipped per time and it raises the transportation cost. The reduction of the volumes shipped increases the impact of customs cost as well. The decision of production off-shoring to China rises the logistics costs. The usage of sea shipment increases significantly the relevance of stock in transit. Instead, it is difficult to describe a priori the behavior of handling cost. In fact, it depends on a large number of factors like: unloading time (truck versus containers), wage levels, building costs, etc.etc.

Table 4.4 – The influence of decisions parameters on logistics costs

	Driver direction	Transportation	Inventory	Customs	Handling
Shipment frequency (Outbound)	+	+	-	+	Not influenced
Production allocation	Offshoring	+	+	+	+ or -
Shipment frequency (Inbound)	+	+	-	+	Not influenced

In Table 4.3, the "negotiable parameters" are divided from the others to indicate that they affect the operations of third parties like suppliers, customers and logistics partners. A change in these variables should be discussed with all the parties affected, since the modification of these variables might affect also their efficiency. In a total cost perspective, the model developed would not be adequate to evaluate fully the impact of these decisions on the supply chain. Alternatively, if the model were focused on the "negotiable parameters", it would have been necessary to extend its scope at least to the first tier of suppliers and customers.

Table 4.5 - Partially independent parameters

Partially independent parameters	Product packaging (volume, weight) Product value Process lead times (production, transportation)

Table 4.5 lists the parameters that are only partially under the control of the company. These factors are influenced by the decisions taken within the organization as well as the technology available for the design of the products and by the requirements of the customers. These parameters are taken as input by the model and can be easily updated. If needed, it is possible to evaluate the effects of potential modifications of these parameters on the supply chain performance.

Table 4.6 - External parameters

External parameters	Final demand Demand variability Freight rates Exchange rates "Harmonized system" codes Country policies Bill of materials value erosion

Finally, Table 4.6 lists the factors that are strongly influenced by the "outside world" circumstances. In fact, parameters like freight rates and exchange rates are greatly dependant on the status of the world economy. At the same time, they have a primary role in determining the efficiency of decisions taken on global supply chains. Thus, it is of primary interest for the managers to understand their effects on the decisions analyzed. In some circumstances, a more robust choice may be preferred to an alternative that seems to be more efficient. To support this type of reasoning, the model should provide the possibility of analyzing different scenarios with the aim of evaluating the effects of uncertainty.

In the following paragraph, the equations representing the relationships between drivers and costs are presented. From the equations, it is also possible to get a better understanding of the information to be collected to run the model.

4.4 Model formulation

In this paragraph the hypothesis, the simplifications and the equations used in modeling the total landed cost are presented. For each of the cost category identified, the links between costs and the input data are explained. The formulas presented are strongly dependent on the context in which the model is applied. So the application of the same model in different contexts would require adapting them to new circumstances.

The planning model is based on a similar approach to the one proposed by Schneeweiss (1998). Starting from the final demand, the expected costs are calculated. For the inbound logistics, the amount of components consumed is directly

determined from the final demand through the bill of materials of the products. The approach taken for cost modeling can be classified as activity-based costing. However, the application of the activity-based costing technique for planning purposes requires its adaptation. Therefore, this classification might result forced.

Since the company operates internationally, the data on the expenses are expressed in different currencies (Euro, Chinese Yuan or RMB, and Estoninan Kroon or EEK). In the model all the costs are converted into Euro. Even though, it is not specified in the formulas listed below, the final costs are influenced strongly by the exchange rates. The analysis made in the following section is organized in accordance to Zeng and Rossetti (2003) cost categorization, as in paragraph 4.2.

4.4.1 Inbound logistics

In this section, the costs, generated by the inbound logistics, are modeled.

Inventory holding costs

In the industry where the case study is operating, the effects of price erosion on the value of the inbound components are significant. So the value loss of the components incurring from the purchase of the component to the sale of the final product has to be evaluated. The price erosion cost is accounted in the inbound logistics costs until the consumption of the components in production. Under the hypothesis that the price of the components is established when the suppliers accept the orders, the delivery lead-times of the suppliers should be considered when the price erosion cost is calculated. Therefore, the value loss of the *l*-components purchased from the *s*-supplier during the replenishment lead-time can be calculated as:

Price erosion cost on stock in transit at the *i*-production plant for the *l*-component purchased from the *s*-supplier [Eur]

$$ICTPE(l,s)_i = CD(l,s)_i * PE(l,s) * VPA(l,s)_i * \frac{DLT(l,s)}{365} \quad \textbf{4.1}$$

Where:

- $CD(l,s)_i$ = Consumption forecast during the planning horizon of the component *l* at the *i*-production plant purchased from the *s*-supplier [unit]. The consumption of components is directly related to the demand of final products. The spreadsheet software does not allow keeping information regarding the bills of materials in the model. Rather, the MRP system computes the consumption forecast of the components based on the demand of the products;
- $PE(l,s)$ = Yearly price erosion of the *l*-component purchased from *s*-supplier [1/year];
- $VPA(l,s)_i$ = Price agreed with the *s*-supplier for the *l*-component at the *i*-production plant [Eur/unit];
- $DLT(l,s)_i$ = Delivery lead-time agreed for the *l*-component with the *s*-supplier at the *i*-production plant [days].

Depending from the contract terms agreed with the suppliers, Alpha might have to cover a part of the costs and risks of the transportation. Through a percentage, it is possible to express the share of the responsibility taken by Alpha. In agreement with Alpha accountant rules, it is hypothesized that the shift of ownership and the economic transaction are realized when the responsibility passes from the supplier to Alpha. Thus, the number of components in transit that has to be considered in computing the inventory holding costs is:

Stock in transit, *l*-component and *s*-supplier at the *I*-production plant [unit]

$$IST(l,s)_i = DLT(l,s)_i * \frac{CD(l,s)_i}{TD} * RS(l,s)_i \qquad \textbf{4.2}$$

Where:

- TD = Number of days in the planning horizon considered [days];
- $RS(l,s)_i$ = Percentage of the transportation process carried by Alpha for the *l*-component purchased from *s*-supplier.

To evaluate the average level of inventory at the inbound warehouses at the production plants, it is necessary to consider the replenishment logics that the company is adopting for the purchase of direct materials. For those components managed through VMI, the stock level is of secondary importance. In fact in this case, the materials become Alpha's property only when they are consumed. The suppliers carry the inventory holding costs so this cost is not considered in the model.

The components managed with MRP logic are organized in ABC categories depending on the consumption volumes and their value per unit. According to the category that the component belongs to, the orders are prepared with different planning horizons. The planning horizons determine the amount of days of consumption that the order should cover and it influences the average level of cycle stock kept in the inbound inventory. The average level of stock can be estimated as:

Cycle stock of *l*-component purcahsed from *s*-supplier at the i-production plant - MRP replenishment logic [unit]

$$if\ (RL(l,s) = "MRP")$$
$$ICS(l,s)_i = \frac{CD(l,s)_i * PH(l,s)_i}{2 * TW} \qquad \textbf{4.3}$$

Where:

- $RL(l,s)$ = Replenishment logic adopted for the *l*-component purchased from *s*;
- $PH(l,s)_i$ = Planning horizon for the purchase of *l*-component at the *i*-production plant from the *s*-supplier [weeks];
- TW = Number of weeks in the planning horizon considered [weeks].

For the components purchased through MRP system, the safety stock of the inbound material are generated by the anticipation of the purchase orders:

Safety stock of *l*-component purcahsed from *s*-supplier at the i-production plant - MRP replenishment logic [unit]

$$if\ (RL(l,s)_i = "MRP")$$
$$ISS(l,s)_i = (\frac{CD(l,s)_i}{TW} * PH(l,s)_i) * \frac{WBC(l,s)}{PH(l,s)_i} \quad \textbf{4.4}$$

Where:

- $WBC(l,s)_i$ = Advance time of order generation for the component *l* purchased from *s*-supplier at the *i*-production plant [weeks].

In case of Kanban replenishment logic, the average inventory for a component depends mainly on the amount of cards and the quantity of components contained in each Kanban box. Under the hypothesis of short lead times (in the case considered, Kanban logic is adopted for components with one day replenishment lead time) and constant consumption, it is possible to approximate the average level of stock.

The average number of cards moving in the system can be estimated as:

Number of *l*-components in movement, purchased from *s*-supplier at the *i*-production plant – Kanban replenishment logic [unit]

$$BM(l,s)_i = [1 + BCR(l,s)_i] * BS(l,s)_i \quad \textbf{4.5}$$

Where:

- $BS(l,s)_i$ = Card size of the *l*-component purchased from the *s*-supplier at the *i*-production plant [unit/card];
- $BCR(l,s)_i$ = Number of boxes consumed during the replenish lead time, which can be calculated as:

Number of cards of *l*-component purchased from *s*-supplier consumed during the replenishment lead time at the *i*-production plant [card]

$$BCR(l,s)_i = \frac{CD(l,s)_i * DLT(l,s)_i}{TD * BS(l,s)_i} \quad \textbf{4.6}$$

Thus, the average level of stock created by the Kanban replenishment logic for the *l*-component is given by the following formula:

Stock of the *l*-component purchased from the *s*-supplier at the *i*-production plant - Kanban replenishment logic [unit]

$$\begin{aligned} &if\ (RL(l,s)_i = "Kanban") \\ &ICS(l,s)_i = \left[BS(l,s)_i * NB(l,s)_i - BM(l,s)_i\right] \\ &+ \frac{BM(l,s)}{2} \end{aligned} \quad \textbf{4.7}$$

Where:

- $NB(l,s)_i$ = Number of cards for the *l*-component purchased from the *s*-supplier at the *i*-production plant [card];

Finally, the average inventory for the *l*-component at the *i*-production plant can be expressed as:

Average *l*-component's stock at the *i*-production plant purchased from *s*-supplier [unit]

$$IS(l,s)_i = ICS(l,s)_i + ISS(l,s)_i \quad \textbf{4.8}$$

The inventory holding costs per unit is a function of the cost of capital and the cost of obsolescence. The price erosion cost instead is treated separately. The cost of capital is taken as input from the "Finance and Administration" department. On the other hand, the obsolescence cost can be estimated from the historical data on the inbound inventory. It can be calculated as the percentage of the inventory value that is scraped during a period of time equal to the planning horizon. The inventory holding costs per unit is expressed as a percentage of the purchasing price of the component:

Holding costs to be considered in the inbound inventory

$$IHC = CC + IOR \quad \textbf{4.9}$$

Where:

- CC = Cost of capital;
- IOR = Obsolescence risk on inbound components.

The inventory holding costs generated by the *l*-component purchased from *s*-supplier at the *i*-production plant can be calculated as following:

Inbound inventory holding costs for the *l*-component purchased from the *s*-supplier at the *i*-production plant [Eur]

$$HCIS(l,s)_i = (IS(l,s)_i + IST(l,s)_i) * \\ * VPA(l,s)_i * IHC \quad \textbf{4.10}$$

The price erosion cost has to be evaluated also for the time that the components spend in the inbound inventory. Under the hypothesis that the materials are consumed through FIFO (First in First out) logic, the average period of time that the *l*-component spends in the inbound warehouse is equal to its "days of supply". It can be calculated as:

Days of supply for the *l*-component purchased from *s*-supplier at the *i*-production plant [days]

$$DoSC(l,s)_i = \frac{IS(l,s)_i * TD}{CD(l,s)_i} \quad \textbf{4.11}$$

Therefore, the price erosion cost is given by the following formula:

Inbound price erosion cost for the *l*-component purchased from *s*-supplier at the *i*-production plant [Eur]

$$ICPE(l,s)_i = \frac{DoSC(l,s)_i * PE(l,s)}{365} * VPA(l,s)_i * CD(l,s \quad \textbf{4.12}$$

Customs costs

The duties to be paid for the inbound components depend on the final destination of the products and the type of materials. The duties are normally expressed as a

percentage of the purchasing price of the component. Hence, the duties to be paid on the *l*-component at the *i*-production plant can be calculated as following:

Inbound duties to be paid on the *l*-component purchased from the *s*-supplier at the *i*-production plant [Eur]

$$IDC(l,s)_i = CD(l,s)_i * VPA(l,s)_i * \sum_{j=1}^{n} \left[DF(HS(l,i,j)) * PS_{i,} \right] \quad \textbf{4.13}$$

Where:

- $DF(HS(l,i,j))$= Duty fee associated to the HS code of the *l*-component imported in *i* and with *j*-final destination. The fee might be different from zero when the country of the production plant coincides with the final destination of the product containing the component;
- $PS_{i,j}$ = Share of the production of the *i*-production plant sold to the *j*-destination. It is hypothesized that the components are sent to the *j*-destination with the same proportions.

$PS_{i,j}$ can be calculated as:

Production share of the *i*-production plant sold in *j*

$$PS_{i,j} = \frac{D(c,k)_{i,j}}{\sum_{j=1}^{n} DC(c,k)_{i,j}} \quad \textbf{4.14}$$

Where:

- $D(c,k)_{i,j}$ = Demand forecast of the *k*-product ordered by the *c*-customer at the *j*-destination to be produced in the *i*-production plant within the planning horizon.

4.4.2 Outbound logistics

Transportation costs

When the transportation costs are calculated, one of the challenges to face is the evaluation of the freight rates. Swenseth and Godfrey (1996) have considered five

different functions for the calculation of the freight rates. The study shows the challenges to build a function of the freight rates. Given the complexity in modeling them, it is decided to let the user choose the appropriate freight rates to be applied on each route. Therefore, the model estimates the average weights and volumes transported on each route. Consequently, the user is required to input the transportation costs per kilogram or m^3. In this way, the user is also allowed to evaluate how changes in the freight rates would affect the total landed cost.

For the construction of the model, it is important to notice that the costs of transportation and customs are influenced by the consolidation of the orders. Therefore, the costs generated by one product are influenced by the decisions taken on the whole supply chain. For instance, the freight rates per product are affected by the total amount of products transported on the same route. Given the relevance of the transportation costs (Figure 4-2), it is necessary to maintain a systemic point of view on the supply chain to get a reliable estimation of the total landed cost. The collection of the data regarding the whole system requires a significant amount of time and resources. So, it is useful to define the minimum part of the supply chain that should be considered to get reliable estimation of the costs. Since transportation and invoices cannot be merged across customers, they can be considered as the minimum part of the supply chain to be considered when the model is applied. In other words, it is possible to get reliable estimation of the total landed cost generated by one customer without collecting data regarding the rest of the organization.

The elements that define a route are: a starting point (*i*-production plant), an ending point (*j*-final destination), a mean of transportation (*z*-mean of transportation) and a final customer (*c*-customer). The hypothesis underlying the calculations is that, Alpha consolidates orders only when they are made from the same customer. In fact from the interviews, it emerged that Alpha does not have the capability of merging orders across customers. The average weight of the goods transported per shipment on the *i, j, z* route for the *c*-customer can be calculated as:

Average weight carried per shipment on the *i, j,z* route, *c*-customer [Kg/Shipment]

$$\overline{QTW}(c)_{i,j,z} = \frac{1}{\max_{i,j} S(c,k)_{i,j,z}} * \sum_{k=1}^{p} \left[\frac{D(c,k)_{i,j} * TS(z)_{i,j} * WSB(k,c)}{SQTY(k,c)} \right] \quad \textbf{4.15}$$

Where:

- $TS(z)_{i,j}$ = Share of the products to be transported with the *z*-mean of transportation on the *i, j* route;
- $SQTY(c,k)$ = Standard number of *k*-products sent to the *c*-customer contained in the delivery box [Unit/Box];
- $WSB(c,k)$ = Standard weight of the delivery box used for the *k*-product, *c*-customer [Kg/Box];
- $S(c,k)_{i,j,z}$ = Number of shipments within the planning horizon planned on the *i,j* route for the *k*-product, *c*-customer with the *z*-mean of transportation [Shipment].

Similarly, the average volume transported per shipment on the route *i, j, z* for the *c*-customer is:

Average volume carried per shipment on the *i, j, z* route, *c*-customer [m^3/shipment]

$$\overline{QTV}(c)_{i,j,z} = \frac{1}{\max_{i,j} S(c,k)_{i,j,z}} * \sum_{k=1}^{p} \left[\frac{D(c,k)_{i,j} * TS(z)_{i,j} * VSB(k,c)}{SQTY(k,c)} \right] \quad \textbf{4.16}$$

Where:

- $VSB(c,k)$ = Standard volume of the delivery box used for the *k*-product, *c*-customer [m^3/box].

The transportation costs on the *i, j* route for the *c*-customer can be calculated as:

Transportation costs for *c*-customer for products transported on *i, j* route [Eur]

$$TRC(c)_{i,j} = \sum_{z=1}^{q} \sum_{k=1}^{p} \left[\frac{D(c,k)_{i,j} * TS(z)_{i,j}}{SQTY(c,k)} * \frac{WSB(c,k)}{VSB(c,k)} * FR_{i,j,z}(c) \right] \quad \textbf{4.17}$$

Where:

- $FR_{i,j,z}(c)$ = Freight rates associated to the average weight/volume carried per shipment on the route *i, j, z* for the *c*-customer [Eur/kg or Eur/ m^3];
- Depending from the different *z*-mean of transportation, the freight rates might be expressed in Eur/kg or Eur/ m^3.

To identify the total transportation costs, it is necessary to sum the costs on all the possible routes *i, j* for all the c-customers.

Inventory holding costs

As shown in Figure 4-1, the final products can be kept in three different locations: at the production plants, in the pipeline and in the local deposits. Since quantities and the inventory carrying costs differ for these categories, the analysis is divided in three sections. The effects of the price erosion are considered in a fourth section. In fact, the price erosion cost is transversal to all the three inventory categories.

- **Inventories at the production plants**

Independently of the production planning logic considered (MTO, ATO and STO), the level of safety stock is considered null at the production plants. Indeed, it is assumed that the production plants have enough capacity to face all the orders received from the customers and the local deposits. The production processes generate two categories of stock: the "work-in-process" stock (intermediate warehouses and components in production), and the final product cycle stock.

The average level of "work-in-process" stock created at the *i*-production plant can be estimated as:

"Work-in-process" stock generated by *k*-product at the i -production plant directed at the *j*-destination for the *c*-customer [unit]

$$WIP(c,k)_{i,j} = \frac{D(c,k)_{i,j} * LTP(k)}{TD} \quad \textbf{4.18}$$

Where:

- $LTP(k)$ = Production time for the lot of *k*-product [days]. According to the interviews, the throughput time of the production lot is constant independently from the lot size. In fact in Alpha production processes, the production times per unit are significantly smaller than the setup times.

The growth pace of the stock of final products is considered constant during production. Thus, the cycle stock created by the orders generated from the *c*-customer for the *k*-product can be modelled as:

Cycle stock of *k*-product at the i -production plant directed at the *j*-destination for the *c*-customer [unit]

$$CSP(c,k)_{i,j} = \frac{D(c,k)_{i,j}}{2} * \frac{LTP(k)}{TD} \quad \textbf{4.19}$$

In paragraph 4.2.2 was discussed that the cost of capital and the cost of obsolescence should be considered in the inventory holding costs. La Londe and Lambert (1977) suggested that the value of the inventory might be evaluated in many ways. Normally, the most appropriate logic is the one currently used by the company for bookkeeping purposes. Therefore in this case, the cost of goods sold is the most appropriate measure to be used in determining the value of the inventory. Instead, the value to the "work-in-process" stock can be approximated to the value of the direct materials. The inventory holding costs generated at the *i*-production plant by the products sold to the *c*-customer can be calculated as:

Outbound inventory carrying costs of "work -in-process" stock generated by *c*-customer's orders at the *i*-production plant [Eur]

$$HCWIP(c)_i = \sum_{k=1}^{p} \left\{ \sum_{j}^{n} \left[WIP(c,k)_{i,j} \right] * COGS(k)_i * \overline{MS} * HC(c,k \right.$$

4.20

Outbound inventory carrying costs of cycle stock generated by *c*-customer's orders at the *i*-production plant [Eur]

$$HCP(c)_i = \sum_{k=1}^{p} \left\{ \sum_{j}^{n} \left[CSP(c,k)_{i,j} \right] * COGS(k)_i * HC(c,k \right.$$

4.21

Where:

- $COGS(k)_i$ = Cost of goods sold of the *k*-product produced at the *i*-production plant [Eur/Unit];
- $\overline{MS}$ = Share of the cost of goods sold covered by the direct material;
- $HC(c,k)$ = Inventory holding costs per unit of *k*-product. It is calculated as the sum of the cost of capital and the cost of obsolescence:

Outbound inventory holding costs per unit of *k*-product ordered by the *c*-customer

$$HC(c,k) = CC + OR(c,k)$$

4.22

Where:

- $OR(c,k)$ = Obsolescence risk of the *k*-product, *c*-customer.

For the calculation of the obsolescence cost, it is assumed that the "salvage value" (La Londe & Lambert, 1977) of the products is equal to 0. The cost of an obsolete product is equal to its value (i.e.. the cost of goods sold). Therefore, the obsolescence probability of the *k*-product can be added to the cost of capital in order to calculate the expected holding cost per unit. The obsolescence risk is a parameter estimated by the company, which mainly depends on the life cycle stage of the product and the behavior of the customer purchasing the product. Indeed, the behavior of the

customer has a great impact in mitigating or increasing the obsolescence risk (Hoover et Al., 2001).

- **Stock in transit**

To evaluate the costs generated by the stock in transit, it is necessary to estimate the average amount of inventory kept in the pipeline of the supply chain. The amount of units carried per route (*i, j, z*) depends on the transportation lead-times and the amount of products to be transported during the planning period. Through the following equation, it is possible to estimate the average amount of *k*-products in transit on the route *i, j, z* per unit of time:

Average number of *k*-products shipped on the route *i, j* on the *z*-mean of transportation per unit of time [unit/days]

$$\overline{SLS}(c,k)_{i,j,z} = \frac{D(c,k)_{i,j} * TS(z)_{i,j}}{TD} \quad \textbf{4.23}$$

The average amount of k-products in transit on the *i, j, z* route is:

Average units of *k*-product in transit on the *i, j, z* route [unit]

$$\overline{ST}(c,k)_{i,j,z} = \overline{SLS}(c,k)_{i,j,z} * TLT_{i,j,z} \quad \textbf{4.24}$$

Where:

- $TLT_{i,j,z}$ = Expected transportation lead-time between the *i*-production plant and j-destination using the z-mean of transportation [days].

The inventory holding costs of the stock in transit generated by the *c*-customer on the *i, j* route can be calculated as:

Outbound inventory holding costs, stock in transit associated to c-customer on the i, j route [Eur]

$$HCST(c)_{i,j} = \sum_{k=1}^{p} \begin{cases} \sum_{z=1}^{q} \left[\overline{ST}(c,k)_{i,j,z}\right] * \\ * COGS(k)_i * HC(c,k) \end{cases} \quad \textbf{4.25}$$

- **Local deposits**

For the consignment deposits, it is necessary to model the average level of final products kept in the warehouses. In the supply chain considered, the local deposits are dedicated to single customers. As outcome of the negotiation process between the customers and Alpha, the lower and upper boundaries of the inventory define the adequate level of stock to keep in the deposits. Alpha has the task to manage the production and the transportation in order to ensure the level of stock agreed. Alpha owns the products until the customer consumption so the company carries the inventory holding costs until the products are moved to the customer production plant. Depending on the contract terms, the customers may take liabilities on the maximum level of inventory allowed. In case of demand interruption for a certain product, the customers have to buy the stock in the deposit until the agreed quantity is reached. For this reason, the cost of obsolescence is covered separately from the cost of capital.

To avoid the shortage of products, a certain amount of safety stock has to be kept on top of the lower amount allowed. Typically, the most significant factors in determining the proper level of safety stock are the demand and transportation uncertainty (Stadtler and Kilger, 2005). Therefore, the average level of stock carried at the local deposits is composed by the minimum inventory level allowed and the amount of safety stock. Finally, the production and transportation lot policies adopted by Alpha generates cycle stock.

Under the hypothesis of constant demand, the average amount of cycle stock of *k*-product kept in the *j*-local deposit can be modelled as:

Cycle stock of *k*-product at the *j*-local deposit [unit]

$$CSH(c,k)_j = \sum_{i=1}^{n} \left[\frac{D(c,k)_{i,j}}{\sum_{z=1}^{q} \left(S(c,k)_{i,j,z} \right) * 2} \right] \quad \textbf{4.26}$$

The cost of capital tied up in the cycle stock at the *j*-deposit can be calculated as:

Cost of capital tied up in the cycle stock generated by the *c*-customer at the *j*-deposit [Eur]

$$CCSH(c)_j = \sum_{k=1}^{p} \sum_{i=1}^{n} \left[\frac{D(c,k)_{i,j}}{\sum_{z=1}^{q} \left(S(c,k)_{i,j,z} \right) * 2} * COGS(k)_i \right] * C(\quad \textbf{4.27}$$

According to the supply chain configuration of Alpha, the safety stock are kept only at the local deposits: so the supply chain can be defined as a single-inventory system (Stadtler and Kilger, 2005). A lot of research has focused its attention in defining the level of safety stock to be kept in the inventory. In dimensioning the safety stock, the objective should be to balance the inventory holding costs and the cost of a lower level of service offered to the customers (Stadtler and Kilger, 2005).

For a single-inventory system, the formula for the calculation of the optimal safety stock is straightforward. Indeed given a certain level of service that the company wants to ensure, it is possible to use the formula suggested by Stadtler and Kilger (2005):

Level of safety stock carried at the *j*-deposit [unit]

$$SS(c,k)_j = LoS(c) * \sigma(c,k)_j \quad \textbf{4.28}$$

Where:

- $LoS(c)$ = Level of service offered to the *c*-customer, which is defined as the probability of no stock-outs during the risk time;
- $\sigma(c,k)_j$ = Standard deviation of the probability distribution of the demand and of the transportation lead-time during the risk time, that is calculated as:

$$\delta(c,k)_j = \sqrt{\delta_D(c,k)^2 * LT(c,k)_j + \left[\overline{\delta_{LT}}(c,k)_j\right]^2 * \left[\frac{\sum_{i=1}^{m} D(c,k)_{i,j}}{TD}\right]} \quad \textbf{4.29}$$

Where:

- $\delta_D(c,k)^2$ = Variance of daily demand of the *c*-customer per *k*-product [Unit^2/Days];
- $\delta_{LT}(c,k)_{i,j}$ = Standard deviation of transportation lead-time on the *i*, *j* route [days].

$$\overline{\delta_{LT}}(c,k)_j = \frac{\sum_{i=1}^{m}\left[D(c,k)_{i,j} * \delta_{LT}(c,k)_{i,j}\right]}{\sum_{i=1}^{m} D(c,k)_{i,j}} \quad \textbf{4.30}$$

$$\overline{TLT}_{i,j} = \sum_{z=1}^{q}\left[TLT_{i,j,z} * TS(z)_{i,j}\right] \quad \textbf{4.31}$$

$$\overline{\overline{TLT}}(c,k)_j = \frac{\sum_{i=1}^{m}\left[D(c,k)_{i,j} * \overline{TLT}_{i,j}\right]}{\sum_{i=1}^{m} D(c,k)_{i,j}} \quad \textbf{4.32}$$

$$LT(c,k)_j = LTP(k) + \overline{\overline{TLT}}(c,k)_j \quad \textbf{4.33}$$

The standard deviation of the demand can be calculated for each customer. The calculation should be based on the historical data and on the hypothesis that the demand distribution can be approximate to the normal one (Stadtler and Kilger, 2005). On the other hand, the expected value and the standard deviation of the transportation lead-time can be estimated through the approximation of the data to the beta distribution. In this case, the logistics partner provides the transportation lead-times in the most likely case, the worst case and the best case.

Given the manufacturing strategies considered by Alpha (see paragraph 3.3), the same code can be manufactured in different production plants and sent to the same deposit. Hence, it is necessary to calculate the weighted average of the cost of goods sold in order to valorise the safety stock. In fact, the model built does not allow tracing of the provenience of the products kept in the inventory.

The weighted average of the cost of goods sold can be calculated as:

Weighted average of the cost of goods sold for the k-product kept at the *j*-deposit [Eur/unit]

$$WACOGS(c,k)_j = \frac{\sum_{i=1}^{m} D(c,k)_{i,j} * COGS(k)}{\sum_{i=1}^{m} D(c,k)_{i,j}} \quad \textbf{4.34}$$

The cost of capital tied up in safety stock at the *j*-deposit is:

Cost of capital tied up in the safety stock at the *j*-deposit for the *c*-customer [Eur]

$$CSSH(c)_j = \sum_{k=1}^{p} \left[SS(c,k)_j * WACOGS(c,k)_{i,j} \right] * C \quad \textbf{4.35}$$

Finally, the minimum level of inventory should be considered in calculating the cost of capital. Even in this case, the value of the products has to be estimated through the weighted average of the cost of goods sold. The inventory holding costs can be calculated as:

Cost of capital tied up in the minimum inventory level required by the *c*-customer at the *j*-deposit

$$CMSH(c) = \sum_{k=1}^{p} \left[mQTY(c,k)_j * WACOGS(c,k)_{i,j} \right] * C \quad \textbf{4.36}$$

Where:

- $mQTY(c,k)_j$ = Minimum amount of stock of k-product to be carried at the j-deposit [unit].

The inventories carried in the local deposits are exposed to obsolescence risk as well. However in some cases, the customers may carry a part of this risk accepting to have liabilities on the stock kept in the local deposits. The expected obsolescence cost has to be considered only for the stock exceeding the customers' liabilities.

The total amount of stock of *k*-product carried at the *j*-deposit is:

Stock of *k*-product carried on average at the *j*-deposit [unit]

$$TSH(c,k)_j = mQTY(c,k)_j + CSH(c,k)_j + SS_j(c,k$$

4.37

The expected obsolescence cost generated by the *k*-product at the *j*-deposit can be calculated as:

Obsolescence cost of the *k*-product at the *j*-deposit [Eur]

$$if \lfloor MQTY(c,k)_j * L(c) - TSH(c,k)_j \rfloor > 0$$

$$OCH(c)_j = \sum_{k=1}^{p} \begin{bmatrix} (MQTY(c,k)_j * L(c) - TSH(c,k)_j) * \\ WACOGS(c,k)_j * OR(c,k) \end{bmatrix} \quad \textbf{4.38}$$

Where:

- $MQTY(c,k)_j$ = Maximum amount of stock allowed of *k*-product at the *j*-deposit;
- $L(c)$ = Liabilities carried by the *c*-customer on the maximum amount of stock allowed in the consignment deposits.

- **Price erosion costs**

The effects of price erosion on the components have to be considered also in the outbound logistics. The cost should consider the loss of value that the components suffer during period elapsing from the time when the components are picked up for production until the sale of the products. In case of MTO and ATO production, this period is set to zero. Indeed, it is assumed that the materials are picked up from the inbound warehouse only when the products are sold. In case of STO production, the products are sold when the customers consume them at the local deposits. Hence, the period is composed of the times for production and transportation as well as of the waiting time before product consumption.

The production lead-time for the *k*-product is defined as $LTP(k)$ and is considered constant independently from the size of the production lot. The transportation lead-times are evaluated at their expected values. The time necessary for transportation

depends on the distances between production plants and deposits as well as on the means of transportation used.

Expected transportation lead-time on the *i* ,*j* route [days]

$$\overline{TLT}_{i,j} = \sum_{z=1}^{q} TS(z)_{i,j} * TLT_{i,j,z} \qquad \textbf{4.39}$$

Under the hypothesis that the customer consumes the products following FIFO logic, the waiting time before consumption is equal to the inventory "days of supply".

Days of supply of the *k*-product at the *i*- production plant [days]

$$DoSP(c,k)_j = \frac{TSH(c,k)_j * TD}{\sum_{i=1}^{m} D(c,k)_{i,j}} \qquad \textbf{4.40}$$

The products are kept within the company's processes for a period equal to the sum of the three times discussed above. Therefore, the price erosion cost can be calculated as:

Price erosion cost for products stored at the *j*-deposit for the *c*-customer [eur]

$$CPE(c)_j = \sum_{k=1}^{p} \begin{Bmatrix} \sum_{i=1}^{m} \left[\left(LTP(k) + \overline{TLT}_{i,j} \right) * (COGS(k)_i * \overline{MS}) * D(c,k)_{i,j} \right] + \\ + DoSP(c,k)_j * (WACOGS(k) * \overline{MS}) * D(c,k)_{i,j} \end{Bmatrix} * \frac{\overline{PE}}{365} \qquad \textbf{4.41}$$

Where:

- $\overline{PE}$ = Yearly average price erosion of the inbound material [1/year].

Customs costs

The customs costs depend on the locations in which the products are produced and distributed as well as on the number of lines per invoice. Alpha has to pay customs clearance fees when the products are trade internationally. In case of the Estonian production plant, the customs clearance fees have to be paid only when the products are exported outside the European union.

Therefore, it is possible to estimate the average number of codes per invoice with the following equation:

Average number of lines per invoice on the *i, j* route for the *c*-customer [lines/order]

$$\overline{LPO(c)_{i,j}} = \frac{IL(c)_{i,j}}{\max_{i,j} \sum_{z=1}^{q} S(c,k)_{i,j,z}} \quad \textbf{4.42}$$

Where:

- $IL(c)_{i,j}$ = Variety of products ordered from the *c*-customer on the *i, j* route [lines].

The number of lines per order allows calculating the customs clearance fees to be paid per each invoice. The total customs clearance cost generated by *c*-customer on the *i, j* route is calculated as:

Customs clearance costs generated by the orders of the *c*-customer on the *i, j* route [Eur]

$$CCC(c)_{i,j} = \left[\max_{i,j} \sum_{z=1}^{q} S(c,k)_{i,j,z} \right] * CCF(\overline{LPO(c)_{i,j}} \quad \textbf{4.43}$$

Where:

- $CCF(\overline{LPO(c)_{i,j}})$ = Customs clearance fee to be paid for the invoices generated by the customer *c* on the *i,j* route [Eur/order].

Handling and packaging costs

The third-party logistics partners managing the consignment deposits define the fees for the handling activities executed in the warehouses (the activities carried at the local deposits were shown in Figure 4-3). Normally the costs are in function of the number of pallets or shipments received at the deposits. The agreements between the customers and Alpha define the responsibilities of the actors on the various activities. In this model, only the costs under the Alpha responsibility are included in the calculations. Under the hypothesis that the products sent to the deposits are equal to the customers' final demand, it is easy to calculate the number of pallets and boxes shipped to the local deposits. The number of pallets sent for each *k*-product can be

calculated as, the final demand toward the *j*-deposit divided per the number of *k*-products contained in each pallet.

4.4.3 Total landed cost

The final objective of the model is to calculate the total landed cost. The company is already running a "cost of goods sold" model so the research did not focus its attention on the production costs. Rather, they are taken as input in the model ("$COGS(k)_i$"). The total production costs are estimated as the multiplication of the cost of goods sold for the expected production volumes. The total landed cost is then calculated as the sum of the total production costs and the total logistics costs, which should be calculated as the sum of the expenses modeled previously.

The total landed cost is finally associated to the products and to the customers. The inbound logistics costs are calculated on the consumption of components. Therefore, it is required to allocate them to final products on the basis of the revenues generated by the products. Thanks to the total landed cost model, the managers can get further information on the expected profitability of customers and products. In the next chapter the practical usefulness of the model and the results obtained through its application are further discussed.

4.5 Validate the model

Kasanen et al. (1993) propose to verify the internal validity of the constructs through the "market based" validation. In this test, the users themselves evaluate the adequateness of the model. In fact, Kasanen et al. (1993) argue that is possible to evaluate the construct built only through real cases applications. Three tests should be met in order to fully validate the model proposed (Kasanen et al., 1993, page: 253):

- "Weak market test", evaluates whether the construct is used in decisions-making situation by the managers of the case study;
- "Semi strong market test", evaluates whether the construct is adopted also by other companies or not;

- "Strong market test", considers whether the application of the model has improved the financial performance of the companies adopting it.

This research is made within the scope of a Master's Thesis so the validity analysis considers only the "Weak market" test. The short time frame of the project makes difficult to observe whether the model is adopted in Alpha decision-making or not. However if the *practical usefulness* (Kasanen, 1993) and the accuracy of the model are demonstrated, there would not be any reason to believe that the model will not be used by the managers in decision-making.

To prove the *practical usefulness* of the construct, it is possible to consider the framework suggested by Kasanen et al. (1993). The authors suggest three characteristics to be respected by the model: relevance, simplicity and easiness of operation. The relevance of the model is further considered in the following paragraphs, whereas the simplicity and easiness of operations of the model are shortly discussed as following.

During the development of the model, the information and data already available in the information system were carefully investigated. As a result, the model is mainly based on data already measured within the organization. Furthermore, the most of the data are generated automatically by the production planning and accounting information systems in use in the company. The usage of spreadsheet software kept the complexity of the model relatively low. Additionally the usage of spreadsheets software makes it efficient to communicate data to the managers (Billington & Davis, 1992). In this way, the requirements of simplicity and easiness of operations are fulfilled.

4.5.1 Accuracy

The aim of this paragraph is to discuss the model adequateness in representing the cause and effect relationships between decisions and supply chain costs. In order to evaluate the accuracy of the model, it is necessary to analyze the model from different point of views.

Firstly it is considered whether the data collected represents properly the current setup of the supply chain. Iterative cycles of interviews were made with the global

logistics manager and with the executive vice-president of the operations with the aim of getting an accurate understanding of the production and logistics processes. Additionally, this report was submitted to them and its validity confirmed. Secondly, the adequateness of the approach and design decisions taken in the model have to be evaluated. In this case, individuals working in the organization (e.g., the executive vice-president of the operations) evaluated and confirmed the appropriateness of the model. Furthermore a presentation of the model was given to the Globenet research group. The research group confirmed the adequacy of the model built. Finally the data created with the model are compared with the historical ones. The model is run on the data that Alpha knew at the beginning of the current fiscal year (2010). The results obtained are then compared with the historical logistics expenses from the beginning of 2010 (i.e., November 2009), until June 2010. Recently the measuring system of the company was improved so it would be challenging to test the model in the previous years. In fact, it would be difficult to get the data needed for the application of the model in the past (e.g. demand forecasts and product costs of good sold).

In evaluating the accuracy of the model, the attention is given to the logistics costs. The "cost of goods sold" model has been used for budgeting activities since three years. This consideration is enough to demonstrate that the model passed the "weak market" test (Kasanen et al., 1993) so its verification is considered out of the scope of this research. In Figure 4-4 the structure of the logistics costs calculated through the model and collected by the historical data are compared. It is possible to observe that the data generated by the model represent well the relative importance of the various logistics costs.

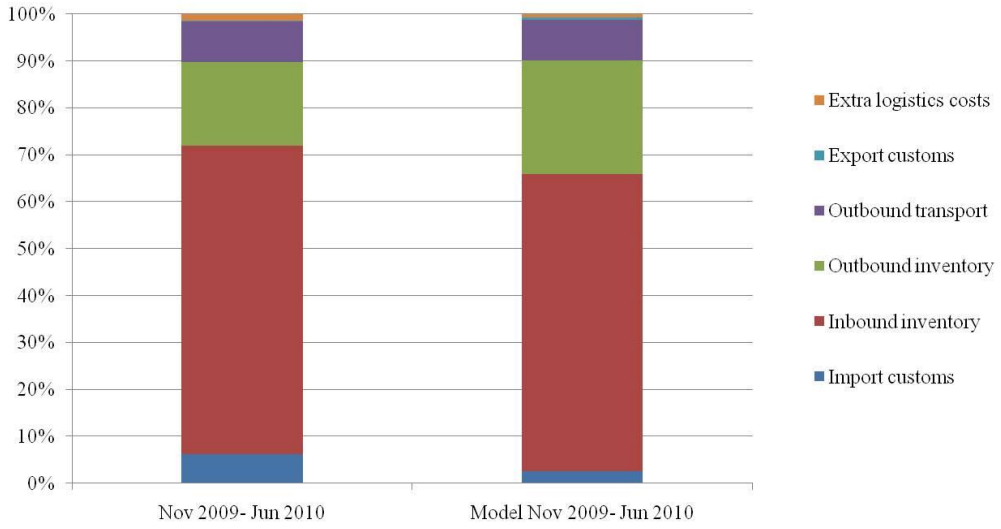


Figure 4-4 - Comparison real data and model

To evaluate the accuracy of the model, it is necessary to compare the absolute values of the costs. From the comparison of the data and the discussion with the managers, it emerges that the model underestimate the total landed cost of less than 10%.

The most significant inaccuracy is related to the estimation of the inbound inventory holding costs:

- Currently the industry in which Alpha is competing is experiencing shortage of components. This situation of the supply market increases the competition among buyers in getting suppliers capacity and makes more challenging the inbound inventory management. Therefore, the status of the inbound inventory departs from the normal functioning assumed in the model;
- In addition to the components kept in warehouse for the current production, components are kept in warehouse in order to ensure the capacity of manufacturing products even after the end of their life cycle. In many cases, the sales department agrees with customers to keep production capacity for few years after the end of the life cycle (for some customers, this period can last ten years). These components are normally recorded in "provision for obsolescence". Depending on the usage levels of the components, they are devalued by 50% or 100% of their original value. The rationales behind the

maintenance of these components in the inventory are more related to sales agreements than to decisions on the operations. For this reason, they are not accounted in the model. The components valued at 50% can partially explain the inaccuracy of the model in estimating the inventory holding costs;

The inaccuracy of the inbound customs costs is related to a decision taken for the realization of the model. In order to limit the size of spreadsheet file, it is decided to consider only the components belonging to A and B categories (that are 500 components instead of 11000). For the calculation of the total inbound costs, it is assumed that the costs are proportional to the value of the components consumed. This hypothesis holds good for the calculation of the inventory costs. However, this is not true for the customs costs. In the countries in which Alpha is operating, electronic components do not require payment of import duties. Instead, components, like plastics and chemicals, require on average to pay duties for 10% of their purchase price. According to the type of products commercialized by Alpha, the most of the AB components are electronic components. For this reason, the customs costs are not evenly distributed on the value of the components consumed. Given the low relevance of the customs costs on the logistics costs (6%) and the difficulties involved in introducing in the model the data regarding all the components, it is decided to accept this inaccuracy. Furthermore, the company is planning to add these costs in the purchasing prices used in the "cost of goods sold".

The tool built aims to support "operations management". To meet the requirements set by management for the total landed cost model, it has been necessary to focus the attention on certain aspects and simplifying others. Therefore as Salafatinos (1996) suggested, the absolute accuracy of the tool has been partially sacrificed to enhance its practical usefulness To sum up, on the one hand it is expected that the model absolute accuracy will improve when the supply chain is operating in normal circumstances. On the other hand, part of the absolute inaccuracy has to be accepted as a constitutive part of the model itself. In accordance with Alpha's management, the "relative clarity" (Salafatinos, 1996) of the model results to be more significant than the exact estimation of the total landed cost. The discussion on the absolute inaccuracy has not revealed any structural mistakes in the model design. In Figure 4-4 was shown that the planning tool respects the relative

importance of the costs. Therefore, the application of the model to real cases would support managers in focusing their attention on the significant issues. The tool developed would support them in better understanding the implications of managerial decisions on the whole supply chain. For these reasons the accuracy of the model is considered to be adequate to its aim.

Chapter 5

5. Results and discussion

To make a scientific research, it is not enough to find an answer to the needs expressed by a case study. The constructive approach (Kasanen, 1993) requires connecting the study with theory and contributing to its development. The goal of this chapter is to show the key results of the research, to link the study to the literature on the topic and to attempt to contribute for theoretical development. In order to show the significance of the information provided by the model, it is applied to potential decision-making situations. Furthermore, the model and the external validity of the model is briefly discussed.

5.1 Understanding customer profitability

In this paragraph, it is evaluated whether the application of the model enhances the managers' understanding on the profitability of the customers and provides useful information to support decision-making. These analyses integrate also the study made on the accuracy of the model. In fact, the analyses confirm the model ability in representing the relationship between decisions and total landed cost. In this case, the analyses are made on the data collected at the end of April 2010 with one-year planning horizon.

As said before, Alpha evaluates customer profitability only with the information regarding production cost. In the case study, the logistics costs cover 4% of the total landed cost (Figure 3-4). However, different products consume logistics resources differently. To show the contribution of the model to a better understanding of the company profitability, a group of products transported from China to Europe is considered. The products are manufactured for the second customer in terms of revenues and they cover 8% of the profitability of the company. The total landed cost

structure of these products is depicted in Figure 5-1. The case confirms the importance of the total landed cost in evaluating the profitability of the products. In fact, even though on average the logistics costs cover 4% of the total landed cost, different products consume differently logistics resources. So there are products in which logistics costs cover 7% of the revenues (or 8% of the total landed cost) and others where the logistics costs cover less than 1%. Through the model application, the products in which the logistics costs assume an important role in determining the total costs are identified. This confirms that, the model can be applied to evaluate production allocation decisions and to better understand the effects of these decisions on product profitability.

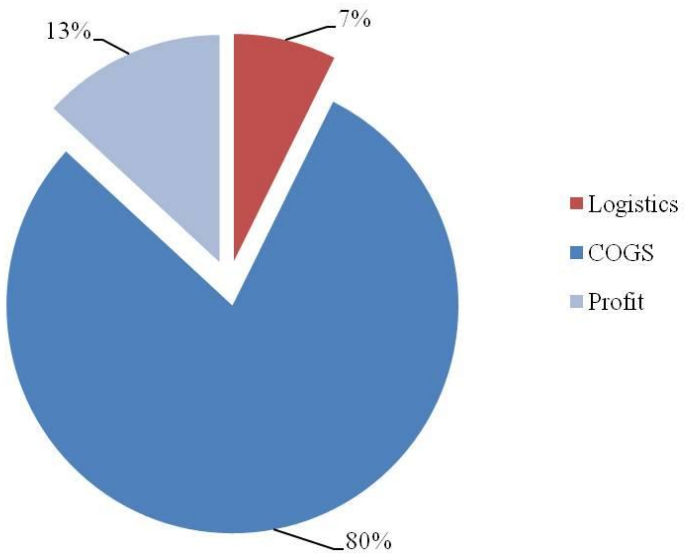


Figure 5-1 – Relevance of the logistics costs for a selection of products

5.2 Scenario analysis

As it was discussed in paragraph 4.3, the profitability of tactical decisions is also influenced by the dynamic fluctuation of external factors (see Table 4.6). Given the uncertainty involved in global operations, it is valuable for managers to understand the effects of uncertainty on the results of their decisions. In particular, academics and practitioners have started questioning the value of offshoring. Goel et al. (2008) has underlined how the soaring oil prices, dollar depreciation against RMB and rising Chinese wages is challenging the efficiency of offshoring production. The total landed cost model enhances a good understanding of the trade-off existing between cost savings linked to offshoring and rising logistics costs. Using a comprehensive

costs model of the supply chain costs allows managers monitoring how this trade-off is changing for each product.

In their study, Goel et al. have recorded during 2003-2008 the rising of crude oil price from 20 $ to 100$ a barrel. In the same period, on average the wage level in China has increased annually of 19%. Through the model developed, it is possible to monitor the effects of these variables on the production allocation decisions.

For the case study, the effects of wage inflation seems to be marginal: 19% wage inflation increases the production costs of 1,1%. Indeed, in the case considered the relevance of direct work and overheads affected by the wage inflation on the total costs is about 12%. On the other hand as it is shown below, the effects of oil price soaring and RMB appreciation have a much stronger effect on the total costs. For this reason, in this paragraph the attention has been limited to these two variables. However, in the long term even the wage level might become a significant parameter to monitor in evaluating production allocation decisions.

For instance, it is considered a production allocation decision for 7 products. These are produced for the second customer in terms of revenues, and they are consumed both in China and Europe. Hence, the decision regarding their production allocation is critical. Three alternatives are evaluated through the total landed cost model:

1. Production is made locally (local production).

2. Production is allocated completely to the Chinese production plant (Production in China).

3. Production allocation is mixed: 15% of the European demand is allocated to the Estonian production plant, along with 85% to the Chinese one (mixed allocation). In this case, the European production plant is used as a buffer to cover demand uncertainty and the use of air transportation can be avoided (Allon and Van Mieghem, 2010). The evaluation of this alternative is made possible by the introduction of the total landed cost model.

In Table 5.1, considering as drivers the freight rate (actual case, i.e. 100%, and possible scenarios, i.e. 120% and 140%) and the exchange rate (actual case 9,3 RMB/€, and possible scenarios), the three alternatives are compared.

Initially, the alternatives 1 and 2 are discussed. When the only production costs are taken into account, the complete allocation of the production in China enhances savings for more than 25% of the cost of goods sold. Independently on the scenarios considered, the second alternative is always the most efficient. When the logistics costs are included in the analysis, the cost advantages are halved (13%).

According to the output data of the model, international transportation (sea and air shipments) increases the logistics costs. The use of sea shipment requires longer transportation lead-times and higher uncertainty (the lead-time ensured by the logistics partner is between 34 and 42 days). The average inventory level in the pipeline increases. The higher uncertainty of the transportation lead-times increases the level of safety stock that the company has to keep in the local deposit. Finally, the longer replenish lead-times of the suppliers of the Chinese production plant and the longer transportation lead-times increase the price erosion cost. As a result, the average time spent by the components in the Alpha internal processes increase from 70 days to 150 days.

The raising of the freight rates and the appreciation of the Chinese currency decrease the advantages linked to the second alternative. When the exchange rate reaches 7 RMB/€ and the freight rates rise by 20%, the most efficient solution is to produce the goods locally (i.e., to produce in Estonia for the European market). The data collected show the significance of the freight rate and the exchange rate in determining the costs linked to the off-shoring decision. The raising of the freight rate by 40% and the depreciation of the Chinese currency until 7 RMB/€ increases the total landed cost by 28%.

The results obtained from the analyses are shown in Figure 5-2 and in Figure 5-3. In the figures, the effects of a possible appreciation of the Chinese currency and increase of freight rates on the total landed cost are shown. In the graphs presented, different colors indicates different cost levels. The case “ Production moved to China” (Figure 5-2) results to be highly affected from the changes applied on the

freight rates and on the exchange rates. Indeed, the increase of the freight rates raises further the logistics costs. Additionally, the appreciation of the Chinese currency decreases the competitiveness of the Chinese facility compared to the Estonian one. On the other hand, these factors do not affect strongly the case "Production made locally" (Figure 5-3).

If only the production costs are considered, the mixed production allocation (the third alternative) proves to be more expensive than the case of complete production allocation to China. When the logistics costs are included in the analysis, the third alternative proves to be more efficient and more robust than the others configurations (see Table 5.1and Figure 5-4).

In summary, maintaining a holistic point of view on the supply chain costs affords a better understanding of the real advantages related to shifts in production from Europe to China. Moreover, it quantifies the effects of external factors on the production allocation decision. In particular, Alpha's managers should focus their attention on the evolution of the exchange rates and freight rates in the near future. Further appreciation of the RMBs and the rise of the freight rates might require reconsideration of the current production allocation configuration.

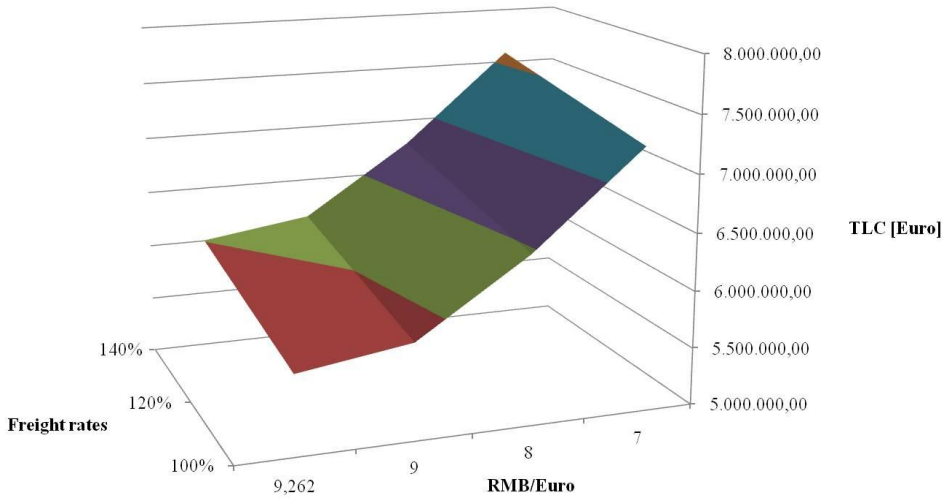


Figure 5-2 – Production moved to China

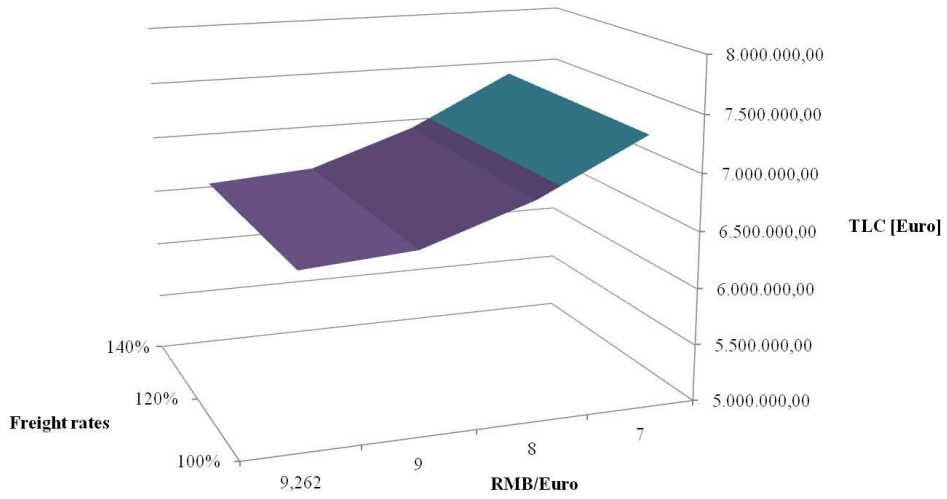


Figure 5-3 - Production made locally

The examples presented show some of the functionalities offered by the model in supporting decision-making. Furthermore, the cases analyzed show the importance of maintaining an holistic point of view on the supply chain costs. The utilization of the model allows the comparison of the cost levels associated to various tactical alternatives. Moreover, it allows comparing the robustness of the alternatives in case of changes in external factors, such as exchange rates and freight rates.

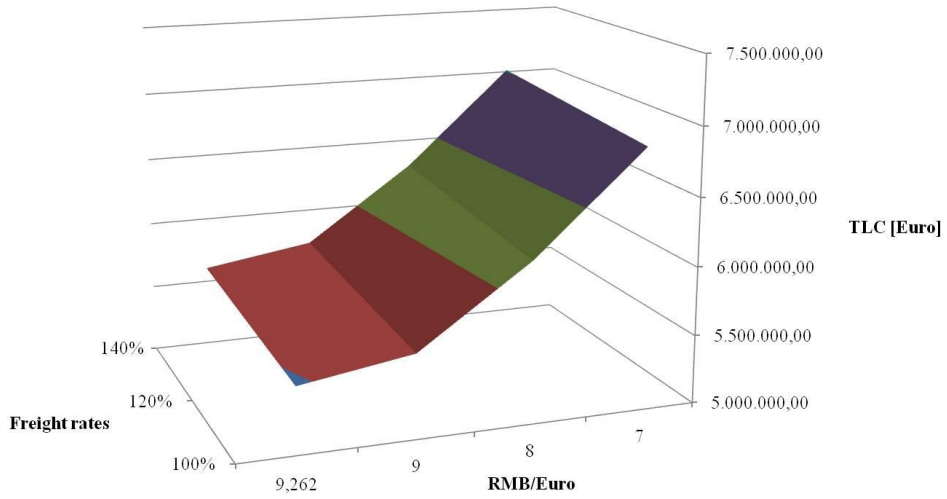


Figure 5-4 - Near-shoring for flexibility

Table 5.1 Total landed cost (TLC) for three production allocation configurations, costs expressed in million of €

Drivers		**Local production (1)**			**Production in China (2)**			**Mixed allocation (3)**			**TLC comparison**		
Freight rate	[RMB/€]	Production	Logistics	TLC	Production	Logistics	TLC	Production	Logistics	TLC	2-1	3-1	3-2
100%	9.3	6,399	112	6,511	4,759	933	5,692	5,005	478	5,483	-819	-1,028	-209
100%	9.0	6,466	112	6,579	4,898	937	5,834	5,128	482	5,610	-744	- 969	-225
100%	8.0	6,786	114	6,900	5,510	955	6,465	5,671	498	6,170	-435	- 730	-295
100%	7.0	7,251	115	7,366	6,297	978	7,275	6,370	520	6,890	-91	- 477	-386
120%	9.3	6,399	122	6,521	4,759	1,089	5,848	5,005	539	5,545	-673	- 977	-303
120%	9.0	6,466	123	6,589	4,898	1,093	5,990	5,128	543	5,671	-598	- 918	-319
120%	8.0	6,786	124	6,910	5,510	1,111	6,621	5,671	560	6,231	-289	- 679	-390
120%	7.0	7,251	125	7,377	6,297	1,134	7,431	6,370	581	6,951	55	- 425	-480
140%	9.3	6,399	133	6,531	4,759	1,245	6,004	5,005	601	5,606	-527	- 925	-398
140%	9.0	6,466	133	6,599	4,898	1,249	6,147	5,128	605	5,733	-452	- 866	-414
140%	8.0	6,786	134	6,920	5,510	1,267	6,777	5,671	621	6,293	-143	- 627	-484
140%	7.0	7,251	136	7,387	6,297	1,291	7,588	6,370	643	7,013	201	- 374	-575

5.3 Theoretical contribution

To discuss the theoretical contribution of this work to the supply chain planning literature, the current study is related to the discussion presented in paragraph 2.5. Instead, the model presented is meant for middle term planning (from six to twelve month tactical planning). Thus, the comparison with the model developed by Erhun and Tayur (2003) results to be challenging. Even though the total cost approach is in common, the different planning horizons considered result in different model designs.

The nearest approach to this research is the one proposed by Zeng and Rossetti (2003). As the model developed by Zeng and Rossetti (2003), this research proposes a static representation of the effects of tactical decisions on the supply chain costs. Compared with the Zeng and Rossetti (2003) approach, the model developed takes a longer term-perspective and its scope results to be wider. In fact, it is not limited to the only evaluation of different transportation alternatives. Rather, this research wants to evaluate the impacts of tactical decisions on the overall production and logistics systems.

In this model, the dynamic research for optimal solutions is sacrificed for broadness of the scope of the model. The study proposed by Zeng and Rossetti (2003) can be considered as the "predecessor" of this research. Both models propose the evaluation of logistics costs through averages and under the hypothesis of system stability. However, this model is not an application of their framework. Indeed considering the same logistics cost categories, this research integrates the logistics and the production costs to build a tool to evaluate the impact of decisions on the supply chain costs.

5.4 Contribution to supply chain costing literature

Before going further with the discussion, it is necessary to differentiate the model proposed from the "standard costs" technique presented by Lambert et al. (1998). As the current research, the "standard costs" technique allows estimating future supply chain costs. The main difference lies in the final objectives of the two approaches. In fact, the "standard costs" technique results to be used for control purposes, whereas the final aim of the model developed is to provide a tool to support managers in

decision-making situations. In the "standard costs" approach, the absolute accuracy is a priority. Typically the collection of a big amount of data and statistical analyses are required to run "standard costs" models. Instead in the current research, the absolute accuracy of the model is balanced with its simplicity and speed in running it.

In the accounting research, this study tries to expand the scope of the studies made by Salafatinos (1996), and Singer & Donoso (2008). In fact, it expands the application of the activity-based costing technique for planning purposes to the whole supply chain. Furthermore in contrast with the findings of Schneeweiss (1998), it is shown that the activity-based costing can be used for tactical planning purposes with enough accuracy.

In the literature, the application of the activity-based costing approach to logistics is not new. Indeed, Lin et al. (2001) apply the activity-based costing technique to the cost categories suggested by Lambert et al. (1998):

- Inventory carrying costs;
- Procurement costs;
- Order processing costs;
- Transportation costs;
- Warehousing costs.

In addition to these categories, the planning models presented in the previous paragraph recognize the relevance of the costs related to international trade (e.g. customs costs and exchange rates fluctuations). As a result in this research, these costs are added to the categories specified by Lambert et al. (1998).

The explicit consideration of the price erosion cost attempts to introduce a novelty element to the accounting research reviewed. Indeed, the cost categories proposed by La Londe and Lambert (1977), Zeng and Rossetti (2003) and Cristopher (2005) as well as the cost categories used in the planning models do not recognize the price erosion cost. In paragraph 4.2, the price erosion cost was defined as: "the value loss that a component experiences during the time elapsing from its purchase to the sale

of the product including the component itself". Therefore, the price erosion is different from the value loss related to obsolescence. On the one hand, the latter is related to the realization of an external event, which decreases the product value, e.g. introduction of better product in the market. On the other hand, the price erosion can be seen as systematic depreciation that products experience in particular industries due to cost competition. The price erosion cost differs from the other inventory carrying costs also for the lead-time on which it should be accounted. In fact, for the calculation of the cost of capital and of obsolescence the times in which the financial or material transactions incur should be considered. For the calculation of price erosion cost the bidding window (from purchase of the component until the final product is sold) should be considered.

In the case studied, the price erosion cost covers 17% of the logistics costs calculated through the total landed cost model. Moreover, the inbound replenishment lead-times differ strongly between the two production plants. The difference in lead-time performance between the Estonian and Chinese production plants increases even more when the consignment deposits are considered. Therefore, the information regarding the price erosion cost can be highly valuable for the managers of Alpha. In certain circumstances, the price erosion cost might take a significant role in determining the profitability of managerial decisions.

5.5 External validity of the study

As a part of the constructive approach, the external validity of the research needs to be discussed. This should be verified through the "Semi strong market test" and by "Strong market test" proposed by Kasanen et al. (1993). The time frame of the project does not allow doing this. Not even the scope of Master's thesis requires this verification. However, it is possible to discuss about the relevance of the research outside the case study and on its general contribution.

It can be argued that the need for a tactical planning model is high in companies. The globalization trends identified in the literature review are increasing the difficulties in decision-making situations. In fact, the location of factories, customers, and suppliers on a global scale as well as the large amount of parameters that should be considered in taking tactical decisions complicate managers' role. Global

operations and the current economical situation increase the elements of uncertainty that managers need to consider when decisions are taken. Moreover economics trends, like the oil price soaring and wages inflation, are challenging the value of production offshoring. Before taking decisions managers should get an accurate understanding of the total landed cost for each product (Goel et al., 2008). Salafatinos (1996) and Askarany et al. (2009) argue that it is not enough to build accounting models for the allocation of historical costs. Rather, managers are calling for models that show the cause-effect relationships between costs and decisions, as well as allow testing the effects of decisions before they are put in practice. At the same time, the models have to be able to balance complexity and accuracy in order to respect the principle of practical usefulness presented by Kasanen et al. (1993). As Salafatinos (1996) highlighted, planning models have to simplify the reality and they should focus the attention of managers only on the significant factors.

In this perspective, the approach suggested by the research might be considered valid and significant even outside the case study. The discussion presented on how the total landed cost should be modeled and the five steps framework proposed might be of interest for other companies in developing a similar model. Furthermore, the input parameters suggested, their categorization and the formulas elaborated could be taken as starting point for the construction of a total landed cost model. The study proposes as well a way for evaluating the price erosion cost. Its evaluation might be considered significant also for other applications.

In case of more complex supply chains, e.g. a bigger number of production plants available or multiple-inventory systems, the simplicity of the approach could be compromised. In these cases the usage of spreadsheets software would not be adequate. So if firms are not willing in investing in more advanced software, further simplifications would be required in order to adopt the approach here presented. Moreover in paragraph 4.1, it was argued that in case of presence of seasonal effects it would be necessary to split the model in multiple periods. For the complete evaluation of the total landed cost on the significant planning horizon, it would be necessary to study how to integrate the various periods.

To sum up, it is possible to affirm that the model might be significant in many other organizations. Its application requires the adaptation to the circumstances in

which the companies are operating. In fact, the input parameters should be adapted case-by-case to ensure the accuracy of the model and to make sure that the model is built on available data. In case of more complex supply chain, balancing the trade-off between accuracy and complexity results to be more challenging than in the current research.

5.6 Limits of the solution

In this paragraph, some of the weaknesses of the tool developed are presented. Firstly, given the complexity of the problem, the utilization of spreadsheet software can be confusing. The proliferation of sheets that is necessary to utilize can compromise the simplicity of the application and the understanding that users have on its functioning (see the Appendix 1). Even the upgrading of the model can be very challenging.

Secondly, in contrast with many of the other planning tools described in the literature, in this case the model is not based on simulation. This allows developing the model on spreadsheet software, which makes it efficient to communicate data to managers. However, it requires basing the model on the assumption that the behavior of the supply chain is stable during the planning horizon. This assumption affects negatively the absolute accuracy of the model. The usage of average values in modeling the phenomena simplifies the real functioning of the supply chain and it may miss significant behaviors of the system. For example, it does not allow estimating the risk of product shortage at the consignment deposits. Consequently, it is not possible to estimate the "shortage costs" (Stevenson, 2002). In paragraph 3.2, it was argued that the "shortage costs" do not have a significant impact in Alpha supply chain. However, getting information on these costs at the consignment deposits would for sure enrich the cost estimation. For instance, if the "shortage costs" are considered, the efficiency of shifting the production to China for the codes stored in the European consignment deposits would probably decrease. Running a simulation model would require the collection of more detailed data, for example data regarding final demand (weekly forecast), production process lead times, production plant capacity and capacity flexibility would be necessary. In the case study, the managers consider the easiness of operations of the model as critical for its practical usefulness. Hence its simplicity and speed of application are prioritized against the

development of simulation model (see paragraph 4.5 for a thorough discussion on model internal validity).

Thirdly, the solution does not provide a dynamic optimization of the problem. As discussed in paragraph 4.1.2, this is not required and it motivates the managers in get a deeper understanding on the output data of the model. However, it may be useful to provide the possibility of calculating the minimum total landed cost. The optimal solution could be used as a starting point in the decision process and it might suggest solutions that are not even considered from the managers. However, dynamic optimization would require utilizing another software and it would complicate data collection, e.g. the transportation costs should be modeled through a function instead of using input from the users. For these reasons, the dynamic optimization is not considered in the current research. In other cases, providing a tool to determine the optimal solution could be more significant. In these situations the development of dynamic optimization should be considered. In doing this, it is highly significant to consider that the usage of dynamic programming requires reducing the "easiness of operation" of the model itself.

Finally, during the research it is stressed that the model is utilizing data already collected by the company. This is a very critical factor in order to ensure the practical usefulness of the model. However, this can result to be also a limitation. Indeed, the accuracy of the model is strongly influenced by the availability of the data within the organization. The development process of such a model should interact proactively also with a project for the improvement of data availability. In the current research the data available are considered only as a constraining factor. Thus, the accuracy of the current model is worse than it would be in case of interactive process between model development and data availability improvement.

Chapter 6

6. Conclusions

In the last chapter, the findings of the research are summed up and the possibilities for further research identified.

6.1. Key findings

To ensure coherence with the research objectives, the presentation of key findings is structured according to the research question and the research goals presented in the first chapter of the report.

How should the total landed cost be modeled in order to support the tactical decisions on how to run the operations in an efficient and effective way?

According to the approach proposed by Kasanen et al. (1993), the importance of the practical usefulness of the model developed is discussed in the report. The total landed cost should be modeled using data already measured within the organization. To ensure the simplicity of the model, it is suggested to use spreadsheet software for the development of the tool. When the complexity of the case does not allow the usage of spreadsheet software, it is necessary to consider other opportunities. e.g. investing in other software or reducing the accuracy of the model for its simplicity.

An adaptation of the activity-based costing technique can be used for tactical planning purposes with enough accuracy. Indeed given the high uncertainties that influence the final outcomes of decisions, the model rather than dictating decisions through dynamic optimization should provide support in decision-making processes. Hence, absolute accuracy can be balanced with the easiness of operation of the model. In the study, it is shown that an adaptation of the activity-based costing technique allows balancing properly the trade-off between accuracy and simplicity.

When the supply chain costs are considered, the effects of consolidation have a significant impact. Thus, it is necessary to take a systemic perspective on the supply chain to get an accurate estimation of the costs. It is suggested to identify the minimum portion of products that should be considered in order to calculate with enough accuracy the total landed cost. The planning horizon of the model has to be decided in relation with the horizon of the decisions to be evaluated. In case of tactical decisions, the planning horizon should be from 6 to 12 months. However, the decision of the appropriate planning horizon should take into account the characteristics of the industry in which the case considered is operating.

A critical step in the model development process is the decision on the cost categories to be considered. The priority should be given to those costs that are linked to the decision variables and that may affect the profitability of the decisions. The price erosion shows the importance of considering even the costs that normally are ignored in accounting because of the challenges in their evaluation (e.g. price erosion cost).

Finally when the model is realized, it is important to evaluate its accuracy. Rather than focusing on absolute accuracy, it is important to demonstrate that the model is able to represent properly the relationships existing between decisions and costs. Models should simplify and enhance the understanding of the managers on the reality. Therefore, it is necessary to accept reducing the "absolute accuracy" of the model for its "relative clarity" (Salafatinos, 1996). The sources of inaccuracy should be analyzed carefully with the managers in order to discover potential mistakes in modeling assumptions. It is important to understand the inaccuracies also to improve the confidence of the managers on the output data.

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(1) To identify the variables that affect the total landed cost for production and delivering of products.

It is very challenging to identify a general list of parameters that can be used for total landed cost modeling. In fact, the parameters to be considered and their relative importance depend strongly on the characteristics of the supply chain studied. Based on the case study, a list of significant factors is provided in paragraph 4.3. The parameters are then classified in the categories listed in Table 6.1.

Table 6.1 - Cost drivers categorization

Decision parameters	Independent parameters
Strategic parameters	Partially independent parameters
Tactical parameters	External parameters
Negotiable parameters	

As shown in the report, it is particularly useful to categorize the parameters in this framework. It allows focusing the attention on the decision variables and on the external parameters that affect the most the total landed cost. Even though the parameters and the categories identified are strongly influenced by the characteristics of the case study, they can be used and adapted in other circumstances.

(2) Develop a total landed cost model for the case study.

As a result of the research project, a model of "the total landed cost" is provided to the company. In chapter 0, the logic behind the model is explained thoroughly. In the validating process, some of the results obtained from the initial applications of the model are presented.

(3) To assess the benefits of introducing a total landed cost model as a supportive tool in the tactical planning processes of the case study.

In a global context, one of the key decisions concerns the allocation of the final demand according to the available production facilities. To support this decision, the estimation of the total landed cost is suggested. The studies identified in literature limit their scopes in terms of products/markets and costs considered. This study proposes to model the total landed cost in a comprehensive way. In the case study, the model enhances a better understanding of customers' profitability and the effects of tactical decisions on the total cost. The data generated by the model has shown that maintaining a holistic point of view on the supply chain costs improves managers understanding of customers profitability.

The possibility of running a scenario analysis allows the effects of uncertainty on the alternatives evaluated to be assessed. In the global environment, it is critical to understand the robustness of the decisions made. For instance, the application of the model has contributed to a better understanding of the effects of oil prices and exchange rates fluctuations on the total landed cost in case of global production. The model can be used to evaluate also other scenarios (e.g. to evaluate the best production allocation mix depending on different external conditions or to identify the exchange rate that makes efficient production backshoring).

6.2. Future research

This study opens opportunities for future research. The gap identified in the literature is only partially filled. During this research, the relevance of a tactical planning tool for the case study is shown. In the discussion part (Chapter 5), it is also argued that such kind of model would be of interest for many organizations. However, it was impossible to find in the literature an adequate framework for developing such a tool. On the one hand, this research can be considered as a first step in this direction. On the other hand, the building of a more general approach is needed. From the theoretical and the practical point of views, it would be interesting to create a meta-model. This should be flexible enough to be adapted quickly to different circumstances and different managerial needs. In order to generate a more general model, it is necessary to extend this research to other companies and other industries.

In the present model, the effects of uncertainties are evaluated through scenario analysis. However, the model is not able to provide any information regarding the occurrence probability of the different scenarios. Moreover, the data given as input to the model, e.g. final demand, exchange rates, freight rates, would be better represented by probability distributions than deterministic values. For this purpose, the benefits of modeling input data with probability distributions should be considered. In this case, the study should evaluate the further complexities resulting from the introduction of probability distributions and compare them with the additional information provided to managers.

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Appendix

Appendix 1

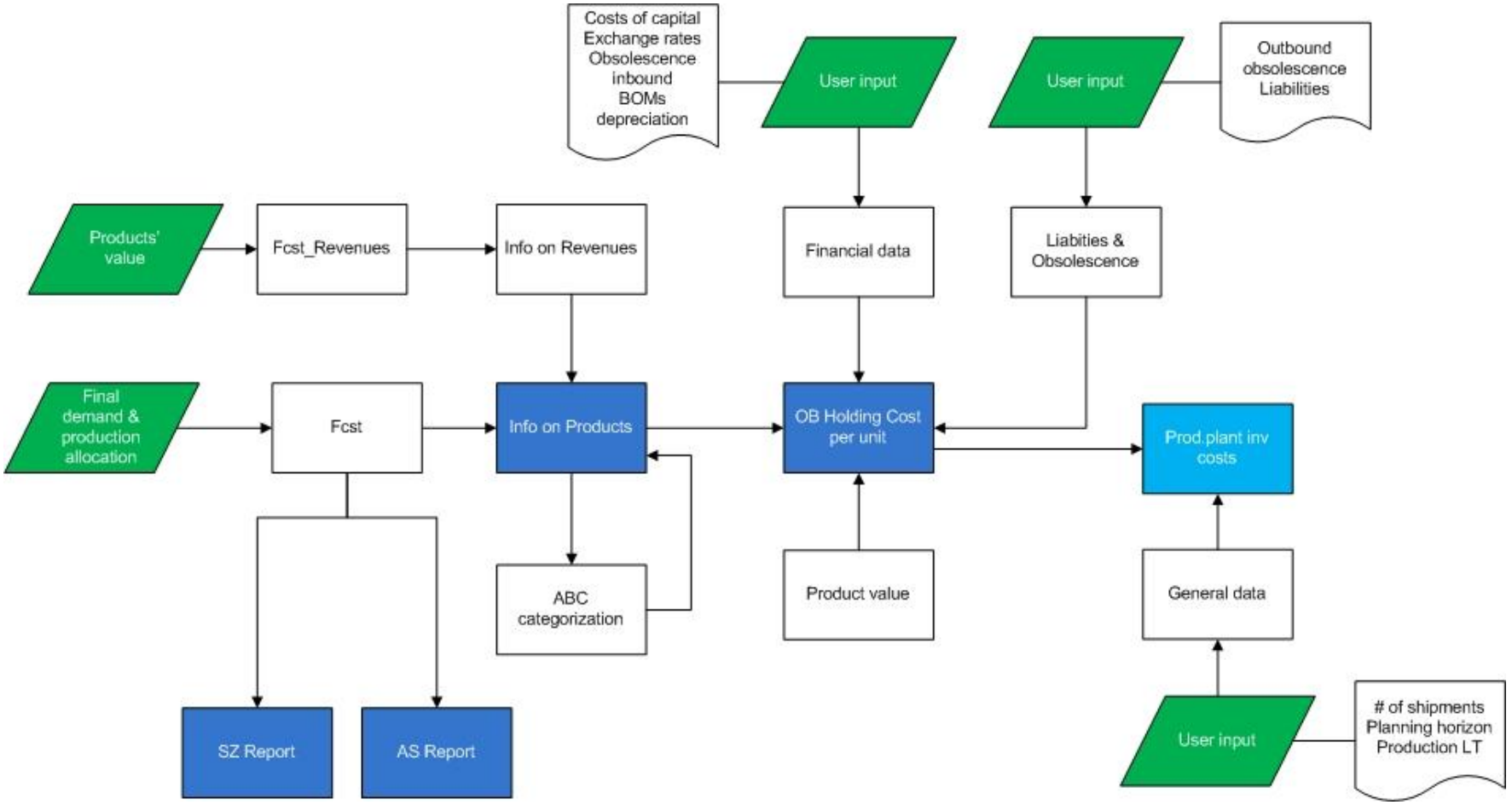
In the appendix, the structure of the model developed through spreadsheet software (Microsoft Excel) is presented. The scheme is divided in four modules: the basic; the inbound logistics, the transportation, and local deposit modules. The boxes with rectangular shape represent the Excel sheets used for the calculation of the total landed cost. In the green boxes, the inputs required to the users are listed. The strategic data, like the locations and the functions of the inventories, are imbedded in the model. Thus they are not required in input from the users. Furthermore, data on the consumption of the components and HS codes are downloaded directly from the MRP system used by the company. The consumption of the components depends directly on the demand of the final products. Indeed in the "Inbound logistics module" figure, it is shown that the data given in input to the MRP information system are created on the basis of the demand forecast.

The sheets containing the cost information are highlighted in light blue. The blue boxes represents the excel sheets that connect the basic module to the others. The total landed cost are calculated as the sum of all the costs computed in the sheets identified by the light blue filling and the total production costs.

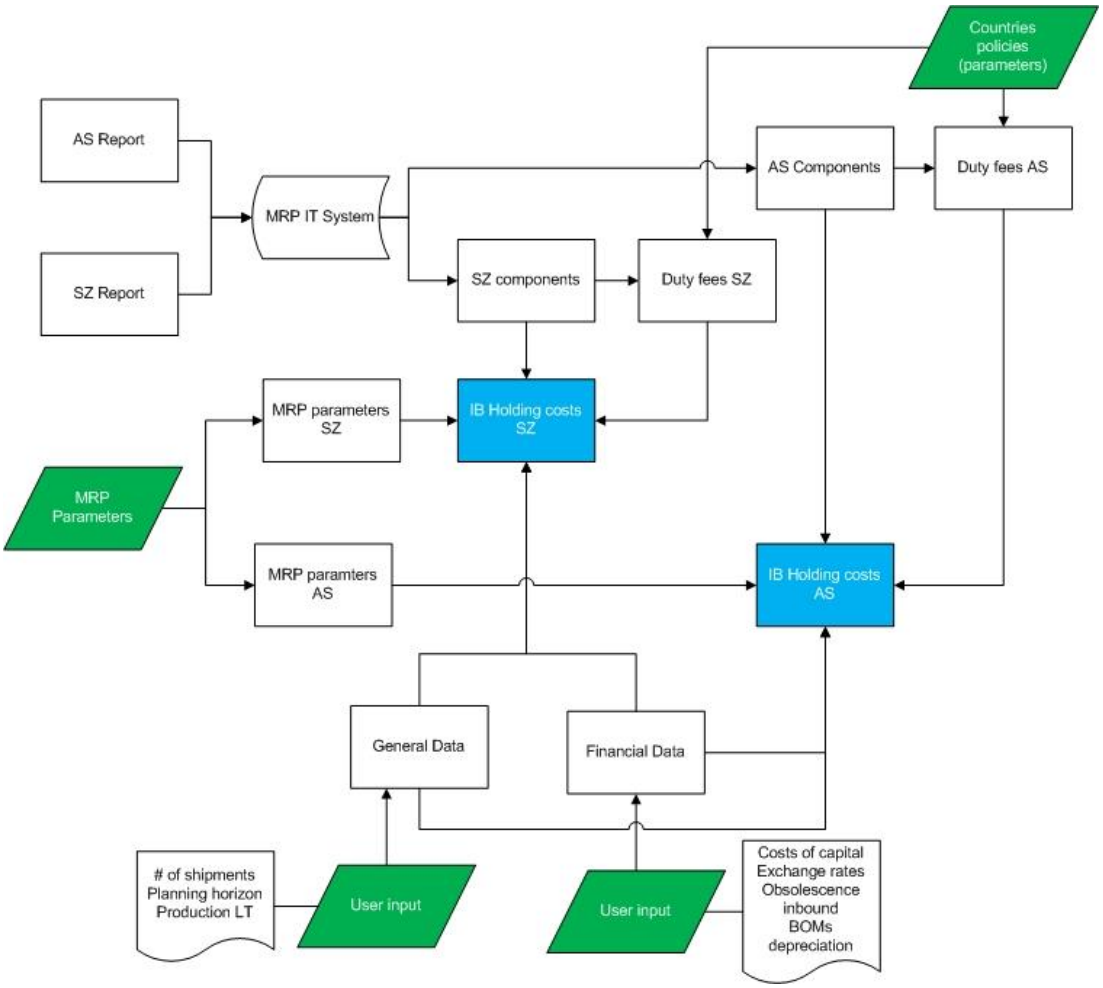
The calculation of the transportation costs result to be the most challenging. Indeed, the consolidation effects require iterating the input process. The numbers, which are associated to the arrows in the diagram, indicate the order in which the activities are carried. For instance, firstly the information on the products is uploaded on the "transportation costs" sheet. Consequently, the data on products dimensions and weights are asked to the user. Then, the average weights and volumes shipped on the various routes can be calculated. Finally, the freight rates to be paid on the various routes can be inserted and the transportation costs computed. A similar logic lies behind the other iterative process shown in the diagram.

The formulas presented in the paragraph 4.4 are embedded in the software for the calculation of the final costs.

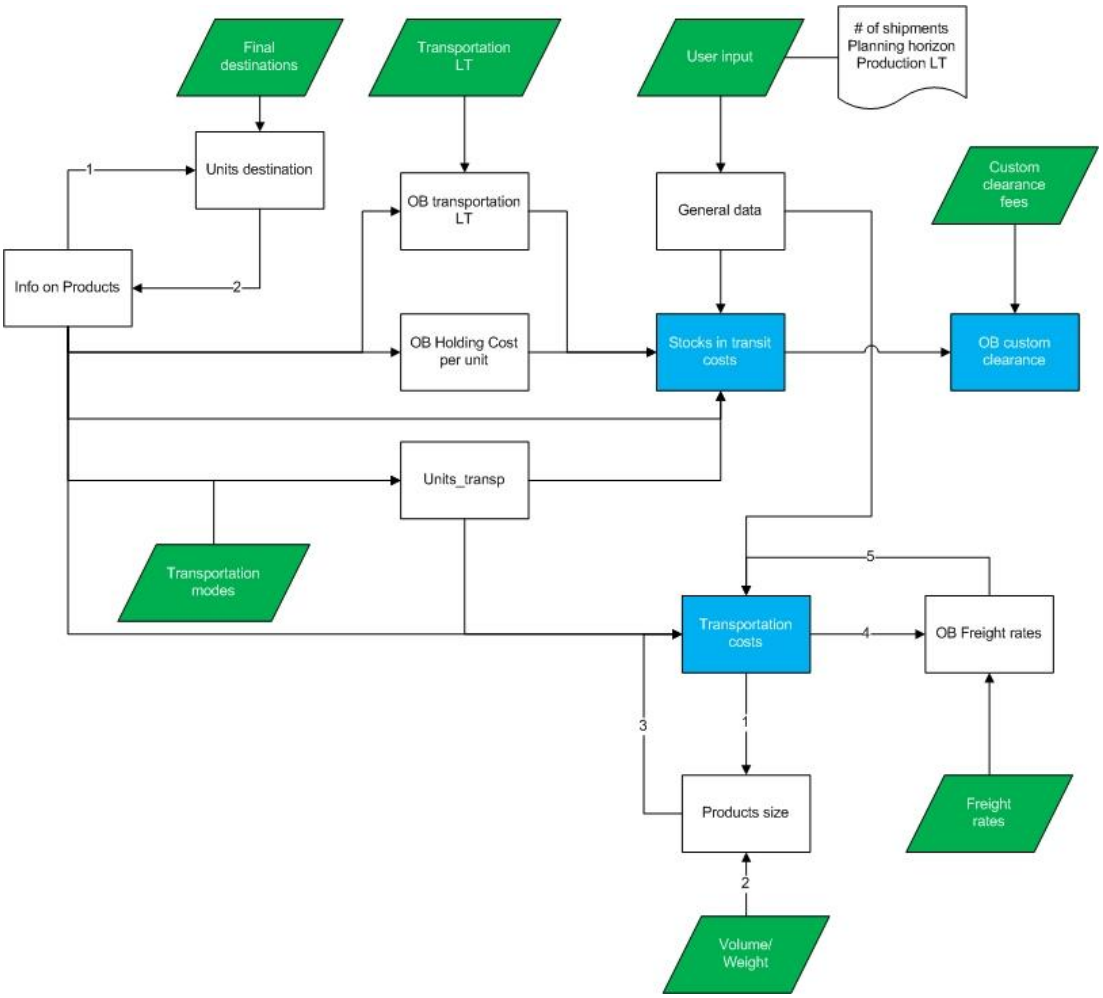
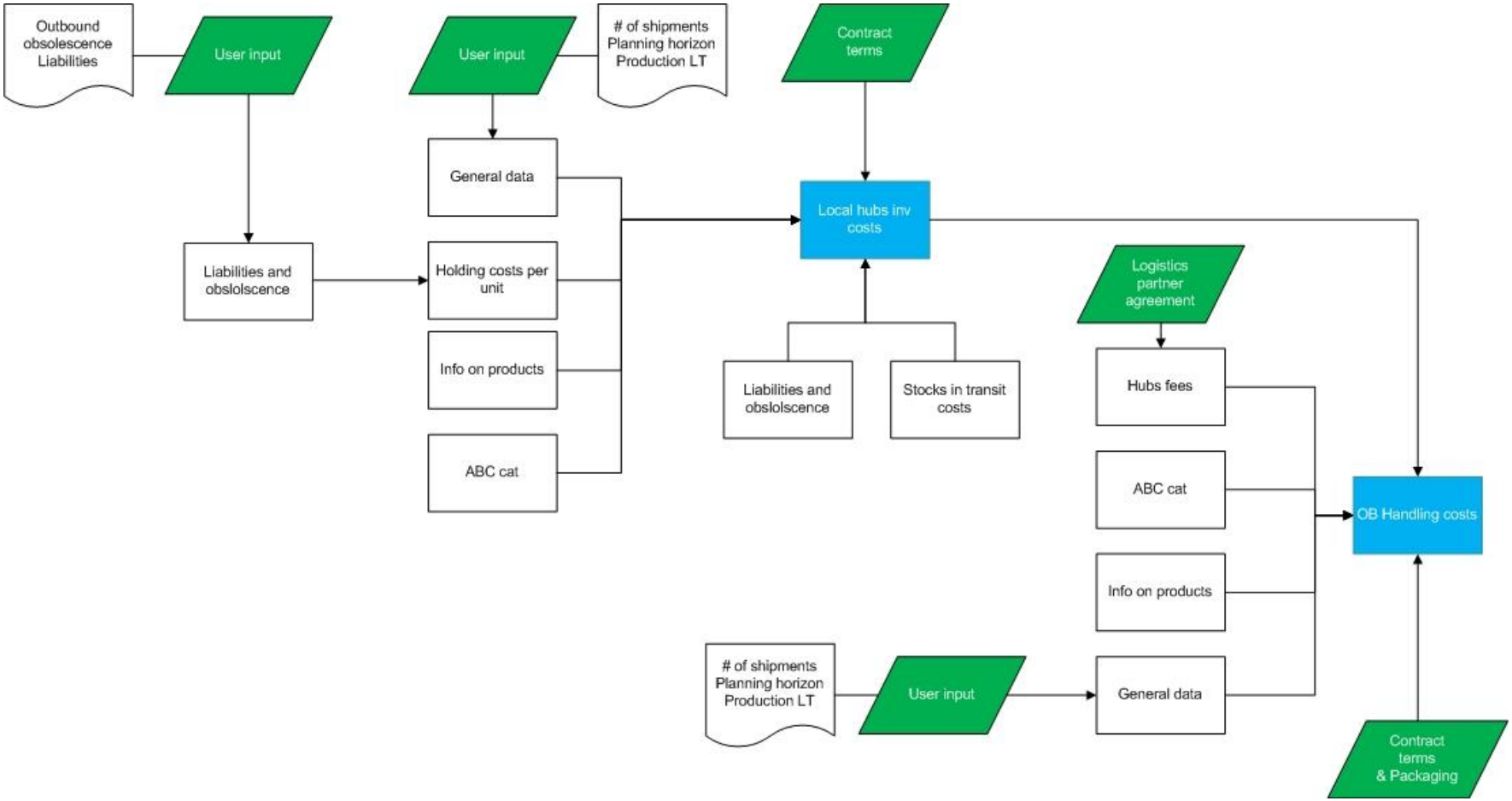
Basic module



Inbound logistics module



Transportation costs



Warehouse costs